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Infrastructure & Cities for Economic Development

Transboundary waters in South Asia

Unpacking evidence of contributions to sustainable development

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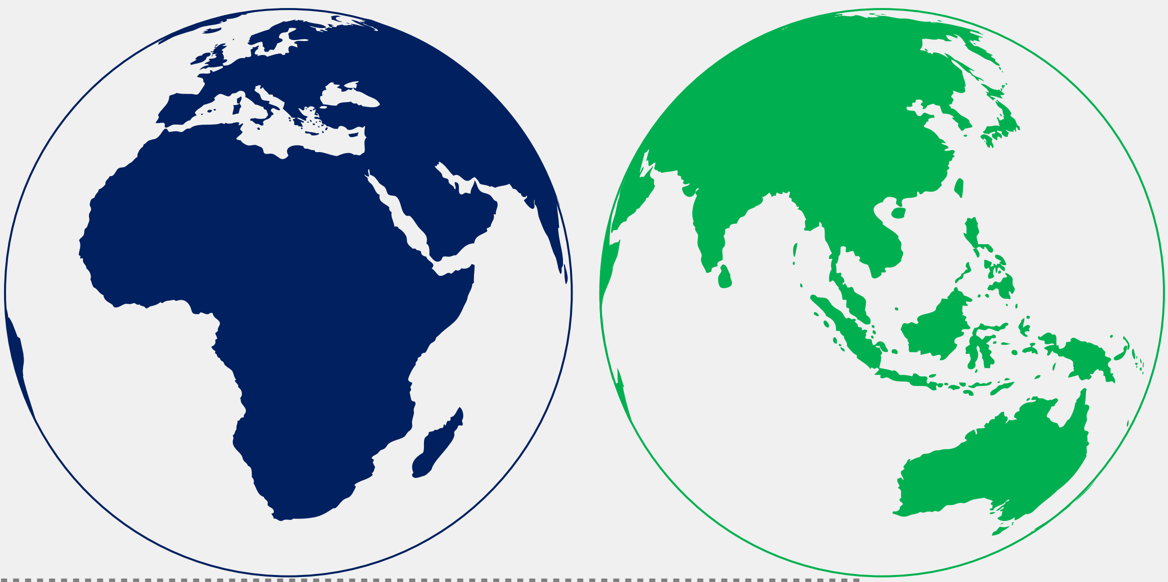


Contents

Introduction

Scope of this note

The objective of this report is to analyse how investing in transboundary water infrastructure and governance contributes to sustainable and inclusive economic development, unpacking the assumptions being made into testable hypotheses and analysing the evidence for these pathways.

Due to South Asia's heavy economic activity around its shared rivers, there is significant economic and hydrological interdependence between countries in individual basins. Recent investment in regional power pools supplied by hydropower has extended this to energy systems. DFID is looking to understand what contribution water investments and their governance has for economic development in the region and the inclusivity of that growth.

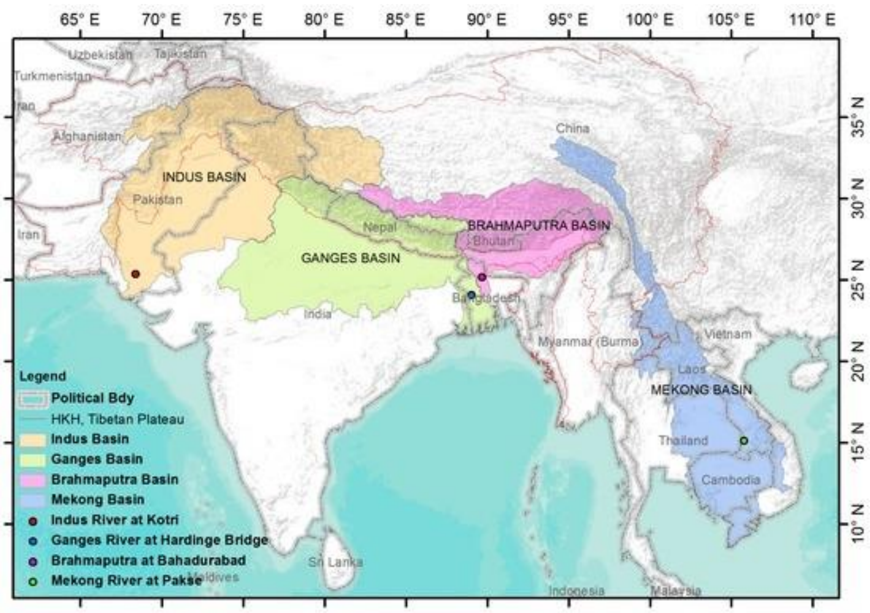
The hydrology of transboundary waters

Transboundary waters are those water assets shared by two or more countries. This includes rivers, aquifers, lakes and basins. There are 263 transboundary rivers [1], 300 transboundary aquifers in the world, and 2 billion people depending on groundwater [2].

The major south and southeast Asian river basins (Indus, Brahmaputra and Ganges) arise from the Himalayas and benefit over one billion people [3]. These rivers connect multiple countries: the Indus basin connects China, Afghanistan, Pakistan and India. The Brahmaputra and Ganges basins connect China, Bhutan, India, Nepal and Bangladesh. All three of them originate in the Himalayas glaciers[4], and are extremely variable with highly concentrated rainfall with the monsoon and frequent droughts and floods, as well as increasing monsoon breaks, more intense rainfall and increasing seasonal uncertainty with climate change [5, 6]. These changes are predicted to reduce the food security of the region and economic productivity of the region [7].

Section 2 provides the context of these basins, covering the main hydrological processes associated with the Indus, Brahmaputra and Ganges basins.

Figure 1. The major south and southeast Asian river basins [3]



Transboundary water governance: shared opportunities and risks

Economic expansion requires water, as input to generation of energy, services and agriculture, and to satisfy the needs of growing populations -especially in cities.

The high seasonality in the region is matched by a high dependence on groundwater extractions to sustain agriculture within countries. Dependency on irrigation increases economies' vulnerability to water stress and the associated risks to investments [8, 9] . For example, Pakistan's economy is very exposed to water shocks (Figure 2). It lies in the upper right quadrant as highly water scarce yet also highly water dependent. Other basin countries are similarly exposed although to a lesser degree (in the case of China and India, with significant water resources beyond the Indus, Ganges and Brahmaputra basins).[8]

There is indeed a strong perception of the links of water and the economy, exemplified by the 1980s India's Finance Minister line "*every one of my budgets was largely a gamble on rain*". New evidence [9] shows a degree of decoupling in the perception, mostly because agriculture is becoming less of a driver to the economy in some Asian countries. However, the exposures to drought and floods in region remains important – see

Figure 3. The figure shows how poorer basins (red dots, clustered in the lower half of the chart which include both the Ganges and the Indus) have invested less in water security, and many face complex hydrologies.

Figure 2. Comparison of water-intensive and water-scarce economies [8]

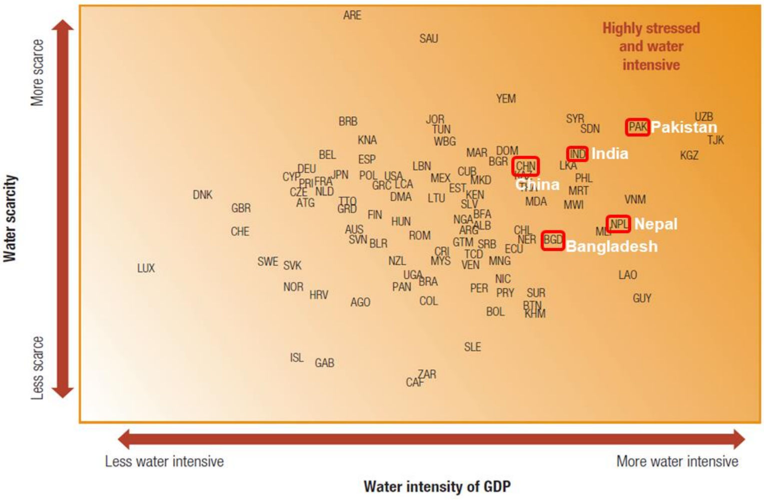
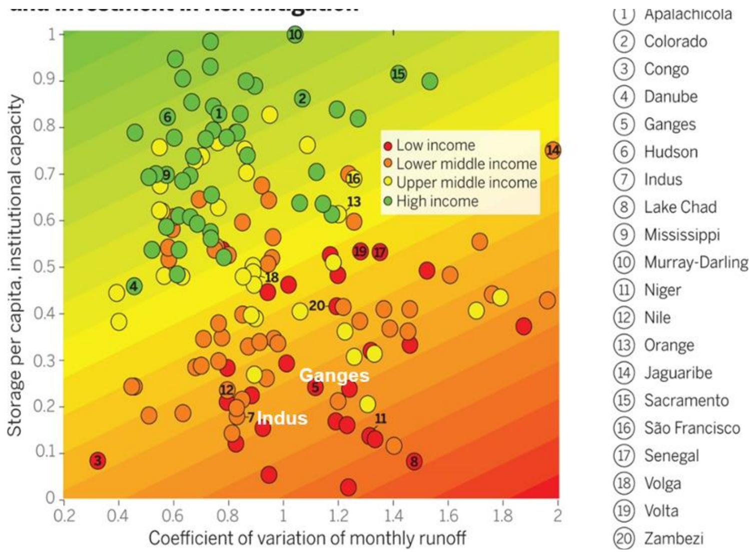


Figure 3. Economic growth, hydrological variability and risk [9]



Note: The horizontal axis summarizes hydrologic variability. The vertical axis is a composite indicator of investment in infrastructure and institutional capacity. The dots represent all river basins with populations greater than 2 million, coloured to indicate high (green), middle (yellow), and low (red) levels of GDP per capita (using World Bank definitions). The coloured contours are a linearly interpolated surface reflecting the association between variability, water security investments, and GDP. Source: Hall et al (2014) in Sadoff et al (2015).

The transboundary nature of water means that increased water abstractions in one country reduce water quantity downstream; poor management of wastewaters reduces water quality within a country and beyond their borders; and, at basin levels, landscape interventions in a country that reduce water infiltration or natural storage in soil and water bodies can increase the severity of floods and droughts downstream.

The way water resources are managed -either actively or through inaction- within a country will have impacts for neighbouring States, often leading to tensions. A global analysis of major transboundary basins shows that between 950-1,500 million people [10] already face some level of water stress due to their local water use alone, without adding the transboundary element. Upstream extractions resulted in substantial increases in water stress levels in some cases.

Transboundary water in South Asia: the pathways to inclusive and sustainable economic development

Water is a key input to a range of economic development opportunities with transboundary implications in South Asia. The seasonality and variability of rainfall mean water availability is a central challenge to economic development [11]. And whilst most of the water challenges in South Asia reflect governance and investment decisions within borders, there several issues that have the potential to affect relations between countries.

This analysis focuses on the second set of issues, identified following a desk-based review and interviews with experts. We explore the potential pathways by which water investment and governance would impact inclusive and sustainable economic development in the region and outline how the evidence supports these pathways:

1. *Improved water allocation decisions maximise inclusive and sustainable economic benefits from investment (macro impacts) through strategic basin planning*:

Water governance across the basin - with shared analysis by stronger institutions collaborating effectively to make strategic choices in investment and allocations - underpin the potential for sectoral investments to maximise the collective economic development outcomes in the region and reduce losses from disaster impacts.

2. *Water is a vital input to electricity services (coal and hydropower), affecting cross-border transmission and water pollution downstream:*

Increasing hydropower for trade in the region could increase the availability and reliability of low cost energy. This would reduce the costs to production of goods and services, improving returns to businesses. *If* increased returns are passed on to workers through improved jobs, pay or through increasing energy access through grid connections, this can also have impacts on the inclusivity of economic development.

With the right design and operation of hydropower networks, they offer cheap energy storage (pump storage) and grid stabilisation - enabling an increasing share of intermittent renewables on the grid. The consumptive use of water for cooling and pollution from coal power stations in water scarce basins reduces the quantity and quality of water available for other uses.

3. *Food security and agricultural led growth is supported by reliable and timely irrigation:*

Irrigation has implications for downstream flows due to water extractions for agriculture, prioritised to achieve national food security objectives, reduce flows downstream.

Increasing water availability can also lead to farmers switching to higher value crops that are water hungry. The export of these crops result in water loss to the basin.

Cheaper irrigation can lead to overuse of water, reducing availability for other uses and damaging soil health.

Reduced river flows at the coastal levels are accelerating salinity process from rising sea levels affecting delta health, affecting millions of coastal rice farmers and undermining fish stocks for fisherfolk.

4. *Water provision to rapidly growing urban centres is increasing competition for water and poor pollution and sewage management is reducing quality*:

Increased extractions for cities and industry and minimum standards for water treatment is severely affecting flows of major rivers.

Untreated waters are used in agriculture, spreading the risks of toxins back to consumers.

Urban water is largely a domestic challenge of allocation between users and management. However, during dry season, over extraction of low river flows and pollution of limited water has potential to create concerns with downstream neighbours.

5. *Inland waterways transport reduce the costs of cross-border trade*:

Cheaper transport for trade support regional markets. Due to requiring sufficient water flow during dry season, this also protects flows to the delta with benefits for reducing salinization and improving coastal ecosystem functioning.

Accumulation of sediments in these rivers with exceptionally high sediment loads reduces potential for waterway trade in South Asia, endangering several new cooperation agreements, or increasing costs due to the requirement for dredging.

The design and regulation of waterway transport systems can be more or less inclusive depending on regulation and the choice of transport infrastructure.

6. *Transboundary natural capital investments reduce the cost water management and increase the inclusivity of economic development.*

Strategic investments in the basin's ecology for locally managed nature-based solutions to supplement infrastructure reduces the cost of water resource management increasing protection from drought and flood.

Investment in locally managed natural capital also increase the potential for inclusive and sustainable local economies that enable the poor to be integrated into national and regional supply chains.

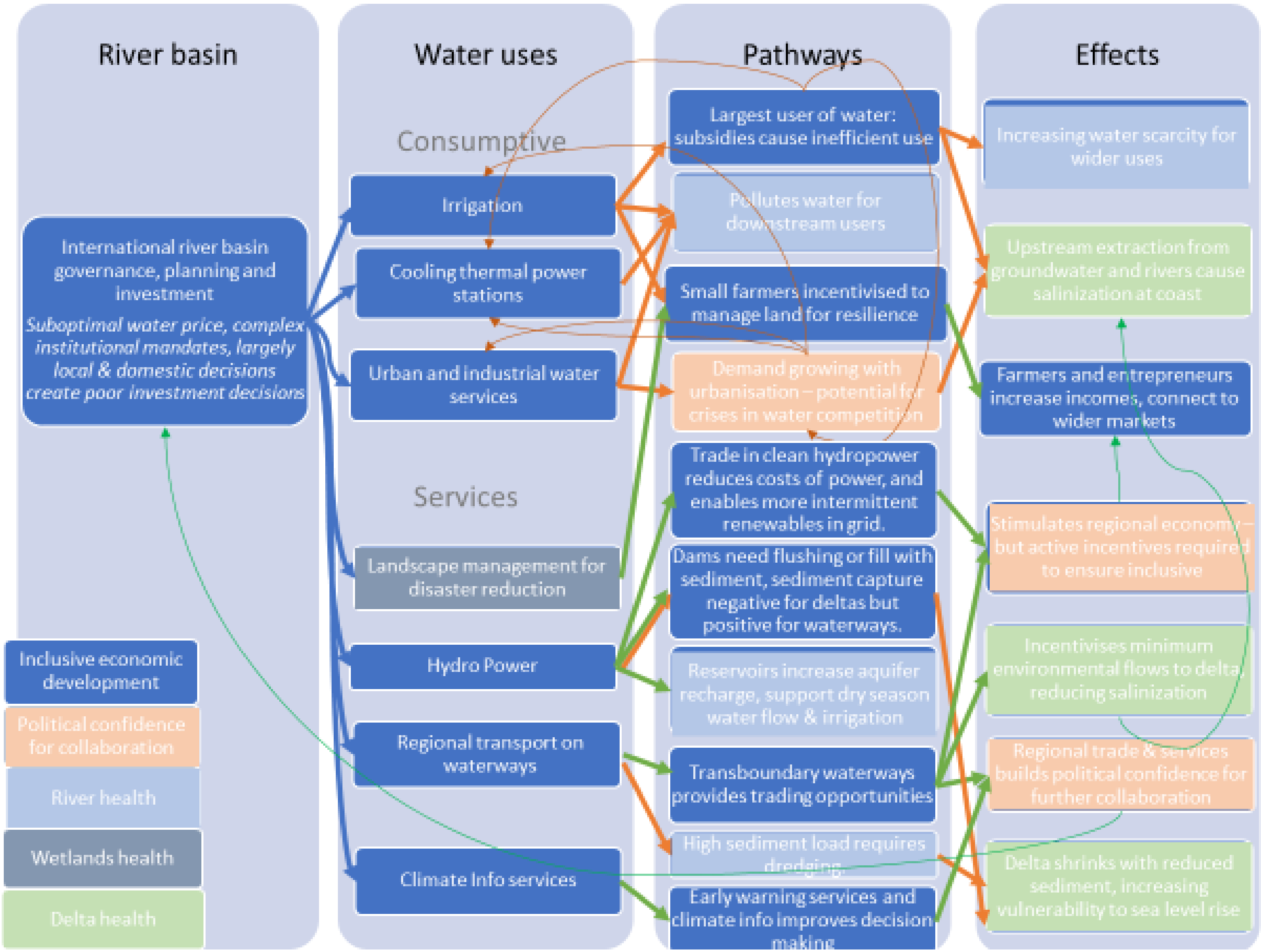
7. *Transboundary data sharing improves the quality of climate information and early-warning systems, which in turn have large multiplier effects on the economy:*

