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Beyond hydropower: towards an integrated solution for water, energy and food security in South Asia

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ABSTRACT

South Asia is energy-poor, water-stressed, and food-deficient, and these problems are expected to intensify with high population growth, rapid economic growth and industrialization, urbanization, and changing climate. Although the water, energy, and food security challenges are interconnected, they are dealt with in isolation, which fails to address the challenge of trade-offs and exacerbates the problems. The increased resource scarcity underlines the need for integrated solutions which ensure optimal resource use and maximize benefits. This article uses a nexus perspective to explore possible integrated solutions that support multiple uses of water at different scales and times. The analysis shows that the potential of water resources is underdeveloped and synergies between water, energy, and food are not fully harnessed. With proper coordination and management, water resources can generate multiple benefits for both upstream and downstream areas, including regional public goods such as regional connectivity and flood and drought management.

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Introduction

Water, food and energy are fundamental for human existence and progress. South Asia is one of the most dynamic and fastest-growing regions in the world. The population of around 1.75 billion (20% of the global population) is growing by around 1.5% annually, while the economy has grown by more than 6% over the last decade (World Bank, 2018). The per capita GDP of the region has doubled over the last 10 years (from USD 957 in 2008 to USD 1840 in 2018). But despite the rapid economic growth in recent decades, South Asia has some of the worst levels of human deprivation in the world. Nearly half of the world's poor (46%) and more than one-third (35%) of the world's undernourished live in the region (Rasul, 2014a, 2016); about 400 million (23% of the population) have no access to electricity; more than 500 million (29%) use traditional biomass for cooking (World Bank, 2018); more than 200 million (12%) lack access to safe drinking water; more than 900 million (52%) do not have good sanitation services (WHO & UNICEF, 2014); more than 200 million (12%) face chronic food shortages; and about 300 million (17%) are undernourished (FAO, 2017).

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With their growing population, rising economy, growing middle class and rapid urbanization, South Asian countries face a number of fundamental challenges, including meeting the growing demand for energy, water and food. Besides energy, water and food insecurity, South Asia also suffers from high poverty (16.2% poverty headcount ratio at USD 1.90 a day), low human development – all these countries have a medium or low Human Development Index, from 0.640 (India) to 0.498 (Afghanistan) – and weak infrastructure (only 2.33 infrastructure index in comparison to 4.37 for European countries) (United Nations Development Programme, 2018; World Bank, 2018). Congested roads, poor waterways, weak regional connectivity and high transportation costs make the region less competitive and hinder socio-economic development (World Bank, 2018). The increased occurrences of drought and increased frequency and magnitude of floods that are likely to result from global warming will further intensify the competition for freshwater and energy resources in the region (World Bank, 2009).

The Himalayan region is geographically integrated and has a high level of economic complementarity and interdependence. It is also closely linked hydrologically, and these links lead to a high degree of interdependence and transnational impact related to water. The Indus, Kabul, Ganges, Brahmaputra and Meghna Rivers, which rise in the Himalayas, connect six mainland South Asian countries: Bangladesh, Bhutan, Nepal, India, Pakistan and Afghanistan (Rasul, 2015). Many major and minor rivers are transboundary; for example, 54 rivers cross between India and Bangladesh. Many important tributaries originate in China, Bhutan and Nepal and supply water to Bangladesh, India and Pakistan. These interconnections mean that floods originating in Nepal affect India, and floods originating in India affect Bangladesh and Pakistan. Not only water, but energy and food security issues in the Himalayan region are also connected and have regional dimensions as a result of the reliance on common transboundary rivers (Rasul, 2015). The Himalayan rivers offer a huge potential for the development of water resources for hydropower, irrigation, navigation, transportation, fisheries, tourism and ecosystems (De Fraiture, Molden, & Wichelns, 2010; Rahaman, 2009; World Bank, 2014). Their management has regional implications, and many of the rivers serve as regional public goods.

Efforts in water resources development in South Asia are mostly single-purpose and sectoral and without a broad regional approach. In transboundary river basins, where water transcends national boundaries, upstream use and management practices affect downstream areas; optimal development of water resources requires both sectoral coordination and transboundary cooperation (Bach et al., 2012; Rasul, 2014b). Due to the sectoral approach and the nationalistic perspective of water resource development, hydropower, irrigation and navigation infrastructure remain inadequate, while floods and droughts create additional challenges for meeting the growing demands for water, energy and food (World Bank, 2014). These piecemeal projects may serve short-term needs, but they can also compromise other potential co-benefits and undermine long-term strategic goals and the integrity of regional public goods.

Many hydropower projects have been planned or are under construction in the upstream areas of Bhutan, India, Nepal and Pakistan to meet the increasing energy demand. These projects are often designed purely to produce electricity, without considering the co-benefits that could be generated for both upstream and downstream riparian populations through better planning and collaboration. Most of the hydropower projects in Nepal and Bhutan are run-of-the river projects, which often not only fail to meet electricity demand during the dry season, when more energy is needed for domestic and irrigation purposes, but also have a limited capacity to generate co-benefits to downstream areas. Projects like these exemplify how plans that only consider how to use water for hydropower generation may actually undermine other potential benefits, such as navigation, regional connectivity, and flood control, with a particularly negative effect on public goods and services at a regional scale.

The growing demand for water for energy, food and other competing uses, combined with increased resource scarcity, underlines the need for integrated solutions. With proper coordination and management, water resources can generate multiple and mutual benefits for both upstream and downstream populations as well as producing regional public goods such as regional connectivity, navigation and transportation, better management of droughts and floods, and support for regional development. With an integrated approach, water used for hydropower can be used to irrigate agricultural land downstream, and water used for navigation can be used for fisheries and tourism, and to improve water security, energy security and agricultural productivity, as well as improving connectivity and reducing the impact of floods and droughts (Brown & Lall, 2006; Clement, 2010; Mostert, 2008).

Despite the pressing need, only limited efforts have been made towards Integrated Water Resource Development at national and transboundary scales. Our current knowledge falls short of integrated solutions (Reid et al., 2010). Better understanding of the mutual benefits that can be derived from multipurpose use of water at the basin level may help policy makers and development practitioners take action towards integrated development. Although integrated management of water resources has received much attention in developed countries since the Tennessee Valley Authority (Downs, Gregory, & Brookes, 1991; Barrow, 1998; Tortajada, 2014), this approach has not been explored optimally in South Asia, though some initiatives were taken in the early 1950s, such as the Damodar Valley Project (Lahiri-Dutt, 2012). As a contribution to this, this article uses a nexus framework to explore the potential benefits of integrated development of water resources at the basin level. It in five sections. This introductory section is followed by a section examining how the key drivers have exacerbated the interactive challenges of water, energy and food security and necessitated integrated solutions. The third section explores the co-benefits of storage-based hydropower development to support multiple uses of water at different scales and times. This section also presents an example of multipurpose water use in the Koshi basin as an integrated solution. The fourth section considers the potential for using water to generate regional public goods, including regional flood moderation, navigation, and adaptation to climate change. The final section draws conclusions and recommends actions for integrated solutions.

Key drivers exacerbating the interactive challenges for water, energy and food security

South Asia is one of the most dynamic regions in the world. Rapid population growth, a growing middle class, urbanization, industrialization and economic growth are leading to rapidly increasing demand for water, energy and food, with climate change further exacerbating the problems. Water, energy and food security are closely linked, and the current drivers are intensifying intersectoral competition for water. The key drivers of change influencing water, energy and food security, and the interlinked challenges they pose, are summarized in Table 1 and discussed briefly below.

