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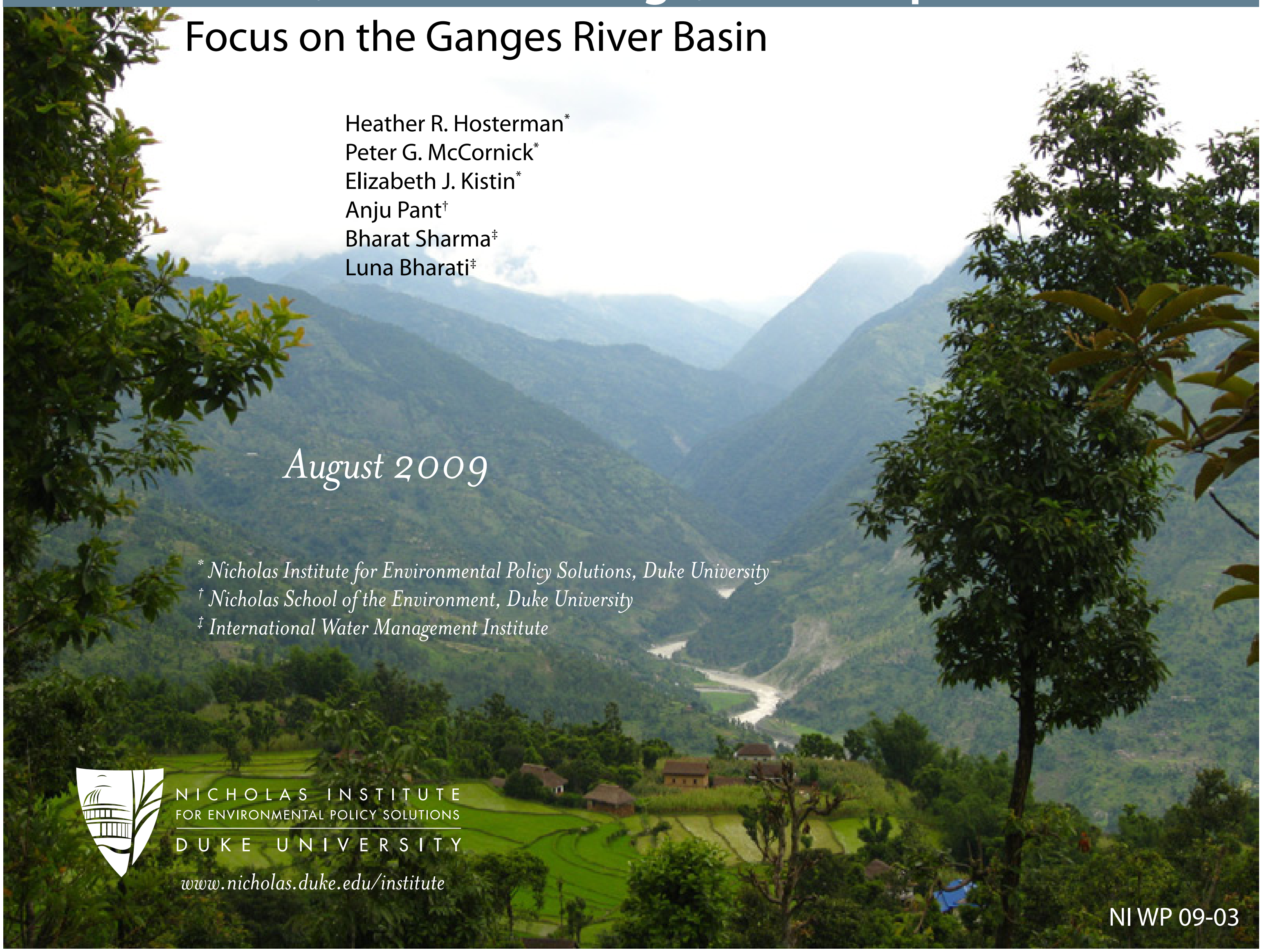

Water, Climate Change, and Adaptation

Focus on the Ganges River Basin

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August 2009

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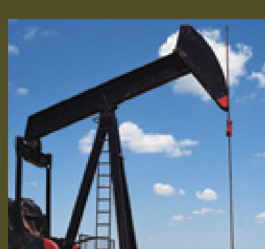
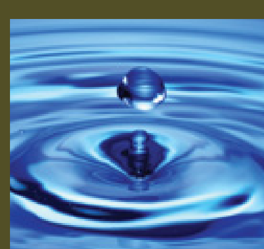
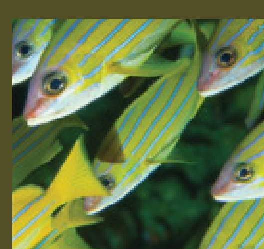
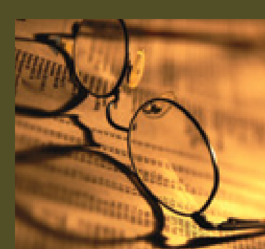

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Contents

1. Water, Climate Change, and Adaptation

Human-induced climate change has wide-ranging and complex impacts on water resources in South Asia and throughout the world. The impacts of climate change through water will also be felt across inherently linked sectors of ecosystems, agriculture, energy, and human health. Strategies for adaptation to climatic variation and other changing circumstances may decrease the adverse effects of climate change, while capitalizing on the opportunities presented by these changes (Smit et al. 2000; Carter et al. 1994). To date, however, water resources have not been adequately addressed in the development of adaptation strategies (Bates et al. 2008).

This working paper explores the intersection between water management, climate change, and adaptation in the Ganges River system, a basin vital to the security, economy, and environment of South Asia. Recognizing that an understanding of both the science and the policy of water management, climate change, and adaptation is rapidly evolving, it is not our intention to encompass all the issues related to these broad fields, but rather to provide a starting framework from which to further develop research questions and priorities for work in water and adaptation. As such, the aim of the paper is to advance the understanding of key issues in this critical basin and to identify strategies for improving water management and adaptation.

In meeting this goal, Section 2 provides an overview of water resources and changing circumstances in the Ganges basin. Section 3 takes an in-depth look at the experienced and anticipated impacts of climate change through water on ecosystems, agriculture, energy, and health in the region. Section 4 examines institutional mechanisms in place for water governance within the basin as well as commitments by each country government to adaptation. Section 5 proposes strategies for improving water and adaptation, and Section 6 discusses five key barriers to the development and implementation of adaptation strategies.

2. Water and Changing Circumstances in the Ganges River Basin

The Ganges is one of the largest river systems in the world and is shared by four countries: India, Nepal, Bangladesh, and China (Table 1).[1] The river originates in the southern slopes of the Himalayas, near the Gangotri glacier (elevation 4,500 m), at the border of India and China. As the Ganges River flows 2,525 km from its headwaters to the Bay of Bengal, its flow increases from large tributaries and decreases from large water diversions. In the Upper Ganges, water is diverted at Haridwar, India, into the Upper Ganges Canal, and at Narora, India, into the Lower Ganges Canal to irrigate nearly 9,000 km^2 of agricultural land in ten districts of Uttar Pradesh and Uttarakhand (Jain 2007). The Ganges River converges with the Yamuna River at Allahabad in Uttar Pradesh, India. From Allahabad, four major tributaries originating in Nepal—the Ghangra, Gandak, Buri Gandak, and Koshi—contribute significantly to water flow (approximately 70% of dry season flow and 40% of annual flows) and sediment discharge into the Ganges River (Alford 1992; Mirza 2004). Approximately 4 km south of the Farakka Barrage in India, the Ganges River splits into two channels. The main arm of the river enters Bangladesh approximately 18 km south of Farakka and joins the Brahmaputra at Goalundo, eventually flowing into the Bay of Bengal. The other arm of the River flows south into India's West Bengal and into the Bay of Bengal through India's Port of Kolkata. (See Figure 1 for a map of the Ganges river basin and see Figure 2 for a line diagram of the flow of the Ganges river.)

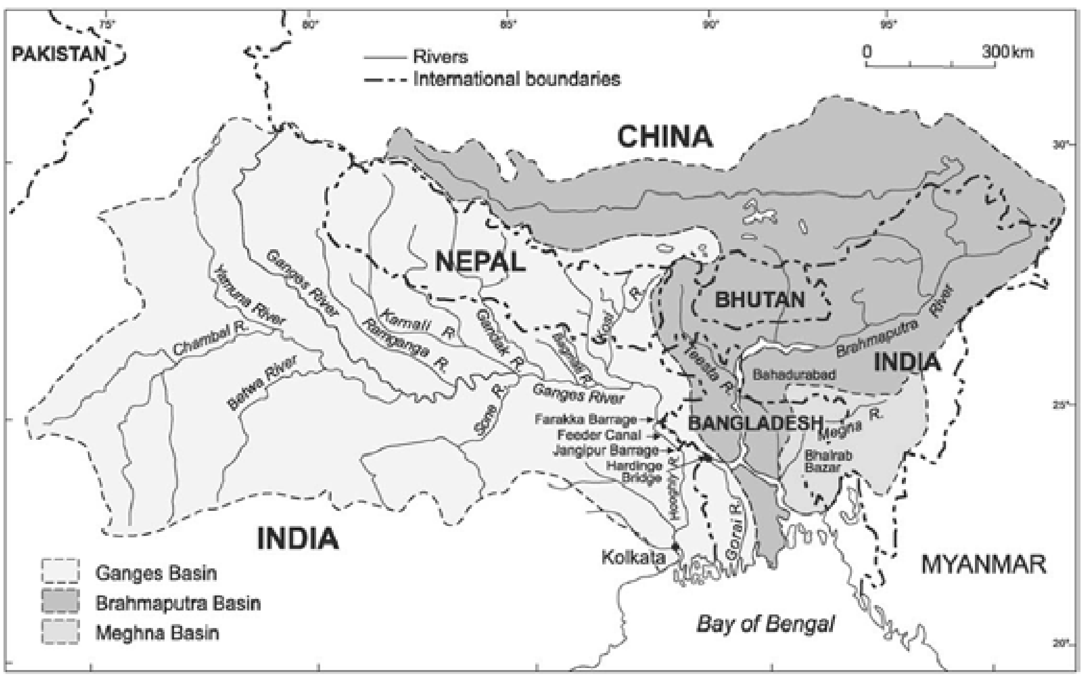
1 China is largely excluded from this working paper due to limited country-specific information.

Table 1. Drainage area of Ganges basin in India, Nepal, Bangladesh, China.

Country/State	Total geographical area (km^2)	Area in basin (km^2)	Percent of basin area in country
India	3,329,000	861,400	26%
Uttarakhand and Uttar Pradesh		294,410	
Madhya Pradesh		199,385	
Bihar		143,803	
Rajasthan		112,490	
West Bengal		72,618	
Haryana		34,271	
Himachal Pradesh		4,312	
Union Territory of Delhi		1,480	
Nepal	146,000	146,000	100%
Bangladesh	144,000	46,000	32%
China	9,596,960	40,000	0.04%

Source: Figures for total geographical area obtained from CIA (2009). Country-specific figures for area in the basin obtained from Pun (2004) and India state specific figures obtained from Jain et al. (2007).

