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Research paper

Water for growth and development in the Ganges, Brahmaputra, and Meghna basins: an economic perspective

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ABSTRACT

The Ganges, Brahmaputra, and Meghna (GBM) river system flows through five countries – Bangladesh, Bhutan, China, India, and Nepal – characterized by large population, limited land resources, and frequent floods and natural hazards. Although the GBM region is well endowed with water sources, this is one of the poorest regions in the world. Its economy and human and environmental health depend on water, and water is thus at the heart of sustainable development, economic growth, and poverty reduction. This paper examines the opportunities for, and potential socio-economic benefits of, water resource management in the GBM region in the face of changing climate. It argues that water can be an entry point for addressing challenges common to the region, particularly through multi-purpose river projects that store monsoon water, mitigate the effects of floods and droughts, augment dry season river flows, expand irrigation and navigation facilities, generate hydropower, and enhance energy and environmental security. The paper emphasizes the importance of effective regional cooperation in water management to achieve these benefits. Upstream–downstream interdependencies necessitate development of a shared river system in an integrated and collaborative manner.

Keywords: Water resource management; regional cooperation; Ganges; Brahmaputra; and Meghna basins; upstream–downstream linkages

1 Introduction

Bangladesh, Bhutan, China, India, and Nepal are connected by the common river system of the Ganges (or Ganga), the Brahmaputra (known as Yarlung Tsangpo in China, and Jamuna in Bangladesh), and the Meghna – here referred to as the Ganges, Brahmaputra, and Meghna (GBM). In terms of freshwater flow volume, the GBM is the largest river system emerging from the Hindu Kush Himalayas (Immerzeel *et al.* 2010) and the third largest river basin in the world after the Amazon and the Congo. This river system, connecting the Himalayas to the Bay of Bengal, is endowed with huge hydropower potential, fertile agricultural lands, and rich aquatic resources that sustain the lives and livelihoods of millions of people in the hills, mountains, and plains.

Although endowed with rich water resources, and despite significant recent socio-economic progress, this region remains one of the poorest in the world. Freshwater, once abundant, is under growing stress due to the increased demand for competing uses. About 20% of the population in the GBM region lacks access to safe drinking water. Per capita energy consumption in this region is among the lowest in the world. The shortage of energy has become a major constraint for industrialization and economic growth (World Bank 2009). The GBM countries face a common challenge in ensuring water, energy, and food security for a burgeoning population.

Climate change is further exacerbating the challenges by increasing the pressure on the basin's freshwater resources. Water availability and water security are becoming more uncertain through changes in temperature and precipitation, shifts in the timing and intensity of the monsoon, increased frequency of extreme events such as droughts and floods, and accelerated melting of the Himalayan glaciers resulting in changes in short- and long-term runoff, snow cover, and melting patterns (Eriksson *et al.* 2009, Shrestha and Aryal 2011). These changes could have significant impact on food, water, and energy security in the region (Webster *et al.* 2011).

The economic structure of the region is highly water-dependent. The vast majority of the people of the region rely on agriculture, livestock, forestry, and fishery for their livelihoods. Agriculture contributes about one-third of gross domestic product (GDP) and provides employment for about two-thirds

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of the rural labour force (Kumar *et al.* 2012). The staple foods of the region are rice and wheat, which are highly water demanding. About 90% of the withdrawn water is used for agriculture. Besides irrigation, the GBM river system supports fisheries, navigation, transportation, and energy production.

Water not only plays an important role in economic growth, but can also bring destruction through drought, flooding, landslides, pollution, and diseases (Mirza *et al.* 2001, ICIMOD 2009). Thus, the quality of life, livelihoods, and economic prosperity of the people of the GBM region depend on the sustainable management of water resources (Babel and Wahid 2011). Rational, efficient, and equitable water management can act as an engine for socio-economic development (Ahmad *et al.* 2001, Ahmad 2004, Biswas 2004) and help the GBM countries meet the growing demand of their burgeoning populations for food, water, and energy in the face of climatic and other socio-economic changes (Iyer 2001). To date, however, the development of the water resources in the GBM basin has remained sub-optimal.

The essential question is whether the water resources of the region could be utilized better to address water, food, and energy security challenges and improving economic and social development on the region. It begins by describing the biophysical, hydrological, and socio-economic characteristics of the GBM region and the availability and use of water. The following section explores the water-based development potential of the region. Finally, the paper examines the role of regional cooperation in water management to realize the potential and promote socio-economic development while facilitating adaptation to climate change.

2 Characteristics of the GBM river system

The GBM river system, which originates in the Himalayas and empties into the Bay of Bengal, passes through five countries and connects them hydrologically, biophysically, and environmentally, forming a large natural region. The unique biophysical characteristics of the GBM catchment include Mount Everest, the highest peak in the world, and Cherrapunji, the second wettest place on Earth. The region's climate varies considerably. However, most of the river system is located in the monsoon belt, and its water regimes are strongly influenced by the monsoon. Rainfall varies greatly over the years and over different parts of the region, ranging from 1000 to 4000 mm (Figure 1). Rainfall is highest in the Meghna basin, high in coastal areas, and lowest in the western part of Ganges basin. The mean annual rainfall is 1200 mm in the Ganges and 2300 mm in the Brahmaputra and Meghna basins.