Burgeoning human population

South Asia's population is growing at about 1.5% annually and is projected to grow from 1.6 billion to 2.1 billion by 2030 (Walsh, 2017). The growing population will lead to increased demand for food, water and energy, with cereal demand projected to more than double by 2030, from 241 million tons in 2000 (FAO, 2012). This will create further pressure on the limited area of arable land, which has already been reduced from 0.4 ha per capita in 1960 to 0.12 ha per capita in 2013 (World Bank, 2018). The shrinking land per capita will necessitate intensifying food production, which will require more water and energy (Table 1).

Rapid economic growth, industrialization and urbanization

The South Asian economy has been growing at an average of over 6% annually for the last decade. Per capita income has almost doubled, from USD 957 in 2008 to USD 1840 in 2018. Rapid growth has been instrumental in reducing poverty and expanding the middle class. At present only a third of the population lives in urban areas, but this is expected to increase to more than half by 2050 (World Bank, 2018). The rapid pace of urbanization and economic growth and the growing middle class will not only create additional demand for water and energy but also shift dietary preferences from plant-based to animal-based. Per capita meat consumption in South Asia is expected to almost double by 2030 compared to 2000 (Hubert, Rosegrant, van Boekel, & Ortiz, 2010). Increased production of meat and dairy products and processed foods will further increase the demand for water and energy (Rasul & Sharma, 2015) (Table 1).

Growing water stress

South Asian countries are already experiencing water stress in both temporal and spatial dimensions. Per capita renewable fresh water resources fell by 65% between 1962 and 2014 (World Bank, 2018), and in both Pakistan and India water availability is now below the water stress threshold of 1667 m^3 per capita per year (Falkenmark, 1986), at 1306 m^3 and 1458 m^3, respectively (AQUASTAT, 2018). There is a great variation in per capita water availability within each region, even within a country. For example, the per capita water availability in western Rajasthan (India) is one of the lowest in the world, while the north-east sates of India have the highest water availability. At the same time, the water demand for agriculture, energy, industry, and human and livestock use in the region is predicted to rise by 55% in 2030 compared to 2005 (Rasul & Sharma, 2015). The existing water stress is likely to be further exacerbated by the changing monsoon pattern, melting of glaciers and reduction in snow. Agriculture is increasingly dependent on groundwater, which is leading to higher demand for energy for pumping, which in turn raises both food prices and emissions (Ringler, Bhaduri, & Lawford, 2013). At the same time, insufficient natural recharge is resulting in sinking water tables, with a loss of natural springs and reduced water availability in the long term. The increasing demands and reduction in availability are leading to a growing problem of competing demands

Table 1. Key drivers of change and their implications for water, energy and food security.

Key drivers	Implications for water-energy-food security	Interlinked future challenges
Growing human population Rapid economic growth, industrialization and urbanization Growing middle class	• Declining per capita availability of land and water • Increased demand for food, water, energy • Greater economic activity will increase energy and water demand • Increasing intensity of water and energy use • Changing food habits – from plant to animal-based food – leading to increased demand for water and energy for production • More energy to transport and supply water to urban areas through pipelines	• Producing more food and energy with limited land and dwindling water resources • Meeting the increased demand for water and energy • Managing the competing demands for water for multiple uses
Growing water stress and increasing use of groundwater for food production	• More energy needed to pump groundwater for food production; higher food prices • Sinking water tables leads to drying of springs and more water stress on marginal land	• Managing the growing demand for energy and water for food production
Growing demand for water for multiple purposes	• Increasing demand for water for competing uses – irrigation, domestic use, biofuel production, hydropower, navigation, industry, and others • Intersectoral competition and cross-country conflicts over water	• Meeting the increased demand for water for competing uses of irrigation, domestic consumption, and energy production, among others • Tackling intersectoral competition for water • Water infrastructure packages that can increase water storage capacity • Improving water use efficiency • Financing water infrastructure projects
Growing demand for energy	• Soaring energy demand • Decline in food production due to shift of land use from agricultural crops to biofuel production • High use of fossil fuels contributing to greenhouse-gas emissions	• Generating and supplying adequate clean renewable energy to meet the rising demands of an increasing population and change in consumption patterns
Climate change – rising temperature, retreating glaciers, increase in extreme events	• Variable weather patterns • More heat and evapotranspiration • Variable water supply with accelerating water demands for energy and food • Frequent floods and droughts • More people exposed to water stress and droughts • More cropland area facing water stress	• Addressing the challenge of more variable water supplies combined with accelerating demand for water and energy • Tackling the increasing incidence of both droughts and floods • Taking adaptation and mitigation measures and harnessing non-renewable energy sources including hydropower
Globalization – increase in trade flows	• Increase in trade flows and access to markets • Increased energy demand for transport • Reduced transportation costs for goods and services	• Increasing physical connectivity • Harnessing efficient modes of transportation like rail and waterways

Sources: Prepared by authors based on Rasul and Sharma (2016); Rasul (2014a); Qureshi (2002); Hussain, Rasul, Mahapatra, and Tuladhar (2016); Hussain, Rasul, Mahapatra, Wahid, and Tuladhar (2018); FAO, IFAD, and WFP (2015).

for water for irrigation, domestic use, agriculture, biofuel production, hydropower, navigation, industry, and other uses.

Rising temperatures and insufficient water hamper crop growth, in combination with extreme events such as floods and drought. Drought has become a severe challenge in South Asia, particularly in rainfed areas. Over 100 million ha of land (54% of the total cultivated land) is under a rainfed regime in six countries of South Asia (Table 2). India and Pakistan suffered major drought at least once every three years in the past four decades, and Bangladesh and Nepal also suffer from frequent droughts. It is estimated that 5000 people were killed and over 1 billion affected by drought during 1975–2015 in South Asia, with total damage of USD 37.43 billion economic losses, about USD 1 billion per year (EM-DAT, 2018).

Growing demand for energy

South Asia is energy poor. The per capita energy consumption in 2014 of 707 kWh was among the lowest in the world (average 3126 kWh); some 20% of the population lacks access to electricity (World Bank, 2018), and most of those with access experience shortages. South Asian countries have been facing huge economic losses from power outages (Abbas et al., 2018; Tortajada & Saklani, 2018). Demand is growing rapidly, however, with a present rate of 3.5% per year, which is expected to increase further, fuelled by economic growth, urbanization and a growing middle class. For example, India's current primary energy supply is 851 Mtoe, of which 303 Mtoe is fulfilled through import (International Energy Agency [IEA], 2018). Energy demand is expected to increase three-fold by 2030 to sustain the current level of economic growth (ADB, 2009). Currently, fossil fuel is the major source of electricity in both India (79%) and Pakistan (65%), and dependence on fossil fuels has even increased in Bangladesh (Shrestha, 2013). The region is fossil-fuel-centric, and energy production is the main source of greenhouse-gas emissions (Table 1). How the region meets the growing energy demand will have far-reaching consequences for global greenhouse-gas emissions and will require a major effort to increase renewable clean energy, including hydropower, to reduce the dependence on fossil fuels and carbon intensity – as committed to by the countries of the region under the Paris Agreement on Intended Nationally Determined Contributions. For example, India has committed to reducing greenhouse-gas emissions by more than 30% by 2030 (Jackson et al., 2015). This commitment is considered to change the energy mix scenario of South Asia and demand more clean energy, including hydro-electricity, as the 'consistency of solar and wind power is limited by natural phenomena (such as the sun setting or pressure systems)' (Pillai & Prasai, 2019, p. 5).