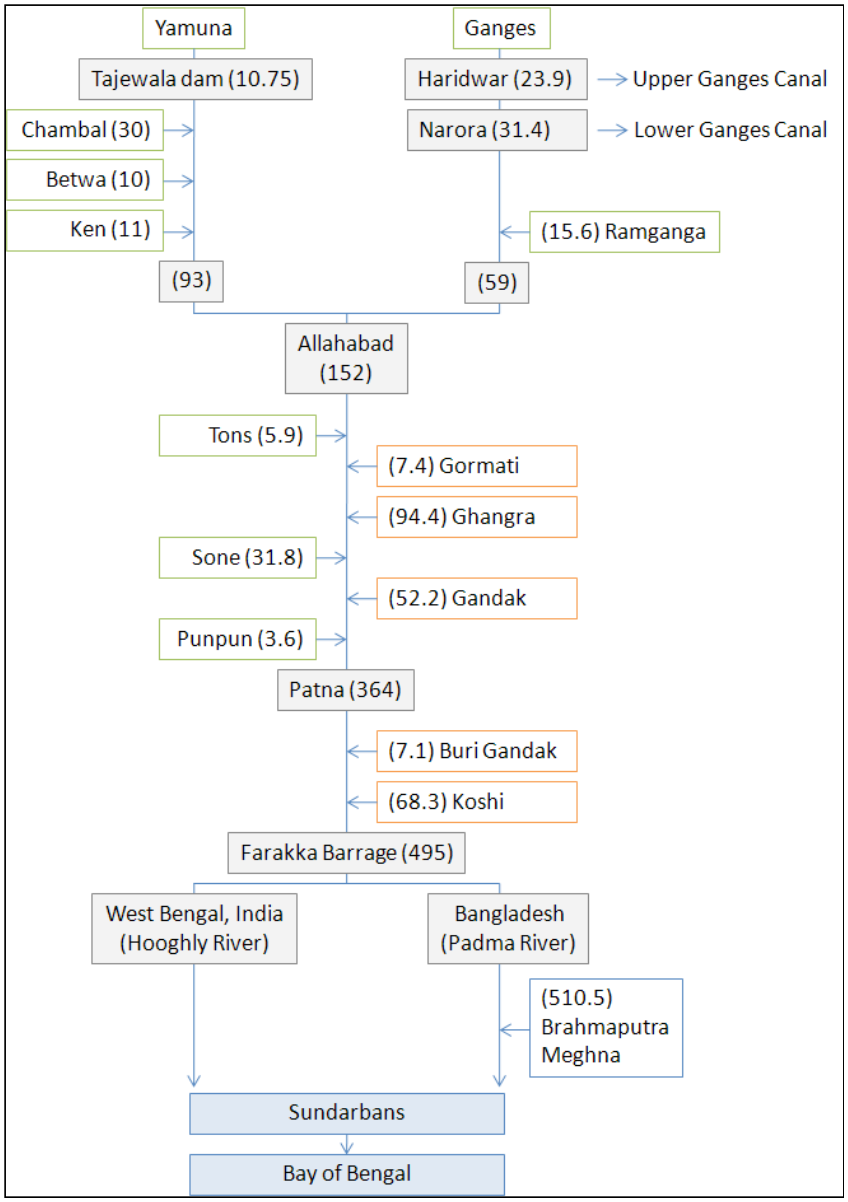
Figure 1. The Ganges, Brahmaputra, and Meghna river basins.



Source: Mirza (2002).

Groundwater is another important source of water supply in much of the Ganges river basin, and farmers are increasingly reliant on groundwater resources due to ease of accessibility, flexibility in controlling the resource, and its quality, which is often superior to polluted surface water (Jaitly 2009). It is estimated that about 34% of the groundwater in the Indian portion of the Ganges basin has been developed. The extent of this development varies considerably, with more than 80% of the resource developed in the drier western states of Haryana, Rajasthan and the western region of Uttar Pradesh, and only about one-fifth of the resource developed in the wetter eastern states (e.g., Bihar and West Bengal) (Sikka et al. 2003). The area irrigated from groundwater sources now exceeds irrigation from surface water systems (Shah 2009).

Figure 2. Line diagram of the Ganges river and its major tributaries. Tributaries originating in India are depicted in green boxes; tributaries originating in Nepal are depicted in orange boxes; and gauging stations are depicted in gray boxes. Numbers are average annual flows in billions of cubic meters (BCM).



Source: Adapted from Jain et al. (2007).

Changing circumstances

Patterns of water flow and utilization in the basin are changing. These changing circumstances are largely driven by a combination of changing climatic characteristics, population growth, economic development, and resource management practices.

Climatic Template

Climate is a major determinant of water supply in the Ganges river basin. The primary source of water in the basin is summer monsoons (June to September) and snowmelt from the Himalaya Mountains in Nepal and the Western Uttar Pradesh region of India. Monsoons provide a significant portion of the region's annual precipitation in only four months, which makes this region's climate the highest seasonal concentration and variability of rainfall in the world (World Bank 2009). During the dry months (December through February) water supply declines throughout the basin, significantly reducing outflow to the Bay of Bengal (Islam and Gnauch 2007; Karim 2004; Majumder 2004; Nishat and Faisal 2000). During these dry months, ice- and snowmelt from the region's mountains is critical. Moreover, when monsoons are weak or delayed, water supply from melting ice and snow may limit or avert catastrophic drought. Snowmelt from the Himalayans provides the Ganges river with approximately 9% of its flow (Jianchu et al. 2007; Barnett et al. 2005).[2]

The climate has been changing in the Ganges basin and, while uncertainty remains regarding the precision of various climate change predictions, forecasts suggest that changes in climate will further exacerbate the existing variability (Cruz et al. 2007).[3] In the Ganges basin, climate change is expected to increase temperatures, resulting in the retreat of glaciers; increase variability in precipitation, resulting in increased magnitude and frequency of droughts and floods; and lead to sea-level rise (Table 2).

Table 2. Country-wise climate risks for the Ganges basin countries.

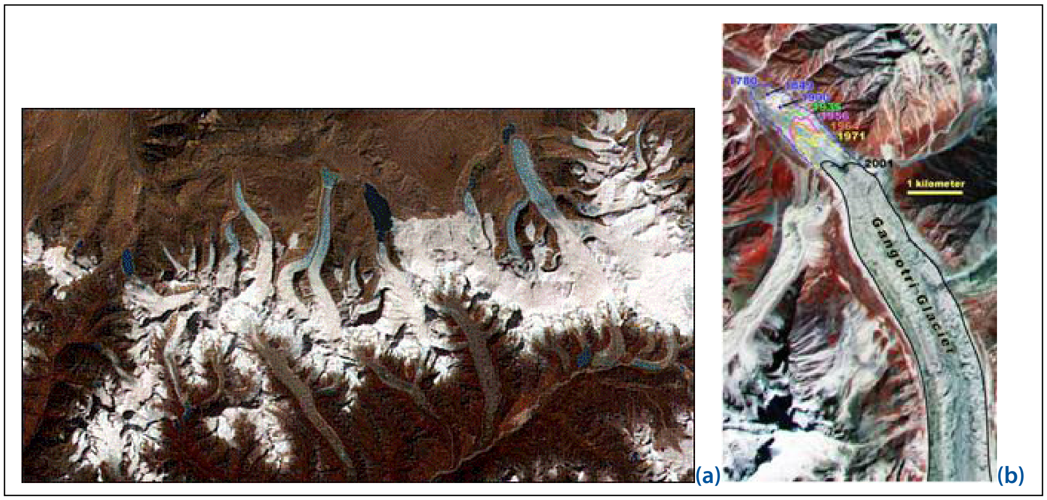
Climate risks	India	Nepal	Bangladesh
Temperature rise	High	Very high	High
Glacier retreat	High	High	—
Frequent floods	High	High	Very high
Frequent droughts	High	High in some areas	High in some areas
Sea-level rise	Modest	—	Very high

Extremes in maximum and minimum temperatures are expected to increase throughout South Asia (Cruz et al. 2007; Mirza 2007; see Table 3) and will vary regionally. To date, surface air warming has been progressively greater at higher altitudes (Liu and Chen 2000). Recent studies show that mean annual temperature in the northwestern Himalayas has increased 1.4° C in the last 100 years (Bhutiyani et al. 2009), whereas the global average temperature has increased 0.74° C (Parry et al. 2007). Increased warming at higher elevations is predicted to result in earlier thawing of snow and ice, formation of glacial lakes, and continued retreat of glaciers (Figure 3). Increased runoff from glacial retreat and ice- and snowmelt could increase annual discharge into the Ganges river in the short term, followed by a reduction of runoff in the long term. Because glacial and snow-covered regions are an important source of freshwater storage, climate change will significantly impact freshwater storage at high elevations and freshwater runoff to lower elevations (Jianchu et al. 2007).

2 Jianchu et al. (2007) note that the contribution of glacial melt to the Ganges river flow is based on limited data and should be taken as indicative only.

3 A high degree of uncertainty remains regarding climate predictions in general. This uncertainty is linked to low confidence associated with regional and local spatial resolution of current Global Circulation Models (GCMs), the inability of GCMs to reproduce weather extremes and climate anomalies, such as tropical storms, and limited confidence in modeled warming trends, rainfall distribution patterns, and seasonality.

Figure 3. ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) instrument aboard NASA's Terra Satellite shows (a) the termini of the glaciers in the Bhutan-Himalaya where glacial lakes have been rapidly forming on the surfaces of debris-covered glaciers and (b) the accelerated retreat of the Gangotri Glacier in India.



Source: NASA, 2002.

Extreme precipitation is also expected to increase in South Asia; severe rainfall is particularly expected over the west coast of India and west central India (Kumar et al. 2006). Storms are expected to intensify and rainfall is expected to increase considerably during the wet season (March to May) while precipitation will increase slightly in the monsoon season (June to August) and decrease during the dry season (December to February) (Table 3). Changes in precipitation are predicted to increase the intensity and frequency of extreme events, with potential for increased flooding during periods of high precipitation and droughts during periods of low precipitation.

Table 3. Projected changes in surface air temperatures and precipitation for South Asia under future emissions trajectories (A1F1, highest emission trajectory, and B1, the lowest emission trajectory) for three time periods.