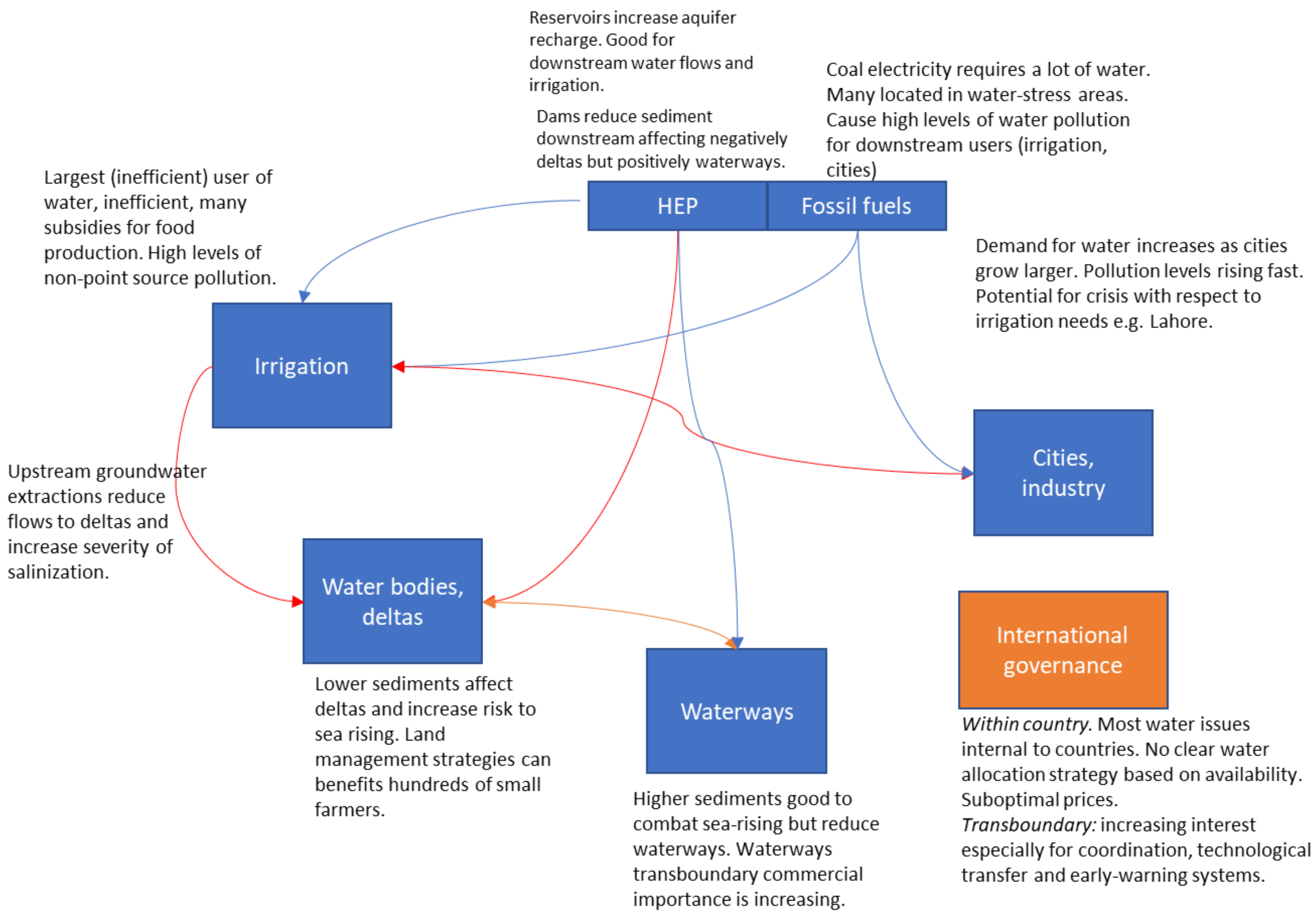
Quality climate information services can reduce exposure to climate extremes through better infrastructure design and land use planning.

Early warning systems also reduce cost of disasters through informing citizens and climate sensitive sectors to take protective action.

Better seasonal and short-term weather forecasts improves farmers agricultural decisions and water resource managers decisions.

Figure 4. Summary of cross-dependencies in key water sectors




Reservoirs increase aquifer recharge. Good for downstream water flows and irrigation.
Dams reduce sediment downstream affecting negatively deltas but positively waterways.
Coal electricity requires a lot of water. Many located in water-stress areas. Cause high levels of water pollution for downstream users (irrigation, cities)
Largest (inefficient) user of water, inefficient, many subsidies for food production. High levels of non-point source pollution.
HEP
Fossil fuels
Demand for water increases as cities grow larger. Pollution levels rising fast. Potential for crisis with respect to irrigation needs e.g. Lahore.
Irrigation
Cities, industry
Upstream groundwater extractions reduce flows to deltas and increase severity of salinization.
Water bodies, deltas
International governance
Waterways
Lower sediments affect deltas and increase risk to sea rising. Land management strategies can benefits hundreds of small farmers.
Higher sediments good to combat sea-rising but reduce waterways. Waterways transboundary commercial importance is increasing.
Within country. Most water issues internal to countries. No clear water allocation strategy based on availability. Suboptimal prices.
Transboundary: increasing interest especially for coordination, technological transfer and early-warning systems.

Section 2: The basin hydrology context

Indus basin

Hydrology

The transboundary Indus river basin has a total area of 1.12 million km2 distributed between Pakistan (47 percent), India (39 percent), China (8 percent) and Afghanistan (6 percent). Very roughly, at least 300 million people are estimated to live in the Indus basin [12]. There are disputed territories in the upper catchment, such as between India and China and between India and Pakistan.

In contrast to the Ganges basin that is mostly monsoon fed, the Indus receives rainfall from four different sources: winter rainfall coming in from the West (then stored in snow in the mountains until summer), the summer monsoon, tropical cyclones from the north Arabian Sea and from snow melt. The glaciers in this catchment do potentially perform an intra and inter-annual water storage function, storing winter rains that fall as snow, although this is geographically very variable, as explored further below.

Box 1 shows the approximate annual flows within and across countries. These figures give an indication of the relative significance of each border crossing of the river. The multiplicity of sources, combined with weak monitoring stations in the mountains means that the hydrology of the system is imperfectly known, and while models exist for some sub basins, accurate models for the whole basin remain to be developed [13]. The figures are therefore indicative.

Box 1. Estimated transboundary water flows in in the Indus basin

- Annual flow from China to India in the Indus basin is around 182 km^3 and it is estimated that the flow generated within the Indian part of the watershed is around 51 km^3, resulting in a flow from India to Pakistan of 232 km^3. Around 170 km^3 of this flow are reserved for Pakistan and 62 km^3 are available for India under the basin treaty
- Total inflow from Afghanistan to Pakistan in the Indus basin is estimated at 22 km^3, 16 km^3 from the Kabul river (of which 10 km^3 comes from the Kunar river, which first enters Afghanistan from Pakistan and then flows back to Pakistan after joining the Kabul river) and 6 km^3 from other tributaries (Pansjir, Gomal, Margo, Shamal, and Kuram).
- The mean annual flow into Pakistan from India through the western tributaries, the Jhelum and the Chenab amounts to 170 km^3, that are reserved for Pakistan's use under the Indus Water Treaty. The mean annual flow into Pakistan through the eastern rivers (the Ravi, the Beas and the Sutlej) is estimated at 11 km^3 and this is reserved for India under the Treaty.
- There are around 2738 km^3 of water stored in glaciers in North Pakistan and 95 km^3 in Himachal Pradesh. This is more than 10 times the average annual flow. More may also be stored further upstream (China/Tibet).

Total water withdrawal in the Indus river basin is estimated at 299 km^3, of which Pakistan accounts for 63 percent, India for 36 percent, Afghanistan for 1 percent, and China for barely 0.04 percent. Irrigation withdrawal accounts for 278 km^3, or 93 percent of the total. Surface water and groundwater account for 52 percent and 48 percent of total withdrawals in the Indus river basin respectively.

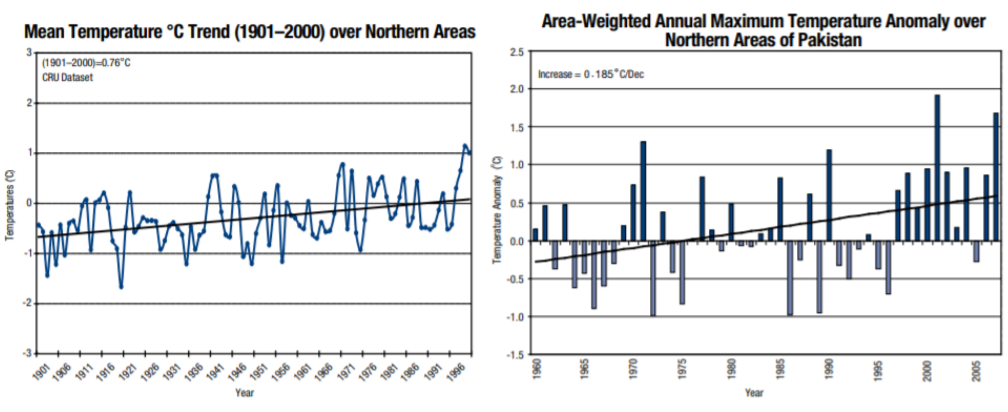
Pakistan possesses the world's largest contiguous irrigation system [12], explaining the dominance of irrigation as a water use in the Indus basin. The irrigation network accounted for USD 300 billion worth of investment and contributes USD 21 billion, nearly 20 percent, to the country's GDP annually. It commands a full control equipped area of 15 million Ha (2008). 36 percent is under Mangla command and 64 percent under Tarbela command and encompasses the Indus river and its tributaries including three large reservoirs (Tarbela, Mangla, and Chashma barrage), 23 smaller barrages/ headworks/siphons, 12 inter-river link canals and 45 canals commands extending for 60,800 km, with communal watercourses, farm channels, and field ditches covering another 1.6 million km^3 to serve over 90,000 farmers' operated watercourses. This high reliance on irrigation increases the country's vulnerability to water stress and risks to investment (discussed in Figure 2 in previous section).

Climate change and flows

Currently available studies indicate negligible ongoing impacts of climate change on river flows in terms of recent mean annual water flows in the basin as a whole. There is no indication at present of changing flows in the main stem of the upper Indus River [13] although a decreasing trend is observed on the Kabul River and in the lower stretches of the Indus Basin at Kotri Barrage [13]. Mean annual flows however hide changes in seasonal flows and extreme events that are significant for basin development and to the livelihoods of those living in the basin.

The Indus river itself has greater glacial dependence than the Ganges and Brahmaputra. And the impact of climate change on glacier dynamics is complex. Some glaciers are retreating, especially in the east of the basin where they face south, while some glaciers in the Central Karakoram are accreting (the Karakoram anomaly which is not fully understood). There is consensus across a range of methods that the overall contribution of glacier melt to the Indus river is reducing with climate change [7, 14]. However, there are widely varying estimates of the pace of change. A significant investment in monitoring of glacier mass-balance is required before definitive conclusions can be drawn. It is evident, however that temperatures in the high mountains are both rising (Figure 5), and rising faster at higher altitudes. By the end of the 1990s, the 30°C isoline was 300 m higher than its position in 1981 to 1985.

Figure 5. Mean temperature anomalies in Pakistan's mountainous north



The chart on the left uses the Climate Research Unit (CRU) dataset 0.76°C during the last century. The chart on the right uses the Pakistan Meteorological Department (PMD) dataset 0.185°C per decade.

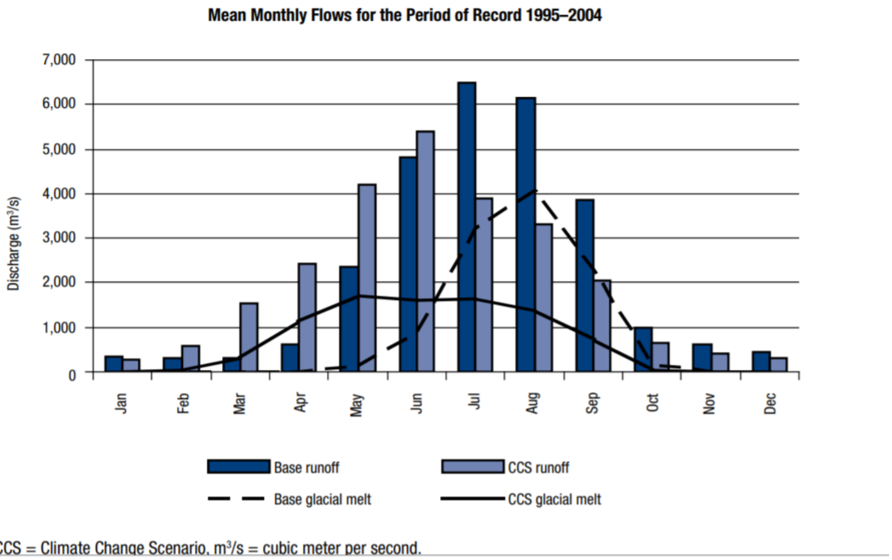
Source: New et al. (2002) and PMD (2009).

ICIMOD has determined a number of trends in the basin and on the basis of current evidence projected a future flow regime as shown in Figure 6. This scenario suggests an early and more sustained snow melt than presently, stretching from April to September, instead of a melt period coinciding with the monsoon during a shorter period from July to September. This would lead to a significantly earlier flood peak with potentially significant, but as yet unquantified, implications for irrigation development and management. These flows would need to be overlaid with storage capacity and seasonal water withdrawal regimes to assess their downstream impact.

Temperature trends are, however, not necessarily consistent. Temperature records at Leh (Jammu and Kashmir, western Indian Himalaya) from 2000 to 2014, showed a significant falling trend in maximum temperature for July (1.7 °C per decade) and August (1.3 °C per decade)[15].

The present monitoring network does not serve the purpose of representing the heterogeneous mountain terrain. Climate varies between valleys and mountain tops, between aspects and orientation, and between different locations. To meet the optimum observational demands, at least 75 automatic weather stations and 35 hydrological measurement stations need to be installed in the mountainous parts of the watershed.

Figure 6. Comparison of base and projected flows in the upper Indus Basin in the wake of climate change [13]

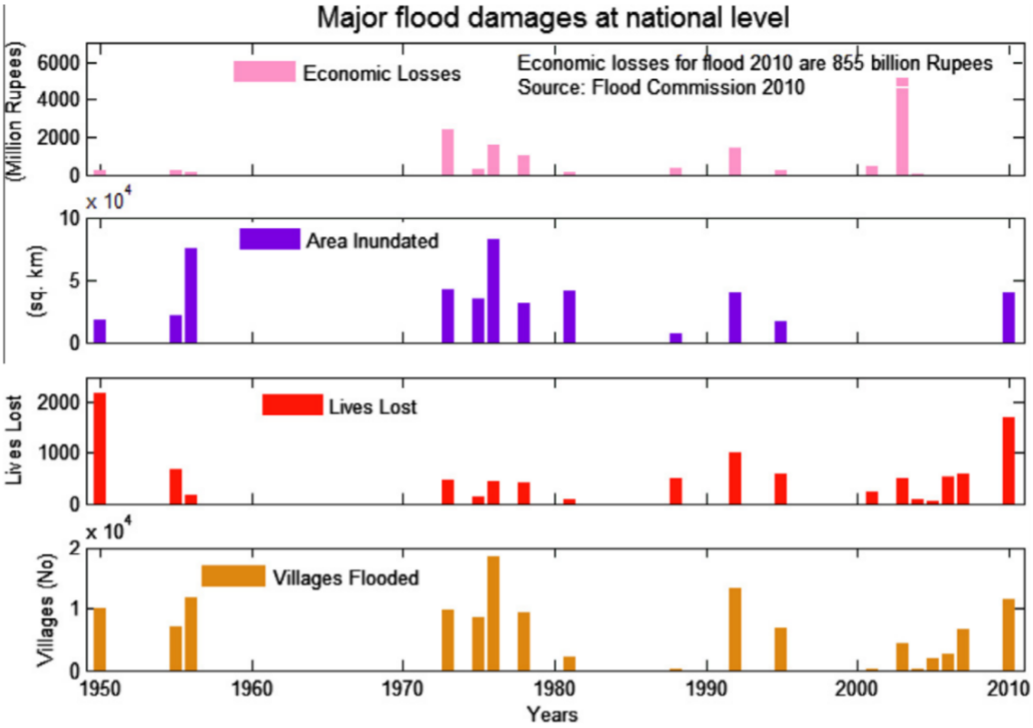


Flooding

In high altitude catchments (Indus and Chenab), snowmelt contributes significantly to flood flows. Maximum snowmelt in the Indus and Chenab basins is experienced in July and floods of high magnitude are generated with monsoon rainfall. The flood peaks of the different rivers do not usually coincide. However, when they do, widespread flooding occurs [16].

Flooding is a regular event along the Indus in Pakistan (Figure 7) with significant economic losses and regular loss of life. From 1950 to 2010, 21 major floods in Pakistan's Indus River Basin killed 9,000 people, affected 110,000 villages, causing a cumulative direct economic loss of $19 billion [17]. Indirect losses that were not quantified included health impacts, land and water quality degradation, temporary disruption of transport, and the slowing down of economic growth [16].

Figure 7. Flood losses details at national level against severe flooding years [16]



Traditionally, flood management has relied on a large-scale investment in structural measures for flood containment. These include embankments, spurs, dikes, gabion walls, floodwalls, dispersions, diversion structures, delay action dams, bypass-structures, and channels for floodwaters. These seek to control the course of rivers to tackle over-bank flooding, counter land erosion and regulate the river's course. 6,700 km of embankments have been constructed along rivers nationwide (15).

The reservoirs of Mangla and Tarbela are effective at storing flood water, although not if floods occur late in the filling season, however their storage capacity is constantly eroded by increasing sedimentation. In recent years it is increasingly recognised that overtopping and breaching of levees is a root cause of economic damage yet a transition to integrating structural approaches and land use planning with natural infrastructure for flood management is taking time to develop [17]. The Asian Development Bank review of flood management in Pakistan concluded however that this was a priority:

> "*A mono-disciplinary approach based on engineering solutions—as in the case of the Indus Basin—cannot fully handle hydrological cycles, ecosystems, and the security of people prone to flood risks. Non-structural measures such as vulnerability and risk assessments, floodplain zoning, and land-use planning and enforcement, are generally not featured in Pakistan's flood management practices. In addition, early flood warnings to communities at risk, and greater flood preparedness on the part of these communities, have not been fully incorporated into the country's flood management planning. Appropriate non-structural measures to reduce flood vulnerability should be introduced*" [17].

The effectiveness of early warning systems depends on location along the river and flood dynamics. From upstream to downstream, the lag time of the 2010 flood wave on the Indus river was 2 days between Tarbela Reservoir and Chashma Barrage, 1 day between Chashma and Taunsa barrages, 7 days between Taunsa and Guddu, 4 days between Guddu and Sukkur, and 17 days between Sukkur and Kotri [17].

Flood warning is largely the responsibility of the Flood Forecasting Division of Pakistan Meteorological Department but the Water and Power Development Authority (WAPDA) also contributes data to improve the ability to forecast. The forecast system was set up in 1975 but has had maintenance challenges[1].

An agreement was signed in 1989 between India and Pakistan to share river flow and rainfall data for flood forecasting. India sends data on a daily basis to the Pakistan Commissioner under the Indus Treaty and the frequency of transmission can increase significantly during flood events.