2.1 *Hydrological characteristics*

The annual flow of the Brahmaputra River from China to India is 165.4 billion cubic metres (BCM), from Bhutan to India 78 BCM, and from India to Bangladesh 537.2 BCM. The annual flow of the Ganges River from China to Nepal is 12 BCM. All

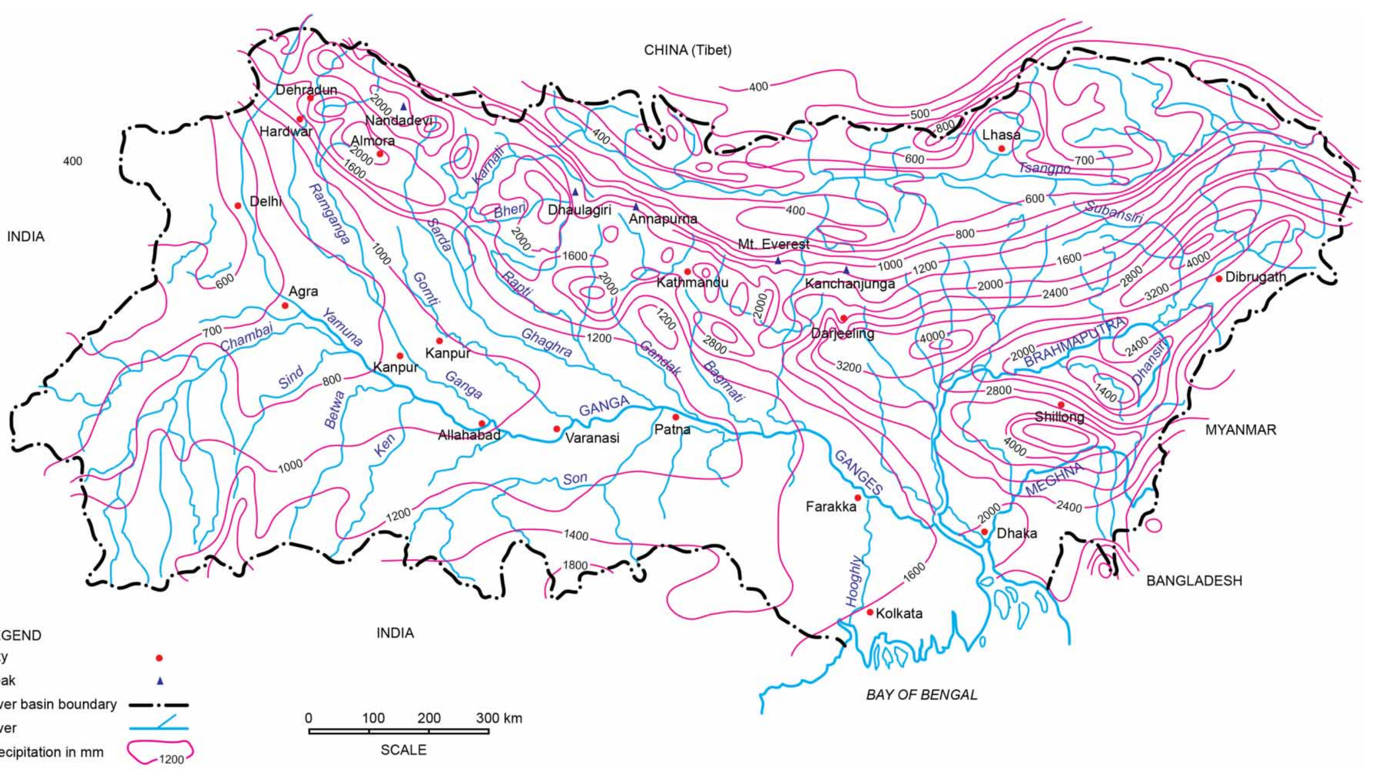

Figure 1 Annual precipitation in the GBM region. Adapted from Bandyopadhyay (1995).

Table 1 Catchment area, population, and water resources in the GBM basins

				Hydropower potential[a] (million kW)	
Country	Drainage area (million hectare)	Population, 2010 (millions)	Arable land (million hectare)	Brahmaputra	Ganges
China (TAR)	32.6	1.8	Negligible	110	
India	110.5	463.24	67.2	66	13
Bhutan	4.5	0.7	0.2	30	
Nepal	14.0	30.05	2.6		83
Bangladesh	12.9	123	9.1	Negligible	
Total	174.5	618.79	79.1	206	96

Sources: Rangachari and Verghese (2001), Brichieri-Colombi and Bradnock (2003), Rahaman (2009); population figures from FAO (2012).
[a]Hydropower potential in the Meghna basin is negligible.

the rivers in Nepal drain into the Ganges River; the annual flow from Nepal to India is 210.2 BCM. The annual flow of the Ganges from India to Bangladesh is 525 BCM. The annual flow of the Meghna River from India to Bangladesh is 48.4 BCM (FAO 2012).

In total, the average annual flow in the GBM region is estimated to be around 1350 BCM, of which nearly half is discharged by the Brahmaputra. The annual average water availability in the GBM region is 771,400 m^3/km^2, which is nearly three times the world average of 269,000 m^3/km^2. In addition to surface water, the GBM region has annually replenishable groundwater resources of about 230 BCM (FAO 2012).

Per capita water availability is 5656 m^3 per person per year in the Brahmaputra basin and 932 m^3 per person per year in the Ganges basin (Table 1). The major source of water is the summer monsoons and snow and ice melt from the Himalayas. Water regimes are strongly influenced by the monsoon. About 84% of the rainfall occurs from June to September, and 80% of the annual river flow takes place in the four months from July to October. The drastically reduced rainfall from November to March has created a flood-drought syndrome in the basin. While huge amounts of water during the monsoon period trigger floods and other hazards, the water in the dry season is insufficient to meet the requirements for irrigation and navigation or to maintain the minimum environmental flow in the rivers. Considerable areas in the GBM region often suffer from both floods and droughts, which cause huge economic and social losses (Sood and Mathukumalli 2011).

2.2 *Socio-economic conditions*

Poverty is endemic in the region. The countries that it encompasses rank between 136 and 157 in human development indices based on social indicators such as education, health, nutrition, child mortality, access to safe drinking water, sanitation, and energy − well behind other regions of the world (UNDP 2013). The region has low life expectancy and high birth rates. Infant and maternal mortality rates are much higher than in other developing countries (Biswas 2004). The vast majority of the people rely on agriculture for their livelihood, and agriculture is the mainstay of the rural economy.