Region	Season	2010–2039				2040–2069				2070–2099			
		Temp. (°C)		Precip. (%)		Temp. (°C)		Precip. (%)		Temp. (°C)		Precip. (%)	
		A1F1	B1	A1F1	B1	A1F1	B1	A1F1	B1	A1F1	B1	A1F1	B1
South Asia	DJF	1.17	1.11	-3	4	3.16	1.97	0	0	5.44	2.93	-16	-6
	MAM	1.18	1.07	7	8	2.97	1.18	26	24	5.22	2.71	31	20
	JJA	0.54	0.55	5	7	1.71	0.88	13	11	3.14	1.56	26	15
	SON	0.78	0.83	1	3	2.41	1.49	8	6	4.19	2.17	26	10

Source: Cruz et al. (2007).

Sea levels have been rising over the past five decades at a non-linear rate, and they are expected to continue to rise, although the long-term trend is unclear (Parry et al. 2007). Sea-level change will have direct impacts on salinity levels, sediment patterns, and ocean currents, and will enhance storm surges (World Bank 2009). Coastal areas will be major climate change induced impacts. Bangladesh is particularly vulnerable to sea-level rise.

Demographic Changes

The Ganges basin sustains approximately 500 million people, with 23 million in Nepal, 440 million in India, and 41 million in Bangladesh (Pun 2004). By 2025, this figure is expected to rise to 720 million people, with 37 million in Nepal, 634 million in India, and 49 million in Bangladesh (Pun 2004). The population density within the basin varies from less than two people per square kilometer in upper reaches of Nepal and China to more than 500 people per square kilometer in parts of Bihar, West Bengal, and Bangladesh. There are 82 large cities in the basin with populations of 100,000 people or more. The annual rate of population growth in each riparian country is fairly similar, with India maintaining a growth rate (1.5% per year) slightly larger than that of Nepal and Bangladesh (1.3% per year) (CIA 2009). The gradual population increase throughout the basin, coupled with increased demand for agricultural production, industrialization, and migration to urban centers within the basin, will contribute to increasing water demands over time (Rashid and Kabir 1998).

In the Ganges basin, there are abundant freshwater resources; however, large populations place considerable pressure on the availability of the basin's freshwater resources (Table 4). In particular, the Indian part of the Ganges basin has been experiencing water stress.[4] Projections for 2025 indicate that the Indian parts of the Ganges basin will be on the threshold of water scarcity. Surface water scarcity in the drier and more developed portions of the basin has led to high levels of groundwater pumping in India (Amarsinghe 2008).

Table 4. Current and projected per capita freshwater availability of Ganges basin countries.

Country	Ganges basin freshwater availability (billion cubic meters or BCM)			2001 Ganges basin population	2001 Freshwater availability in cubic meters per capita per annum	2025 Ganges basin population	2025 Freshwater availability in cubic meters per capita per annum
	Total	Surface	Ground				
Nepal	230	217	13	23 million	10,000	37 million	8,649
India	671	500	171	440 million	1,525	634 million	1,060
Bangladesh	218	197	21	41 million	5,892	49 million	4,449

Source: Pun (2004).

Socioeconomic changes

In addition to the demographic changes in the basin, economic growth and development aspirations in each riparian state will affect water utilization in the basin. According to 2007 estimates, annual Gross Domestic Product (GDP) growth rates for the riparian states were 5.6% in Nepal, 6.6% in India and 4.9% in Bangladesh (CIA 2009) (Table 5). Agriculture is an important sector in terms of its contribution to GDP as well as its use of freshwater resources. Despite high growth rates in the industrial and service sector, particularly in India, agriculture is likely to dominate the use of freshwater resources (Jaitly 2009). Moreover, as these countries continue to grow, and development aspirations and diets change, the demand for water from the Ganges as well as other international and national river systems in the region is likely to increase (Amarasinghe et al. 2008).

Table 5. Gross domestic product (GDP) and annual GDP growth rates by riparian country.

Country	Real GDP growth rate (%)	GDP per capita (PPP$)	GDP Composition by sector (%)			Freshwater withdrawal by sector, in 2000 (%)		
			Agriculture	Industry	Services	Agriculture	Industry	Domestic
Nepal	5.6	1,100	32.5	16.6	50.9	96.27	0.59	2.94
India	6.6	2,800	17.2	29.1	53.7	86.38	5.45	9.63
Bangladesh	4.9	1,500	19.1	28.6	52.3	96.22	0.65	3.19

Source: GDP figures are 2008 estimates obtained from CIA (2009). Freshwater withdrawal figures obtained from FAO, AQUASTAT database (2000).

4 The Falkenmark water stress index measures per capita water availability and defines per capita water availability between 1,000 and 1,700 cubic meters (m^3) per year as regular water stress; between 500 m^3 and 1,000 m^3 as chronic water scarcity, where the lack of water hampers economic development and affects human health and well-being; and below 500 m^3 as absolute water scarcity (Falkenmark and Widstrand 1992).

Water management practices

A final key factor influencing water availability and utilization patterns in the basin are changing water management practices, including the further development of new sources and facilities. The demand from the urban, agriculture, industrial, and energy sectors will drive the development of new diversions, storage facilities, and other infrastructure, as well as further development of groundwater (Scott and Sharma 2009), where resources are available. This will likely include new intrabasin transfers, such as the proposed Ken Betwa link in India (Alagh et al. 2006) and the Melamchi water supply project for Kathmandu in Nepal. Of particular importance in the Ganges basin will be the development of flood management capacity, and further development of hydropower. In some of the Ganges river sub-basins, the transfer of water from agriculture to urban areas and the transfer of water from lower- to higher-value production will continue. The increase in urban uses will have a commensurate effect on the volume of wastewater being discharged into the river system. Recognition of the need for in-stream flows and corresponding allocations would alter water availability in the basin.

In addition to supply management, conservation of water will also play a major role in changing practices in the basin, particularly with the further adoption of micro-irrigation techniques, promotion of groundwater recharge, and the planned reuse of water, although in volumetric terms the latter is likely to be relatively small.

Implications of changing circumstances

The climatic, demographic, socioeconomic, and ecological features that characterize patterns of water flow and utilization in the Ganges river have important implications for the quantity and quality of water resources in the basin as well as relationships among and within riparian states. While the impacts of climate change on key sectors are explored in-depth in the subsequent section, broad implications of changing circumstances are considered briefly here.

First, changing circumstances in the Ganges basin are contributing to detrimental fluctuations in water quantity and availability. Rising populations and the related increase in water demand for agricultural, domestic, and industrial uses and declining supply in the basin contribute to situations of water scarcity in the basin, particularly during the dry season and in specific sub-basins, such as the Kathmandu Valley. In addition to problems of too little water during the dry season, basin inhabitants are faced with problems of too much water in the forms of flooding and inundation as the result of increased precipitation and flows and inadequate water and land management.

Second, changing circumstances in the basin pose a threat to the quality of surface and groundwater resources in the Ganges river. The Ganges currently suffers from serious industrial, domestic, and agricultural pollution problems. More than 1.5 million cubic meters (m^3) of raw sewage, industrial effluent, and agricultural discharge are released into the Ganges every day as the river flows through the Indian states of Uttar Pradesh, Bihar, and West Bengal (Nishat and Faisal 2000). Among the tributaries of the Ganges, the Yamuna carries the entire sewage flow from Delhi, estimated at 350,000 m^3 per day, as well as an additional 260,000 m^3 of industrial waste from hundreds of factories along the river's banks, 6 million tons of chemical fertilizers, and approximately 9,000 tons of pesticides from agricultural practices in the basin (Sharma 2004). Groundwater in Uttar Pradesh, India, is contaminated due to improper disposal of industrial and municipal waste, as well as from permeating pesticides and insecticides from agricultural production (Krishna 2004). Groundwater in Bangladesh is contaminated by naturally occurring arsenic (Polizzotto et al. 2008; Smith et al. 2000). The incidence of arsenic contamination of groundwater in parts of West Bengal and Bangladesh has dangerously increased due to seasonal over-pumpage and a decline in the water table (Acharyya et al. 1999).

Finally, the cumulative changes in water quantity and quality have the potential to exacerbate existing tensions between groups trying to protect their interests at multiple scales. While the historical record has shown that globally, cooperation is more common than acute conflict where countries share international river basins (Wolf 2003), lower-level tensions between the riparian countries in the Ganges river basin are well documented[5] and may be exacerbated if the rapidly changing circumstances in the basin are not met with strong and coordinated strategies for adaptation. Taken together, these implications suggest that efforts to maintain water quantity and quality and riparian relationships within the Ganges basin will require the development, strengthening, and maintenance of adaptive water management systems that can both recognize and respond to the range of changes impacting the basin over time.

3. Intersection of Water and Climate Change on Key Sectors

The impacts of climate change through water will be felt across sectors. This section provides an in-depth look at how the experienced and anticipated effects of climate change on water resources will impact key sectors. Particular attention is paid to how changes in water quantity, quality, and extreme events are likely to affect ecosystems, agriculture, energy, and human health within the Ganges river basin. In doing so, this section highlights not only the critical consequences of climate change, but also the interconnectedness of each sector and the cross-cutting effects of various changing circumstances.

Ecosystems

Ecosystems are critical to water supply, water quality, and biodiversity in the Ganges river basin. Downstream productivity and human health depend on functioning upstream ecosystems. High-altitude wetlands store water, regulate seasonal flow regimes, recharge groundwater aquifers, and maintain biological diversity. These wetlands also provide goods, including food, fuelwood, timber, and medicine. In the Ganges basin, high-altitude wetlands are often a sacred place for local people. Downstream and coastal ecosystems protect against sedimentation, floods, coastal erosion, and storm surges.[6] These ecosystems are also critical to biodiversity. The Sundarbans, the largest mangrove forest in the world, contains 330 plant species; 400 species of fish; over 270 species of birds; 35 species of reptiles; and 42 species of mammals, including the world's last population of mangrove-inhabiting tigers (Majumder 2004). The Sundarbans also contribute to the local economy, accounting for 45% of the timber and fuelwood production in Bangladesh and generating local employment in both Bangladesh and India (Majumder 2004). The health of the entire Ganges river ecosystem is critical for water supply to millions of people and for regional economic development. The river ecosystem also supports large freshwater species, particularly the endangered Ganges River Dolphin and the rare freshwater shark.

Impact of climate change on water and ecosystems

Ecosystems in the Ganges river basin currently face serious threats, including land-use change, water pollution, invasive species, and overfishing. For instance, shrimp farming has been largely responsible for the 45% reduction of Bangladesh's mangrove wetlands (Khan et al. 2004). Climate change and other changing circumstances will continue to increase pressure on the region's already fragile ecosystems. Climate change will alter ecosystems largely through changes in water quantity and water quality, as well as through changes in biodiversity.