Droughts

The Indus basin is drought-prone with differentiated impacts on those farmers reliant on rainfall fed farming versus those benefiting from irrigation. For example, during the 1999-2002 drought, there was a reduction in annual rainfall with a minimum of 13% for DI Khan and a maximum of 78% at Nawab Shah. The reduction in annual rainfall was more in the Lower Indus (34-78%) as compared to areas in the Upper Indus (13-26%). During the drought, overall canal diversions were 12-25% less than preceding years. Impact on crops was also variable with yields in Sindh more affected than in Punjab, with a 25% decline in annual wheat and rice yields. Impacts of drought were partially relieved by extensive ground water pumping, reducing waterlogging from 6 to 2% in Punjab and 65 to 40% in the Lower Indus [18]. This improved productivity in subsequent years.

The Indus delta's aquatic ecosystems are highly sensitive to flow reduction [17, 19]. Upstream dams have altered downstream water flows, reducing fish diversity and catch, such as a 47% decline in the shrimp catch in the ten years to 2009. The impact of dams is most significant in hindering the natural flows during dry seasons, when water is diverted to irrigated lands. The delta has also seen a 46% reduction in area under natural vegetation [19]. In 1980, the mangrove cover in the Delta region was 34,5000 ha whereas by the early 2000s this fell to 15,8000 ha (FAO and UNEP 1981, PFI, 2004 reported in [19]).

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[1] The flood early warning system was initiated in 1975 when a real-time VHF telemetry system was introduced for hydrological data collection from 16 river gauges and 24 rain gauges (Ali, 2013). A total of about 40 stations were established at all rim stations and within the Mangla Dam catchment area. The number was gradually reduced to about 20 due to maintenance problems. About 22 high frequency radio sets were installed to serve as a double support for automatic gauging and the telemetry system as a backup for telemetry and the meteor burst system.

The Pakistan Meteorological department's Flood Forecasting Division plays a key role in flood forecasting and early warnings. Its flood forecasting and early warning system comprises (i) 10-centimeter, S-band, quantitative precipitation-measuring Doppler radar facilities in Lahore and at Mangla Dam that remotely sense rainfall over the catchments of the Beas, Chenab, Ravi, and Sutlej rivers; (ii) meteor burst communications for the transmission of the hydrometric data; (iii) 5-centimeter weather surveillance radar facilities in the cities of Dera Ismail Khan, Islamabad, Karachi, Rahim Yar Khan, and Sialkot; and (iv) the Indus River system mathematical model, which computes stream hydraulics, including stage and discharge hydrographs along the rivers, to estimate the areas vulnerable to inundation as a basis for the issuance of flood warnings.

Ganges-Brahmaputra-Meghna basin

Hydrology

The GBM transboundary basin covers portions of six countries and almost 2 million square kilometres from the high Himalayas to the Bay of Bengal (Figure 8). All three rivers converge in the low delta country of Bangladesh. By the time the rivers discharge into the Bay of Bengal, they constitute the world's third largest source of freshwater flow to the ocean. The Ganges flow at Farraka is around 525BCM annually, although accurate time series are unavailable while India considers flow data to be confidential [20]. All three rivers are fed by monsoon rainfall (largely falling between June and August) on steep mountain slopes and some glacial melt. The delta is the world's most populous river delta [21, 22].

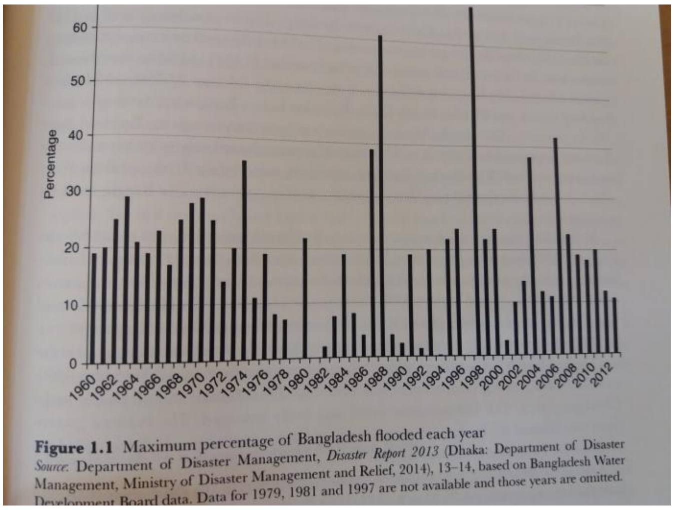
Figure 8. Map: The Ganges-Brahmaputra-Meghna River Basins [22]

Portions of both the Ganges and Brahmaputra basins lie in China, Nepal lies entirely within the Ganges basin. Bhutan lies entirely within the Brahmaputra basin. Large fractions of all three basins lie in India. Bangladesh lies entirely in the flat plains of the delta and 20-33% of the country may be affected by flooding in any one year depending on the severity of the event (

Figure 9). A small area of the catchment lies in Myanmar.

The annual flow [23] of the Brahmaputra river basin from China to India is 165.40 km3 and from Bhutan to India 78 km3. The annual flow of the Brahmaputra river basin from India to Bangladesh is 537.24 km3. The annual flow of the Ganges river basin from China to Nepal is 12.0 km3. All rivers in Nepal drain into the Ganges river with an annual flow of 210.2 km3 to India. The annual flow of the Ganges basin from India to Bangladesh is 525.02 km3. The annual flow of the Meghna river basin from India to Bangladesh is 48.36 km3. This gives a total annual GBM river basin inflow into Bangladesh from India of 1 110.6 km3.

Figure 9. Maximum percentage of Bangladesh flooded each year. Source [24]



The Brahmaputra and Ganges rivers are characterised by local flash flooding and large slow onset flood events that take many days to build from tributaries flowing south from the Himalaya and then transit the system from the mountains to the delta. Localised intense rains lower in the catchment also provide significant flows and adequate drainage and protection of communities living on the flat Gangetic plains have long been a concern.

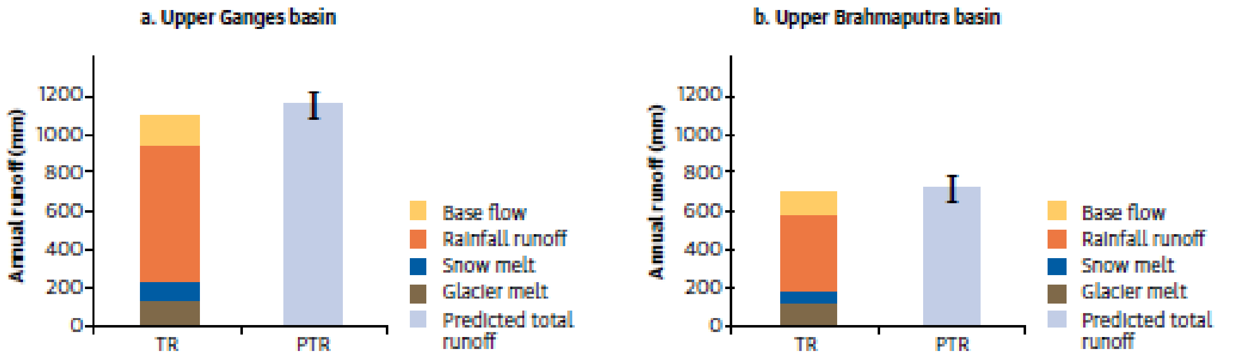
The upper catchment of the Brahmaputra and Ganges is dominated by steep slopes, with thin soils and unstable geology. Monsoon run-off on these slopes is therefore rapid, groundwater recharge is limited, and erosive flows carry sediments downstream. Glaciers occur throughout the mountain ranges, although apart from in the upper mountain catchments, are of less importance for storage and river flows than in the Indus (see climate change below). Earthquakes are common. The remote and inaccessible nature of the terrain makes monitoring of water resources (from rainfall through flows, sediments and glacial mass balance) extremely challenging.

Surface and groundwater interactions are complex; however, aquifers are a significant source of irrigation and drinking water. The recharge dynamics are imperfectly understood. The Ganges Strategic Basin Assessment suggest that dams could potentially double low flows in dry months, but similar storage volumes could likely be obtained through better groundwater management [25].

Climate change impacts on flows

The analysis of impacts of climate change on Ganges and Brahmaputra mean annual flows has not proved conclusive and there remains considerable uncertainty. Total run off is not predicted to change significantly (Figure 10) ([7, 14, 22]) but the possibility of more extreme events and shift in monsoon timing to coincide more with the cyclone period may cause problems in the flood prone regions in India and Bangladesh. In contrast to the Indus, increased glacial melt due to future temperature rise is not predicted to bea significant factor in these rivers as glacial melt coincides with the monsoon period and glaciers play a less significant role as an inter or intra-annual water store compared to the Indus

Figure 10. Current and projected annual runoff in Upper Ganges and Upper Brahmaputra Basins[22]



Sources: Lutz et al. 2014, © Nature Publishing Group. Redrawn by the World Bank from data provided by A. F. Lutz, with permission from Nature Publishing Group; further permission required for reuse.
Note: The bar plots show the current total average annual runoff (TR; 1998–2007) and projected future average annual runoff (PTR; 2041–2050) for the Upper Ganges and the Upper Brahmaputra basins. Both upper basins are rainfall-dominated (orange) due to monsoon influence. Both are projected to experience greater runoff in the future (light blue), primarily due to an increase in precipitation.

Flooding

The GBM basin has always been prone to significant flooding – either as local flash floods, riverine tsumanis caused by glacial lake breaks or landslides, monsoon slow onset floods from far upstream, or tidal and cyclone generated surges in the lower reaches.

WRI estimates that $14.3 billion of GDP in India is exposed to flooding on average, each year (0.84% of national GDP). Similar figures are $5.4 billion in Bangladesh (4.75% of national GDP) and $218 million in Nepal (1.3% of GDP). WRI estimates that India's current $14 billion exposure could increase ten-fold to $154 billion by 2030 with economic growth[26].

Bangladesh ranks first in the world in terms of percentage of country GDP regularly exposed to inland flooding (4.75 percent on average per year) and second in terms of population exposed (3.48 million) after India with 4.84 million [22]. The damage caused by 67 floods recorded between 2000 and 2010 in the Ganges-Brahmaputra-Meghna system cost an estimated £19.44 billion.

A Ganges basin flood with a 100-year return period inundates 75,000 km^2 of land. A Ganges basin flood with a two-year return period (a relatively minor flood) inundates 47,000 km^2 of land [22] affecting 47 million people or 10 percent of the basin population (see

Table 1). 45 percent of this affected population live in India, with Bihar and Uttar Pradesh having the highest numbers— 18 million and 17 million people respectively. In Bangladesh, the Rajshahi Division has the highest number—0.99 million. In Nepal, the Tarai region would be hardest hit, with 0.16 million people affected. Such chronic and regular flooding is a significant brake on local development.

The average annual losses are not evenly distributed (Table 2). High economic losses are mainly driven by impacts on high value infrastructure (buildings, roads, railways etc) rather than on crops, livestock and livelihoods as local people remain impoverished. Within the delta area, where land rarely exceeds 5m above sea level, maintenance of mangroves provides some protection from storm surges, while a sinking delta area (5mm/year on average) [21] will exacerbate the salinity intrusion and cyclone impacts of sea level rise.

Table 1. Ganges Basin Risk Assessment: most severely affected States and Provinces

State/province	Affected population (millions [%])	State/province	AAL (US$, millions)
Rajshahi, Bangladesh	0.99 (44%)	Bihar, India	221
West Bengal, India	3.53 (30%)	Uttar Pradesh, India	205
Delhi, India	3.75 (22%)	Delhi, India	101
Bihar, India	18.12 (17%)	West Bengal, India	40
Uttar Pradesh, India	17.31 (9%)	Rajshahi, Bangladesh	14
Eastern Province, Nepal	0.15 (3%)	Eastern Province, Nepal	1
Mid-Western Province, Nepal	0.06 (2%)	Mid-Western Province, Nepal	1

Sources: Priya 2016; original data from RMSI 2016a.
Note: Data show states and provinces most severely affected by a flood with a return period of two years, listed in descending order for both population on left (number of people and as a percentage of the resident population) and AAL on the right. AAL = average annual losses.

Table 2. Average annual losses within the Lower Ganges Subbasin by State or Province

Country	State/province	AAL (US$, millions)
Bangladesh	Kushtia	4.39
	Pabna	0.62
	Rajshahi	5.30
India	Bihar	119.32
	Jharkhand	3.83
	West Bengal	16.18
Nepal	Eastern Province	0.04

Source: RMSI, 2016a.
Note: AAL = average annual losses.

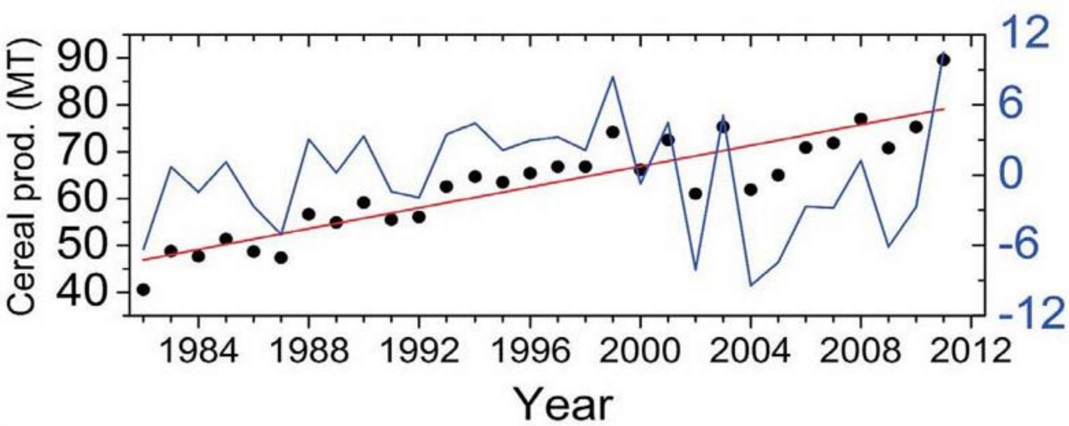
Droughts

The flows of the Ganges are highly seasonal, and during the dry season they dwindle considerably. This is also the season of maximum sensitivity for irrigation and therefore demand for withdrawals coincide with lowest water levels.

Figure 11 shows the variation in total cereal production in the Upper and middle Gangetic plain (UMGP) which indicates that severe drought can cut yields by 10-15%. Many documents talk about the impact of periodic droughts but there is little analysis that demonstrates the scope of economic impacts, or their underlying causes, or whether particular crops or periods of the year are most affected. In particular, there is little distinction between crop losses due to reduced local monsoon rainfall, or due to reduced river flow that may affect dry season irrigation.It is therefore challenging to disaggregate local impacts and transboundary impacts.

In Bangladesh, the low dry season levels primarily affect river and soil salinity, the former due to saline intrusion from the sea, the latter due to soil desiccation and capillary action drawing saline groundwater to the surface. Low river levels also drain groundwater towards the river. All of this affects the production of crops in the delta and floodplains, especially in the north and south west of the country [27].

Figure 11. Changes in total cereal production, technological growth and natural disasters [28]



Notes from figure: Changes in total cereal production (black dots) and trend attributed to technological growth (red line), along with actual changes in cereal production due to natural disaster (blue line), in the UMGP region. Mathematically, if CP = total cereal production (black dots), TI = the trend in cereal production due to technological growth (red line), and CCP = actual changes in cereal production due to disaster (blue line), then CCP = CP-TI

Summary

Indus

- More than 95 percent of the annual surface water flow is appropriated for irrigation. While management to maximise economic gains require some level of guarantee on flows from upstream, considerable efficiency gains can also be achieved from improved water management *within* Pakistan. Maintaining the delta ecosystem requires definition and protection of an environmental flow.
- Flooding patterns and dynamics are extremely complex, some have local solutions (a mixture of engineering, natural infrastructure and resilience measures), others require basin-wide approaches. In all cases, a multi actor approach is necessary and only for basin wide events will early warning be of significant value. However, the level of economic damage from basin level floods (eg 2010) justifies basin wide approaches to planning infrastructure and for forecasting and early warning.
- Pakistan's agricultural output makes a significant contribution to the national economy yet is at risk from drought events and a shift of Indus flow timing under project climate change scenarios.
- A better understanding is needed of the role of the cryosphere in maintaining Indus flows and their seasonality.

Ganges-Brahmaputra-Meghna basin

- Steep, high altitude Himalayan slopes mean that land use management, which is often technically feasible in many less challenging catchments, will not significantly reduce flood events and sediment flows basin wide.
- Sediment is redistributed in the river system by annual flood events. Knowledge on sediment sizes, flows and redistribution is weak. The Ganges is an unstable system and continues to change course, with the main river course moving gradually eastwards. Channels in the lower Brahmaputra also evolve and widen (the Jumuna river was 3.5 km (30%) wider in 2010 than in 1973).
- The Gangetic plains are subject to local monsoon flash floods as well as slow onset floods coming from far upstream. Simultaneous provision of good drainage systems (for the former) and protection dykes (for the latter) is technically difficult to achieve. Dykes slow the drainage of floodwaters back to the river. Room for the river approaches are therefore likely to be more effective than traditional embankments.
- The Himalayas valleys are too steep and narrow and the monsoon flows to large that it is not possible to store enough water to reduce downstream floods through building dams. So, scope for basin level coordination is limited.
- Hydropower dams in the mountains run risks from earthquakes, sediment flows and landslides in the unstable terrain. In some places, concentration of agricultural land in valley bottoms makes resettlement of dam affected people out of dam-flooded valleys unfeasible. Recent advances in dam design can however improve sediment management through flushing – but this reduces overall electricity production.

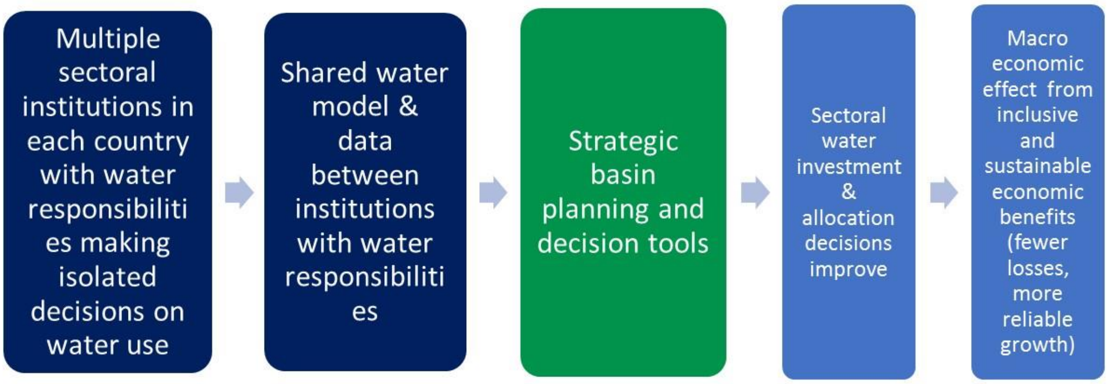
Modelling approaches are assisting with flood forecasting to support early warning systems (see Section on Shared data and Early Warning Systems)

Multilevel Linkages: section summary

	Transboundary	National	Poverty/ gender
Section 2: Basin hydrology	Big rivers with catchments cutting across countries; some disputed territories in shared catchments (e.g. India/China; India/Pakistan). Flows/drought affected largely by weather. But excessive extractions drain groundwater and reduce downstream flows. Without data it is challenging disaggregate local impacts from transboundary.	Weak monitoring and understanding of existing hydrological processes; Flooding/droughts regular processes with significant economic losses and regular loss of life and indirect impacts on health, land and water quality degradation, temporary disruption of transport and slowing down of economic growth. Investments target structural measures but increasing call for non-structural (i.e. land management, community flood preparedness) practices.	• Home to millions and big industries: irrigation, energy. • Chronic flooding/droughts puts a break to local development and tend to affect mostly those without access to alternatives or in direct contact with water bodies. • Aquatic ecosystems sensitive to flow reduction – e.g. 47% decline shrimp catch, decline in mangrove cover, etc. Direct impact on local livelihoods for coastal and riverine communities.