Table 2. Drought-affected area and population in South Asia.

	Afghanistan	Bangladesh	Bhutan	India	Nepal	Pakistan	Overall
Total cultivated area (million ha)	7.9	8.4	0.11	169.3	2.6	31.2	219.3
Rainfed area (million ha)	4.7 (59)	3.4 (41)	0.08 (82)	103 (61)	1.0 (41)	11.1 (36.6)	119.3 (54.4)
Drought-affected area (% of cultivated area)	4.3	34	11.7	39.4	24.6	36.8	37.3
Population affected by drought (millions)	2	1.5	0.2	233	0.6	55	292.3

Note: The values in parenthesis are percent of cultivated area.
Sources: World Bank (2018); AQUASTAT (2018); Amarnath, Alahacoon, Smakhtin, and Aggarwal (2017); OCHA (2014).

Climate change

Higher temperatures, more variation in rainfall, melting glaciers, reduced snowfall, higher frequency and intensity of floods, more droughts, and other extreme events induced by climate change are expected to bring additional challenges to water, energy and food security (World Bank, 2009). India and Pakistan have experienced a major drought at least once every three years over the past four decades. Floods and droughts affect cropped land and food production across the region. Climate change is likely to increase water and energy demand for food production (Table 1). Water demand for crop production is projected to rise by 6–10% for every 1 °C increase in temperature (IPCC, 2007; Beniston & Stoffel, 2014). Cereal production in South Asia is projected to decline by 4–10% due to climate change and the resultant water scarcity (IPCC, 2007). Climate change might also affect hydropower, particularly run-of-the-river hydropower projects. Water availability in the Indus, Ganges and Brahmaputra Rivers is expected to become less reliable, particularly in the dry season, when water demand for irrigation and energy production is highest (Immerzeel, Van Beek, & Bierkens, 2010).

In summary, the different drivers of change presented above interact and bring interconnected challenges for water, energy and food security in South Asia. The conventional silo approach is unable to deal with these interactive challenges in a sustainable way; an integrated solution is called for.

An integrated approach to harness the multiple uses of water

The complex interactions among the different drivers discussed earlier implies a need for an integrated approach and collective action for multiple uses of water to manage trade-offs and harness synergies among water, energy and food. Water has multiple uses, both consumptive – for example, drinking water, which when drunk is no longer available for other uses – and non-consumptive, for example hydropower generation, where the water remains available for other uses (Meinzen-Dick & Jackson, 1996; Rasul, 2014b) – see Box 1. Water moves from higher to lower elevations if not regulated, and flow varies with the season. Although water is essential for all living organisms, too much water can be harmful, with floods and other water-induced disasters threatening lives and property. Large rivers and lakes may be shared by a number of countries, so their management has regional dimensions, bearing on regional public goods and shared benefits. Water has a very wide range of uses in domestic consumption and sanitation, irrigation and food production, energy production, transportation, industry, environmental regulation, recreation, and many others. These often compete, especially when resources are scarce, and when designing water projects it is important to look at possibilities for creating co-benefits that support multiple uses.

Tapping monsoon water for multiple uses

One of the most promising ways of providing multiple benefits in South Asia is the use of storage reservoirs to capture the monsoon water and release it in the dry season. In addition to hydropower, water from reservoirs can be used to provide water for urban areas and irrigation, regulate extreme flows, maintain environmental flows, and push back saltwater intrusion in downstream areas (Kumar, 2010; Tortajada, 2014). The availability of additional surface water from multiple reservoirs can reduce groundwater

Box 1. Multipurpose water use in the Koshi basin: example of an integrated solution.

The Koshi River basin provides a concrete example of how Himalayan water can be used for *both* consumptive and non-consumptive purposes at different scales and generate greater benefits.

The Koshi River is a transboundary perennial river fed by monsoon precipitation and glacier melt. It originates in the Tibetan Plateau of China and flows through the mountains and plains of Nepal to meet the Ganges in the flood-plain areas of Bihar, India, eventually draining into the Bay of Bengal. Although the region benefits from rich annual water resources, communities in the Koshi basin and downstream are generally poor and suffer from floods, droughts, poor access to electricity, and water shortages. With better planning and more collaborative investment by the riparian countries, the river could generate considerable economic and social benefits for both upstream and downstream countries. First, water can be used for hydropower production (a non-consumptive use) at several upstream sites, particularly along the tributaries with a steeper slope. Water flowing downstream can then be used for navigation (non-consumptive), fisheries (non-consumptive), agriculture (consumptive), flood moderation, dry-season augmentation of the Ganges at Farakka, and flushing saline water in the flood plains of the deltas, as shown schematically in Figure 1. The different benefits are described in more detail in the following.

Hydropower in the upstream

The Koshi has a theoretical hydropower potential of 23,000 MW (Hussain & Mark, 2004), with 10,000 MW potentially economically viable (Hussain & Mark, 2004; KC, Khanal, Shrestha, & Lamsal, 2011). In 1985, the Japan International Cooperation Agency identified 11 potential hydro projects (seven run-of-the-river and four storage) along different tributaries, and various surveys have suggested that more than 6,000 MW of hydropower could be generated, but current hydropower generation is less than 200 MW (WECS, 2011).

A series of hydro projects have been proposed upstream (Figure 1), with the outflow stored in a large reservoir near Barahachhetra, Sunsari, in Nepal. The proposed reservoir at Chattara would cover 195 km^2 behind a dam 269 m high, with a gross storage capacity of 13.5 km^3 and 9.3 km^3 of live storage (Rahaman, 2009). It would generate 3300 MW of hydropower – approximately equivalent to the present electricity demand for the whole of Nepal. Any surplus production in Nepal could be exported to Bangladesh and India.

Irrigation

The seasonal nature of the small and medium-size rivers that supply water to most of the irrigation facilities in the Ganges basin poses a major challenge for year-round irrigation. The proposed large reservoir at Chattara in Nepal could supply year-round irrigation in the downstream areas. A proposed barrage on the Saptakoshi about 8 km below the dam would regulate water for irrigation and navigation. Currently, annual water availability in the Koshi is 48 km^3, which is mostly untapped; only 14% is being used, mostly in agriculture (Bharati, Gurung, Jayakody, Smakhtin, & Bhattarai, 2014) The proposed dam could irrigate more than 1.5 million ha. It could tentatively irrigate 546,000 ha in Nepal, in the districts of Mahottari, Dhanusha, Siraha, Saptari, Sunsari, Morang and Jhapa, and about 1,053,000 ha land in Bihar State, India (JPO-SKSKI, 2016). Diversion of the Sunkoshi to the Kamala River is also a part of this multipurpose project, which would enable irrigation of an additional 175, 000 ha in the central plains of Nepal. It would also help stabilize year-round irrigation systems in Nepal, as most of the irrigation systems in Nepal are fed by the Siwalik and Mahabharat ranges and suffer from water shortage during the dry season.