Changes in water quantity

Seasonal and permanent drying up of high-altitude wetlands, lakes, and streams and reduced seasonal stream flow can have significant impacts on water quantity. The drying up of streams and lakes for extended periods of time could reduce ecosystem productivity due to the impacts of lower oxygen levels on aquatic species. As dry seasons become longer and dryer, the functionality of high-mountain ecosystems to store freshwater and regulate flow regime may be compromised. Lower stream flows will have profound effects on

5 For a history of the dispute between riparian countries in the Ganges see Crow and Singh (2000); Nishat and Faisal (2000); Verghese (2001); and Gyawali (2003).

6 For details on the economic benefits of mangrove wetlands in protecting against storm surges, see Das 2007.

biodiversity and river ecosystem productivity within the Ganges river basin. Already reduced flows to the Sundarbans wetland ecosystem have resulted in salinity intrusion in the southwestern part of Bangladesh, loss of biodiversity, and loss of ecosystem functionality (Islam and Gnauck 2007). Increased salinity in the Sundarbans has driven natural selection to replace high-value timber species with low-value shrubs (Majumder 2004; Karim 2004). Climate change impacts could further reduce the winter flow of freshwater into the Sundarbans, which would be detrimental to the existing forest species, as well as other species and services provided by the wetland ecosystem.

Changes in water quality

Water quality will largely be impacted by increased sedimentation from more intense monsoons and storm surges and may be impacted by increased water temperatures in tributaries and freshwater ecosystems of the Ganges. High monsoon rainfalls between June and September have resulted in high sediment loads in the Ganges River (Hasnain and Thayyen 1999). Predicted increased intensity in storms and increased rainfall will increase sediment runoff, resulting in water quality problems for downstream species, particularly the Ganga freshwater dolphin, a keystone species currently threatened with extinction.

Increased water temperatures can disrupt or eliminate existing communities and species assemblage (Smith et al. 1996). Increased water temperature will have more dramatic effects in the tributaries, streams, and freshwater ecosystems of the Ganges river. Habitat for fish species with strict thermal tolerances, such as the Golden Mahseer found in the Indian Himalayas, will likely be reduced as water temperatures increase. Currently, however, there are no studies that indicate the affect of temperature increases on the range of species' habitat in the basin.

Changes in biodiversity

Freshwater ecosystems are less studied than terrestrial ecosystems, and their overall biodiversity is poorly understood. That said, the Millennium Ecosystem Assessment (2205) states that the highest rate of species decline is found in freshwater ecosystems. Climate change has already impacted freshwater biodiversity. Over the past 30 years climate change has shifted the distribution and abundance of species (Parmesan and Yohe 2003; Hughes 2000), changed species' productivity and growth (Hughes 2000), and has resulted in species' extinction (Pounds 2001). Future climate change is expected to increase rates of extinction (Thomas et al. 2004), particularly for species with restricted habitats or specialized niches. Species in low-lying areas can be affected by sea-level rise through salt water intrusion and inundation. Changes in water levels and seasonal flows can also influence feeding traits and spawning migrations (Poff et al. 1997) and changed the breeding season for migratory birds (Butler and Vennesland 2000). To date, there no substantial studies from the Ganges river basin that link climate change to biological changes.

Agriculture

Globally and within South Asia, agriculture will be significantly impacted by the effects of climate change on water. The use of water for agricultural production varies throughout the vast Ganges river basin. In the upper catchments of the basin, within the Himalayas, agricultural production is relatively low (Sharma et al. 2009). In contrast, the agricultural sector in the western portion of the basin is highly developed and relies on large-scale surface water and groundwater irrigation facilities to produce rice, wheat, and other rice-based cropping systems. Cotton, sugar cane, and other high-value crops are also under production in the western portion of the basin and require relatively reliable water supplies (Amarasinghe et al. 2008). Rice, wheat, and rice-fish cultivation is prominent in the eastern part of the basin, spanning Bangladesh and the eastern Terai. Despite the water abundance in the eastern portion of the basin, agricultural production has thus far been less productive due to institutional, social, and economic constraints, including transboundary governance disputes and frequent floods. In the south and southwestern portions of the basin, rainfed oil seeds and pearl millet constitute the primary crops under production.

Historically, large-scale agricultural production in South Asia has been associated with public irrigation systems developed during the "green revolution." Presently, however, production throughout the basin relies heavily on surface and groundwater irrigation in combination with rainfed production. Recent studies indicate that the area irrigated from groundwater in India now exceeds that from surface water, with reliance on groundwater in the agricultural sector expected to grow in the future (Amarasinghe et al. 2008). While knowledge is still lacking regarding the precise characteristics of groundwater resources throughout the Ganges river basin, initial estimates suggest that aquifers in the western portion of the basin may be nearing over-abstraction, while groundwater resources in the eastern part of the basin remain underdeveloped (Shah 2009; Jain et al. 2009).

Impact of climate change on water and agriculture

As described above, agriculture in the Ganges basin will be significantly impacted by the effects of climate change on water. This section examines the impacts of climate change on the agricultural sector through changes in water quantity, increased occurrence of extreme events, and through changes in surface air temperature.

Changes in water quantity

The increased uncertainty of the availability of water from direct rainfall, surface runoff, and groundwater recharge as a result of climatic variation and other changing circumstances has serious implications for agricultural and food production throughout the basin. Rainfed systems, vital to the production of most of the staple crops in the region, are highly susceptible to changes in precipitation patterns. The increased uncertainty in precipitation due to climate change, coupled with the relatively low productivity of staple crops, may discourage investment in this area of the agricultural sector. Changes in precipitation, natural storage, and surface water runoff from the Himalayas will also threaten the operation of surface water irrigation systems. Predictions show that warming climate may enhance the availability of surface runoff through the melting of glaciers in the short- and medium-run and reduce supplies in the long run (Barnett et al. 2005). Himalayan glaciers have shown an overall reduction from 2,077 km^2 in 1962 to 1,628 km^2, an overall deglaciation of 21% (Kulkarni et al. 2007). This has important ramifications for the western portion of the basin in particular, where the variability of anticipated flows and inadequacies of the drainage systems may affect output in the basin's most productive agricultural region. While more work is required to understand the projected impacts of climate change on groundwater recharge globally and within the basin, diminishing rates of recharge would affect groundwater irrigation systems throughout the basin.

Extreme events

In addition to the impacts felt on the agricultural sector due to changes in water quantity, the anticipated effects of climate change on extreme events will also impact the agricultural sector in the Ganges river basin. Higher storm surges, increased flooding and droughts, and rising sea levels will all disrupt existing agricultural systems in the basin.

Photo library, Groundwater Governance in Asia Project, IWMI, New Delhi (Bharat Sharma/ Aditi Mukherji)

Inundation and salinization associated with sea-level rise, for example, are threatening the productivity of agriculture in coastal areas (e.g., Sundarbans) within the basin. The projected increase in droughts, floods, tropical cyclones, heavy precipitation events, and heat waves will result in greater instability in food production and threaten the livelihood security of farmers.

Changes in air surface temperature

Finally, changes in temperature associated with climate change will impact agricultural productivity and water-use patterns throughout the basin. The elevated temperatures caused by climate change are expected to increase evapotranspiration rates and extend growing seasons, both of which could lead to increased water demands. Research is under way to determine more precise impacts of this anticipated change as well as the possibility that increased evapotranspiration may in part be offset by higher CO_2 levels that alter other elements of plant physiology, but the overall expectation is that additional water resources may be needed to maintain current levels of productivity (Svendsen and Kunkel 2009). Within the Ganges basin it is estimated that the productivity of wheat may decline over a wide range due to enhanced temperatures, but that the productivity of rice and soybean may be enhanced due to higher temperatures and higher CO_2 levels (Patil et al. 2009).

The combined impact of these factors is estimated to result in the loss of 4–5 million tons in wheat production with every rise of 1° C temperature throughout the growing period. Losses for other crops, especially kharif crops, are still uncertain but they are expected to be smaller (Rai et al. 2009).

Energy

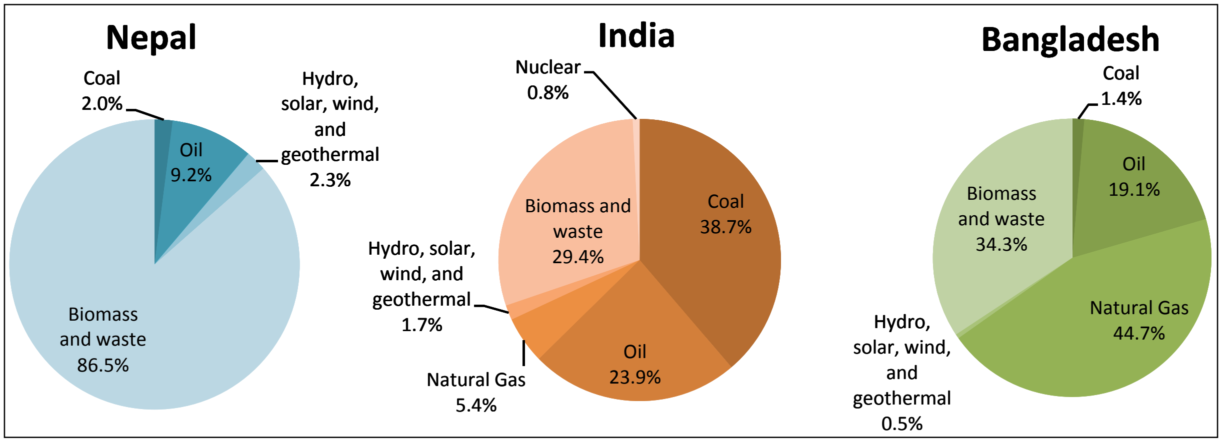
Energy consumption in the countries of the Ganges river basin is low (Table 6), and currently energy is largely supplied by biomass (Figure 4). Demand for energy, however, is high in the basin, resulting in common—and costly—energy shortages. In Bangladesh, electricity generation capacity is approximately 4,300 megawatts (MW), with a peak output of 3,500 MW to 3,800 MW on most days (Nishat 2001). Peak demand, however, often exceeds 5,000 MW (Nishat 2001). The poor quality of power supply in Bangladesh costs the country as much as 2% in GDP growth each year and manufacturers have indicated that power shortages cost them around 12% in lost sales annually (World Bank 2003). In India, energy demand has been growing at an annual rate of 5.7% in recent years (Srivastava and Misra 2007). By 2012, Northern India is estimated to need an additional 34,000 MW and the whole of India is expected to require an additional 100,000 MW by 2017 (Karki 2006). In Nepal, demand is currently supply-driven, and more than 60% of the population still lack access to electricity, primarily in the rural areas of the country (WECS 2005).

Table 6. Global and Ganges basin countries per capita commercial energy consumption in 1990, 2000, and 2005.

Per capita energy consumption in kilograms of oil equivalent (kgoe)	Ganges basin countries			Global
	Nepal	India	Bangladesh	
1990	304	377	123	1,668
2000	334	452	145	1,657
2005	338	491	171	1,778

Source: International Energy Agency (IEA) Statistics Division (2007), in UNDP (2007).