Section 3: Pathways to economic development

Water governance, dialogues and "human software"



Pathway to inclusive and sustainable economic development

Shared analysis and strategic basin planning leads to improved water allocation decisions that maximise inclusive and sustainable economic benefits (macro impacts).

Water governance across the basin - with shared analysis, institutional strengthening and collaboration to make strategic choices in investment and water allocation - underpin the ability of sectoral investments to maximise the collective economic development outcomes in the region.

Evidence

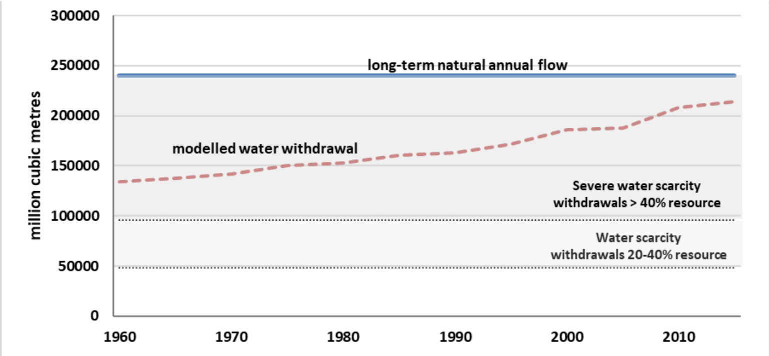
The complex politics of the shared rivers in South Asia undermine the potential for strategic planning of these basins. Although there has been some progress in sharing data and creating or strengthening technical platforms for dialogue, acceptance of shared analysis remains largely elusive.

A full political economy review of the region is beyond the scope of this analysis. However, the management of water occurs in a context where stresses and tensions in other areas (over land territory and related insurgency or geopolitical positioning for example) can easily spill over into water management. Fluctuating cooperation on water management is more a consequence of disputes on other issues than a driver of them.

The Indus flows through countries that have a complex set of historical and strategic relations. India and Pakistan signed the Indus Water Treaty in 1960, which allocates priority to India on the eastern tributary rivers, and to Pakistan on the western rivers, defining flow volumes to be respected at the frontiers. There is an ongoing debate about whether this agreement remains fit for purpose, and with what it might be replaced, and so little indication that the parties are inclined to review it at this point. The Treaty has rigid provisions that may be appropriate in the early stages of water storage and abstraction, but as withdrawals approach the mean annual flow (Figure 12) [29] and resources become scarcer, more sophisticated management approaches will be required that are better able to respond flexibly to floods and droughts as well as structural flow changes due to increasing consumption patterns, possibly overlain with climate change..

There are no formal overarching treaties between Pakistan and Afghanistan or China that frame water sharing between the countries, although large projects under the Belt and Road Initiative involve signing various MOUs between the countries [30]. However, some authors cite continuing tensions on major hydropower investments threatening a stop to investments [31]. Advances are taking place on potential energy cooperation (mostly on gas and diesel) for a network involving India Bangladesh, Bhutan, Myanmar and Nepal, which can offer a space to further coordinate water strategies [32].

Figure 12. Water resources and indicative withdrawal [29]



China occupies a strategic upstream position in the GBM basin, and, as with the Ganges and Mekong, it has tended not to participate formally and transparently in collective shared hydro diplomacy and data sharing at basin scale, preferring to make *ad hoc* and limited bilateral arrangements.

India depends on rivers that originate in China for one third of its renewable water supplies [33]. So it was a significant step forward when, following severe floods in 2000, the President of the People's Republic of China visited India, and it was agreed, in 2006, to establish an expert-level mechanism for discussion, interaction, and cooperation regarding flood season hydrological data on the Brahmaputra river, emergency management, and other issues regarding transboundary rivers. In 2017, India claimed that China was not providing the data as envisaged but these have recently been reinstated (May, 2018).

Good relations have been threatened by cyclical mistrust between the parties and other disputes (over land for example) that spill over into water management cooperation. There is real concern in India that China might transfer water from the Brahmaputra to inland regions. However, China appears to have diverted very little of the flows that it controls into agricultural projects and inter-river transfers would be a significant engineering challenge**.** Xie et al reviewed Sino–Indian relations and concluded:

> *"distrust has resulted in the development of complicated dynamics in Sino–Indian water disputes. China has displayed vested interests in its water diplomacy. Not only is the Chinese government seeking economic profits such as through the generation of hydropower, it also seeks to protect its strategic interests through the domination of hydrological data and water policy information. Such strategic interests may obstruct foreign relations unless substantial cooperative water sharing initiatives are implemented. As India has displayed varying interests in the diplomatic process, the outcomes are proving limited and risky. In the absence of substantive collaborative initiatives over water management, the mismatched interests over the GBM Basin have the potential to further strain the already unstable relations between two of the major powers in South Asia. [34]*

India also has complex relations with its other neighbours, Bangladesh, Nepal and, Bhutan that affect water management directly or indirectly. In Bhutan, the Indian government has successfully invested in hydropower dams while finding agreement with the Bhutanese government on what percentage of generation to distribute in-country in return, and exporting the remainder to Indian markets (about 30-70% in the practice[35]). In contrast, agreement and common ground has been less easy in Nepal, traditionally more nervous about giving Indian actors control over their local resources. Indian power sector off taker monopolies also make negotiating favourable energy prices for export challenging for a government with limited capacity. However, there has been recent progress with a number of deals that had been stalled for years reaching closure, accompanied by World Bank involvement.

The 1996 Ganges Treaty[2] between India and Bangladesh is a water sharing agreement in its simplest sense: it establishes India's right to withdraw up to 40,000 cusecs of flow at the Farakka Barrage between 1 January and 31 May every year. If availability at Farakka falls below 70,000 cusecs, the flow will be divided equally between the two countries, while guaranteeing a minimum of 35,000 cusecs to each over alternating 10-day periods between 11 March and 10 May annually [36]. The definition of fixed volumes in the Treaty leaves little scope for managing exceptionally low flows, or unexpected events. It does not involve other riparians. Recent agreement (2015) on land border disputes between the two countries may indicate a growing willingness to cooperate across borders. The Ganges Treaty is agreed for a period of 30 years so is up for renegotiation in 2025.

Mistrust between the basin countries has led to founded and unfounded accusations being made as to the cause of individual drought or flood events and claim and counterclaim have long prejudiced a collective mutual understanding of the hydrological potential, and risks, that face the countries of the basin. Data secrecy [37] and the lack of shared and mutually agreed databases and models of Ganges, Indus or Brahmaputra flows mean that this climate of tension has yet to be dissipated by a shared acceptance of the available hydrological facts, nor is there yet the transparent basis for a shared vision for the future of the basins and the opportunities for each country within it.

On the other hand, the development of technical dialogues between state and non-state institutions within the basins and the development of models – currently only at national level but creating the potential for regional analysis - offer important signs of progress. Likewise, the investment in better quality reporting on the rivers eg Indus, appear significant. These dialogues cover the Indus basin (IWMI led India-Pakistan technical dialogue), the Brahmaputra (China-India formal technical committee on data sharing and SaciWATER's technical dialogue), the Sundarbans (Bangladesh-India formal Sundarbans Regional Cooperation Initiative), flood modelling in India and the basin model for Bangladesh. Whilst the Ganges Strategic Basin Assessment has never been formally accepted, at a technical level it provided insights and understanding for the region, such as increasing attention to the importance of groundwater for water storage and the challenges facing the development of significant upstream storage at scale.

There is a global call to improve the way transboundary water dialogues are implemented, and who takes part in them [38]. Transboundary management and dialogue are usually driven by water delivery concerns rather than society, for example on investments that centre on infrastructure, technologies and command and control. These top-down measures will often ignore or not be able to capture the granularity needed to address societal issues linked to those who rely more directly on the water resources and the ecosystems that affect their delivery: vulnerable groups, local communities and women. [39]. It is important that dialogues are

[2] This treaty is for 30 years and will expire in 2025.

accompanied of proposals for actions that recognise women's role in safeguarding water management at higher levels of governing domains, e.g. in legislation, policies and strategies of organisations (e.g. requirements of minimum women participation in public leadership positions to ensure community water entities include women [40].

Summary

The regional tensions at basin scale affect the way in which neighbours work together to solve common problems and share information. Equally, the national concerns within the basin are not the same. China has different preoccupations to Bangladesh for example. Given this dynamic and noting the existence of a series of bilateral agreements, tailored more specifically to the needs of the partners, it may be feasible to initially build more bilateral agreements (eg Afghanistan-Pakistan; Nepal-India) that address a shorter, more specific number of relevant issues than trying to bring five or six basin countries together in a single overarching agreement.

There is every indication in the literature that there are many levels of exchanges between scientists, water managers and high level government staff from different countries, through informal opportunities offered in the absence of a formal basin wide structure. These should be maintained and supported wherever possible, perhaps through an annual 'Ganges/Indus Forum' that focusses primarily on science and understanding. Information does indeed flow between the parties, and it could be argued that the lack of formal transboundary processes is not necessarily a brake on investment. Indeed, in the hydropower sector it appears that from today's perspective energy sector reform is a more important driver than transboundary water relations.

What is evident, though, is that water resource availability (per sector, per capita, per country) is unlikely to increase in coming years, and if climate change predictions on the Indus prove correct, the negative consequences in Pakistan could be considerable. It will be easier to set the framework and mechanisms for basin collaboration today, wherever possible, rather than awaiting the inevitable resource scarcity and upstream-downstream tensions that will be exacerbated in 15-20 years time as countries proceed towards the erection of 400 or more dams within these catchments, and further investment in large scale irrigation investments downstream.

Key issues on transboundary governance include:

- Successful investments that affect and are affected by transboundary water need active cross-border dialogue and collaboration between institutions. Investments in "human software", such as communication, shared values and analysis that complement technical competences are critical drivers of successful water governance [41]. Shared analysis and strategic basin planning leads to improved water allocation decisions that maximise inclusive and sustainable economic benefits (macro impacts).
- No wars for water have been fought but there is lack of trust and cooperation. Part of the reason is the lack of political acceptance of the mutual benefits from shared approaches to water governance, rather than seeing cross-border deals as a zero sum game, where if one wins the other will lose.
- According to Hanasz (2017) [42], there are challenges for engaging in dialogue and cooperation, which make transboundary issues not a priority for riparian states. Hanasz suggests ways to improve transboundary water interaction: addressing the political context and historical grievances; building trust and reducing power asymmetry between riparian states; creating political will for cooperation; de-securitising water; taking a

"problemshed" view; strengthening water sharing institutions; and moving beyond narratives of water scarcity and supply-side solutions.

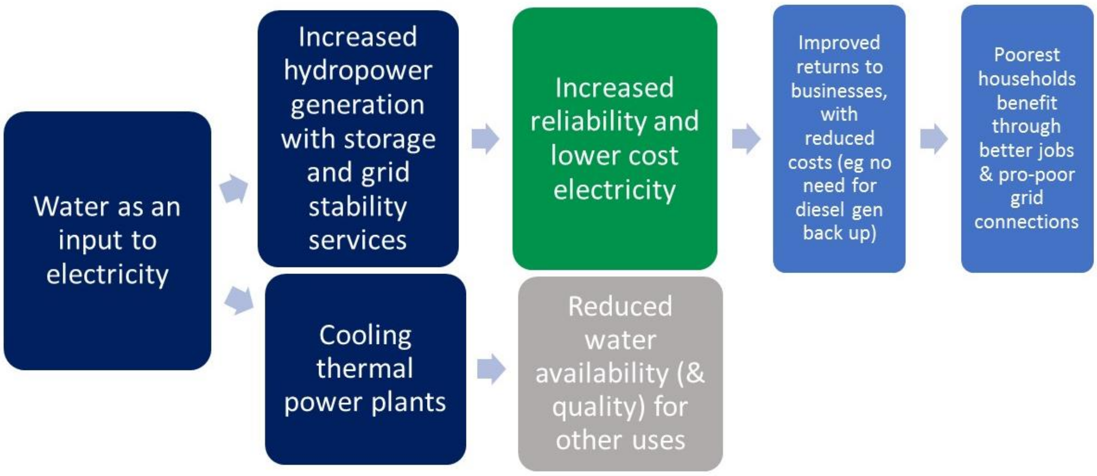
- Most sharing of data, flood warning etc seems to happen on an *ad hoc* basis, scientists and technical staff seem to have informal networks that function, using conferences and workshops to exchange on "essentials" outside a formal political agreement. Remote sensing technologies increasingly allow countries to measure indicators (e.g. rainfall) without requiring data from neighbouring countries.
- Women's roles in safeguarding water management at local levels needs to be visible at the top, including in transboundary negotiations. There is a call to increase the visibility of women in international water for a and dialogues, matched by equal power in decision-making.
- There is no evidence yet that shared analysis in strategic basin planning will improve collective investment decisions. However, given the political context given above, the progress that has been made is important.

Multilevel linkages: section summary

	Transboundary	National	Poverty/ gender
Section 3: Pathways: Water governance, dialogues and "human software"	Complex politics over territories, borders, can spill over into water management. Treaties can be bilateral (India/Pakistan) or informal *ad hoc* arrangements e.g. BRI (China/Pakistan/Afghanistan). No wars have been fought yet, but there is no evidence that shared analysis will improve collective investment decisions. But any progress is some important.	Investments in 'human software' such as communications and technical competences are critical drivers to successful water governance.	Women's roles in safeguarding water management at local levels needs to be visible at the top, including in transboundary negotiations. There is a call to increase the visibility of women in international water for a and dialogues, matched by equal power in decision-making.

Water and energy

Pathways to inclusive, sustainable economic development



Water is a vital input to electricity services allowing cross-border transmission of hydropower and cooling of local coal powered thermal plants.

Increasing regional trade in hydropower could increase the availability and reliability of low-cost energy (and cleaner in relation to coal). This could reduce the costs to production of goods and services, improving returns to businesses.

If increased returns are passed on to workers through improved jobs, pay or by increasing energy access through household grid connections, this will also have impacts on the inclusivity of economic development.

With the right design of hydropower plants and commercial operation of energy networks, dams offer cheap energy storage (pump storage) and grid stabilization that enables an increasing share of intermittent renewables to be included in the grid – reducing the costs of power and mitigating greenhouse gas emissions from thermal alternatives.

The consumptive use of water for cooling from coal power stations in water scarce basins reduces the quantity of water available for other uses. Washing coal reduces the water needed in energy production, but can pollute downstream water bodies, reducing water quality.

Evidence

Water is a major input to both coal burning thermal plants and to hydropower production. For example, thermal power generation in India accounts for 1-2% of water demand withdrawal [43]. ,This relations is however often ignored. For example, a recent ADB study [44] of cross-border power trading in South Asia does not mention “water” when analysing the economic potential of these investments.

Most countries of the region are energy poor, with significant unserved populations and growing demands from existing consumers – see country energy profiles. Each has also followed different generation paths depending on their natural resource base, with India focusing on coal, and Nepal on hydropower, for example. Power shortages cost millions to the economy: as much as 2-3% of the annual GDP in Bangladesh [45]. MDBs are increasing their lending portfolio for new projects, and strengthening the institutional framework for collaboration across the region regarding energy trade and investments to help address energy shortages in S Asia. The acceleration in investments in electricity are seen as important steps towards various SDGs beyond SDG7.1. For example, declining costs and access promotes jobs and new business models that make use of digital, mobile-enabled platforms (which require electricity) [46]. There are however still challenges which directly affect women and children, particularly in relation to clean cooking. Cleaner energy for cooking can reduce the time spent collecting biomass, cooking, and reduce premature death toll from household air pollution. Despite the advances in electrification in India, nearly 60% of the population (780 million) rely on biomass for cooking, and the number of people without clean cooking access over the last 15 years has increased by 80 million [46].

This section does not attempt to review the energy sector in detail but focusses on the role of hydropower and water as an input to thermal energy and the opportunities and constraints for mobilisation of shared water resources for energy generation, as the two main sources of energy in the region. In addition, transnational energy grids and connections are also considered, as a physical requirement necessary to transfer power from one country to another.

It should be noted, however that India, Pakistan and Bangladesh have all instituted public subsidies for domestic energy consumers which mean they do not pay the full costs of energy generation. This market distortion makes it harder for private investors to develop large hydropower projects and sell to the grid as the regulatory context is not stable enough to underpin the financial business case for such large, long term investments. Politicians are driven towards short term supply solutions. The World Bank is supporting structural reform to enable a clearer investment environment.

Hydropower in the energy mix

Energy from hydropower presents a number of advantages within an energy grid. It provides rapid supply in the event of spikes in power demand, as well as stabilizing frequency fluctuations within the grid. As a lower emitter of greenhouse gas emissions (at worst 25% of the most efficient gas-powered plant per kWh, and at best less than 1%) hydropower is a low carbon source that is not subject to the intermittency of solar or wind. In fact, it can be used to stabilise a grid with a high proportion of renewables providing variable voltage instead of “must run” or slow response thermal power from coal or nuclear. The cost of hydroelectricity generated is generally low (but very site-specific), with small hydro projects being very competitive to supply off-grid rural electrification schemes [47].

Pump storage designs for hydropower – with two reservoirs, enabling water to be pumped back above the turbine at times of excess energy availability within the grid- are the gold standard in energy storage as they are are relatively low-cost systems (for short-term storage in relation to batteries [47]) to solve the other challenge to increasing intermittent renewables on the grid, energy not being generated when it is in demand. While used in the USA, Japan and Austria it is less common in S Asia.   There is however few pump storage hydro plants currently operating in the region[3] (all of them in India). This is important as the costs from other sources are falling rapidly: onshore wind was estimated to be 6c/kWh globally in 2017, compared to 5c/kWh for hydro and 5-17c/kWh for fossil fuels [48], with prices suggesting the industry expect prices in 2018-2020 for wind and solar to continue to fall rapidly [48].