Flood moderation

The proposed water storage in Saptakoshi could store more than one-fourth of the total annual water flow (Rahaman, 2009; Bharati et al., 2014). Monsoon flow is 70.8% of the total flow (Bharati et al., 2014) and provides around 34 km^3, which means that almost 40% of the monsoon water could be stored (if the reservoir is emptied before the onset of the monsoon), which would have significant impact on flood moderation downstream. The storage would help moderate floods during the peak flood period and prevent multiple cascading impacts (Pun, 2004; Poff & Olden, 2017).

Navigation

Development of a 165 km navigation canal from Chattara (downstream of Barahachhetra) to Kursela would link Nepal to India's Inland Waterway No. I along the Ganges, facilitating the import and export by both countries at low prices using water for transport. For example, Nepal could import petroleum products, fertilizer, vehicles and salt from India, and export off-season vegetables, fruit and tea produced in the Nepalese hinterlands. Nepal could also export stone and sand to Bangladesh and India (Thapa, 2004; Pun, 2004).

Dry-season water availability downstream

After fulfilling non-consumptive navigation requirements, the river water could also be used to some extent to improve dry-season water availability downstream, including in Farakka, where dry-season water availability is low. This additional water would create an additional irrigable area, push back saline water, and increase water productivity. Thus, multipurpose dams built in Nepal would benefit Nepal, India and Bangladesh (Institute of Integrated Development Studies, 2000).

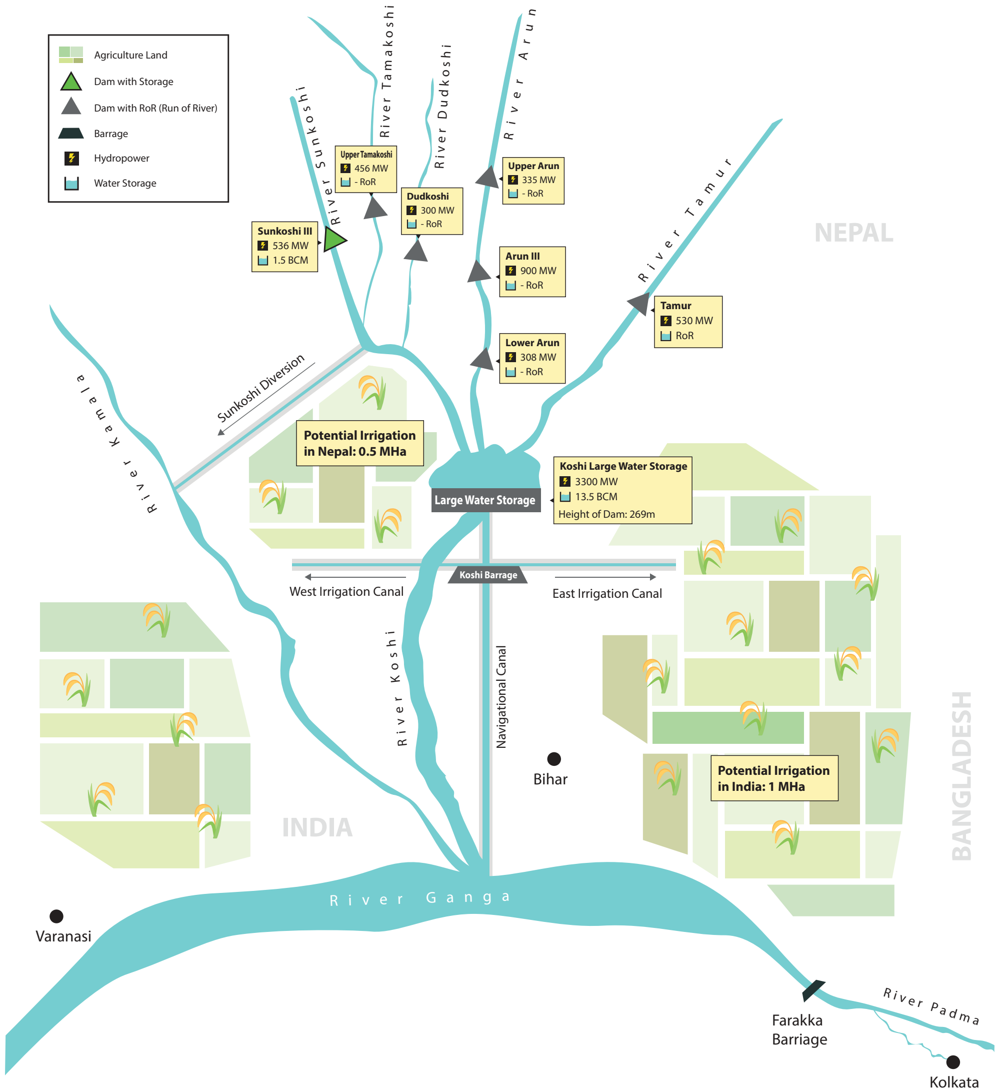

Figure 1. Schematic presentation of the potential benefits of multipurpose water resource development in the Koshi basin

withdrawal and the energy cost of pumping, and help irrigate additional land through groundwater recharge (Misra et al., 2007). Well-planned multipurpose hydropower projects can generate additional co-benefits, enhancing water and energy security, increasing security against climate risks, including moderation of floods and droughts, and helping increase regional connectivity by developing and expanding waterways for navigation (Biswas & Tortajada, 2001; Tortajada, 2014).

The steep terrain and mountain gorges offer a huge potential for large water storage in the Himalayan river basins (Table 3). The average annual water flow in the Ganges-Brahmaputra-Meghna region is estimated at around 1,350 km^3 (Brahmaputra 700 km^3,

Table 3. Water storage potential and current status in the Indus and Ganges-Brahmaputra-Meghna basins (km^3).

Basin	Current annual withdrawal	Current storage	Surface storage potential	Groundwater potential	Total potential
Ganges (in India)	281	25.4	94	171	265
Ganges (in Nepal)	9.7	0.1	121	28	149
Brahmaputra (in India)	28	1.8	53	35	88
Meghna (Barak)	No data	No data	15	No data	–
Indus	343	45	No data	No data	–

Sources: Biswas (2008); Infrastructure Development Finance Company [IDFC], (2011); Andermann et al. (2012); Biemans et al. (2013); Whittington and Wu (2013); Biemans et al. (2013).

Ganges 500 km^3, Meghna 150 km^3) (Ahmad, Biswas, Rangachari, & Sainju, 2001; Biswas, 2008), and in the Indus, 175 km^3 (Qureshi, 2011). But the existing water storage capacity is much smaller than in other industrialized countries, with a per capita water storage in India and Pakistan of only 220 m^3 and 150 m^3, respectively, compared to 2200 m^3 in China, 6000 m^3 in the US, and 5000 m^3 in Australia (Qureshi, 2011). The Murray–Darling and Nile Rivers store 100–200% of the mean annual flow for multi-year storage and operations (Sadoff et al., 2013), compared to less than 10% for the Ganges (Jeuland, Harshadeep, Escurra, Blackmore, & Sadoff, 2013). Nepal's rivers contribute close to half of the annual flow of the Ganges, and 75% during the lean season (March to May) (Pun, 2004), but Nepal currently stores less than 1% of total annual runoff, and there are no big reservoirs along the large tributaries of the Ganges in Nepal (Jeuland et al., 2013). In Nepal, more than 30 sites have been identified as suitable for building reservoirs, with a total capacity of 121 km^3, equivalent to 18% of the total annual flow of the Ganges (Biswas, 2008).