Figure 4. Ganges basin countries commercial energy consumption in 2005.



Source: UNDP (2007).

Given Nepal and Northeastern India's abundant supply of water and mountainous terrain, the region has the potential to generate a large amount of hydroelectric power. Nepal's hydroelectric potential, for instance, has been estimated at 42,000 MW (WECS 2005). To date, the country has harnessed less than 2% of its potential, and all but 92 MW of Nepal's hydropower is from run-of-river schemes with daily pond storage (WECS 2005). Development of hydropower in Nepal has been slow, largely as a result of the recent conflict, financial constraints, and access to markets (Nishat 2001). That said, the country has identified hydropower as a priority export commodity and forecasts meeting the country's electricity demand over the next 20 years and exporting approximately 100 MW by 2012, 450 MW by 2017, and 700 MW by 2027 (Table 7). Nepal's forecasted electricity export is far lower than the regional demand. In India, hydroelectric potential has been calculated at 64,744 MW, with 36% of this potential in the north region and about 48% in the northeast region of the country (Bhatia 2007). Currently, there is approximately 22,000 MW of installed capacity, or roughly 30% of the total hydropower potential of the country[7] (Ministry of Renewable Energy 2007). Development of India's hydropower has been constrained by competition from the agricultural sector, concerns over the potential ecological damage, displacement of people, and institutional bottlenecks (Briscoe and Malik 2006).

Table 7. Electricity demand forecast for Nepal in megawatts (MW).

Year	Demand (MW)	Electricity production (MW)	Export (MW)
2012	960.1	1,076.6	116.5
2017	1,355.4	1,794.6	439.2
2022	1,894.6	2,480	585.4
2027	2,661.4	3,345	683.6

Source: Nepal National Water Plan (2005). The NWP uses the Power Sector Master Plan base-case scenario for future demand forecast for electricity. It assumes undertaking of proposed schemes and a long-term growth rate of about 7.4% per year.

Impact of climate change on water and energy

Hydropower is adversely affected by variations in water availability as a result of erratic precipitation, rapid glacial recessions, and extreme events.

Changes in water quantity

Many of the rivers with hydropower potential have snow and glacial area in their upper catchments and traverse through deep valleys and gorges. Any change in river storage or discharge patterns can have profound impacts on the hydropower potential of this region, and can affect investment confidence in the state's

7 See Hydropower in India: Small Hydropower Programme. Ministry of Renewable Energy, Government of India, http://mnes.nic.in (accessed August 6, 2009).

hydropower schemes. Decreased river flow in the upper catchments of the Ganges river and its tributaries as a result of changes in precipitation patterns, particularly monsoons, and glacial retreat may diminish potential hydropower generation in the region.

Change in water quality

Increased sedimentation from more intense monsoons and storm surges, as predicted in the region, coupled with already high sediment load from natural processes, deforestation, mining, intensive agriculture, and landslides within the basin, will adversely affect dam storage capacity and hydropower generation.

Extreme events

Increased frequency and magnitude of extreme events, particularly flooding, can increase potential damages to hydropower facilities and impact energy production from these facilities. Moreover, glacial and snowmelt in the Himalayas has resulted in the formation or expansion of glacial lakes behind terminal moraines (Eriksson et al. 2009). The moraine dams are often weak and unstable, and can breach suddenly (Jain 2001). Referred to as a glacial lake outburst floods (GLOFs), the breaking of a high-elevation moraine dams can result in catastrophic torrents and floods, devastating downstream communities, infrastructure, and ecosystems. The frequency of GLOF events has increased in recent decades, and 204 glacial lakes in the Himalayan mountains have been identified as potentially dangerous (Eriksson et al. 2009). Increased potential for GLOFs can affect investment confidence in new hydropower projects.

Health

Millions of people die each year from diseases brought on by poor water quality, water shortages, or floods. According to Pruss-Ustun et al. (2008), one-tenth of the global disease burden could be prevented through improved water supply, sanitation, hygiene, and management of water resources. The large population of the Ganges river basin (CIA 2009; Table 4), high poverty rates (MDG 2008), and susceptibility to extreme events increases human health risks within the basin. Moreover, human health is largely impacted by adverse effects of climate change on the agricultural sector and freshwater ecosystems.

Photo: Peter G. McCornick

Impact of climate change on health

The experienced and anticipated effects of climate change on water resources pose a number of challenges for the health sector in the Ganges river basin. Changes in water quality and quantity and extreme events are likely to contribute to or exacerbate problems of malnutrition, disease, loss of life, loss of property, population displacement, and poverty.

Accessibility and adequacy of drinking water

The combination of climatic, demographic, and water-use changes in the Ganges basin is contributing to increasing levels of water scarcity in certain areas. Estimates suggest that in certain areas of India, water supply will decline by 2050 (Morrison et al. 2009). This lack of access to water has serious health implications, not only for direct water consumption, but also for cooking, sanitation, and agricultural and industrial production for which water is a vital component.

In addition to the impacts of water quantity on drinking water, climate variation is also likely to affect the quality of the water in the Ganges river basin. Changes in precipitation, temperature, humidity, and salinity have a measurable effect on the quality of water used for drinking. Intense groundwater pumping in the basin is also threatening water quality in certain areas (UNEP 2008). Increased sedimentation, algal and bacterial blooms, and saltwater intrusion as a result of climate change have the potential to compound serious water quality concerns in the Ganges basin related to the introduction of industrial pollutants and the natural occurrence of high levels of arsenic in the river.[8]

Malnutrition

The impact of climate change in the agricultural sector is likely to have secondary effects throughout the health sector. Current estimates suggest that crop yields within South Asia could decrease up to 30% by the mid-21st century as a result of climate change (World Bank 2009). Unless the decline in production is compensated for by efforts to improve agricultural productivity or increase importation and better distribute food throughout the region, the risk of malnutrition will likely increase throughout the basin. Malnutrition will further increase the vulnerability of those affected to infectious and water- and vector-borne diseases.

Disease

There are a range of factors contributing to the transmission of water-borne diseases in the Ganges river basin, some of which are likely to be bolstered by the anticipated effects of climate change. For instance, E. coli is currently present in the Ganges river basin in Varanasi, India (Hamner et al. 2007), largely due to lack of a proper sewage collection and treatment system, with most of the city's sewage being released untreated into the Ganges river. Consequently, individuals using the river for religious bathing, washing laundry, and cooking are vulnerable to contracting E. coli infections and other water-borne diseases. The use of wastewater in agricultural irrigation, which is practiced in many of the major cities in the basin, exposes workers' risk to water-borne diseases and presents a significant health threat to urban populations where the produce irrigated by wastewater are marketed (Scott et al. 2004). Extreme events, exacerbated by the effects of climate change, have the potential to overwhelm existing sewage and water treatment systems and contribute to the prevalence of diseases such as diarrhea and cholera.

Disease outbreak is common after flooding; water-borne diseases and toxic contamination are particularly problematic if access to clean water and sewer systems is limited. Increases in diarrheal disease, cholera, dysentery, and typhoid are of specific concern (World Bank 2009). For instance, an outbreak of cholera-induced diarrhea was caused during flooding in West Bengal, which resulted in 276 deaths (Sur et al. 2000). In 2004, more than 17,000 cases of diarrhea outbreak were found after flooding in Bangladesh (Watson et al. 2007). Several studies have associated previous floods in Bangladesh and India with outbreaks of diarrhea (Kunii et al. 2002; Mondal et al. 2001; Biswas et al. 1999). Flooding may also increase the risk of vector- and rodent-

8 For more information about arsenic contamination in the Ganges, see Polizzotto et al. (2008) and Smith et al. (2000).

borne diseases. After flood events, stagnant water provides breeding grounds for mosquitoes, which supports the spread of malaria (Ahern et al. 2005). High temperatures and favorable precipitation patterns can prolong the transmission of diseases. In Bangladesh, prolonged breeding periods have increased the breeding rates of mosquitoes, thus accelerating the transmission of Japanese encephalitis virus (Shahid 2009).

Loss of life and property

In 2007, floods resulting from monsoon rains killed over 2,000 people and displaced more than 20 million people in Bangladesh, India, and Nepal (World Bank 2009). Cyclone Sidr, which struck the coastal and central areas of Bangladesh in 2007, caused over 3,400 deaths, injured over 55,000 people, and destroyed houses, crops, livestock, trees, educational facilities, and infrastructure (UNEP 2008). Droughts can also result in loss of life and property. A study in Bangladesh, for instance, found that drought and lack of food increase the risk of mortality from diarrheal illness (World Bank 1990). As extreme events become more intense and frequent due to climate change, risks to human health will continue to increase and the destruction caused by such events will have far-reaching implications for human health.

Poverty and displacement

Poverty rates in the Ganges basin are already high, making the region vulnerable to poor health conditions. The effects of climate change on water resources within the basin may further exacerbate poverty levels. For example, industries dependent on freshwater resources (i.e., agriculture and fisheries) may be harmed by climate change impacts resulting in the loss of employment, income, and livelihoods for inhabitants of the basin. Rises in the frequency of floods are also likely to affect household income sources in coastal areas and mega-delta regions (UNEP 2008).

Droughts, floods, and other extreme events in the Ganges basin result in the displacement of populations and the attendant loss of livelihoods. In 2008, the Koshi river changed its course, inundating downstream areas, particularly the Indian state of Bihar. Severe flooding affected millions of people and left hundreds of thousands homeless (Sunil 2008). Internal or transboundary displacements increase human susceptibility to disease and mental health problems. Anxiety, depression, and post-traumatic stress disorder are common after severe weather events (World Bank 2009). Population displacement or migration may also lead to an increase in communicable diseases and malnutrition as a result of scarcity of water and food (Menne and Bertollini 2000) and improper sanitation.

4. Current Commitments to Adaptation

International adaptation principles and frameworks

The United Nations Framework Convention on Climate Change (UNFCCC) has been at the center of developing principles and frameworks for international climate change. The Convention, ratified by 192 countries, requires signatory countries to adapt to anticipated impacts of climate change and to cooperate in preparing for this adaption (UNFCCC 2007a). Nepal, India, and Bangladesh are members of the UNFCCC. To facilitate adequate adaptation to climate change at the national level, the Convention provides member countries with guidelines under the National Adaptation Programs of Action (NAPA). The NAPA is a requirement for receiving adaptation funding under the Convention's Least Developed Countries Fund. Bangladesh has developed its NAPA, and Nepal is in the process of doing so as well (see section on Bangladesh below for more information). In addition to the Least Developed Countries Fund, the Convention has three additional funding sources for adaptation: Strategic Priority on Adaptation, Special Climate Change Fund, and Adaptation Fund (see Porter 2008; UNDP 2007; Bouwer and Aerts 2006).