The overall socio-economic conditions of the countries of the GBM are summarized in Table 2. To improve these conditions and eradicate poverty in the region, large-scale development efforts are needed, and water can provide a basis for this (Biswas 2004, Chaturvedi 2012).

3 Water-based development potential

Water is essential for economic production and human well-being. Securing a reliable supply of water for key economic areas is critical to achieving economic growth. Because water is vital to many other sectors such as agriculture, food, hydropower, navigation, transportation, and flood management, management of and investment in water resources often form the basis for broad regional and national development (Malik 2008). This section briefly explores the key areas in which water management offers potential for development in the GBM region.

3.1 *Water for food security*

The GBM river system is vitally important to food security; its flood plains are the bread baskets of the region. Rice and wheat are the staple foods in the GBM region, providing about 50% of dietary energy. These two crops require huge amounts of water – about 1000 tonnes to produce 1 tonne of grain (Brown 2009) – and depend on irrigation in the dry season.

Demand for foodgrains in the GBM region is increasing owing to the growing population, increasing income, and a change in dietary preferences towards more consumption of meat (Rasul 2012). Agricultural land is relatively scarce in the region. Per capita land availability ranges from 0.05 to 0.13 ha per person (Kumar *et al.* 2012) and has been declining sharply over the years owing to population pressure (Rasul 2011).

Table 2 Socio-economic status of the GBM countries

Socio-economic features	Bhutan	Bangladesh	India	Nepal
Estimated population in millions, 2008	0.7	160	1140	28.8
Population annual growth rate, 2008 (2008)	1.6	1.6	1.4	1.7
Dietary energy consumption, 2006−2008 (kcal/person/day)		2270	2360	2340
Undernourishment in total population, 2006−2008 (%)	n/a	26	19	17
Life expectancy at birth (year) (2012)	67.6	69.2	65.4	69.1
Infant mortality rate, 2011 (per 1000 live births)	54	46	61	48
Maternal mortality rate, 2011 (per 100,000 live births)	180	240	200	170
Access to safe water, 2006 (%)	80	80	86	89
Access to sanitation, 2006 (%)	52	36	28	27
Prevalence of child malnutrition under age 5, 2004 (%)	40.0	43.0	44.9	50.5
Non-literate adults, 2007 (%)	n/a	53	66	57
Population below national poverty line (%)	23.2 (2010)	31.5 (2007)	29.8 (2006)	25.2 (2011)
Population below PPP USD 1.25 a day (%)	10.2 (2010)	43.3 (2007)	32.7 (2006)	24.8 (2011)
Per capita GDP PPS, 2008	1900	520	1040	400
Human development index, 2012	0.538	0.515	0.554	0.463
Gender inequality index, 2012	0.464	0.518	0.610	0.485
Access to electricity, 2010 (% of population)	n/a	46.5	70	76.3
Per capita electricity consumption, 2011 (kWh)	236	274	626	103
Energy use, 2010 (kilogram oil equivalent per capita)	n/a	205	575	381
Annual freshwater withdrawal for agriculture (% of total freshwater withdrawal)	94	88	90	98

Source: World Bank (2013) and UNDP (2013).
Note: PPP = purchasing power parity; GDP PPS = gross domestic product purchasing power standards.

Yarlong Tsangpo, the upper Brahmaputra in China originates in Mount Kailash in the Tibetan Autonomous Region of China and flows eastward in Tibet for 2200 km, supporting livelihoods of pastoral communities in the Tibetan plateau grasslands (Brahma 2007). This region is endowed with vast glaciers and snow, which is the lifeline for downstream population in India, Nepal, and Bangladesh.

The scope for increasing food production by bringing additional land under cultivation is limited, as most of the suitable land is already cultivated. Since higher agricultural production has to come from the same amount of land, agriculture must be further intensified with more inputs and new areas brought under irrigation. Higher foodgrain production in this region in the last several decades has been driven primarily by the expansion of irrigation facilities making it possible to grow high-yielding varieties. One of the world's areas of largest irrigation concentration is the Ganges basin.

Agriculture is well developed in the Ganges basin, particularly in its western portion (i.e. Haryana and western Uttar Pradesh states in India) which has large-scale surface water and groundwater irrigation facilities. In the Brahmaputra basin, however, the agricultural sector is less productive owing to limited investment in water infrastructure, particularly in irrigation and flood control. Thus, despite high surface water availability − about 653 BCM, more than one-third of India's water resources − Northeast India suffers from water poverty (Sharma *et al.* 2010). About 4.26 million hectares of land have potential for irrigation in Northeast India. The area presently under irrigation is less than 20% of the potential. In Assam, a large state in Northeast India, only 5% of the sown area is irrigated (Sharma *et al.* 2010). As a result, the agriculture of this area mostly depends on rain, which is extremely unreliable. The area also suffers heavily from drought and floods, which affect the economy considerably. Northeast India has a foodgrain deficit of about 2 million tonnes (Giribabu 2013).

Similarly, in the basin of the Koshi River, a major tributary of Ganges, agricultural productivity and food security suffer from inadequate investment in irrigation and flood management. Rice yield in the Koshi basin in the state of Bihar, India, is about 1021 kg/ha, which is less than one-third of India's average rice yield (3358 kg/ha) and just one-fourth of the global average (4334 kg/ha) (Wahid *et al.* in press).

The impacts of climate change on water resources and on agriculture will vary in different parts of the GBM. However, most populations will be highly vulnerable; recent studies conclude that the Himalayan region and its downstream areas, including the GBM region, are particularly vulnerable to climate change (Ramanathan *et al.* 2005). Increased uncertainty regarding the quantity, quality, and timing of water poses significant challenges for agricultural production throughout the region. The expansion of irrigation facilities, along with consolidation of the existing systems, would be critical for increasing food production in the region, especially in the face of increased uncertainties of water availability due to climate change.