Enhancing water, energy and food security using hydropower reservoirs

The topographic relief and abundant water resources in mainland South Asia are favourable for hydropower generation. The six south Asian countries have a total hydropower potential of around 388 GW (Table 4). Currently only 16% of this potential is utilized, compared to 80% in the industrialized countries (Briscoe & Malik, 2006). Realizing this hydropower potential requires both developing infrastructure to store monsoon water and getting competitive markets for electricity. Water distribution is highly skewed: about 80% of total precipitation falls in the four months from June to September and flows quickly to the sea. Run-of-the-river hydropower projects cannot function properly in the dry season due to the lack of water. Storing monsoon water so that it can be released gradually not only allows the full potential of hydropower generation to be realized, but also generates co-benefits by

Table 4. Hydropower potential in South Asia.

	Afghanistan	Bangladesh	Bhutan	India	Nepal	Pakistan	Total
Theoretical potential (MW)	23,000	755	30,000	184,700	80,000	100,000	388,006
Commercially feasible potential (MW)	23,000	755	24,000	84,004	43,000	59,000	236,350
Installed (MW)	442	230	1615	51,756	867	7,320	62,230
Current utilization (% of theoretical potential)	1.9	30.4	5.3	28	1.1	7.3	16

Sources: Bergner (2013); International Hydropower Association (2017).

augmenting water availability in the dry season for irrigation, navigation, recreation, fishery, and flushing salty soil, while moderating both floods and droughts.

The water released in the process of hydropower generation during the dry season can be used to fill many of these needs. A number of studies suggest that upstream reservoirs built for hydropower generation can be used to store water during the monsoon and augment river flow during the dry season, mitigating water stress (Rahaman, 2009; World Bank, 2014; Wu, Jeuland, Sadoff, & Whittington, 2013).

There is a significant gap between attainable and actual yields in the region, which is at least in part due to access to irrigation facilities. The overall yield for irrigated crops is 2.7 tonnes/ha, which is higher than the 1.3 tonnes/ha for rainfed crops but considerably lower than the global average of 3.7 tonnes/ha (De Fraiture & Wichelns, 2010). The average rice yield in the Ganges and Indus basins of 2.5–3.5 tonnes/ha (Cai & Sharma, 2010; Sharma et al., 2010) is considerably lower than the 6.2 tonnes/ha achieved in neighbouring Punjab (Sharma et al., 2010). There is considerable room to improve rice and wheat yields through better irrigation facilities and water management (Cai & Sharma, 2010; Sharma et al., 2010). Molden (1997), (2001)) calculated a water value of USD 0.07–0.17/m^3 for wheat production from irrigation.

Construction of medium-size and large reservoirs in the Himalayas would not only help bring more agricultural land under irrigation (Misra et al., 2007; Rahaman, 2009) but also help sustain the existing canal irrigation systems, which are declining due to shortage of water in the dry season (Mukherji, Banerjee, & Daschowdhury, 2009). Over 5.5 million ha of canal-irrigated areas were lost in India and Pakistan between 1994 and 2001 (Mukherji et al., 2009) due to water shortage. Moreover, the greater hydropower production from these reservoirs and the resulting better electricity supply could increase agricultural productivity through groundwater irrigation, particularly in areas where groundwater is abundant (Rasul, 2014a). The combination of more irrigated land, higher productivity, and less flood damage would provide significant benefits for the region, with the greatest benefit to agriculture in India and Bangladesh, where there is greater scope to increase the irrigated area.

Managing water for regional public goods

There is a growing demand for regional public goods to tackle shared problems, address emerging challenges and opportunities, share prosperity, manage shared resources, manage regional disasters, and adapt to climate change. Regional connectivity, cross-border infrastructure and transport networks, transboundary river basin management, and cross-border disaster management for flood and drought are all regional public goods, as they benefit more than one country (Lee & Kim, 2018; Moinuddin, 2010; Sandler, 2006). Managed properly, Himalayan water could generate regional public goods and benefits for South Asia. For example, most of the floods in South Asia affect more than one country and require regional action, while cross-border waterways improve overall regional connectivity. It is important that water planning include generation of regional public goods as a target.

Improving regional connectivity through development of waterways

Afghanistan, Bhutan, Nepal, and the mountainous parts of India and Pakistan lack direct access to the sea and bear higher transportation costs for the movement of goods (Table 5). Nepal, for example, pays an average of 41% of the import value in transportation costs to import goods from South Asia, compared to 16% for India (Pyakuryal, Roy, & Thapa, 2010; Shively & Thapa, 2017). These landlocked mountainous countries and states suffer from poor infrastructure and inaccessibility as a result of the difficult topography. The cost of transportation determines to a large extent the volume of trade and size of industry and thus a country's economic growth (Radelet & Sachs, 1998), and poor transportation infrastructure and high transportation costs are major impediments to economic growth in mountain areas. Cheaper transportation reduces the price of raw materials and makes industry more competitive through trade and market enhancement, as well as introducing products into the regional and global market which bring dynamism to the economy.

Due to the lack of alternative modes of transport, the landlocked countries and states in South Asia mainly depend on road transport for regional and international trade and are confronted with a variety of bottlenecks which increase trade costs (Arvis, Marteau, & Raballand, 2010). Road transport is slow and expensive. For example, Nepal imports most of its goods and services via the nearest sea port, at Kolkata. It takes 19 days on average to bring goods by road along the 1300 km from Kolkata through Birgunj to Kathmandu, and 27 days if cargo is transported by rail up to Birgunj (Taneja, Prakash, & Kalita, 2013). Water has been used as a means of transport since ancient times. Many countries depend heavily on inland water transport, especially for large and bulky cargo, as it is cheaper, more reliable, less polluting, and more environmentally friendly than transporting goods by road or rail. With huge river networks and upstream and downstream reaches, South Asia has considerable potential for developing more extended regional networks and navigation facilities for water-based transportation, particularly connecting the less accessible mountain areas to the large river systems. All of the rivers originating in or passing through Nepal and Bhutan merge with the Ganges or Brahmaputra in India to ultimately reach the Bay of Bengal through Bangladesh. In earlier times, the Ganges was a busy waterway, but after partition in

Table 5. Trading time and cost to import and export a container in the landlocked and coastal countries of South Asia.

Country	Export		Import	
	Time (days)	Cost (USD per container)	Time (days)	Cost (USD per container)
Afghanistan	86	5,045	91	5,680
Bangladesh	28	1,281	33	1,515
Bhutan	38	2,230	37	2,330
India	17	1,332	21	1,462
Nepal	40	2,545	39	2,650
Pakistan	21	765	18	1,005
South Asia average*	38	1,603	40	1736
OECD average	No data	1,028	No data	1080
World average	21.5	1,559	24	1,877

*Average for South Asia, based on data from the six countries in this table.
Sources: World Bank (2018).

1947 the watercourses were neglected, and many transboundary waterways became dysfunctional.