Regional water adaptation initiatives and treaties

At the regional level there have been a number of multilateral and bilateral discussions about water and adaptation. The South Asia Water Initiative is a multilateral water initiative, with potential to be a platform for adaptation discussions. The Mahakali Treaty and the Ganges Water-Sharing Treaty are bilateral agreements signed by India with Nepal and Bangladesh, respectively. These treaties are described in more detail below.

Multilateral

The South Asia Water Initiative (SAWI) was launched by seven countries that share waters draining from the Greater Himalayas—Afghanistan, Bangladesh, Bhutan, China, India, Nepal, and Pakistan—and is facilitated by the World Bank to encourage cooperative management of shared waters. The initiatives will bring together senior government officials from each country to develop knowledge, relationships, and capacity for cooperation.

Bilateral

Where national boundaries intersect river basin and aquifer systems, they separate sovereign nations with distinct interests, management policies, legal frameworks, and political practices, creating potential barriers to the coherent regulation and management of the water resources as a whole (Kistin and Ashton 2008). In the absence of a supranational authority responsible for governing such internationally shared resources, countries can address these differences by developing principles, rules, and decision-making procedures to jointly govern and regulate the management of internationally shared waters (McCaffrey 2001). Over the last century, the riparian countries in the Ganges river basin have established a variety of institutional mechanisms for managing shared waters (Tables 8 and 9). Overall, however, the level of collaboration and implementation has been low. Improving the nature and outcomes of cooperation between all three riparian countries in the Ganges basin will be critical step for enabling adaptation (see Sections 5 and 6).

Upstream, Nepal and India have entered into a number of agreements regarding power and water sharing. As Table 8 illustrates, attempts between the two countries to jointly develop water resources for irrigation, power generation, and flood mitigation extend back nearly a century. Early agreements between the two countries facilitated the construction of joint water management projects in addition to Indian aid for hydroelectric development within Nepal (IPPAN and CII 2006). Yet, despite the number of agreements reached and joint studies undertaken, India and Nepal have made little progress on the implementation of more recent projects due to substantial political tensions between the two countries (IPPAN and CII 2006; Gyawali 2003; Verghese 2001). Development of the proposed Karnali (Chisapani), Pancheshwar, and Koshi High Dam projects have been under discussion for over 30 years with little progress. More recently, India and Nepal signed a bilateral agreement on the electric power trade. While there have been several challenges for the implementation of this agreement, it has helped to pave the way for international, public-private collaborations for the joint development of hydropower and electricity (IPPAN and CII 2006).

Table 8. Agreements between India and Nepal pertaining to water resources in the Ganges basin.

Year	Agreement	Details and Implications
1920	Agreement on the construction of the Sarada Barrage	India (under British rule) traded land for the construction of the barrage on the Mahakali. Allocates irrigation water to Nepal.
1954	Agreement on the construction of the Kosi Barrage	Established joint project to generate hydropower, increase irrigation, and mitigate flooding. Amended in 1966.
1959	Agreement on the construction of the Gandak Barrage	Established joint project to generate hydropower, increase irrigation, and mitigate flooding. Amended in 1964.
1971	MOU regarding the importation of electricity	Specified provisions for importing electricity to Nepalese border towns from the power grids of Uttar Pradesh and Bihar.

Year	Agreement	Details and Implications
1978	Agreement establishing the Nepal-India Joint Committee	Tasked with investigating the feasibility of the Pancheshwar Dam on the Mahakali.
1987	Agreement establishing the Joint Commission	Committed parties to cooperation in the areas of economics, trade, transit, industry, and water.
1988	Agreement on the development of the Karnali (Chisapani) project	Committed parties to the joint investigation of the Karnali (Chisapani) project with an estimated generation capability of 10,800 MW.
1995	Agreement on the construction of the Tanakpur Barrage	Committed parties to the joint investigation of the Tanakpur project with an estimated 120 MW hydroelectric capability.
1996	Agreement on the integrated development of the Mahakali river	75-year life span. Established guidelines for the development and management of the Mahakali river, including Sarada Barrage, Tankapur Barrage, and the proposed Pancheshwar Dam.
1996	Agreement on the Electric Power Trade	50-year life span. Allows any party in either country to enter into an agreement for power trade between Nepal and India (including semi-governmental and private enterprise).

Downstream, India and Bangladesh have also established multiple agreements regarding shared water resources in the Ganges. As Table 9 shows, the issue of dry season allocation at Farakka Barrage has been a major issue and source of tension between the two countries. Shortly after the Barrage became operational and India commenced with diversions from the Ganges to the Port of Calcutta, Bangladesh complained about the adverse impacts of the diversion during the dry season and appealed to the United Nations in protest of India's withdrawal (Verghese 2001). Subsequently, the two countries attempted to manage dry season allocations through a string of interim agreements and Memoranda of Understanding. While they succeeded in establishing interim management protocols, the discussions were fraught with tensions. No resolution was reached for the dry season of 1985 as the result of political disputes and the countries never agreed on joint strategies for the augmentation of flows at Farakka. In 1996, the parties came to a longer-term agreement (30 years) for the management of flows during the dry season, but challenges for implementation and quelling political disputes still remain.

Table 9. Agreements between India and Bangladesh regarding water resources in the Ganges basin.

Year	Agreement	Details and Implications
1972	Treaty establishing the Joint Rivers Commission (JRC)	Treaty designed to address water resources development and allocation, flood management, and border specification. JRC tasked with determining dry season flows at Farakka Barrage, which became operational in 1975 .
1977	Interim agreement for the management of dry season flows at Farakka	Specified water use between January and May for 5 years. Allocated 34,500 cusecs (cubic feet per second) to Bangladesh and 20,500 cusecs for Calcutta port during the leanest 10-day period (21–30 April). Specified schedule on 10-day basis with a minimum of 80% flows to Bangladesh. Established Joint Committee established to implement agreement and consider joint projects to augment flows. Expired in 1982.
1982	Memorandum of Understanding (MOU) for managing dry season flows at Farakka	Specified water use between January and May for 2 years. Introduced provisions for burden sharing as opposed to minimum flows. Mandated pre-feasibility studies of augmentation proposals.
1985	MOU for managing dry season flows at Farakka	Specified water use between January and May for 3 years, starting in 1986. Reiterated provisions for burden sharing. Called for revised augmentation proposals.

Year	Agreement	Details and Implications
1996	Treaty for sharing Ganges waters at Farakka for the dry season	Specifies water use between January and May for 30 years. Mandates a roughly 50-50 split of dry season flows at Farakka with 3 guaranteed 10-day periods in which when each party gets 35,000 cusecs. Calls for increased cooperation in resolving dry season allocation disputes. Separates issues of water sharing from water resource augmentation.

National adaptation policies and planning

Adaptation policies and planning vary by country within the Ganges basin and are influenced largely by existing water and other sectoral laws and policies. This section provides a brief overview of national water governance structures for Nepal, India, and Bangladesh and describes the country's current commitments to adaptation.

Nepal

In 1956, Nepal began a planned process of development. The National Planning Commission has been responsible for the planning process, developing periodic national plan documents. The process is largely oriented towards a top-down approach; although there have been attempts to orient it towards a bottom-up approach in recent years. In addition to national plans, the country has developed a number of sectoral plans, such as the Agricultural Perspective Plan, Forestry Master Plan, Irrigation Master Plan, River Basin Master Plans, and the Tourism Master Plan. In contrast, water resource planning and development has been slow. This is largely due to the decentralized nature of water planning in the government. Nepal has over thirteen ministries and several more departments and agencies that have a stake in the country's water sector. In 1981, Nepal created the Water and Energy Commission Secretariat (WECS) as an overarching body to assist government entities in formulating water-related policies and projects in a way that coordinates their efforts. WECS has been responsible for developing the National Water Plan (NWP) to strategically identify output activities that contribute to maximizing the sustainable benefits of water use (WECS 2005). The NWP was finalized in 2005 and embraced the key policy principle of Integrated Water Resources Management (IWRM), in which the development and management of water resources is undertaken systematically and each river basin is managed holistically (WECS 2005).

Nepal's NWP (2005) recommends research on climate change and its impact on the environment in one of its ten Action Programs (WECS 2005) and indicates that the country's Department of Hydrology and Meteorology will establish a Himalayan Climate Change Study Center since Nepal is in a "unique position to study the cycles and trends of the ongoing climate change in Asia" (WECS 2005: 51). Nepal's Ministry of Environment, Science, and Technology (MoEST) is also in the process of developing a national climate change policy. In order to access funds from the UNFCCC's Least Developed Country Fund, Nepal is developing a National Adaptation Program of Action (NAPA). World Wildlife Fund-Nepal is working closely with MoEST on the NAPA.

India

India has a long history of water development; however, prior to 1987 no well-documented water policy exists for India. In 1987, the country finalized its National Water Policy as an umbrella policy to be supported by various states' water policies and sectoral policy documents. To date, many states have formulated their state policies; however, state policies rarely consider the physical, geopolitical, and economic situation of the state (Mohile 2007). In 2002, the National Water Policy was revised to incorporate the Integrated Water Resource Management (IWRM) principles; it now places a larger emphasis on river basin management and environment-related concerns (Mohile 2007).

On June 30, 2008, Prime Minister Manmohan Singh released India's first National Action Plan on Climate Change (NAPCC), which outlined existing and future policies and programs to address climate mitigation and adaptation. The plan identifies eight core "national missions" running through 2017. The National Water Mission aims to ensure integrated water resource management aimed at conserving water, minimizing waste, and ensuring more equitable distribution across and within states. Also relevant to water and climate change adaptation, the National Mission for Sustaining the Himalayan Ecosystem aims to conserve biodiversity, forest cover, and other ecological values in the Himalayan region where glaciers that are a major source of India's water supply are projected to recede as a result of global warming. These missions are to be institutionalized by the respective ministries and each mission will be tasked to evolve objectives through 2017.

Bangladesh

Bangladesh has been relatively progressive in water resource management, as well as in planning for climate change adaptation. The country has developed a series of water and flood management policies and plans, with the most recent being the National Water Management Plan, approved in 2004 (MOWR 2004). The investments in such plans have produced comprehensive and relatively accessible information bases, and developed the in-country capacity to undertake rigorous simulations and other decision support activities, among other things.