The GBM river system holds significant potential for the development of irrigation (Table 3). At present only a small

Table 3 Water resources and their development in the GBM river system

River basin	Total renewable water resources (BCM)	Potentially usable water resources (BCM)	Per capita water availability (m^3)	Water withdrawals (BCM)	Sown area (million hectare)	Irrigated area (million hectare)	Water resources developed (%)	Surface storage potential (BCM)
Ganges	525.0	386.5	1039	266.8	44.99	22.41	44	94.35
Brahmaputra	585.6	77.9	11,782	9.9	3.50	0.85	11	52.94
Meghna	48.4	10.2	n/a	2.4	0.94	0.22	15	n/a

Source: Amarasinghe *et al.* (2005) and Gaur and Amarasinghe (2011).

portion is developed, particularly in the Brahmaputra and Meghna basins. With optimal development of water, it would be possible to feed not only the river basin populations, but also those distant from the river. The Bhakra-Nangal dam system in Himachal Pradesh, India is an example. Constructed in the early 1960s, it provides irrigation water for the states of Punjab and Haryana and enables the production of foodgrains that reach urban populations throughout India (Malik 2008). These dams enabled the country to achieve self-sufficiency in food production, becoming an icon in India's developmental history (Dharmadhikary *et al*. 2005).

3.2 *Water for energy security*

The availability of energy, particularly electricity, is a necessary condition for industrialization, economic growth, and poverty alleviation. The GBM region is one of the world's energy-deficit areas, with persistent shortages of energy in all of the countries of the region except Bhutan. The demand for power will increase because of the rapid pace of industrialization and urbanization and the increased demand for food for ever-growing populations. Energy is needed not only to sustain the region's growth but also to improve socio-economic conditions and human development.

Hydropower is a renewable and economical source of energy, less polluting than fossil fuels and relatively environmentally benign. The GBM river system offers huge potential for hydropower. Abundant rain-fed and snow-fed water resources and steep topographic relief provide an excellent opportunity for generating an enormous amount of hydropower. The terrain of the Himalayas also provides excellent opportunities for storage of water for hydropower (Biswas 2004).

Of the world's rivers, the Brahmaputra is among the largest in hydropower potential. The location where it drops 2300 m from the Tibet Autonomous Region in China to Arunachal Pradesh in India has immense potential (Cathcart 1999).

Nepal and Bhutan also have high hydropower potential which could be harnessed at a relatively low cost compared to alternative energy sources (Biswas 2004). The hydropower potential of Nepal's rivers that would be economically feasible to develop is estimated to be 43,000 MW and of Bhutan's almost 24,000 MW (Table 4). The rivers in Northeast India have an estimated potential of about 35,000 MW (Rao 2006).

In total, the GBM river system is estimated to have about 200,000 MW of hydropower potential, of which half or more is considered to be feasible for harnessing (Chalise *et al.* 2003). Exploitation of the region's hydropower potential could meet the energy requirements of the region and the surplus could be exported. However, bringing China in cooperative development of hydropower is important. Growing apprehension about diversion of the Brahmaputra water to northern China is a huge concern for India and Bangladesh.

Hydropower is a niche product of mountain regions, and many hydropower schemes are financially attractive. For instance, out of 72 schemes identified for hydropower in Northeast India, 30 schemes with an installed capacity of 23,286 MW would have a first-year tariff less than INR 2.50 (~USD 0.04) per kWh (Jain 2012). Similarly, the Ganges Strategic Basin

Table 4 Hydropower potential and per cent exploited in South Asian countries

Country	Total hydropower potential (MW)	Economically feasible potential (MW)	Actual installed hydropower capacity (MW)	Currently exploited (% of total potential)	Currently exploited (% of economically feasible potential)
Nepal	83,280	43,000	658	0.8	1.5
India	149,000	84,000	24,630	16.5	29.3
Bhutan	50,000	23,760	1465	2.9	6.2
Bangladesh	800	n/a	180	22.5	n/a

Source: Pokharel (2010) and Vaidya (2012).

Assessment study, which identifies potential investment areas in hydropower development in the Ganges basin in Nepal, suggests that the magnitude of potential economic benefits from hydropower projects is huge − around USD 5 billion from the Koshi basin alone (at 2010 prices) (Sadoff *et al.* 2013). However, involvement of private sector in the hydropower development has remained considerably minimum due to unfavourable policy and institutional environment, including limited access to financial resources, inadequate domestic market in Nepal and Bhutan, and their low capacity along with lengthy procedural requirements and political uncertainties (Sovacool *et al.* 2011).

3.2.1 *Under-utilization of hydropower potential*

Despite the huge potential, the utilization of hydropower in the GBM is minimal (Table 4), particularly in comparison with developed countries which use up to 70% of their hydropower potential (e.g. Switzerland 70% and Norway 68%). As a result, the per capita energy consumption in the region is very low. GBM countries on average have an electricity shortage of 15–30% with respect to peak load demand (Pokharel 2010). Whereas the world average per capita electricity consumption in 2001 was 2159 kWh, in Bangladesh, it was a mere 94 kWh, in India, 365 kWh, and in Nepal, 336 kWh. Less than 60% of the region's population has direct access to electricity or to other modern forms of energy, either because of lack of supply or prices too high for poor people to afford. About 80% of rural mountain people depend on biomass and other traditional sources for energy. Shortage of energy is a severe constraint to economic growth, poverty alleviation, and improvement in standards of living (Lama 2000, Dhungel 2008, Malla 2008).