Emerging opportunities

Regional cooperation for the development of waterways has gained momentum in South Asia (Haran, 2018). Recently, the government of India declared 106 additional waterways and amended the bilateral navigation protocol between India and Bangladesh to allow third countries to use their waterways. Waterways along the Brahmaputra and Ganges Rivers could provide a basis for sub-regional connectivity for South Asia, connecting Bangladesh, Bhutan, the north-eastern states of India, and Nepal to the sea via the Ganges-Brahmaputra-Meghna basin. Nepal could be directly connected to the ports of Haldia and Kolkata through India's National Waterway 1 (Figure 2), Bhutan could be connected through the Manas River to the Brahmaputra at the Jogighopa confluence, and north-east Indian states could be connected to many ports on the Brahmaputra through National Waterway 2 (Figure 3). The best option for Nepal is likely to be linking by road to the proposed Kalighat terminal (Figure 2), which would substantially reduce the distance and cost of transportation to the ports of Haldia and Kolkata compared to current road and rail links. The proposed Koshi High Dam offers

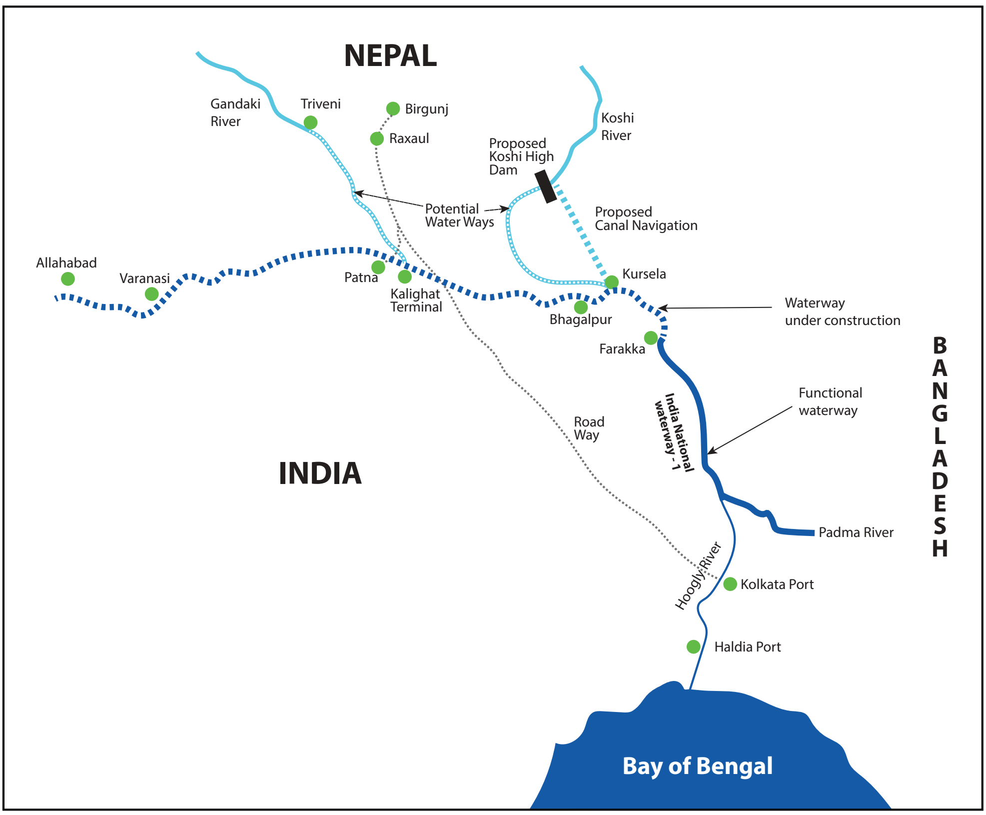

Figure 2. Potential waterways to connect Nepal with the Bay of Bengal.

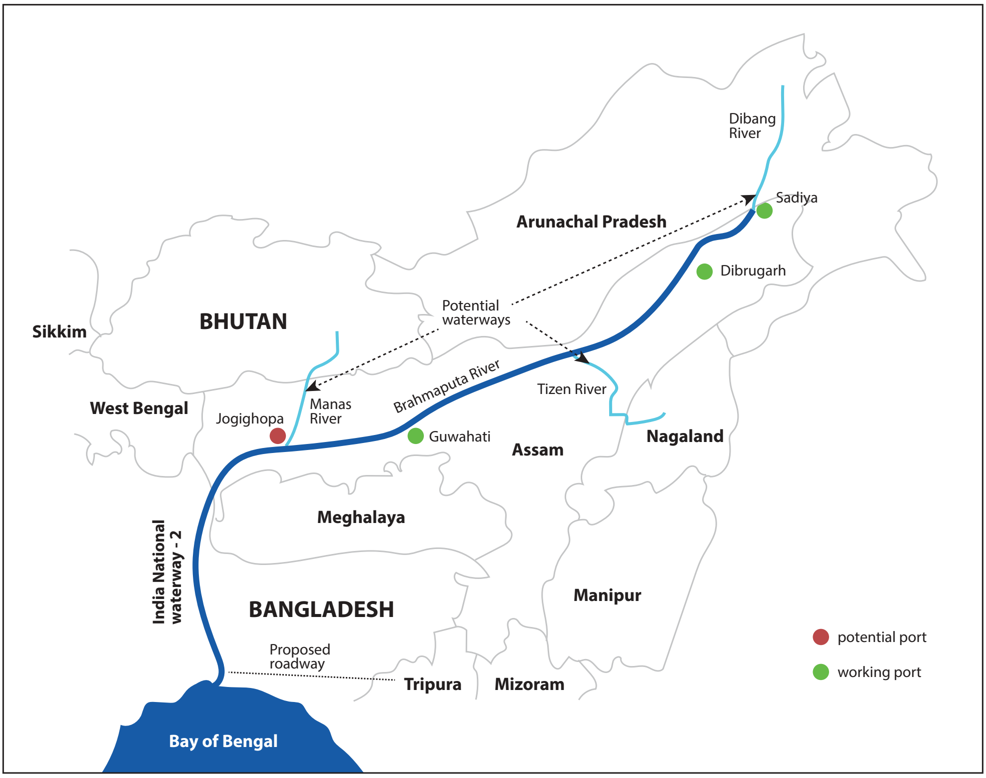

Figure 3. Potential waterways to connect Bhutan and North East India to the Bay of Bengal.

another option. The proposed navigation canal from this is 165 km long, of which 120 km lies in India (Dhungel & Pun, 2009; Thapa, 2004) and could provide a direct link to India's National Waterway 1 (Figure 2). In view of these opportunities, the prime ministers of India and Nepal made the decision to develop the inland waterways for the movement of cargo within the framework of trade and transit and are now working to operationalize the agreement.

The policy development between India and Bangladesh has also opened other opportunities for Nepal to improve transport and trade. In addition to the Indian ports, Nepal can use the ports of Chittagong and Mongla, in Bangladesh following the recent development of the Bangladesh, Bhutan, India, Nepal Motor Vehicle Agreement and the revised India-Bangladesh Navigation Protocol. Although Bhutan has not yet approved the Motor Vehicle Agreement, Bangladesh, India and Nepal have agreed to take it forward. A canal could be constructed in the Terai region of Nepal to convey water from the Gandaki and Koshi Rivers to augment the dry-season flows of the Mahananda River in West Bengal and the Korotoya and Atrai Rivers in Bangladesh. This canal could also serve as an international navigational route, giving Nepal access to the sea via India and Bangladesh. North-east India would also benefit. For example, Assam tea, which is in high demand in Europe, has to travel 1400 km through a bottleneck to reach Kolkata, and this could be shortened by more than 60% if goods were transported directly from the Chittagong port to Kolkata.