[3] https://www.hydropower.org/hydropower-pumped-storage-tool suggests that there are 11 working pump storage plants in India.

As pressure continues to reduce greenhouse gas emissions from energy generation and meet the Paris agreement obligations, hydropower has the ability to support expansion of intermittent renewables within the energy mix. To be effective this requires sophisticated grid management and commercial frameworks that can manage supply through commercial contracts according to fluctuating demand. The existence of subsidies within the energy market potentially distorts the emergence of an effective system.

On the downside, large dams affect downstream flows, may impact on biodiversity and economic values of downstream ecosystems and may have significant impacts on local people whose villages or lands are flooded by the reservoir. Disruption to the river flow generally demands some interaction and transparency from upstream parties to those downstream to avoid or mitigate any negative impacts. Keeping hydropower dams full for generating purposes can also lead to the dams releasing water in the event of significant rainfall, with consequent downstream flood damage (eg see Damodar River Development corporation [49]).

The potential for hydropower in each country depends on local issues such as the topography (which determines the suitability of dam sites) and the river flows, that provide the energy to run the turbines. Risks due to seismic activity need to be managed. Some countries have already developed some of their hydropower potential, and others are still to do so – some examples shown in Table 3. Data of this kind are not easily available for India, China and Afghanistan.

Table 3. Hydropower capacity in the area

	MW installed	MW potential	Power generated
Bhutan	1615 (2015)	24,000	7780 GWh (2015)
Pakistan	7,320 (2016)	60,000	34.42 TWh (2016)
Nepal	753 (2015)	43,000	3,635 GWh

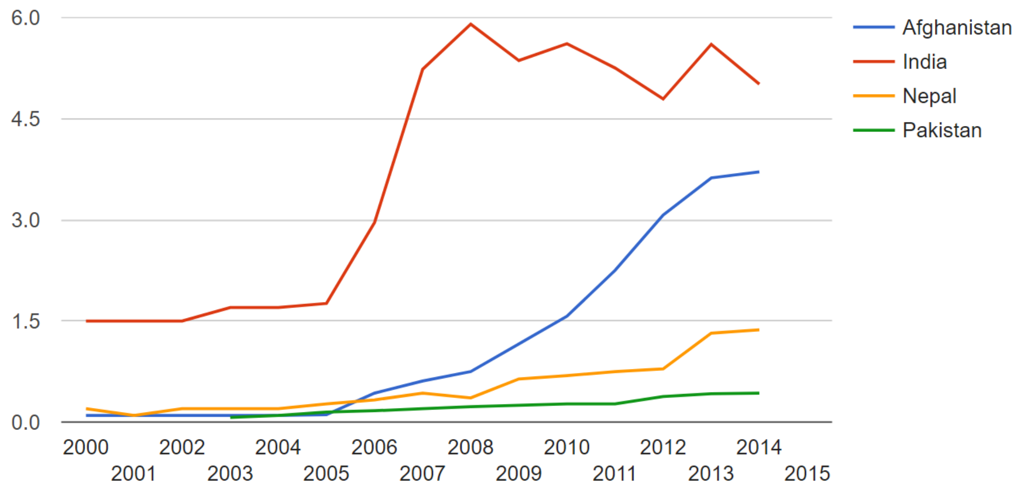
China has announced plans for 4 dams on the Brahmaputra of which one is operational. Data on hydropower potential in the region are not publicly available but China has declared its intention to improve electricity supply in Tibet through investment in hydropower. An important number of investments along the Belt and Road Initiative are linked to hydropower.

India has many hydropower plants on the drawing board or in development however most are not in basins shared with neighbouring countries. They may however also cause disputes between upstream and downstream States even when entirely located within India as these have delegated responsibility for water management. On international transboundary basins, the government recently announced plans for six hydropower projects on the Chenab river, a tributary of the Indus in Indian Kashmir that would triple hydropower generation in Jammu and Kashmir from the current level of 3,000 MW to 9,000 MW. Pakistan has expressed its concerns at these plans within the context of the Permanent Indus Commission although India is within its legal rights to develop these projects as long as they don't impact flows into Pakistan. India and Pakistan have also clashed over the 450 MW Baglihar project completed in 2010.

Energy within and cross-border

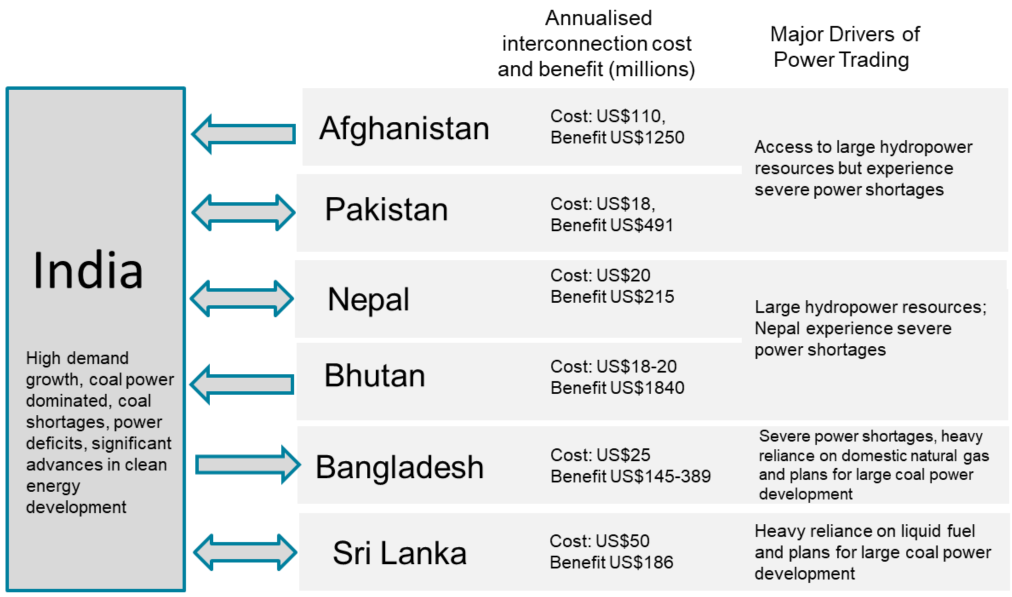
Countries of the region have gradually increased their cross border trade in electricity (Figure 13) and more connectors are being constructed and international agreements beginning to be discussed [32]. The first large-capacity interconnection between India and Nepal (1,000 MW) was completed in February 2016 [50]. Summaries of electricity outlooks per country are presented directly below.

Figure 13. Electricity imports, billion kilowatt-hours [50]



International trade includes various cross-border electricity transmission interconnections (Bhutan-India, India-Nepal, India-Sri Lanka, Bangladesh-India, India-Pakistan). There are also connections between Tajikistan, Kyrgyzstan, Pakistan and Afghanistan developed through the Central Asia-South Asia power project (CASA 1000). ADB also calls for investments in large scale interconnections, with benefit to cost ratios ranging from 3.7 to 102 which are also expected to benefit about 300 million people as yet unconnected to the grid [44], Figure 14.

Figure 14. Costs, benefits and direction of electricity trade [44]



Source and notes: based on ADB's report [44]. The economic, reliability, and environmental benefits for each interconnection project is assessed by comparing demand-supply scenarios with and without the incumbent project. Annualized cost includes capital cost of transmission projects calculated using a Weighted Average Cost of Capital of 7.5% and life of 30 years. Benefits include reliability benefits, operating cost benefits (e.g. avoided cost of expensive fuel) and capacity benefits.

Unpredictable water availability, especially in water stressed basins, affect local production and puts pressure on required imports/exports and costs of linked power outages. For example, poor monsoons and long dry seasons reduces hydropower availability, increasing demand from coal generation and often leading to electricity shut downs from hours to days [51]. Dry season shortages led to the shutdown of the 1130 MW Parli coal plant in Maharashtra in 2013, whilst in July 2012, there was a two-day blackout affecting almost 700 million people.

Regional outlook: India [52]

India's energy sector is dominated by coal, with less than 10% of generation provided by hydropower. Over the last twenty years, India has heavily invested in coal fired generation while hydropower has remained fairly stable since 2000 (Figure 15). Over recent years only limited hydropower has been added to the energy mix in India and this is unlikely to change under the five-year plan. Less than 5% of recent capacity has been in hydropower. India also has plans to extend energy imports from neighbouring countries (Table) but this remains minor within a plan that seeks to add 187,000 MW during the 12th plan (2017-2022) and a similar amount up to 2027 [52] (India draft energy plan 2016, Central Energy Authority).

Net Electricity (Hydro) Import from neighbouring countries

(All figures in MW)

	Bangladesh	Nepal	Pakistan	Bhutan	Total
Export	1,500	400	500		**2,400**
Import		10,000		14,000	**24,000**
Net Imports					**21,600**

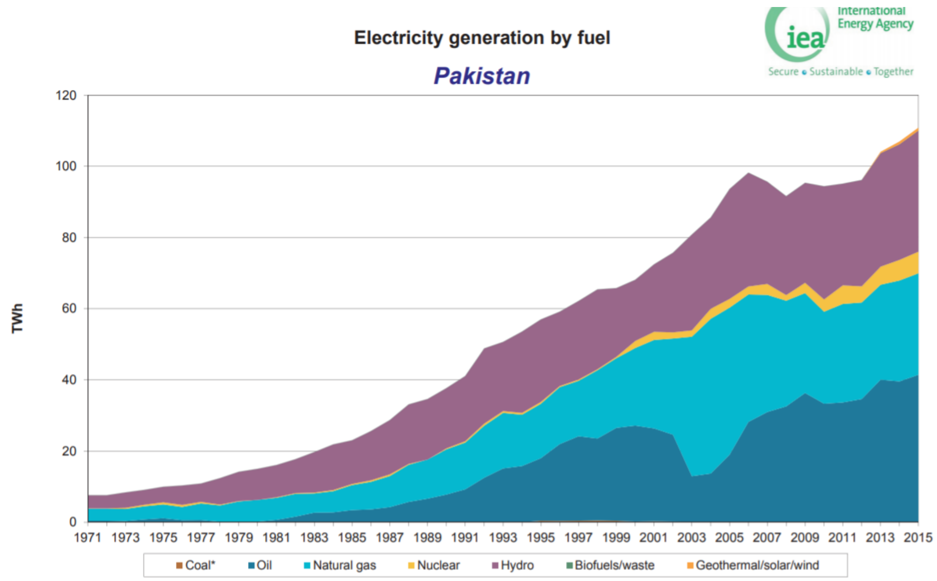
In the context of India delivering electricity supply growth, hydropower, either within the country or importing from Nepal and Bhutan remains a minor contribution to the energy mix and is not currently seen by the government as a strategic resource for meeting the country's demand. Looking ahead to the 2030s, even if the totality of the hydropower potential in Bhutan and Nepal was mobilised to deliver India's demand, this would only represent a small part of the required installed capacity according to the master plan.

Regional outlook: Pakistan [54]

In Pakistan, the energy mix is much more diverse, and hydropower represents around 23% of the capacity (Figure 16

Electricity generation in Pakistan [53]

Source	MW installed
Hydroelectric	7,602
Thermal (Public and Private)	17,173
Nuclear	1,065
K-Electric	2,341
Wind	796.5
Solar	486
Other Renewable Sources	564
LNG	1,400
Imported (Iran)	105
Coal	1,628
Total Installed Capacity	**33,161**



). Recent investments have been made in upgrading generation capacity at Tarbela. Pakistan has a hydropower potential of 60,000 MW. Although the data quality is poor, 99% of people are claimed to (still) have access to electricity [55] and there is no data on reliability of electricity. Meeting the growth in demand could however be an easier ambition than for those countries where much of the population remains unconnected.

Regional outlook: Bangladesh [54]

In Bangladesh, 67% of the population has access to electricity. Access to hydropower is only available by importing such electricity through India. Two connectors have been built and more are planned. The institutional framework for pricing and management of transmission remains to be fully matured. For the time being, Bangladesh can purchase electricity from India, however, not yet from Nepal and Bhutan through India. These opportunities will depend on sector reform and transmission networks through India. Progress in energy trading relationships between India and Bangladesh was partly driven by Bangladesh agreeing to gas being traded across its land from Myanmar to India.

Regional outlook: Nepal

Nepal depends on hydropower for the large majority of its electricity supply (Figure 18). Although the recent interconnection with India is increasing the reliability of the grid through dry season supply and during intense rains (when turbines are closed due to the high sediment flow), 30 percent of Nepalese have no access to electricity. The government is incentivising investment in decentralised off grid systems for remote communities, and by 2014, more than 1,000 Micro hydro plants with a total generation capacity of 22 MW had been developed, providing off-grid electricity access to 20 % of the population [56]. These plants will in future be grid compatible as the network expands and small plants can also feed the national demand.

Current energy demand of 4430 GWh is predicted to double by 2018 and to exceed 17,400 GWh by 2027 [57]. While long term hydropower development plans target an additional 10,000 MW of installed capacity by 2020 (according to the 10-years hydropower development plan) the pace of development is slower than initially envisaged. Financing for investment has always been a constraint to large dam development in Nepal, with an uncertain investment climate for private investors, limited confidence in negotiating deals and reticence to see private investors exploiting national resources all acting as brakes on development. Recent support to negotiations has however increased confidence and there is some progress in setting an investment and regulatory framework for private sector investment that will also accelerate growth. The World Bank is supporting sector reform and dam construction (Upper Arun and Ikhuwa Khola hydroelectric projects [9]).

Figure 15. Electricity generation by fuel: India[58]

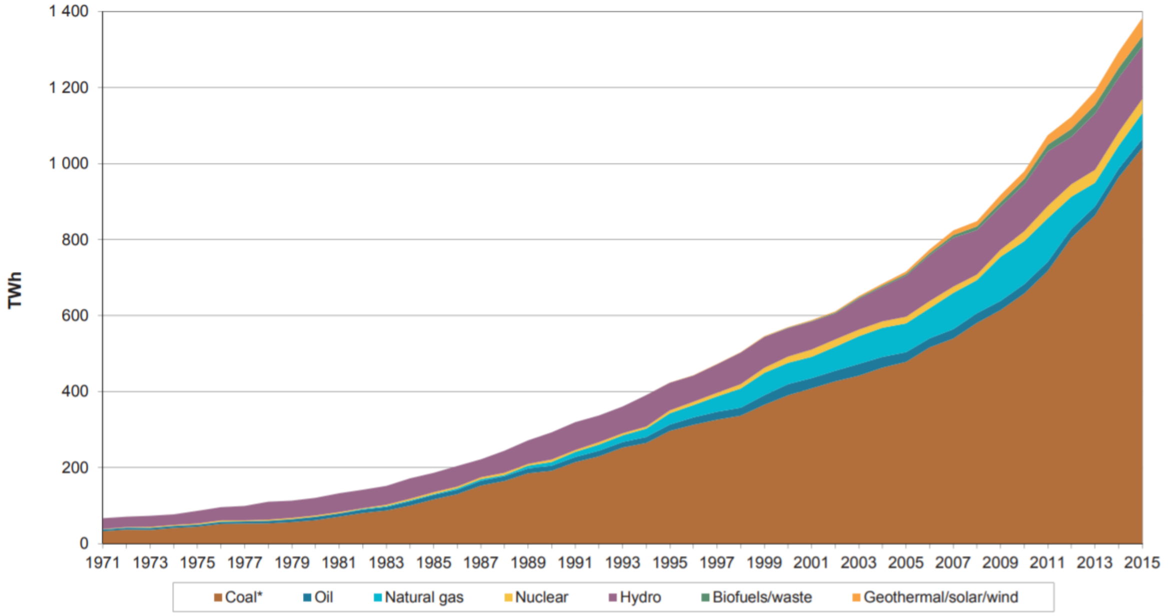


Figure 16. Electricity generation by fuel, Pakistan [58]

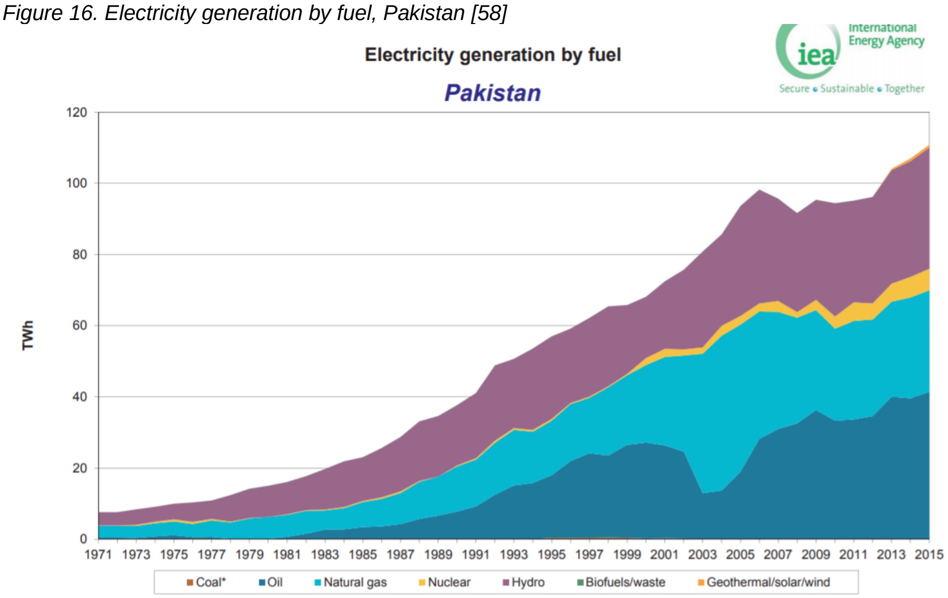


Figure 17. Electricity generation: Bangladesh [58]