Nepal, for example, has installed only 658 MW (Table 4), while estimated electricity demand was 984 MW for 2010 and 1579 MW for 2015 (Sharma and Awal 2013). As a result, Nepal faces 10–12 h of load shedding (scheduled power cuts) every day in winter (Sovacool *et al.* 2011). Furthermore, Nepal must depend heavily on imported petroleum products. In 2010/2011, the cost of petroleum products (USD 1.05 billion) exceeded the total value of Nepalese exports (USD 0.88 billion) (Sharma and Awal 2013).

Underutilization of hydroelectric potential is not only the wastage of an important national resource, it also limits their capability in adapting to climate change and meeting energy, food and water demand of the region.

3.3 *Minimizing damage from water-induced disasters*

While water is a source of life and prosperity, it can also cause destruction and poverty if not properly managed. The GBM region is one of the most disaster-prone regions in the world owing to the high concentration of rainfall during the monsoon, accelerated glacier melting, and environmental degradation (Molden *et al.* 2014) which lead to glacial lake outburst, debilitating annual floods, drought, and landslides causing massive damage to the economy and society (Table 5).

In the GBM region, Bangladesh bears the brunt of the flooding. One-third of the land area is flooded every year, and in an exceptionally high-flood year (e.g. 1988 and 1998) 50–60% of the country may be affected. Each year, floods and drought affect about one-tenth of the population of Bangladesh and cause on average around 6000 deaths. Nepal and several Indian states within the GBM region such as Assam, West Bengal, Uttar Pradesh, and especially Bihar are also highly flood prone. In Bihar alone, the annual average economic damage is INR 458 million (USD 11.63 million). The Koshi River, one of the tributaries of the Ganges, is known as 'the river of sorrow' in Bihar. In 2008, flooding in the Koshi basin affected about 2.8 million people in India and Nepal and caused huge economic losses (Ghani 2011). In India, more than 22 million people are affected by floods per year.

3.3.1 *Floods in a changing climate*

Climate warming has recently been linked to intensification of heavy precipitation events over roughly two-thirds of the continental Northern Hemisphere (Min *et al.* 2011), and climate change is likely to aggravate the existing flood problems in the GBM region. Increased precipitation during the monsoon season and accelerated glacier melt are likely to increase the incidence and intensity of floods (Huntington 2006). Indeed, the frequency of major floods and the population affected has been

Table 5 Economic and social costs of natural disasters in the GBM countries

		People affected per annum on average			Economic loss (annual average from 1971 to 2008)		
Country	Mortality 1971–2008 (average no. of people dying annually)	Drought (2000)	Floods and storms (2000)	Share of population (%)	Droughts (million USD)	Floods and storms (million USD)	Largest loss per event (% of GDP)
Bangladesh	5673	658	8751	9.1	0	445.6	9.8
India	2497	25,294	22,314	7.2	61.6	1055.4	2.5
Nepal	137	121	87	2.0	0.3	25.8	24.6

Source: World Bank (2010).

increasing over recent decades in all the GBM countries (Mirza *et al.* 2001, Dhar and Nandargi 2003). Floods have been observed to cause a gradual increase in human suffering and damage to property (Figure 2) as well as increased loss of life and economic costs (Doocy *et al.* 2013), although socio-economic factors must also be taken into account (Bouwer 2011).

The increased frequency and severity of floods have placed enormous constraints on the development potential of the GBM countries. As all the countries in the region are low-income economies, their efforts towards economic growth have been thwarted by recurrent natural disasters such as floods. The frequent occurrence of droughts and floods in the GBM region has had huge impacts on regional food and energy security (Webster *et al.* 2011), as well as on ecosystems and public health (Molden *et al.* 2014). Effective flood management is vital to counteract the harmful socio-economic impacts.

3.4 *Water for navigation*

Water transport has an important role in industrial growth and economic development in any country. The industrial development of Bhutan, Nepal, and Northeast India is hindered considerably by their landlocked position. In these cases, one of the important goals in water resources development is to gain access to the sea. The GBM rivers flow into Bangladesh from three directions and merge into a single outlet; they thus constitute a vast water network for transportation. Historically, the three rivers and their principal tributaries served as major arteries of trade and commerce. The Greek historian Megasthenes recorded that the Ganges and its main tributaries were navigated from the fourth century BC (Nagabhatla and Jain 2013). During the colonial period, the navigational system was further developed. Nepal, however, was not connected owing to the steepness in some of the rivers and non-navigability in the dry season.

It is technically feasible for Bhutan, Nepal, and Northeast India to gain direct access to the sea through development of the water resources in multi-purpose projects. Experts suggest that there is potential for developing water transportation on the Gandaki, Karnali, and Koshi in Nepal; the Ganges and Brahmaputra in India; and the Brahmaputra and Meghna in Bangladesh. Boats could travel on the Hooghly in India, alongside the Ganges in Bangladesh, via Farakka and Kanpur in India to several points in Nepal such as Bhardaha on the Koshi, Narayanghat on the Gandaki, and Chisapani on the Karnali (Malla *et al.* 2001, Sainju and Shrestha 2002, Upreti 2006). The Karnali River (known as the Ghagra in India) probably has the highest potential for navigation, from the Indo-Nepalese border to the confluence with the Ganges. The Gandaki River is an important waterway serving central Nepal and could connect it with eastern Uttar Pradesh and eastern Bihar in India if it is linked with India's National Waterway No. 1 on the Ganges, which runs from Allahabad to Haldia below Kolkata (Figure 3). Construction of high dams on these rivers could improve their navigability as well as provide other benefits including water-based tourism.

Water transport is cost effective compared to other forms of transport, particularly for bulk commodities. In Nepal, road transport costs nearly 10 times as much as transport by water (Upreti 2006). Yet, most of the freight from Nepal is transported by road; only 130,000 tonnes of freight are shipped annually along the Karnali, Gandaki, and Koshi rivers (Ahmad 2004).