The navigation opportunities for Bhutan are the least explored. The transboundary Manas River connects Bhutan with Assam State in India. Bhutan could benefit immensely from expansion of National Waterway 2 in India, and in 2017 signed an memorandum of understanding with Bangladesh to use Bangladesh's inland waterways for transportation of goods and services through the Chittagong and Mongla ports for both import and export.

The Indus River system also offers opportunities for navigation. The government of Punjab Province in Pakistan has taken an initiative to start a 200 km commercial waterway on the Indus River between the districts of Punjab-Attock and Daudkhel (Abbas, 2016; Lead, 2018). Through a public–private partnership, the government has established the Inland Water Transport Development Company to connect Port Qasim in Karachi, a coastal city and an economic hub, with Nowshehra District of Khyber Pakhtunkhwa Province, an upstream area (Abbas, 2016). If water storage reservoirs are constructed in the upstream areas, it would not only improve water supply to irrigation systems but also stabilize the water availability in river systems for navigation in the dry season, when connected with the eastern tributaries of the Indus originating in India, and the Kabul River originating in Afghanistan (Abbas, 2016).

Under a 1921 treaty between British India and Afghanistan, British India used the Kabul River for navigation. This river still maintains its navigation potential to facilitate trade and commerce in the basin (Lead, 2018). Pakistan and Afghanistan have annual bilateral trade of about USD 2 billion, with more than 50% of this being exports from Pakistan, and transit trade of about USD 3 billion. Transit trade involves the movement of 50,000 containers of commercial cargo. It costs approximately USD 4000 to move a single container from Karachi to the Pak–Afghan border. If waterways are developed well, moving this cargo from Karachi to Kabul through waterways could significantly reduce the transportation cost (Lead, 2018).

Besides providing connectivity, waterways can contribute to food security and reduce carbon emissions by facilitating transportation of food at lower cost and enhance the timely access and food availability in food-deficit areas. Upstream mountain countries mainly import food from downstream countries and bear high transportation costs. For example, Nepal imports more than 800,000 tonnes of cereals annually from India (FAO, 2014; TDB, 2014). Connecting upstream landlocked areas in Afghanistan, Bhutan, Nepal and north-east India with the downstream areas through waterways could reduce food transportation costs and improve food security by supplying food at lower prices. Water transportation can also help reduce carbon emissions by reducing fuel use. For example, 406,275 tonnes of cargo passed through Birgunj into Nepal in 2008/2009. Switching the road freight to water would reduce CO_2 emissions by about 60,000 tonnes.

Moderating flood and drought risk and damage

Climate change is increasing the risk of flood and drought in South Asia, and wise use and strategic management of water resources is needed to mitigate the impacts of floods and droughts.

Moderating flood effects

With better technologies and better knowledge of flow forecasting, it is now possible to manage reservoirs for flood moderation (Das, Gupta, & Varma, 2007; Mei, Dai, Van Gelder, & Gao, 2015; Yang et al., 2017). Analyzing water level data from 38 rivers in the United States, Mei et al. (2015) concluded that dam construction could reduce annual flood peak discharge by 3–7%. There are several examples of flood moderation through management of multipurpose water storage. Empirical evidence indicates that multiple projects along the Damodar River in West Bengal in India moderated flood events by 64% over the last 50 years (Biswas, 2015). Similarly, construction of the Three Gorges Dam in China reduced flood height by 1.7 m on average and changed the flood characteristics by moderating discharge and flood levels, mitigating overall flood risks downstream (Yang et al., 2017). Similarly, the Hirakud Dam project constructed along the Mahanadi River in Orissa in India for hydropower and irrigation also provides flood protection to 9500 km^2 of delta area (Das et al., 2007), and although the Bhakra Dam in India was not intended for flood moderation, it also absorbs peak floods and helps considerably to moderate floods (Das et al., 2007; Poff & Olden, 2017). The Indus River basin also has been facing frequent floods recently. The flood events and their effects can be reduced with an integrated approach (Box 2).

Mitigating drought effects

The strong seasonality and low dry-season flow in the South Asian river basins increase the risk of climatic and hydrological drought. Multipurpose reservoirs can be used to supply additional water during the dry season and substantially mitigate drought impact, as shown in a number of examples. A reservoir in the Tagus River basin in Spain helped reduce the impact of prolonged drought on agriculture despite a decline in water availability and an increase in water demand from non-agricultural sectors (Lorenzo-Lacruz et al., 2010). Similarly, Harou et al. (2010) studied different adaptation options against a backdrop of 72 years of prolonged droughts in California and suggested that water storage was the most economically viable option for improving agricultural production and reducing aggressive groundwater withdrawal. Wu et al. (2018) also showed that with proper operating rules, water reservoirs can help mitigate

Box 2. Potential for flood moderation in the Indus River basin.

In Pakistan, from 1950 to 2011, the Indus River basin faced 22 major floods, resulting in loss of billions of dollars to the economy, killing around 10,000 people, and affecting a cumulative area of 446,000 km^2. The flood in 2010 was the most destructive, causing loss of USD 10 billion to economy and affected an area of 40,000 km^2. More than 50% of the loss was in the agriculture and livestock sectors through damaging crops and killing livestock (Asian Development Bank, 2013).

Constructing new reservoirs in upstream areas has high potential to mitigate flood risks and improve agriculture productivity and hydropower generation. Proposed reservoirs such as the Diamer-Basha and Kala Bagh Dams would improve capacity in all three dimensions (Sharjeel, 2006). For example, the Diamer-Basha Dam would store 6.4 million acre feet (MAF) of water, and generate 4500 MW of electricity (Institute for Policy Studies, 2016). Though the flood moderation benefits of the Diamer-Basha Dam would be limited, the Kalabagh Dam could play a vital role in flood moderation by trapping flood water from the Kabul, Chitral, Swat, Haro and Soan Rivers, in addition to its role in irrigation and hydropower generation. The Kalabagh Dam reservoir could store up to 6.1 MAF of water, generate 3600 MW of hydropower, and manage about 2.2 million cusecs of floodwater (Luna & Jabbar, 2011; Butt, Khan, & Ahmad, 2015).

Box 3. Regional drought mitigation through water resource management.

The following example illustrates how regional cooperation for water resource management can augment river flows and mitigate drought.

In 2015, water levels in the lower Mekong River hit a 100-year low following an El Niño that contributed to drought (Larson, 2016). The riparian areas in Thailand, Cambodia, Laos and Vietnam experienced water scarcity, and the Mekong Delta – the largest rice producer in Vietnam – suffered saltwater intrusion. Drought and saltwater intrusion destroyed at least 159,000 ha of paddy fields worth USD 10.5 million, and about one million people lacked water supply for domestic use (UN, 2016).

To mitigate the impacts, China released 12.65 km^3 of freshwater into the river during March and May 2016 from the Jinghong Dam, a reservoir built to generate hydropower (Mekong River Commission, 2017). The discharge accounted for 40–89% of the flow in different sections of the river and increased water levels by 0.18 to 1.53 m (602–1010 m^3/s). The discharge of water by China benefited people in Laos, Myanmar, Thailand, Cambodia and Vietnam.

hydrological and meteorological drought, and there have already been successful examples in Asia (Box 3). In future, multipurpose reservoirs in South Asia should be designed to support drought mitigation.