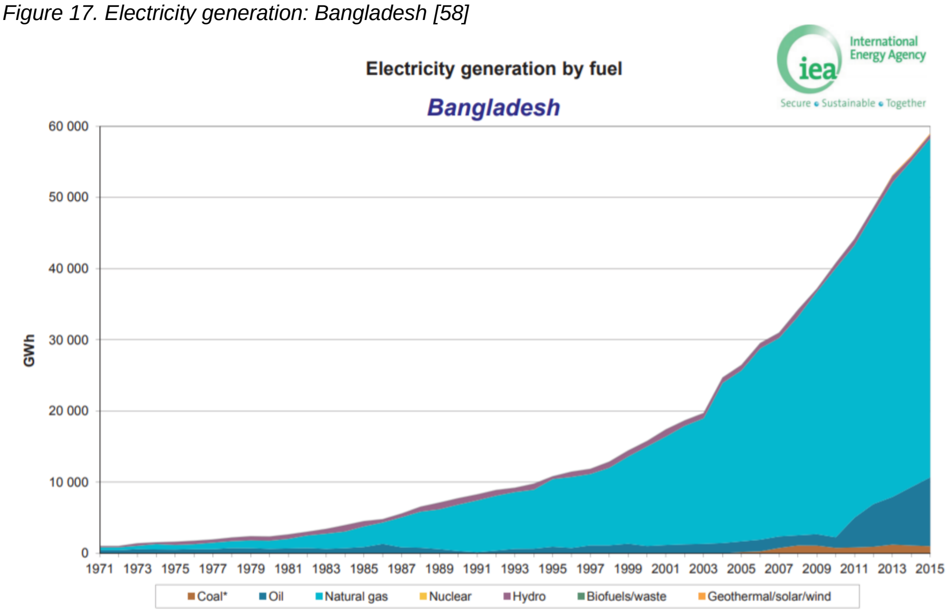
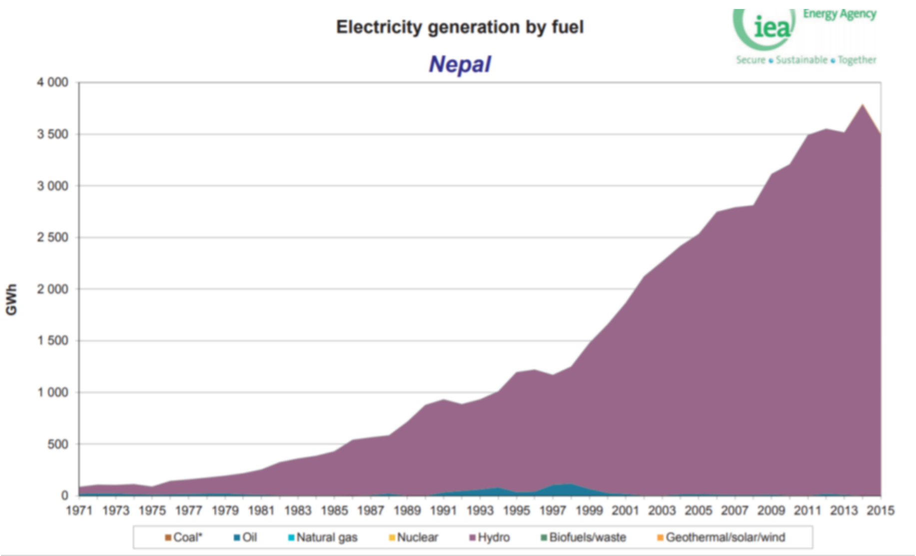


Figure 18. Electricity generation by fuel: Nepal[46] [58]



Summary

As the international grid develops, trading between countries will become increasingly technically feasible, however it is the institutional and regulatory framework that will determine how well the system will function as a whole. Given the tensions that exist between countries, and manifest themselves in only limited transboundary water cooperation, it remains to be seen whether these can be transcended in the energy sector or whether countries will seek to maximise national energy security rather than promote a regional energy pool. However, in 2017 India announced its intention to develop an energy cooperation network with Bangladesh, Bhutan, Myanmar and Nepal, which while focusing on gas and diesel pipelines, still offers a potential platform for developing a regional energy market [32].

The opportunity to use hydropower for grid stabilisation and energy storage to enable increasing intermittent renewables on the grid has yet to be fully recognised in national energy planning but has significant potential. Improving electricity grid performance is likely however to have limited returns for inclusive growth without significant reform to the structure of the electricity market in each country.

The interest in, and outlook for hydropower is very different for each of the basin countries. India remains the major industrial consumer of electricity in the region and yet depends on an improvement in the investment climate in Nepal to allow private sector development. Recent hydropower deals in Nepal suggest conditions are improving. In Bhutan, India already plays a strong role and more transmission infrastructure is required to meet potential. In both India and Pakistan subsidies within the energy sector as well as monopoly of off takers are a constraint for private sector players for all generation types.

The significance of hydropower is different for each country. In Nepal, almost all domestic electricity generation is generated by dams. The main issues are the regulatory framework for hydropower dams that will facilitate or act as a brake on asset investments developed by the Indian and wider private sector, and the regulations that will apply to power export to India. The connecting infrastructure are being constructed so one infrastructure impediment to investment has been removed. Donors are assisting with public sector hydropower projects', but these are insufficient to mobilise the total potential or to meet demand. With increasingly competitive energy generation from wind and solar in the region, Nepal's ability to benefit from exporting hydro-electricity in the future will rely on designing and operating the hydropower plants for energy storage, balancing and stabilising the grid – and so maximise its potential with increasing intermittent renewables in the electricity grids of the region.

For India, the hydropower sector electricity imports have to be cost competitive with other sources – with benefits for the resilience of their grid supply through diversifying their energy mix. However, they do not appear to constitute a central plank of either plans to increase electricity access or reduce GHG emissions. The hydropower potential in Nepal and Bhutan is however only going to be one source given India's future requirements.

For Bangladesh, imports of power from Nepal or Bhutan must traverse India where sector reform is needed to deliver a pricing and transmission policy that makes hydropower imports feasible.

For both Pakistan and India, subsidies in the electricity sector remain a brake on private sector infrastructure and business plans as consumers do not pay the real price of power. Sector reform is also necessary to unlock additional private sector investments in a context of scarce public funds.

In hydrological terms, there is little evidence that negative downstream impacts on flows are a constraint on investment. While Pakistan has objected to current and proposed dams on the Indus tributaries and India has expressed concern about the impacts of China's current and proposed dams on the upper Brahmaputra, the evidence to legitimise these concerns is not apparent. The timing of the filling of new dams being the most significant issue. At present they appear to be motivated by ongoing regional tensions rather than underpinned by hydrological impact analysis.

The impact of dams is more likely to be felt locally, decreasing downstream as more tributaries feed the main river course so that long distance basin level impacts will be more diffuse. International disputes may therefore be expected to arise more at the level of individual heavily exploited sub catchments where upstream dams in one country are affecting flows just over a downstream border, rather than at the basin scale.

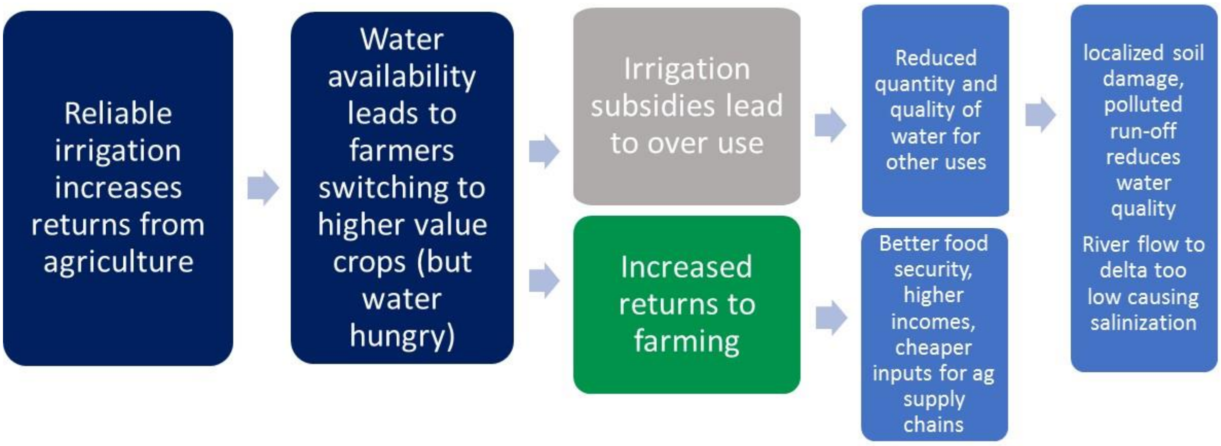
Multilevel linkages: section summary

	Transboundary	National	Poverty/ gender
Water for energy	Water is a key input for all forms of energy generation. Energy	Energy security high in each country's agendas to ensure	Reliable electricity important to sustain new models of

	imports and exports driving big levels of investments within countries. International trade includes various cross-border electricity transmission interconnections (Bhutan-India, India-Nepal, India-Sri Lanka, Bangladesh-India, India-Pakistan). There are also connections between Tajikistan, Kyrgyzstan, Pakistan and Afghanistan developed through the Central Asia-South Asia power project.	economic development with lower outages. The impact of dams is more likely to be felt locally, decreasing downstream as more tributaries feed the main river course so that long distance basin level impacts will be more diffuse. International disputes may therefore be expected to arise more at the level of individual heavily exploited sub catchments where upstream dams in one country are affecting flows just over a downstream border, rather than at the basin scale	development including digital, mobile-enable platforms accessible to many. But challenges to clean cooking still remain and women and children still affected by household pollution.

Food security and agriculture

Pathways to inclusive and sustainable growth



Food security and agricultural led growth is supported by reliable and timely irrigation:

Irrigation has been a central response to the frequency of drought in the region and the availability of sustained river flows. Irrigation has implications for downstream flows as water extractions for agriculture, in support of national objectives for food security, reduce flows downstream. Agricultural water draining back into river systems can be highly polluted, reducing quality but also feeds groundwater that can then be reused

Increasing water availability can lead to farmers switching to crops that are often water hungry. .

(Often) subsidised irrigation can lead to inefficient use and waste of water, reducing availability for other uses and damaging soil health.

Reduced river flows to the deltas are accelerating salinity intrusion from rising sea levels affecting delta health, and so affecting millions of coastal rice farmers and undermining fish stocks for fisherfolk.

Evidence

Water is a major input for agriculture. Water for agriculture uses 80% of the water withdrawn from Asia and Pacific watercourses [4]. By 2050, agricultural intensification worldwide will need to produce 100% more food for developing countries, while water resource availability is more likely to decline than to increase [4].

Table 4 Irrigation proportion in major basins [7]

Parameter	Indus	Ganges	Brahmaputra
Total area (km^2)	1,005,786	990,316	525,797
Total population (10^3)	209,619	477,937	62,421
Annual basin precipitation (mm)	423	1,035	1,071
Upstream area (%)	40	14	68
Glaciated area (%)	2.2	1.0	3.1
Annual upstream precipitation (%)	36	11	40
Annual downstream precipitation (%)	64	89	60
Irrigated area (km^2)	144,900	156,300	5,989
Net irrigation water demand (mm)	908	716	480

Agricultural investments are linked to irrigation in the region, which in turn has been driven by the economic impacts of drought – with some analysis suggesting this is far greater – if harder to quantify - than that of floods [59] and has driven vulnerability and inequality in the region [60].

Afghanistan, Bangladesh, India and Pakistan have reported significant droughts every three years over the last 50 years and much of Nepal also having frequent episodes [59]. Droughts affected over 1 billion people and killed 4.25 million people in India from 1900 to 2015, resulting in poor agricultural production, purchasing power and food security while increasing rural unemployment [60]. From early 2000, a period of severe drought affected the Indus basin, with millions affected in western India and south and central Pakistan. In 2012, Pakistan declared a state of emergency in two districts due to severe drought, with people having to be resettled. The worst record drought of 2011 in Afghanistan afflicted 14 out of 34 provinces of the country affecting 2.6 million people. The winter of 2008-09 was the worst drought in Nepal on record. The 1978–79 drought in Bangladesh directly affected 42% of the cultivated land and 44% of the population.

But due to the slow onset of drought, the complexity of impacts given the high level of irrigated agriculture and often localised rainfall patterns during the South Asia monsoon, it is less visible and more complex in its impacts on households. The regularity of drought has driven political support for irrigation and diesel subsidies for pumping groundwater. But this in turn as led to falling aquifers, with many in the Indus basin having reached critical levels. Further disaggregation of the effect of drought that are attributable to irrigation from river flows, as distinct from local rainfall, is needed in order to make an effective assessment of the usefulness of basin wide systems in managing drought impacts in the downstream floodplains.

The seasonal patterns normal in South Asia have been incorporated into farming practices and complemented with groundwater extraction. Section 2 discussed in detailed the hydrology of the region and how climate change is expected to affect this variability with increasing extreme events, more monsoon breaks and potential shift in the timing of the monsoon [61]. These changes are already affecting production and some analysissuggest significant impacts on agricultural production [62] [7].

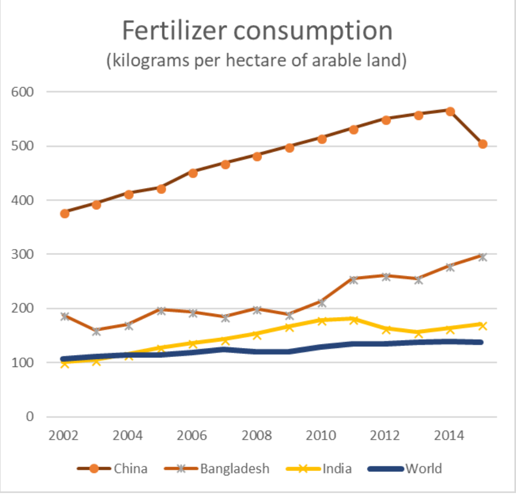
The major issues arising from irrigated agriculture are not so much in terms of annual water supply but the management of highly seasonal flows, the loss to leakage in low flow periods and the effects of agriculture in terms of water quality (from fertilizers and the impacts on salinity), access to water and subsidies, and impact on soils of poor irrigation management (waterlogging at the head, salinization from over irrigating).

Groundwater irrigation: South Asia copes with high seasonality and annual variability in surface and rain water availability by relying heavily on groundwater. Ninety percent of groundwater extractions in India are for irrigation (94% in Pakistan), with little monitoring on quality, quantity and recharge [63]. Bangladesh, India, Nepal, and Pakistan use about 23 million pumps with an annual energy bill of $3.78 billion for lifting water[64]. As aquifer levels decline, pumping costs increase, gradually affecting the economic viability of irrigation. Diesel subsidies introduced to reduce costs to farmers, lead to[65] inefficient irrigation practices. This generous approach to irrigation can create an “illusion of abundance”, continuing the cultivation of water-intensive crops in water stressed areas, leading in turn to higher losses when droughts are more severe or more frequent [8].

Solar irrigation increases the potential for households away from the main grid to access irrigation. And planned subsidies in Bangladesh and India are likely to stimulate rapid uptake. However, support could also usefully consider stimulating the productive use of energy, or over extraction and inefficient use of groundwater will increase rapidly. This could be through enabling households to sell their excess electricity to neighbours, e.g. through the solar swarm grids, or associating financing for solar panels with investment in drip feed irrigation and agricultural processing technologies [66, 67].

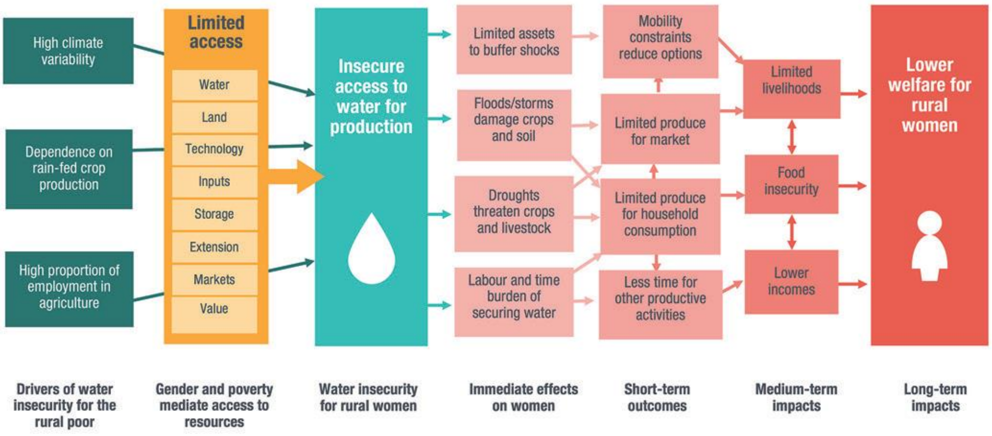
Agricultural pollution: The increasing use of fertilizers in an effort to increase agricultural yield result in higher water pollution. Consumption of fertilizer in Asia is well above the world average [68] – see **Error! Reference source not found.**. Bangladesh's fertilizer consumption is i ncreasing rapidly. India is above the world average but lower than China and Bangladesh. Excessive levels of nutrients found in 50% of rivers in Asia and moderate levels in 25% [69]. High nutrients cause eutrophication and severely damage freshwater.. Use of pesticides in India grew by 750% since the mid 1900s[70], exceeding international recommendations in the Ganges River [71]. The combination of pollution and dam building is referred as turning transboundary rivers between India and Bangladesh into a "dirty sludge, unable to sustain life"[72].

Figure 19. Fertilizer consumption (kg/ha of arable land) [68]



Water, food security and gender: [39]. Rural women's household responsibilities (including boys and girls) are more water-intensive than rural men -e.g. fetching water for domestic use and watering household gardens [73, 74] yet women have little power over water decisions. Women, compared to men, have less control of access to assets, or off-farm labour or migrate to cities, that can be used as coping strategies to buffer the effects of variable rainfall and have implications on food security [75]. Caste-based discrimination e.g. untouchability against *Dalit* households contributes to socio-political exclusion affecting access to collecting actions for irrigation resources [75]. Figure 20 presents a conceptual framework that helps to understand women's relation to water in the context of food security [65].

Figure 20. Conceptual framework for rural women's water insecurity [65]



Salinity: Coastal communities at the deltas of these rivers are affected by the reduced levels in fresh water (from river flows and groundwater levels) and higher sea levels. This has effects on health by affecting drinking water as well as on farming strategies. Salinity is linked to worsening health [76]: salinity intrusion in drinking water are associated with a 17% higher chance of being hypertensive than those who consume freshwater (women had 31% higher probability than men). Salinity in aquifers (shallow and deep) are predicted to increase [77]. Interviews with key experts during the preparation of this document suggest that at the deltas in Bangladesh, farmers are switching crops to crab rearing and shrimp farming due to this increasing salinity, but this reduces food security, particularly when farmers are poorly integrated with markets for these products.

Summary

Irrigation is the largest consumer of available water in these basins. The incentives created by traditional command and control irrigated systems and subsidies for diesel pumps have led to highly inefficient agricultural production systems with significant negative externalities for other water users as well as the ecological health and integrity of the basin. If irrigation is to meet growing food demands significant reforms are required to re-orientate agricultural production so that it is both more efficient, consumes less water and is more resilient to climate shocks. These reforms could include analysis of impacts of subsidies, grants for improvements, new technologies (with attention to household disaggregation to address inclusion and vulnerable groups) to manage water along key rivers like the Ganges and Indus.

Whilst the reforms required may be politically challenging domestically, the likelihood of real crises between water users (urban, industrial, energy and agriculture) in sub-basins could create political moments for reform. There may be a risk however, of escalation of the blame game particularly within sub-basins that lie across national borders.