The establishment of links among the inland water transport networks of Bangladesh, India, and Nepal could provide Nepal access to the ports of Kolkata (India) and Mongla (Bangladesh). India and Bangladesh have a bilateral protocol for India to use

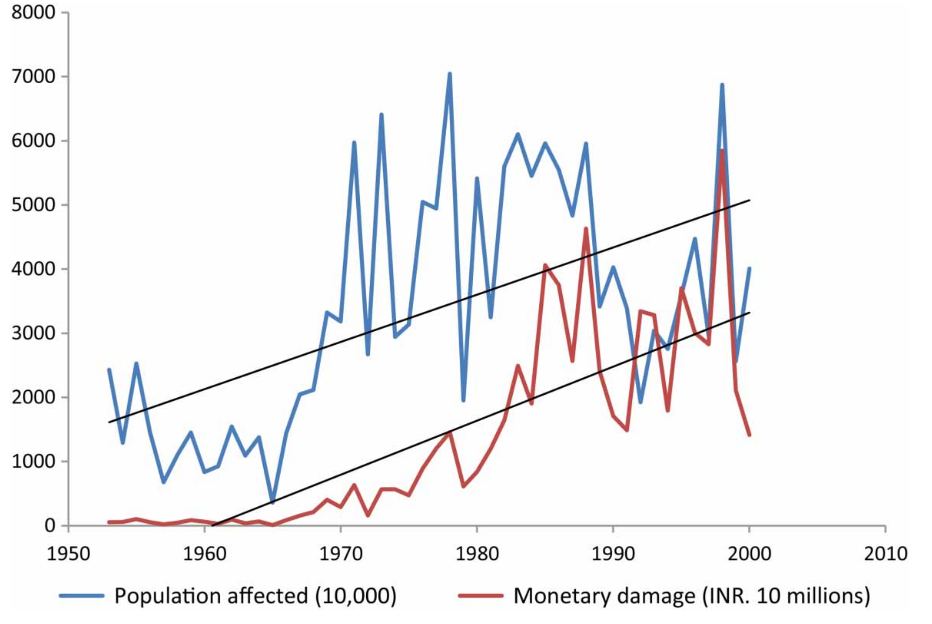

Figure 2 Population affected by floods in Bangladesh, India, and Nepal from 1950 to 2000.Source: Based on data from Mirza *et al.* (2001).

Figure 3 India's National Waterway No. 1.

the GBM river system for water transit between West Bengal and Assam. This protocol is renewed every two years. A navigational link to the Ganges and Brahmaputra could go a long way to expand trade and promote industry and regional development.

4 Regional water cooperation for enhanced development

The GBM countries depend on each other for water and water-related services. For example, 91% of the total river flow in Bangladesh, 34% in India, and 6% in Nepal originates outside the national borders (Karki and Vaidya 2009). Thus, resolving issues of energy security, water security, agricultural sustainability, and food security within one country is difficult, but regional cooperation can provide win–win solutions. In transboundary rivers, cooperation at basin level helps to increase economies of scale and enables large-scale actions (Grey and Sadoff 2007). To harness the full potential of the GBM river system requires regional and integrated development of water resources. The countries of the GBM are realizing this need for regional cooperation and are making efforts, albeit slowly, to resolve differences over water issues. This section provides some examples of the potential and progress in realizing it to date.

4.1 *Water storage*

Because of seasonal variation in water availability − which is becoming more dramatic with changes in climate − water storage is critical for enhanced water security. The water storage capacity of the GBM region is very low, well below estimated needs for buffering against drought and floods and maintaining stable food production (Brown and Lall 2006). Construction of storage reservoirs on the tributaries in the upper GBM, to hold a small portion of the vast monsoon runoff, could help augment low dry season flow in downstream areas (Onta 2001). Water storage in the upper GBM could also provide considerable flood-related benefits in the downstream if planned and managed properly.

Because of the lack of storage capacity, rainy season water in the GBM largely flows to the Bay of Bengal. Since 1974, Bangladesh and India have been discussing the need to augment dry season water availability in the Ganges basin through storage of monsoon water. The existing dry season flow at Farakka in India is only about 26 BCM, whereas it is estimated that about 55 BCM are needed to meet the requirements of south-western Bangladesh for irrigation, domestic and industrial water supply, and maintenance of navigation (Chaturvedi 2012).

In India, the 1986 Brahmaputra Master Plan of India identified 18 storage sites in Northeast India, five classified as large, with a total gross storage capacity of 80 BCM. One large storage site (Tipaimukh) has been identified in the Meghna (Barak) system with a gross storage potential of 15 BCM (Mohile 2001).

Nepal and Bhutan have many excellent sites for storage of monsoon water. Construction of large storage reservoirs on the Ganges tributaries originating in Nepal would benefit Nepal, India, and Bangladesh. Nepal has identified about 30 potential reservoir sites, nine classified as large (>5 BCM), with an aggregate gross storage capacity of 110 BCM. It is estimated that seven large dams in Nepal could increase the dry season (January–May) water availability of the Ganges by 70 BCM (Chaturvedi 2012). However, this total is still only about 20% of the mean annual flow of the Ganges (about 500 BCM).

The storage and redistribution of monsoon water within a framework of regional cooperation can not only support water supply and irrigation, but also provide substantial hydropower to support socio-economic benefits in the region. In this way, an integrated regional system for planning water use can also assist in adaptation to water variability, enhancing resilience to the impacts of changing climate. Water storage is not only a mechanism for adaptation to climate change but also critical for ensuring water, food, and energy security.