As one of the countries most naturally vulnerable to climate change, Bangladesh has taken steps over the past few years to become better prepared, and thus, less vulnerable to climate change. In the 1970s Bangladesh began to develop an early warning system to decrease the impact of natural hazards on its population and economy. The system has been continuously updated; a number of these early warning improvements helped reduce mortality during the 2007 Cyclone Sidr, which killed approximately 40 times fewer people than a 1991 cyclone of similar magnitude (IRIN 2007). In 2005, Bangladesh developed its NAPA, and in 2008, the country adopted the Bangladesh Climate Change Strategy and Action Plan (BCCSAP). The BCCSAP, prepared by the Ministry of Forests and Environment in consultation with all relevant stakeholders, is a ten-year plan to build Bangladesh's capacity and resilience in meeting the climate change challenge. In the first five years (through 2014), the plan estimates a financial need of about $5 billion. The government of Bangladesh has recently established a Climate Change Fund from its own resources with an initial capitalization of $45 million. To complement the government's initiative, a Multi-Donor Trust Fund for Climate Change has been established by development partners in Bangladesh, which is to be administered by the World Bank with a proposed initial contribution of about $100 million.

5. Strategies for Adaptation

Given the impacts of changing circumstances on key sectors through water, this section looks at seven key strategies for adaptation in the Ganges river basin. The concept of adaptation, or coping with changing circumstances, is not new to water users and managers. As Kundzewicz (2007) notes, "adaptation to changing conditions in water availability and demand has always been at the core of water management." In outlining these seven strategies, this section emphasizes that adaptation to climatic variation and other changing circumstances should not be viewed as a separate project, but rather a goal and perspective that must be incorporated into every level of planning and decision making. The section highlights some of the existing strategies for adaptation in the Ganges river basin and acknowledges the need for additional research to identify other adaptations currently under way at the local, national, and international levels and the factors that have enabled and constrained their success.

Enable flexible institutions and facilitate interscalar and intersectoral collaboration

At its core, the process of adaptation requires the ability to recognize and respond to changing circumstances. Strategies for enhancing this ability include the incorporation of flexibility mechanisms into water agreements and regulations and the facilitation of thinking, planning, implementation, and monitoring across scales and sectors.

Incorporating flexibility mechanisms into agreements and regulations

International agreements over shared water resources and national and state water policies establish rules, regulations, and decision-making procedures that help to stabilize expectations regarding water deliveries, utilization, and demand (McCaffrey 2003; Fischhendler 2004). Worldwide, existing freshwater agreements are often ill-equipped for the multitude of changes impacting the social and ecological systems they aim to address (Goldenman 1990; Dellapenna 1999). Incorporating mechanisms into water agreements and regulations that anticipate climate change and other changing circumstances will be critical for enabling adaptation in the Ganges river basin. McCaffrey (2003) and Fischhendler (2004) identify at least four sets of flexibility mechanisms relevant to water agreements and regulations in the Ganges:

1. flexible allocation strategies that divide resources not on the basis of fixed volumetric quantities, but according to alternative measures, such as the percentage of flow contributed by each party or the timing and duration of river flows[9];

2. drought response provisions that include allowances for diminished water deliveries in exceptional circumstances, allowing parties time to respond to crises while keeping the existing agreement intact;

3. mechanisms for amendment and review that provide parties with an opportunity to establish guidelines for unforeseen circumstances and to resynchronize national and basin-wide strategies in light of new knowledge and/or changing circumstances; and

4. granting management organizations at various levels the power and jurisdiction to undertake and adjust management practices as necessary.

As noted in Section 4 of this paper, the three major riparian countries in the Ganges basin have made national-level commitments to adaptive management and planning. However, current international agreements are still lacking in clear and flexible provisions for water utilization, and the existing organizations for binational water governance remain weak.

Facilitating interscalar and intersectoral collaboration

The discussion of sectoral impacts in Section 3 highlighted the substantial interconnectedness of each sector and the cross-cutting effects of various changing circumstances. Despite the interdependence of different sectors (i.e., agriculture, hydropower, and forests) and user groups (e.g., farmers, residential, industrial, and commercial) at various scales (i.e., basin, national, community), existing water management institutions in the Ganges basin and worldwide are rarely equipped to facilitate research, dialogue, planning, implementation, and monitoring beyond one or two sectors at a time (World Bank 1999). As in many basins worldwide, the policy process in the Ganges basin is often restricted to strategic planning in specific sectors, with a disconnect within each country between the agendas set by representatives in agriculture, energy, the environment, and public health. Equipping organizations and decision makers with the tools for evaluating and selecting various tradeoffs will require increased linkages across these sectors and groups as well as efforts to establish and communicate the mutual benefits of cooperation (Payne et al. 2004 in Kundzewicz et al. 2007). Efforts to educate and train professionals who are equipped not only with expertise in their specific discipline or field but also with the skills to collaborate and communicate across boundaries will contribute to this wider aim.

9 See Matthews and Le Quesne (2009) for a discussion of developing flexible allocation systems and agreements that protect essential environmental flows and social needs while permitting flexibility in responding to climate change impacts on water availability.

Develop and conjunctively manage water resources

Develop "new" water resources

As climate change threatens to alter water supply in the basin, the development of additional water resources ranging from community-level local rainwater harvesting and groundwater recharge to large-scale intra-basin and even basin transfers will be used to meet rising water demands in riparian countries. India has developed an ambitious plan for the interlinking of major river basins with the aim of mediating frequent floods and droughts and transferring surplus flows from the eastern region to the water-scarce basins in the South and West. In addition, improvements in wastewater management in the basin can provide opportunities for water re-use and address some of the challenges faced in the health sector from pollution (Qadir et al. 2008).

Conjunctively managing water resources

To date, groundwater and surface water resources throughout the world are often managed separately. As knowledge about the location and interconnectivity of groundwater resources in the Ganges increases, it is critical that these resources be managed and regulated conjunctively with surface water resources. In India's Punjab region efforts of this nature are already underway. State agricultural minister Sucha Singh Langah placed restrictions on extracting groundwater earlier in the season, with major fines for farmers who prematurely pumped groundwater rather than wait for the on-set of the monsoon rains.[10]

Furthermore, accounting for endowments of rainfall and soil water is critical for optimizing utilization (Falkenmark et al. 2007; Hoff 2008), and increasing the productivity of rainfed systems. The enhanced management of rainfed systems offers significant potential for improving the overall productivity, and if appropriately developed, reduces the risk to the individual farm families—a particularly relevant benefit under climate changing conditions (Sikka et al. 2003). Relevant interventions include soil-water conservation (Resource Conservation Technologies), small-scale water harvesting, and deficit irrigation, although the latter requires a relatively high degree of understanding by the farmers of the crop-water relationship under such conditions. As with other water-related interventions, the impact on the overall water resources needs to be understood and appropriately planned, especially when taken to scale. As observed by Ahmad et al. (2007), the application of Resource Conservation Technologies in the Indus basin improved the efficiency of water use at the farm scale, yet because of subsequent water spreading, it resulted in less water being available downstream.

Increase water productivity

Augmenting returns per unit of water used will help facilitate adaptation while facilitating economic development. Key policy options for increasing water productivity include 1) improved crop breeding; 2) facilitation of intrasectoral allocation and market linkages; and 3) facilitation of intersectoral transfers.

Improve crop breeding

There have been significant gains in water productivity for staple crops (i.e., rice and wheat) through crop breeding or genetic modification. As such, further productivity gains from crop breeding are likely to be marginal. Future efforts need to focus on generating crops with increased resistance to climate change impacts, such as droughts and floods and increased salt tolerance, and increased productivity for rainfed crops (Molden and Oweis 2007).

Facilitating intrasectoral allocation and market linkages

Modifications to agricultural and aquacultural practices will be an important element of adaptation in the Ganges river basin. This may include the substitution of higher-value crops destined for the export market for staple crops currently under cultivation. The transfer of water to higher value crops (i.e., sugar and milk)

10 See The Tribune, March 22, 2008, available at http://www.punenvis.nic.in/news315.htm and India Information, April 11, 2008, available at http://news.indiainfo.com/2008/04/11/0804111816_langah.html. Last accessed July 31, 2009.

has been observed in the Krishna basin in southern India (Venot et al. 2008). Such strategies may entail the expansion and shift of irrigation practices where appropriate (Oweis and Hatchum 2004). A variety of technical, financial, and training inputs will be required to implement such strategies at different scale. Additionally, investment in the processing and marketing of agricultural products, including the reduction in waste in the market chain, will help increase the returns per unit of water used (Lundqvist et al. 2008). Overall, efforts to facilitate intrasectoral allocation strategies should be pursued with the wider basin picture (including relative natural endowments and the impacts on other users in mind).

Facilitating intersectoral allocations

In addition to opportunities to improve the productivity of water resources within the agricultural sector, opportunities exist to increase the productivity of water by shifting it among the agricultural, industry, ecosystem, and tourism sectors (Phillips et al. 2008). Within the Ganges basin approximately 90% of water is used for agricultural production (FAO 2000; see Table 5). While recognizing the importance of agriculture to the overall food security of the region and for rural livelihoods, the economic returns from staple and export crops in some parts of the basin are relatively small compared to returns from the industrial and services sectors. Within this process of allocation, careful selection and promotion of high-value/low-impact industry is important as well. Moreover, water allocation for hydropower should ensure adequate water resources for downstream agricultural, industry, ecosystem, and tourism sectors. Facilitating strategic intersectoral allocations will require the development of strong institutions and interdisciplinary research teams that can augment the understanding of water productivity across sectors and develop and implement plans for strategic water utilization.

Improve the strategic use of the storage continuum

Re-thinking water storage at a wider scale in the Ganges basin will be imperative in ensuring adequate water resources for sanitation, agriculture, industrial and environmental needs. Decisions regarding the type, size, placement, and functions of future storage facilities should be made in the wider strategic context of the basin as a whole. For instance, placing larger-scale hydropower facilities in the more deeply incised, higher valleys should result in reservoirs with relatively lower evaporation losses as temperatures in the basin increase. In addition to taking current physical characteristics and potential climate change effects into account, discussions about increasing water storage at the local, national, and international level must include the full spectrum of natural and artificial storage options.[11] In addition to addressing the needs for new storage facilities, adaptation strategies must consider approaches for protecting and restoring natural storage capacity in the basin and updating existing infrastructure (Smith and Lenhart 1996).

Improve water quality

Freshwater is only beneficial if its quality is sufficient to sustain ecosystems and allow its use in specific applications (Phillips et al. 2008). Coping with changing circumstances will require efforts to mitigate the degradation of water supplies in the Ganges river basin by decreasing the introduction of pollutants and eliminating pollutants in the system. Decreasing water pollution will require effective regulation of industrial and commercial waste streams, stronger controls on the use of agricultural chemicals (i.e., fertilizers and pesticides), and improved management of domestic wastewater. All three countries in the basin have significantly reduced the number of people without access to an improved water supply, with India and Nepal now at 11% and Bangladesh at 20% (WHO and UNICEF 2008). In addition to augmenting the capacity of treatment plants throughout the basin, efforts to protect natural environmental pollution filters (through the protection of groundwater recharge areas, the improvement of land use, or the implementation of environmental flows) should be an important part of local, national, and international strategies for improving water quality.