Multilevel linkages: section summary

	Transboundary	National	Poverty/ gender
Food security and agriculture	Subsidies for water extraction within countries reduce flows downstream. Not enough information to understand complexity of combination of inefficient use + temporal rainfall patters + climate change. The combination of dams, reduced flows, and pollution from agriculture and cities is turning key transboundary rivers between India and Bangladesh into a “dirty sludge”.	Agricultural decisions that affect water driven food security agenda. Large scale of irrigation investments. in response to droughts. Increasing need to promote efficiency (technologies, grants, subsidies, etc) within national jurisdiction that may have impacts on transboundary flows.	Some analysis suggest that flood/draughts drive vulnerability and inequality in the region and there has been increase in subsidies for water pumping etc. But impacts within households are more complex to assess. Women usually don’t have land on their name and this may affect their access to subsidies for irrigation. Caste-based discrimination e.g. untouchability against *Dalit* households contributes to socio-political exclusion affecting access to collecting actions for irrigation resources.

Transboundary waters and the rise of cities

Pathways to inclusive and sustainable economic development

Unplanned and rapid urbanisation puts pressure on basic needs such as energy, water, food, waste and mass transportation. India's cities are expected to house an additional 315 million people by 2040, and it is estimated that the country needs a cumulative US$2.8 trillion in investments in energy supply [78]. Many countries in South Asia are undergoing similar demographic transitions that are not being adequately planned for, in terms of infrastructure and water resources, which puts pressure on the availability and quality of water across basins. As demand for water approaches the limits of supply, decisions will have to be made around what water is available for irrigation and how much is required for industrial and drinking water within cities. The age of simply increasing supply to meet demand will be replaced by the need to manage and allocate limited resources, which requires different instititions, knowledge and skillsets. It also carries political risks if all demands cannot be properly satisfied at reasonable cost.

Pollution and poor sewage management in rural and urban areas reduces the quality of supply. Untreated industrial and domestic wastewater spreads the risks of infection back to consumers in rural and urban areas. In practice, the environmental risks linked to untreated wastewater are most likely to be disproportionality experienced by low income and marginalised groups [79]. Users, or Government, are necessarily going to have to pay more if water pollution is to be reduced Meeting domestic, industrial and agricultural water needs requires effective understanding of formal and informal water sources, regulation of abstraction, detailed data on flows, groundwater and rainfall across basins, and effective cooperation between institutions across scales and boundaries throughout basins. It requires a significant step change in policy and institutional capacity.

Evidence

The WWF Basin Assessment Scenario Intervention Tool (BASIT) demonstration project (http://www.wwfpak.org/wwf-projects/BASIT.php) started in 2018 in the Indus River basin – specifically the River Ravi sub-basin to encourage corporation to understand the current and projected health of an entire watershed. The Ravi is one of the five eastern tributaries of the Indus River in Pakistan, which is a major source of water for irrigation in the region. Studies have shown that approximately 50% of all river pollution in Pakistan originates from Ravi. The Ravi River is under intense pressure from industrial and municipal wastewaters from major cities including Lahore, Sheikhupura, and Faisalabad. There is insufficient data on the broader implications of water pollution on riverine ecosystems.

Six million people in Lahore receive water from 484 tube wells at various depths and locations, with little continuous monitoring – see detailed case study below. Water demand has increased from 180 litres per capita per day in 1967 to 274 litres in 2013. The total groundwater extraction from these 484 tubewells is about 2.2 million cubic metres per day (MCM/day). 78 per cent of households in the utility serving area are connected to the piped water supplied by WASA (Water and Sanitation Authority) whereas in non-WASA areas 50 per cent of households have access. The 50% receive water from hand pumps, public water stand posts or directly through groundwater pumping by using small suction pumps. Lahore depends on groundwater for its industrial and domestic water needs, but the water table depth in the central part of the city is below 40 m, with a projected decline to 100m by 2040, which will mean that accessing water may not be technically or financially feasible. This combined with energy crises and deteriorating groundwater quality will pose serious challenges to the water utility. With the current extraction rate, increasing demographic growth and land development rates; it is more likely in future that this declining trend will end up in exhausted aquifer [80]

Cities are particularly important for water security: about 48% of the population in Asia and the Pacific now lives in urban areas, and this figure is expected to rise to 64% by 2050 [81]. These millions of people directly require water for their needs, and indirectly as input for their food and energy demands. Urban areas affect hydrology in a basin: the increase of impervious cover –like pavements and buildings – dramatically alter the hydrological regime by reducing infiltration and increasing flash floods. In the Qinhuai River basin [82] in southern China, a 3 fold increase in urbanization and a 27% reduction in rice paddy fields resulted in a 58% increase in streamflow and 23% reduction of evapotranspiration between 1986 and 2013. Waste from poor urban sanitation is a big problem for water ecosystems: many rivers in Asia and the Pacific hold up to three times the world average for human waste derived bacteria [71]. As mentioned in the section under agriculture and pollution, rivers shared by India and Bangladesh are experience unsustainable levels of pollution. For example, the river Mahananda, where most of the 400 tonnes of daily waste from the city are dumped in the river. The concentration of waste in the water is higher as flows decrease from being diverted for irrigation e.g. along the Teesta river between India and Bangladesh [30, 72]. Air pollution, a rising problem in Asia, also contributes to water pollution as different pollutants (PM10 and PM2.5, sulfur and nitrogen oxides, tropospheric ozone and volatile organic compounds) fall to the ground as dry particles or are carried by rain, snow or fog.

Lack of water access and quality in urban areas tend to disproportionally affect poorer households [79]. There is however limited information on how multiple scales interlink in relation to multiple forms of equity, especially along informal city settlements. In Dhaka for example [83] insecure land tenure, power relations and poverty affect water inequalities that emerge as the gap between demand and capacity of the public water utility DWASA grows and puts women and children at risk:.

> *“Hanchett et al [84]use the example of a five-member household in Ahura slum to illustrate this, with a woman working as a maid, husband as a beggar, and 3 children. After paying Tk 4003 per month in rent, Tk 60 per month for water point membership, and Tk2 daily for water, sometimes the family cannot afford to feed their children. The compromise between food and water means on some days they don’t have the spare money for the daily water charge, and instead the woman must go to the swamp to bathe, putting herself at risk from polluted water and water-borne diseases”*

Women’s participation in legislation, policies and strategies of organisations is limited, and as a result they have little say in policies that will directly affect them. Action is required to introduce requirements of minimum women participation in public leadership positions to ensure community water entities include women [38] and include clear and measurable indicators to monitor gender participation [85].

Cities and agriculture case study: The Ravi River and drinking water supply in Lahore – potential crisis hotspot?

This case study highlights the challenges of balancing growing urban population requirements and pollution impacts for water with agricultural demands for water -especially irrigation.

The total population of the district of Lahore was 6.3 million in 1998 and it increased to over 11 million in 2017 (census). The population density is about 7,000 persons per square kilometre.

Access to surface water from the Ravi River is restricted due to the Indus Water Treaty that allocates the water in this tributary to India. Upstream use has caused flows to decline significantly since construction and filling of the Thein Dam in 1999. The average flow in the Ravi river from 1922-1961 was 1,300 MCM/day which was reduced to 800 MCM/ day between 1985 and 1995 and further declined to its lowest level of 175 MCM/day from 2000 to 2009. WASA has therefore depended on groundwater supplies from the large aquifer that lies under the plains around the city which is also used by farmers for irrigation.

The Water and Sanitation Authority (WASA) supplies drinking water to the city through around 500 tube wells. These tube wells are located in different areas and their depth varies from 150 to 200 m. Over time, water demand has increased from 180 litres per capita per day in 1967 to 274 litres in 2013 (a very high figure, considering that average per capital consumption in UK is 150 lpcd). Water is distributed from source to households through a network of 7,700 km long water supply lines and 600,000 connections. 78 per cent of households in the WASA serving area are connected to the piped water whereas in non-WASA areas service coverage falls to 50 per cent of households. The remaining 50 per cent of households get water through groundwater pumping, from hand pumps, public water stands or small suction pumps.

More than 10,000 tube wells have been installed for agricultural purposes. The total surface water diverted to serve for irrigation is 6.02 MCM/day. However, the surface water available for agricultural use is only 3.0 MCM/ day as the rest is lost en-route due to seepage from the main and distributary canals, percolation losses from watercourses and farmer fields. This leakage is one recharge source for the aquifer.

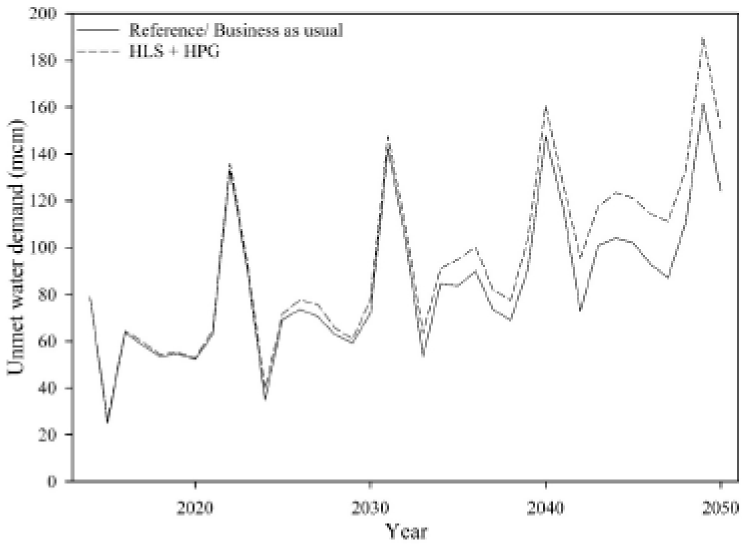
Groundwater is significantly less polluted than surface water. In 1960, the groundwater table depth was 4.6 m. The extensive use of groundwater and the gap between extraction and recharge, which is estimated at around 0.67MCM/day, has led to the lowering of the water table by about half a metre per year during the last 30 years. In 1987, the depth of the water table ranged from 8 to 20 m, and declined to 51 m in 2011 [86]. As the aquifer declines, pumping costs increase and threaten the financial stability of WASA and consumers' ability to pay.

There are about 2,700 industrial units registered in Lahore, of which 75 per cent (2025) are categorized as large scale factories. These large industries are the main users of groundwater. The textile industry makes up 20 per cent of the total industry and is the largest user of water (69 per cent of the total industrial water consumption). Water is also pumped by industries other than textile. These include the chemicals sector (10 per cent), paper industry (5 per cent), food industry (5 per cent) and other industries (11 per cent). Others include electronic, marble, leather and steel. Levels of water consumption by industries is not well monitored. According to WASA, there are over 4,000 private tube wells in Lahore with a total capacity of 480,000 m3 /day, which supplies water to industries and other private businesses.

Surface water is increasingly polluted from untreated sewage discharged directly into rivers and drains, combined with multiple untreated industrial effluents. As the aquifer declines there is increased risk of exposure to arsenic in some areas. In 2010, 85% of samples exceeded the WHO guideline of 10µg/L for arsenic [87]. In 2013, a survey of 140 proposed tubewells in July 2013 found that 96% of samples were above 10µg/L. It is anticipated that by 2030, WASA will need to increase the water supply to 3,200 MCM/year from a current level of 1,985 MCM/year which will require installation of 358 more tube wells. However, with a declining resource base, more wells are unlikely to provide a sustainable solution.

Modelling suggests that water needs will continue to grow in future (**Error! Reference source n ot found.**) and that seasonal fluctuations in demand (due to agriculture) are significantly larger than any decadal uncertainty due to climate variation.

Figure 21. Future projections of the unmet water demands in the Upper Indus Basin under the reference, high population grown and high population growth + higher living standards scenarios for the periods 2014-2050 [88]



Lahore's water supply is clearly unsustainable in the face of an increasing population, unmet needs and a declining and increasingly polluted water resource base (urban and industrial waste and arsenic). In addition, JICA studies point to deteriorating infrastructure and significant maintenance and upgrade needs for the tube well network as well as a cost recovery ratio of only 55% of real operating costs in WASA. This will deteriorate further as pumping costs escalate.

With the prospects of obtaining more water from the Ravi River circumscribed in the short and medium terms by existing treaties, extensive existing appropriation upstream within India, and the political situation between India and Pakistan, better management policies for limited water are required within Pakistan. Pollution control and demand side management (for both agriculture and drinking water) may need to be complemented by a political debate on whether the 3MCM/day used by agriculture is more or less important than providing adequate drinking water to a rapidly growing city and to protect the jobs provided by industry. If not, then what is the future of land use and agriculture on the plains around Lahore and what measures will be required to shift farming practice and/or compensate farmers for loss of this irrigation water?

Summary

Improvements in the management of water resources and wastewater and delivery of water services are largely local but will have to be incremental. The extent and potential of formal and informal sources of water and wastewater need to be recognised and engaged to progressively improve the management and allocation of water resources and treatment of wastewater.

Groundwater use in cities is largely unregulated, and there are significant concerns about depletion and contamination. Even though groundwater is a key water source for households in

Lahore, it does not feature in government plans as a source that could help meet the water needs of cities during dry years, nor is it effectively monitored.

Accurate, consistent and timely data on water resources and services within cities and across basins (transboundary) is vital. Investing in long term, structured data collection and monitoring is essential to develop the database required for effective decision making. Planned improvements would also benefit from more collaboration, data and knowledge sharing between formal and informal actors and institutions involved in water and sanitation provision in cities and basins.

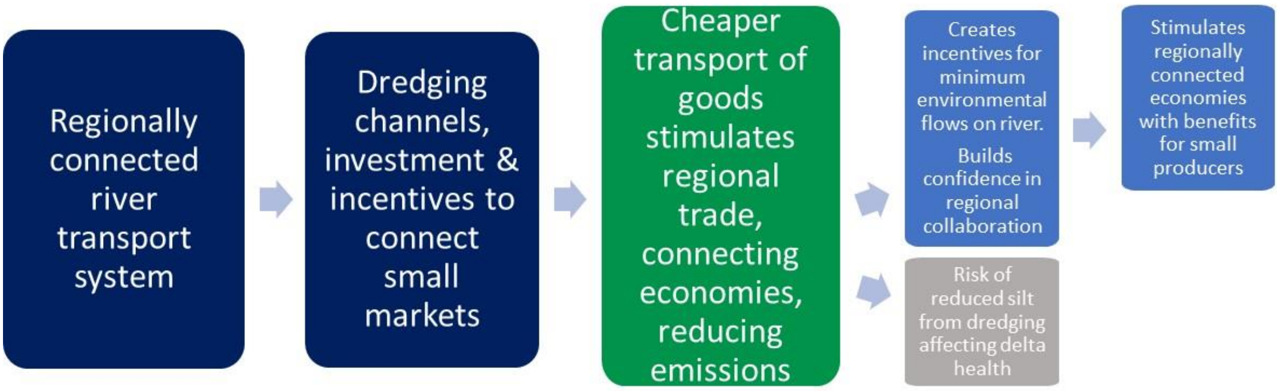
Urban water is largely a domestic challenge of access, allocation between users and management. However, during dry season, over extraction of low river flows and pollution of limited water has potential to create concerns with downstream neighbours. If competition for water increases, particularly with upstream user, water managers must adopt a flexible and adaptive approach based on better transboundary knowledge of the available resources and their fluctuations with rainfall and climate change

Multilevel linkages: section summary

	Transboundary	National	Poverty/ gender
Cities	Water for cities are mainly a local or national issue but increasing pollution and perceived reduction of downstream flows of transboundary rivers is problematic.	Largely local water quantity and quality problems in urban areas affecting major rivers. Reduced quality of surface sources increases groundwater extraction and puts aquifers to risks.	Urban poor, especially in informal settlements affected disproportionally. Poor women and children vulnerable to increasingly contaminated urban open water sources.

Inland waterways and cross-border trade

Pathway to inclusive and sustainable economic development



Cheaper transport for trade supports regional markets. Due to requiring sufficient water flow during dry season, this also protects flows to the delta with benefits for reducing salinization and improving coastal ecosystem functioning.

Accumulation of sediments in these rivers with exceptionally high sediment loads reduces potential for waterway trade in South Asia, endangering several new cooperation agreements, or increasing costs due to the requirement for dredging.

The design and regulation of waterway transport systems can be more or less inclusive depending on regulation and the choice of transport infrastructure.

Evidence

Waterway trade has been historically important in the region. As early as the 1840s tea was being transported by steamboat from Assam to Kolkata by the East India Company. Subsequent political unrest disrupted river transport for many years. For example resolving protocol navigation issues between India and Bangladesh, where joint dredging projects in Sirajganj-Daikhawa (146 km) on river Yamuna and in the Ashuganj-Zakiganj stretch (309 km) on river Kushiyara in Bangladesh have been long delayed [89]. There has also been notable lack of resources to invest in inland waterways with more focus on railway. As a result of the diversion of investments away from rivers many communities traditionally associated with riverwork ended up poor and marginalised, away from flows of economic trade.

Nevertheless, waterways are becoming increasingly important for the economic development of the region. MDBs are financing waterway investments (e.g. IDA loan of US$360 million for Bangladesh for infrastructure and riverbank management [90]). Estimates for India suggest that it is 10 times less expensive to move cargo by river than by road and generates substantially less CO_2 emissions [91]. Initial estimates from intra-regional trade suggest increases from US$5 billion to US$20 billion per year if barriers to trade are removed[90]. This includes the provision of waterway infrastructure (e.g. with governments supporting infrastructure such as navigation, channel operation and maintenance, external connectivity infrastructure, and private players undertaking terminal development, cargo and passenger handling, and building low-draft vessels and related repair facilities –[89]) to complement political agreements between neighbouring countries.

Navigable waterways are proposed as means to give access to markets to isolated villages, if regulation encourages local transport links. The recently agreed movement of vehicles across the Bangladesh-Bhutan-India-Nepal (BBIN) sub-region can bring multiple benefits to countries in the region. For example, land-locked countries like Bhutan and Nepal can reach sea trade routes through Bangladesh. A lot of the cargo at the moment is fly ash, grains, over-dimensional cargo for capital projects, boulders and construction materials.

The rivers of South Asia do however have very high sediment loads with large movements of river channels during the monsoon with flood events. Although Bangladesh has a large waterway network, "it faces serious problems with sedimentation and seasonal low flows…which can only be resolved by larger management of Brahmaputra and Ganges river basins" [92]. Navigable channels have traditionally been maintained by dredging – but this is costly as the channels quickly refill. Dredging has also been shown to reduce fish numbers and diversity (e.g. USA, Nigeria [93], [94]) and is being contested in India as potentially in detriment to the socio-ecological complexities of rivers, community rights, danger from spillages during transport of hazardous goods, and the potential negative impacts to fishing communities [95].