4.2 *Regional approaches to hydropower development*

Regional cooperation can help to overcome the main impediments to hydropower development, i.e. lack of financial resources, markets for hydropower, and technical expertise and skills to develop the necessary infrastructure and power capacity, along with the investment risk associated with single buyers (i.e. loss in bargaining power). Cooperation can help countries harness the necessary financial resources, suitable technologies, guaranteed markets, and institutional mechanisms for sharing the costs and benefits of joint efforts, for the benefit of the entire region (Lama 2000, Dhungel 2008). Joint development of the huge untapped hydropower resources in Nepal, Bhutan, and Northeast India could fuel industrialization and economic growth. It can also assist in mitigation of climate change by supporting a transition to a decarbonized energy supply chain.

Currently, cross-border energy trade in the region is minimal and exists only at the bilateral level, with hydropower trade between India and Bhutan and between India and Nepal taking place on a small scale. The Chukha Hydel Project in Bhutan – in which India provided the technology and the finance, bore the completion risks, and in turn received a low-cost reliable source of hydroelectricity for its eastern electricity region – is a good example of how the countries sharing a river basin can successfully manage transboundary water for regional economic development. The project was fully funded by the Government of India with 60% grant and 40% loan with an annual interest of 5%. Nearly 87% of the power generated from Chukha is supplied to meet the energy requirements of the Indian States of West Bengal, Bihar, Jharkhand, Orissa, and Sikkim. For Bhutan, the earnings from export power tariff amounted to nearly 30% of its revenue. The success of this project has paved way for implementation of several other mega hydropower projects in Bhutan including 1020 MW Tala project, 1200 MW Punatshangchhu-1 and 1020 MW Punatshangchhu-2, and the 720 MW Mangdechhu projects (Dhakal and Jenkins 2013).

Multi-purpose regional projects to store monsoon water for dry season irrigation along with hydropower production would go a long way to ensuring food security and agricultural sustainability in the GBM region. Examples include the proposed Sapta Koshi High Dam in Nepal, which would have enough storage capacity to provide both north Bihar (India) and Bangladesh with a flood cushion and with augmented dry season flows after meeting Nepal's full irrigation requirements. The proposed Sunkosh Dam in Bhutan could also store water for hydropower (4000 MW) in addition to improving flow in the dry season (Ahmad 2004). Hydropower storage projects often have better economic performance than irrigation projects; multi-purpose water storage projects providing both services can offer energy benefits as well as improve food security in an economically feasible manner. In addition to flow management, these prospective reservoir projects could improve navigability along the length of the river and its tributaries. However, hydropower development is complex and it brings a range of economic, social, and environmental risks. Although technology for hydropower development has advanced considerably and there are techniques available to study the dynamic behaviour of dams and reservoirs in case of earthquake with greater assurance of safety (Jatan 1999), appropriate safety and stringent guidelines are still critical to minimize potential environmental and social risks.

4.2.1 *Cross-border grid interconnections*

Establishment of an inter-country power grid could facilitate the integration of different power systems and the export of excess hydropower from Nepal and Bhutan to India and Bangladesh. Cross-border grid interconnections are increasing all over the world. Such interconnections already exist in North America, Europe, and southern Africa; they include the Nord Pool (Denmark, Finland, Norway, and Sweden) and the South African Power Pool (12 countries). The establishment of power grid networks and introduction of power trading can promote the use of untapped water resources and increase energy security in the region. The development of the GBM basins' hydro-potential could pave the way for formation of a GBM regional power grid and foster cooperation among the countries in the region.

India has agreed to export 500 MW of electricity to Bangladesh, and a grid connection between the two countries has recently been completed, with trade in power begun in September 2013 (The Hindu 2013). Cross-border 400 kV electricity transmission lines between Nepal and India are under construction.

The Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC), which has Bangladesh, Bhutan, India, and Nepal as members, established an Energy Centre in Delhi in 2011 to coordinate, facilitate, and strengthen cooperation in the energy sector in the region. This will help to develop the cross-border energy trade and a regional market for hydropower from Nepal and Bhutan.

4.3 *Regional cooperation in flood management*

Management of floods in the GBM region has strong regional dimensions as all the major rivers are transboundary. Often, floods generated in one country affect another country, and erosion in one country can deposit sediment in another. Lower riparian countries are generally subject to runoff from the upper catchment area after heavy rainfall and snowmelt. Although both structural and non-structural measures have been taken at the national level to prevent and mitigate flood hazards, they have not been very effective; flood problems and associated damage persist and are even increasing. Because of the hydrological and ecological links between upstream and downstream areas in a river basin, transboundary cooperation is essential.

As discussed above, the construction of storage reservoirs in the upstream areas of the GBM is technically and economically feasible, provided that such reservoirs are used for hydropower generation, irrigation, and dry season flow augmentation. The exploration of potential reservoir sites and reservoir construction should form part of a long-term regional flood management vision. However, storage alone is not enough. For effective flood management, it is important to develop effective flood forecasting and early warning systems, which are found to be a vital alternative to costly structural measures.

The value of flood forecasting increases as the lead time increases. Flood warnings can provide a grace period of 2–14 days, depending on the size of the river (Zawahri 2008), during which arrangements can be made for evacuating people and transporting food, water, and medicine to the region. The lead time for flood forecasting can be increased substantially through exchange of real-time data on river flow from upstream areas of the basins. Downstream states also depend on upstream neighbours for data warnings about low precipitation which could lead to drought.

Flood forecasting is thus highly dependent on communication of information and on infrastructure capacity. At present, flood forecasting is carried out by national agencies in many countries of the region, but these efforts are constrained by the generally inadequate access to real-time hydrometeorological data. The existing flood forecasting and warning capacity could be more effective if real-time data could be acquired from cross-border upstream areas within the GBM catchment, where runoff is generated. Some exchange of data has occurred through bilateral agreements between Nepa1 and India, Nepal and Bangladesh, Bangladesh and India, and China and India. However, real-time data sharing among the countries of the GBM remains insufficient (Thakkar 2006). Regional cooperation can help strengthen flood management through better access to data and information from upstream on hydro-metrology, river flow, and climatic conditions, which can save lives and reduce economic losses in downstream countries.