11 Natural storage strategies include soil, ice, wetlands, permafrost, lakes, and aquifers, while artificial options encompass reservoirs, dams, canals, and pumping plants.

Recognize and protect ecosystem services

The protection of diverse ecosystems is critical for decreasing vulnerability and enabling adaptation. Two specific policy options, valuing ecosystem services and the allocation of environmental flows, have the potential to augment social and ecological resilience in the Ganges river basin. First, adopting the valuation of ecosystem services into the research and decision-making processes, policymakers will be able to engage in strategic planning that takes a more comprehensive view of the costs and benefits over the short and long term. Within the basin, some progress has been made in adopting the valuation of ecosystem services. In India, for example, researchers and policymakers have recognized that the preservation of coastal mangrove forests is more valuable than the short-term benefits from harvesting or removing these resources (Das 2007). Second, the allocation of water to environmental flows (i.e., the amount of water left untapped within the river system to supply ecosystem needs) may also augment adaptive capacity in the basin. Currently, there is some support for the adoption of environmental flows within the Ganges, but no formal allocation has yet been assigned at national or international levels.

Both of these strategies will require significant resources to facilitate research regarding ecosystems in the basin, the services they provide, and their thresholds. Additionally, gaining political interest and powerful support for legislating, adopting, and enforcing these strategies as standard practice will be critical. This will likely require increased awareness of the multiple ways in which the Ganges river basin ecosystems and their services are fundamental for human well-being in the short and long term (Christoplos et al. 2009).

Support risk management

Enabling adaptation within the Ganges basin will require efforts to support and enhance risk management from the local to the global level. Specific policy options that contribute to this aim include the enhancement and expansion of early warning systems, the provision of access to credit and insurance, and the investment in education and training to facilitate collaboration and enable the pursuit of alternative livelihoods.

Enhance and expand early warning systems

Early warning systems constitute an important mechanism in the Ganges basin for recognizing and responding to changing circumstances, including extreme events such as cyclones and tsunamis as well as droughts, floods, and disease outbreaks. In South Asia, Bangladesh has been active in developing and refining an early warning system. The system is low-tech, but highly effective. It uses community-based volunteers who provide education on disaster preparation and establishes committees of groups for disaster warning, first aid, and relief. The Bangladeshi system is continuing to be refined. As a response to rising sea levels, the government is working to increase the height and strength of cyclone shelters in coastal zones.

Increase access to credit and insurance

The diversification of household income has been noted as an important component of adaptive capacity (Moench and Stapleton 2007; UNDP 2007). Community-level efforts to adapt through intra- or intersectoral transitions often require credit and/or insurance to offset the costs and risks of these important transitions. In India, there has been a history of agricultural insurance, with the most recent program, the National Agricultural Insurance Scheme, having mixed success in terms of coverage and financial viability (Moench and Stapleton 2007). Bangladesh and India are also beginning to examine opportunities to combine microfinance and microcredit with insurance for extreme events, including earthquakes, droughts, and floods (Moench and Stapleton 2007). Moreover, Moench and Stapleton (2007) indicate that insurance tools can be developed to encourage changes in "risk making" behaviors. Through active engagement with the insurance industry, water managers can use insurance rates and access to coverage to "discourage investment in vulnerable regions or to encourage shifts from vulnerability activities to activities that are less affected by climate change" (Moench and Stapleton 2007).

Invest in research, education, and training
Adopting adaptive approaches to resource management will require significant investments in research education and training to fill information gaps about changing circumstances in the basin, develop leaders equipped for interscalar and intersectoral collaboration, and enable the pursuit of alternative livelihoods. Each sector has research, education, and training needs. For instance, in the agricultural sector, there is a need to strengthen research on development of "adverse climate–tolerant" genotypes and land-use systems to ensure adequate food production. Biotechnology and modern tools of information technology, space technology, and communication have an important role to play in this sector (Rai et al. 2009).

6. Barriers to Strategy Development and Implementation

There are a number of conditions necessary for the adaptation strategies outlined in Section 5. This section takes an in-depth look at five key sticking points, or barriers to the development and implementation of adaptation strategies. This identification of physical, informational, capacity, sociopolitical, and institutional obstacles to adaptation is intended to help guide future research and policy engagement in the field of water resources management and adaptation in the Ganges river basin. As this section aims to demonstrate, a comprehensive consideration of these five obstacles will be fundamental for developing and implementing successful policies. Efforts to address information gaps and capacity issues, while important, are unlikely to be successful if they do not also take into account the power and interests of different players in the basin.

Physical

The range of strategies and opportunities for adaptation available in different parts of the Ganges basin will be partially constrained by the geography and physical characteristics of the basin (Kundzewicz et al. 2007). Noting that there is no one-size-fits-all strategy that can be applied throughout such a large basin, specific efforts to expand irrigation or increase storage capacity will have to take a close look at the physical characteristics of the locale within the wider strategic context of the basin as a whole. For example, selecting sites for hydroelectric dams should consider the relative effect of climate change on the total evaporation from the reservoir. Acknowledging these physical limitations, however, there are ample water resources in the Ganges river basin, and riparian countries are in a good position to adopt and integrate adaptation measures before the basin becomes over-allocated.

Data and informational

As Sections 2 and 3 of this paper highlighted, the effects of climate variation and other changing circumstances in the Ganges river basin are likely to be significant, but they are also uncertain. While the foundation of knowledge regarding the nature and effects of global climate changes is rapidly increasing, there is still a certain level of uncertainty surrounding our understanding of how anticipated changes might impact water resources in the Ganges river basin and the secondary effects for ecosystems, agriculture, energy, and human health. Climatic, demographic, and socioeconomic circumstances in the basin are constantly changing, as is the level of understanding of the nature of and interaction between these variables and their impacts on water resources. However, water policy, decision-making processes, and institutional structures do not always reflect this non-stationarity (Fischhendler 2004). Recognizing the inherent uncertainty in this complex field and seeking to increase our understanding of resources and interactions is important. Yet, it is also critical that this acknowledgement of uncertainty not paralyze action, but rather encourage policy engagement in a different, more adaptive way. Adopting an adaptive approach to resource management will require the ongoing collection and assessment of data and information as an integrated part of the policy process. Currently, gaps in the knowledge and information about water resources and changing circumstances stem from a lack of data and information as well as deficiencies in the exchange and compatibility of information. These causal factors underpinning current levels of uncertainty are further linked to issues of technical, financial, and human capacity; political interests; and institutional structures.

Capacity (technical, financial and human)

One of the primary barriers to the development and implementation of adaptation strategies is the lack, or perceived lack, of technical, financial, and human capacity. While the process of adaptation is known to be resource-intensive (Miller et al. 1997), the cost of continuing with the status quo is expected to be far more costly in the long run (Stern 2007). For example, gaining the long-term anticipated benefits of crop diversification may require a range of resources. These include the technological, financial, and human resources to conduct research on climate impacts and changing circumstances in the Ganges river basin as well as crop varieties and cultivation techniques. Shifting production may also necessitate new tools for planting, harvesting, and watering, and additional training and education for the production, processing, and marketing needed to maximize returns.

Most of the strategies listed in Section 5 will require continued capacity development at various levels from the local to the international to enhance the outcomes of adaptation strategies. Increasing cooperation and communication between riparian countries in the Ganges river basin, for example, may help increase the exchange and compatibility of information in the basin, which could contribute to the robustness and utility of early warning systems. Of course, the true effectiveness of such systems in protecting human life and livelihoods will depend on the simultaneous development of technological, financial, and human capacity in vulnerable communities, so that these communities can avoid or cope with harmful situations once warned of extreme events or changing circumstances.

Further research to identify adaptation occurring at the local, national, and international scales in the Ganges river basin and the resource endowments that have enabled and constrained the outcomes will be critical. The financial needs for supporting adaptation are high, and funding commitments are growing (see Porter et al. 2008; UNDP 2007; UNFCCC 2007b; UNFCCC 2008). As national governments and international donors seek to engage in global adaptation efforts, particularly in the Ganges river basin, reflection on the lessons from successes and failures of previous efforts to support adaptation through the enhancement of technical, financial, and human capacity will assist in policy improvement.

Sociopolitical

Sociopolitical barriers to the development and implementation of strategies for adaptation arise where strategies are viewed as undesirable or unnecessary by certain stakeholders (Goulden et al. 2008; Miller et al. 1997). The process of prioritizing and integrating adaptive approaches or developing and implementing adaptation strategies can be a source of conflict and tension as asymmetric interests collide. At the highest level, national governments are unlikely to prioritize or incorporate resource-intensive strategies without a belief that such strategies will be beneficial and cost-saving in the long run. Furthermore, each of the strategies listed in Section 5 is likely to generate resistance at some level. For example, efforts to design and enact environmental flows in the Ganges river basin are likely to confront general discussions about the prioritization and allocation of water uses as well as about the scale, jurisdictions, monitoring, and commitments associated with different plans. Similarly, strategies to increase water productivity through intra- and intersectoral allocation are likely to generate resistance from individuals and groups with vested interests in maintaining the status quo. At the farm level, producers who feel like they lack the adequate technical, financial, and human resources to shift cultivation practices will also be reluctant to change. Understanding the multiplicity of interests and power asymmetries at play in the Ganges river basin is critical for the development and implementation of strategies for adaptation. Overcoming the barriers posed by competing interests requires attention to developing mutually beneficial approaches to adaptation as well as strengthening institutions at every level to enable them to handle difficult decisions about tradeoffs.

Institutional

Institutions can both help and hinder adaptation by different stakeholders and at different scales (Naess et al. 2005). Like many international river basins, the Ganges is a complex system that crosses multiple jurisdictions and influences the functionality of multiple sectors. Yet, existing institutions are not well-equipped to handle such complexity. This is due in part to the fact that existing rules and regulations lack flexibility mechanisms and impede alterations to current management practices. Additionally, adaptation in the Ganges is hindered by the limited cooperation between countries in the basin. While the three riparian governments have entered into some bilateral agreements, tensions upstream and downstream have hindered the development of strong institutions for basin-wide or bilateral water governance (Verghese 2001). The flow of the Ganges through multiple subnational jurisdictions also complicates decision making and strategic planning. Within India, for example, the Ganges is shared among seven states and the Union Territory of Delhi, each with different rules and management structures for the management of water resources (see Table 1 for the geographic area of each Indian state in the Ganges basin). Efforts are under way to improve joint governance within the country, but more work is required to enable strategic planning and implementation. In addition to the challenges posed by jurisdictional boundaries, sectoral and disciplinary boundaries also present barriers for developing and implementing strategies for adaptation (World Bank 1999). Recognizing that not all efforts to develop water resources in the basin will span multiple scales or sectors, management institutions at all levels still must be equipped to see individual interventions within the wider strategic context of the basin.

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