Conclusion and recommendations

South Asia is energy-poor, water-stressed, and food-deficient, and these problems are expected to intensify with high population growth, rapid economic growth and industrialization, urbanization, changing consumption patterns, increased globalization and modernization, and climate change. The demand for water, energy and food is growing fast, and the scarcity of resources is increasing, posing a threat to long-term sustainability. Although the water, energy and food security challenges are strongly connected, they are dealt with separately, in a sectoral approach which fails to use available resources optimally and exacerbates resource scarcity. Climate change and its cascading impacts on water, energy and food further compound the challenges.

Development of hydropower will play a pivotal role in achieving energy security in South Asia, which is energy-starved. However, hydropower projects should not be used only to generate power. To maximize their potential, they should be planned as multipurpose projects with additional benefits for water and food security and able to produce the regional public goods which are critical for overall regional development. To ensure the efficient and optimal use of water resources, hydropower development upstream needs to consider the ways in which hydropower reservoirs can generate additional benefits to society through multiple uses at multiple scales, both upstream and downstream. The growing demand for, and increased pressure on, limited water, energy and land resources, and their interconnected challenges, underline the need for an integrated approach that captures synergies and manages trade-offs among different sectors and at different scales. It is now clear that the traditional ‘silo’ approach cannot harness the potential synergies or address the interconnected challenges facing South Asian countries today.

Many of the rivers in South Asia are shared across national boundaries, and collaborative action will be critical in harnessing the full potential of water resources and providing regional public goods for better management of climatic and environmental risks and achieving shared prosperity through the positive externalities of regionalization. Properly coordinated, water storage for hydropower can be used to help moderate floods and droughts, expand regional connectivity through waterways, establish regional early-warning systems, and develop mitigation and adaption options. It is therefore necessary to move from single-purpose to multipurpose, from sector-driven to integrated, and from nationalistic to river-basin approaches, taking an integrated river basin approach to tap the wide range of potential benefits and support long-term development of the region. Although piecemeal projects can serve interim needs, they can undermine the long-term societal benefits and strategic goals at both national and regional levels.

A number of the world's large river basin development programmes have combined hydropower generation with generation of water-based public goods such as navigation and flood control, including the Tennessee Valley Authority of the 1930s and the Yangtze Basin development project. Waterway improvements along the Rhine stimulated traffic and increased cargo transport along the Rhine tributaries; industries flourished, and economic growth increased (Pauli, 2010). The Danube River in Europe provides passage to the sea for many landlocked countries, as does the Paraná River for landlocked Paraguay in South America, and the Mekong River for Lao PDR in Asia.

While multi-sectoral water development can great high economic benefits, it may also bring environmental and social risks if not designed well and if benefits and costs are not shared equitably. Inadequate resettlement and rehabilitation is the primary cause of opposition to dam construction (Bandyopadhyay, Mallik, Mandal, & Perveen, 2002). Appropriate mechanisms need to be developed to share costs and benefits equally following international norms and practices (Turton, 2008; Vollmer et al., 2009). Different models of benefit-sharing in transboundary hydropower projects are available (Hensengerth, Dombrowsky, & Scheumann, 2012). In the Senegal River basin, Mali, Mauritania and Senegal collaborated and developed a multipurpose project for hydropower, irrigation and navigation. Benefits from the multisector project were mutually agreed by the riparian countries (Hensengerth et al., 2012).

One of the major challenges of implementing multi-sectoral transboundary projects is lack of confidence and trust among the riparian countries (Crow & Singh, 2000; Rasul, 2014b). As we argued elsewhere (Rasul, 2014b), transboundary water resources in South Asia are seen from a nationalistic perspective, aiming at sharing water rather than expanding the benefits through cooperation at basin level. This narrow perspective often leads to unilateral and fragmented decisions as well as a sectoral approach to water resource development, and hinders the collaborative development of water resources for multiple purposes.

Moreover, implementation of multi-sectoral transboundary water infrastructure is complex and requires extensive coordination across different sectors and at different scales, as well as strong political will. Dealing with this complexity requires appropriate institutional arrangements that are able to deal with multi-sectoral issues at a basin scale. The currently prevailing conflict and mistrust and inadequate political will represent major constraints on developing multi-sectoral transboundary water projects in South Asia. Recently, some positive changes have taken place towards multilateral cooperation. The governments of India and Nepal have agreed to develop inland waterways, and Bangladesh and India have amended their bilateral navigation protocol to allow third countries to use their waterways. Bangladesh is allowing India to transport food and other goods to north-east India through Bangladeshi territory; and in 2018 Bangladesh and Nepal signed a memorandum of understanding for power cooperation and trade. Bangladesh now seeks transit facilities through India to import electricity from Nepal and Bhutan. All of these indicate a positive move towards multilateral cooperation, although the region is diverse, interest is heterogeneous, and it will require concentrated efforts to overcome mistrust, develop shared understanding, and galvanize political will to find integrated solutions for water, energy and food security in South Asia.

Policy recommendations

A comprehensive regional approach and long-term strategies are required which maximize cross-sectoral synergies and manage trade-offs for maximum benefit at both national and river basin levels. A nexus approach can provide a starting point as it integrates potential synergies and trade-offs across multiple sectors and scales. Harmonizing policy approaches and incentive structures across the three sectors of water, energy and food will promote further synergies and deeper integration.

A concentrated effort and multi-track diplomacy are necessary to overcome the existing mistrust and build common understanding of the benefits of cooperation and the costs of non-cooperation. One of the reasons for mistrust has to do with the sharing of costs and benefits (Thapa, 2013). Mechanisms for sharing the costs and benefits of co-operatively developed transboundary water resources need to be established following international standards. Dispute-resolution mechanisms and institutional arrangements also need to be developed to settle disputes among the riparian countries.

Water management institutions in South Asia are weak and lack the technical, financial and human capabilities needed to develop and implement comprehensive plans for multi-sectoral projects. Building the capacity of national and regional institutions and establishing a basin-level coordination committee is critical to promote better planning and coordination.

Integrated approaches are knowledge-intensive and require enhanced regional knowledge and cooperation for understanding of key socio-economic and climatic drivers, their linkages, trade-offs, and synergies, and the costs and benefits of action and inaction, as well as emerging risks and opportunities. A river information system will be essential to support joint investments and better decision making. In preparing projects for water resources development, due diligence is necessary to assess cross-sectoral interactions, possible synergies and trade-offs, and positive and negative externalities.

Joint investments in regional public goods for mutual benefit will be vital. There is a need to develop mechanisms for sharing costs and benefits in an equitable manner in the provision of regional public goods, particularly along transboundary rivers and in regional infrastructure development.

Attention needs to paid to demand management just as much as to supply management ensure climate-resilient development. Actions are needed to increase water productivity in agriculture and promote water- and energy-efficient infrastructure, transportation and agricultural practices.

Greater efforts need to be made to engage policy makers and other key stakeholders, including the private sector, think tanks, research organizations and civil society on the future interactive challenges of water, energy and food security on the regional level, possible regional approaches, and the potential benefits of integrated management of transboundary water resources at the basin level.

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