Although flooding cannot be completely avoided, regional cooperation in flood mitigation could save billions of dollars and reduce vulnerability substantially (Ahmad 2004). An integrated system of flood forecasting and early warning must be based on cooperation among governments and with the river basin populations. The International Centre for Integrated Mountain Development (ICIMOD) has been developing such a regional flood information system based on comprehensive data sharing and joint modelling and scenario development among the GBM countries. Sharing of hydrometeorological information among countries will not only reduce disaster risk, but will also increase confidence building among participating countries and institutions and promote awareness of the mutual and regional benefits of sharing data and information. The benefits of regional-level flood forecasting and early warning have been demonstrated in the Danube basin: in the past two decades, the GBM and the Danube each experienced 24 large floods. While in the GBM 18,000 people lost their lives (about 30 people per million), deaths in the Danube numbered 274 (about 3.5 people per million) (Bakker 2009).

5 Discussion and conclusions

The GBM region is rich in water resources, but they have not been developed fully. As a result, the region is challenged in ensuring food, water, and energy security in the face of increasing uncertainty in water availability with a changing climate. Farmers have limited access to water for irrigation. Recurrent floods and droughts thwart food and livelihood security. Power shortage cripples many economic activities and thwarts industrial growth. Most of the rural population depends on biomass and other traditional sources of energy living in poverty and suffers from recurring floods as well as bearing the costs of under-developed water transportation.

The economy and environment of the region depend heavily on water resources for agriculture, food security, energy, industry, transport, healthy ecosystems, and sustainable development. Therefore, the management of water resources has strong implications not only for ensuring water, energy, and food security but also for overall economic growth. Water, if planned and managed well with coordination among relevant stakeholders, could contribute significantly to the economy of the region by boosting agriculture and industrial growth, enhancing energy security, and reducing damage from floods and other climate change related hazards. As Iyer (2001, pp. 1235 − 1245) rightly notes, 'Water is in fact the magic key to future prosperity in this region'.

The countries of the GBM share a strong hydrological linkage. Floods and erosion originating in one area may greatly affect another; water storage facilities exist in one country and water demand in another; hydropower potential exists in one country and the energy market in another; and data and information generated in one country can mitigate disasters from flooding and drought in another. These interdependencies necessitate cooperative efforts. Indeed, water provides the most appropriate entry point for cooperative regional development.

As demonstrated by the World Bank's Ganges Strategic Basin Assessment (Wu *et al.* 2013), the potential benefits from this cooperation are large and the cost of non-cooperation is huge. Even the most water-rich country, Nepal, suffers from severe water shortages during the dry season owing to insufficient infrastructure and faces load shading of 10 − 12 h per day. As long as poor management of shared water resources continues, avoidable economic damage from flooding and drought will continue, economic growth and industrialization will be constrained, and society will suffer huge costs. Poor access to safe water and modern energy has serious implications for society and particularly for women and children, who are responsible for fetching water in this region.

Despite huge benefits, regional cooperation has remained suboptimal due to institutional rigidity, mistrust, and traditional mindset of seeing water from nationalist standpoints rather as a shared resource to be managed with shared perspective (Gareth Price *et al.* 2014). Cooperative development of transboundary water resources is inevitable not only for ensuring growing challenges of water, food, and energy security but also for peace and security of the region. It is heartening that some positive change has taken place recently after the visit of Indian Prime Minster to Nepal. India and Nepal signed a Power Trade Agreement in September 2014. South Asia Association for Regional Cooperation (SAARC) foreign ministers signed the SAARC Framework Agreement on Energy Cooperation (Electricity) during the 18th SAARC summit held in Kathmandu in November 2014. This is expected to promote regional energy trade and pave the way for regional cooperation water, hydropower, and disaster mitigation. Policy-makers in the region seem to be taking a much more positive and balanced view of the necessity of regional cooperation. Regional cooperation in data sharing, flood management, hydropower development, and energy trade could be a starting point for a new era of collaborative development. The region should move from a geo-politics to geo-economic development approach.

Development of water resources, however, needs to be considered judiciously taking into account social, ecological, and environmental implications of water resources development and considering the views of diverse stakeholders. Strategic environmental assessment including detailed studies of technical and economic feasibility are required to identify potential hydropower areas and to demarcate fragile zones where heavy construction must be avoided, for example at high altitude and in vulnerable watersheds (Rasul 2014). Similarly, resettlement of affected people should be well planned and managed so that their lives could improve further and their ownership is built. Joint research and fact finding are critical to support informed decision-making at transboundary level. In developing water resources, it is not enough to develop physical infrastructure alone; development of institutional capacity is also critical as weak institutional capacity not only poses a major obstacle for planning and implementation of complex transboundary project but also causes serious damages as happened in the breach of Koshi Dam in 2008. The catastrophe of the dam breach could have been avoided with timely repair and maintenance of the weak part of the dam, which was identified well in advance (Pun 2009).

Making water a part of economic development calls for multidisciplinary research, not only on technological issues but also on issues of social, economic, legal, and environmental concerns, as the problems of water resources management are multidimensional.

Sustainable water development in the mountains and the mitigation of natural disasters in river basins depend on large-scale measures to protect upstream water sources, forests, and soils in mountain areas. Protection and conservation of the mountain environment are thus critical for long-term sustainable economic development of downstream areas. Successful resettlement following international guidelines following the World Commission on Dams (2000) and a well-considered benefit sharing mechanism and development entitlement will be required to make mountain people the partners of hydropower development and to ensure that they receive a fair share of economic benefits generated from these projects (Dore 2014). At present, there is no such policy or institutional mechanism for sharing the benefits generated from mountain water and hydropower resources. If these issues are addressed, water cooperation has the potential to change the economic and social landscape of the region as well as serve as a means to improve trust and peace-building in the region.

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