There are ways of clearing channels without removing the sediment from the river system, contracting dredging to only clear a certain height, pushing silt away rather than scooping it out and incentivising the use of flatter bottomed barges - so reducing both the costs of dredging and the loss of sediment needed at the active deltas. Likewise, managing the basin landscapes (including upstream watersheds) to live with riverine flooding rather than using embankments to stop flooding that also change sediment movement. And instead constructing structural measures to keep drainage and navigable channels open, would allow a more natural system of sediment deposits across the basin that are also beneficial for downstream communities that use natural flow of sediments for livelihoods [96, 97].

Sea-level rise and navigation case study: managing sediment flows in the Ganges Brahmaputra

- *This case study presents evidence on sediment deposition and what are the big gaps in understanding winners (e.g. sediments which provide a buffer against sea level rises) and losers (e.g. reducing water storage and waterways for navigation). Despite uncertainty, sediment management is potentially a useful and sustainable tool to combat rising sea levels in the long term*

The Ganges River carries one of the highest sediment loads of any river in the world. It delivers around 1,000 million tonnes of sediment per year to a point around 200km upstream from the ocean. Within the Ganges basin it is hard to properly model sediment flows as field data has not been gathered systematically over long enough time periods or is not made available (e.g. river flows). Total sediment flow models do not currently present the final deposition sites of sediments, either within the river system, or in the delta and marine environment. They can however predict fairly accurately the total quantities of sediments transported by different flow regimes. The publications available do not mention, or model, sediment sizes and their distribution.

The main contributors to high sediment yield are the catchment agricultural lands covering 57.2% of total area (contributing 57.1%) and barren, uncultivated and non-forested lands that cover 20% of total area and contribute 30% of the sediment yield [98]. The deposition of sediments within the river affect navigation, reduce water storage in reservoirs and affect water conveyancing in canals. Where they are deposited in the delta they also serve to compensate for land subsidence and erosion and may provide a buffer to sea level rise. The importance of sediment accumulation in protecting deltas from cyclones has been increasingly recognised since the impacts of hurricane Katrine (2005) on the Mississippi delta in Louisiana.

With the intensification of monsoons, sediment loads in the Ganges River are predicted to increase by 16–18% in the middle part of the 21st century and by 34–37% by the end of the 21st century compared to the baseline (1981–2000) period, although with large uncertainties (due to uncertainties in the climate projections and anthropogenic impacts in the catchments). Sediment load is expected to decline in the Upper Ganges reaches, but increase in the downstream reaches due to river morphology and bank erosive processes [98]. The Brahmaputra's fluvial sediment load is predicted to be more sensitive to future climate change [99].

With sea level rise expected to be of the order of 7mm/year, increased sediment flows to the GBM delta could be 48 to 53 mm per year greater than they are now by the end of the century and these two figures are of a similar order of magnitude. Current assessments estimate that the delta is sinking by 5.6 mm/ with a standard deviation of 7.3 mm/yr [21]. While these generalisations make the somewhat unrealistic assumption that no sediment will flow to the sea and all is deposited evenly across the delta area (despite flood protection measures and polders), they nevertheless indicate that sediment flows are significant and growing, and are potentially one of an arsenal of approaches to combatting the complex impacts of sea level rise in the delta area.

The World Bank Ganges strategic assessment concluded that "*The Ganges is one of the three most sediment-laden rivers in the world. Most of the sediment comes from erosion in the high Himalaya. Both the high volume and the source of this sediment make it extremely difficult to manage. The volume of sediment is so large that capturing it behind large dams would be extremely costly; the reservoirs behind these large, expensive structures would fill quickly and, thereafter, produce very few benefits. The high altitude and terrain of the sediment source regions, as well as the nature of the sediment and the ongoing tectonic processes, make it impossible to undertake the scale of watershed management interventions necessary to have any measurable impact on basin sediment loads. Sediment, like floods, is a challenge that must be managed in the Ganges; it cannot be fully controlled."*

Summary

The revamping of navigable rivers brings back several issues to the transboundary management agenda [100]:

- Trading gains using rivers introduces a joint motive to address transboundary water management and builds confidence for wider collaboration
- Navigation requires minimum flows, which can be beneficial towards maintaining ecosystem flow requirements. Higher river flows will benefit coastal communities, reducing the severity of salinization from rising sea levels;
- Apart from being affected by monsoon variations, river navigation presents challenges regarding depth and are often affected by shallow depths on bars especially in river bends and deltas. Lack of funding for waterway maintenance and inappropriate dredging practices fail to address the process of sedimentation.
- Ganges River carries one of the highest sediment loads of any river in the world. Some are natural and linked to the terrain but the problem is increased by unsustainable practices especially in agricultural and barren lands. Excess deposition of sediments within the river

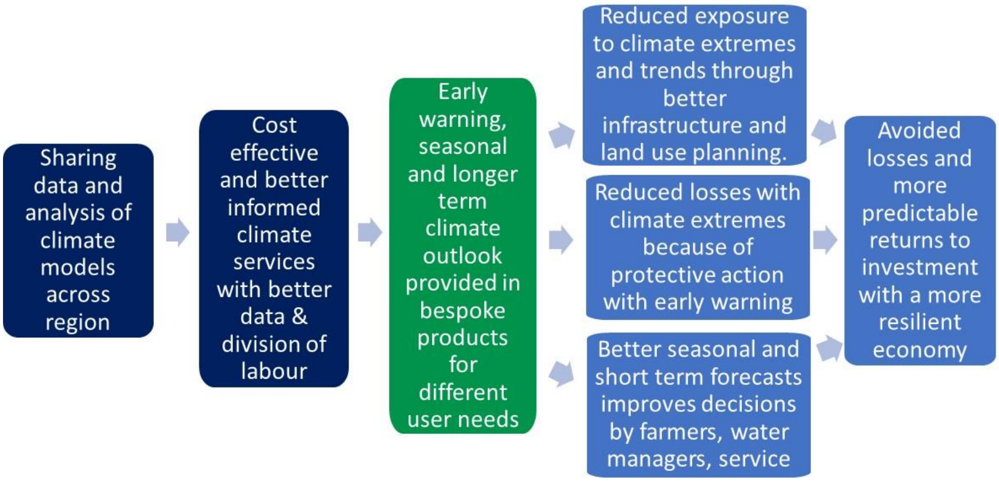
affect navigation, reduce water storage in reservoirs and affect water conveyancing in canals. There is a need for innovation and coordination in investments to secure river flows -such as shallow dredging to clear not remove sediment, riverine landscape management and the use of shallow barges – to reduce the negative impacts for fishing communities located along the rivers as well as coastal communities reliant on sediment flows to the deltas -e.g. as protection against cyclones.

Multilevel linkages: section summary

	Transboundary	National	Poverty/ gender
Inland waterways and cross-border trade	Drive to expand trade and explore potentially lower-transport (and emissions) trade routes across countries. Trade and navigation protocols mostly inexistent just now and work informally.	Investments can be shared but much of the work will remain within national boundaries. Sediments and low flows is a wider watershed issue.	Traditional focus on motorways infrastructure led to poor riverside communities. Dredging can seriously reduce livelihoods.

Transboundary data sharing and early-warning systems for disaster management

Pathway to inclusive and sustainable economic development



Transboundary data sharing improves the quality of climate information and early-warning systems, which in turn have large multiplier effects on the economy:

- Quality climate information services can reduce exposure to weather events and extremes through better infrastructure design and land use planning.
- Early warning systems reduce cost of disasters through informing citizens and climate sensitive sectors to take protective action.
- Better seasonal and short-term weather forecasts can help improve farmers agricultural decisions and water resource managers decisions

Evidence

Shared science in transboundary ecosystems can be very useful to broker relations, placing a focus on gathering data and developing a consensual knowledge base about a shared resource that crosses politically sensitive borders ("environmental diplomacy") [101].

Cross-border early-warning systems help to mitigate natural disasters that affect multiple countries across the region, such as floods and droughts. Shared information can be used to design and monitor institutional structures and infrastructure for disaster reduction and increase resilience of farmers. Faster responses and better planning combined with village to village support is helping in reducing the number of deaths from flooding. Examples of the regional collaborations (with different levels of effectiveness of their warnings and timings) supporting this include:

- South Asian Association for Regional Cooperation (SAARC) Disaster Management Centre.
- SERVIR-HKH – ICIMOD-NASA regional collaboration in satellite information to inform weather and climate information services integrated with geospatial data for planning support tools.
- HICAP – ICIMOD-CICERO-GRID Arendal regional collaboration for sharing data and improving modelling to understand climate impacts in transboundary ecosystems, informing investment.

According to the World Bank [22], good progress has been made to link up communications between countries in the main basins - Nepal and India have autonomous and joint monitoring stations and communicate flood levels to downstream affected areas in Bihar and Utter Pradesh. Similarly, India finances 32 monitoring stations in Bhutan for early warning purposes on the Brahmaputra. The status of flood levels in India (Ganges (two sites), Teesta (one site), Brahmaputra (four sites), and Barak rivers (one site) is also transmitted to Bangladesh. The National Centre for Atmospheric Research (NCAR) flood forecasting system now provides 1- to 16-days-in-advance water-level forecasts for 87 river locations across the Ganges-Brahmaputra-Meghna (GBM) river basins (http://indiawbg.rap.ucar.edu/index.php/).

Model accuracy is affected by overall data quality and availability that is challenging to gather in the Himalaya – given the limited number of automated weather stations and the mountainous terrain creating a high diversity of locally specific weather conditions

Early warning of slow onset flood events can provide 1-8 days warning depending on the location (*Box 2.*) although models do not always concur in their forecasts. These are more accurate for larger basins with longer onset times (see Figure 12 for example) and these should therefore give a more reliable return (in terms of damage avoided) from any future investments than smaller basins with shorter onset times. Warning of flash floods could improve with greater use of satellite monitoring combined with a more extensive network of automatic ground and river observation.

The social impacts of better warning systems can be important. Poorest communities tend to live in places and conditions that expose them to natural hazards, and have less ability to recover. A high proportion of victims are women and girls, who have less access information, financial services, land and property rights, health and education that reduce their resilience to disasters [102].

Early warning systems can help to prepare for disasters but the real impact on people will be highly linked to the country's capacities to respond to these warnings, and what governments consider "disasters" in terms of their response, e.g. cyclones, earthquakes or tsunamis can have the same impact on losing assets for poor people as strong storms or floods that damage crops but for which there is no government support. *"Poverty, like wealth, is often transmitted from generation to generation and is sustained by disasters that deplete or destroy assets and resources of the poor"* [102].

Box 2. **The economic benefit of flood forecasting in Bangladesh [103]**

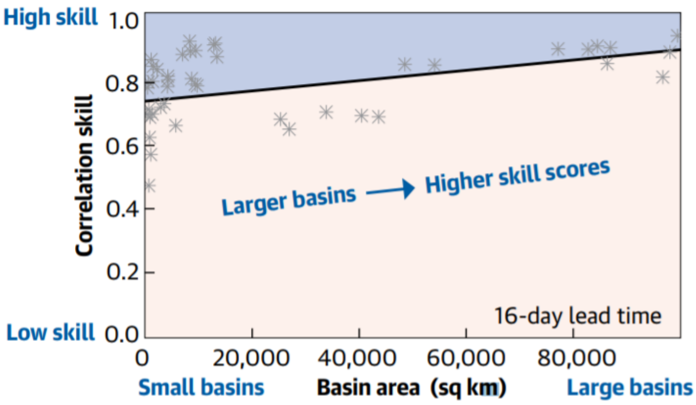
Floods in Bangladesh occur annually, although the exact timing and extent of flooding is variable from year to year. Early warning allows farmers to harvest crops (including fish and shrimps) early, and to move assets and livestock. The benefits of an early warning system for the floods of 2007, that were moderate with a return period of 5 years, were estimated.

An early warning system would have reduced damages by US$ 207.9 million. To estimate the cost savings for floods of other magnitudes and return periods, the 2007 flood damage reduction was scaled up and estimated at about US$ 1700 million over a 10-year period. This is more than 500 times the 10-year early warning system cost of US$ 3.1 million.

Early warning systems are particularly cost effective for sites where events are regular, and damage is high. Additional factors include the accuracy of forecasts and the effective lead time.

Figure 22. Effect of basin size on forecast skill at 16-day lead time

FIGURE 3.5. Effect of Basin Size on Forecast Skill at 16-Day Lead Time



Source: T. Hopson, NCAR.

Note: This graph shows one measure of forecast skill. The higher the skill score, the better the forecast. Each "star" symbol represents one subbasin (catchment). All of the forecasts show some utility, regardless of basin size (that is, they almost all score better than 0). Forecasts for larger basins display generally better skill than forecasts for smaller basins. Compared with the group as a whole, forecasts for basins in the blue area perform very well; those in the pink area are "underperforming."

Summary

"*Given the transboundary nature of many river basins, and the need for their collaborative management, improved and effective water quality management strategies in Asia require the collection, analysis, and sharing of accurate data. Currently this task is, with some exceptions, generally poorly implemented. In most countries sporadic or patchy data collection prevails, and it is often accompanied by inadequate analysis*" [71]

The recent progress in sharing data and with the regional intergovernmental body, ICIMOD, developing more collaborative programmes on climate information services is significant after years of highly politicised positions on sharing climate data given the implications for river flows and water sharing. There is also signs of progress in strengthening national systems – building the confident institutions needed for regional collaboration.

Regional collaboration in weather and climate observation and modelling would significantly improve the quality of advisories as well as reduce the costs of introducing new technologies.

Both the Indus and the Ganges-Brahmaputra basins suffer from frequent floods and droughts with significant impacts on economies and livelihoods. While the infrastructure and event response is specific to each location, the availability of accurate forecast information is found to be critical for saving lives and planning responses for basin scale events that have relatively slow onset times.

More accurate forecasts, that inspire confidence in those called upon to respond to them, are essential, including more extensive monitoring in the mountain areas (remote sensing and ground stations) and the development of advisories specifically designed to predict outcomes of rainfall patterns on different actors. As the basins become more developed, improved models would also support understanding downstream impacts of individual infrastructure proposals and their cumulative impacts. As countries collaboration is still slow, research networks could be developed that can develop this capacity using “big data” approaches, in the public domain, that do not necessarily depend on government information considered confidential. ICIMOD has already made significant steps in this direction.

Infrastructure approaches, seeking to store more water at the head of the catchment and thereby attenuate downstream flood peaks, are generally recognised to be ineffective in flood control on these rivers as they are expensive and not at the scale required. Equally, land-use interventions to slow run off, or promote groundwater recharge are hampered by steep, barren, friable slopes in remote and inaccessible mountains. The same can be said for general sediment management at the scale of the basin, and for the same reasons There is little opportunity for a transboundary management response to flood control beyond better forecasting and early warning. Downstream countries will have to manage locally the quantity of water and sediments they receive, rather than working together to intervene upstream in an effort to modify flows at the top of the catchments. However local land use practices could improve water storage and sediment management for the basin as a whole – restoring wetlands, watershed management and Room for the River approaches are likely to be effective given both basins’ experience of localised flash flooding.

This review has found regular mention of the ‘severe impact of drought’ on farmers in both the Ganges and the Indus – with some analysis suggesting that the economic impact of drought is far greater than that of floods [59]– driving vulnerability and inequality in the region [60]. The region has reported significant droughts every three years over the last 50 years – with many affecting regions with significant scale [59]. For example, from early 2000 a period of severe drought affected the Indus basin, with millions affected in western India and south and central Pakistan. Droughts affected over 1 billion people and killed 4.25 million people in India from 1900 to 2015, resulting in decline in agricultural production, purchasing power and food security while increasing rural unemployment [60]. Due to the slow onset of drought, the complexity of impacts given the high level of irrigated agriculture and often localised rainfall patterns during the South Asia monsoon, it is less visible, more complex in impacts and harder to quantify economically than floods. The regularity of drought has driven the political support for extensive investment in irrigation and diesel subsidies for pumping groundwater – leading to falling aquifers, with many in the Indus basin reaching critical levels. Further disaggregation of the effect of drought that are attributable to irrigation from river flows, as distinct from local rainfall, is needed to fully assess the usefulness of basin wide systems in managing drought impacts in the downstream floodplains.

Multilevel linkages: section summary

	Transboundary	National	Poverty/ gender
Early warning systems	Early warning systems work better across large scales (rather than for smaller basins with shorter onset times. There is limited number of automated weather stations with a very variable mountainous terrain across the Himalayas and plains. Access to satellite information can help overcome need for coordination.	EWS can work at national level for a large country like India. Better weather information (not only for emergencies) can help design more informed agricultural decisions.	Poor and vulnerable communities often located in areas more at risk. Women and girls represent high proportion of victims. They would benefit from early warnings if information is passed on, if there are actions accompanying warnings, and what governments consider “disasters”.

Transboundary nature-based water investments

Pathway to inclusive and sustainable economic development

Transboundary natural capital investments can reduce the cost of water management and increase the inclusivity of economic development.

- Strategic investments in shared basin's ecology for locally managed nature-based solutions to supplement infrastructure reduces the cost of water resource management, increasing reliance and protection from drought and flood. See examples of interventions in Table 5.
- Investment in locally managed natural capital also increase the potential for inclusive and sustainable local economies that enable the poor to be integrated into national and regional supply chains.

These investments should also consider wider issues such as regulation, price signals and engagement with multiple actors across basin. The Mekong River Commission is an example of this transboundary engagement that can inform similar approaches in the Indus, Brahmaputra and Ganges basins.

Table 5. Intervention examples for different purposes also inducing water buffering capacity [104]

	Management focus	Primary goal	Example measures
Water storage as complimentary spinoff	Managing the water source	• Improve water availability	• Protection and flood management • Conjunctive use, demand management
	Managing agricultural farming practices	• Increase production/ reduce erosion / reduce time or machine need	• Controlled / bio drainage • Contour farming, minimum tillage • Composting, nutrient management
	Managing agroforestry	• Increase production/ reduce erosion	• Farm forestry, controlled tree felling
	Managing rangelands	• Increase production/ reduce erosion	• Controlled intensive grazing
	Natural resource management		• Control mining (sand and gravel)
	Physical infrastructure management	• Transport • Create new land / reduce erosion • Improve water conveyance	• Road water harvesting / retention • Warping dams to create land • Improved karezes

Evidence

There is strong evidence that well-managed natural and man-made ecosystems provide many benefits in terms of water regulation, quantity and quality[4]. Land use changes affect hydrological processes such as evapotranspiration, interception and infiltration, which alters surface water flows and underground recharge. Cloud forests (present in the Himalayas and in high degree in Bhutan) for example contribute to increase water flows by intercepting moisture from clouds providing regular flows for hydroelectricity. River basins, lakes and wetlands store water and help to buffer against floods during storms. Ecosystems also influence water quality. Wetlands, for example, contribute to pollution control and detoxification of agricultural runoff and sewage

[4] See various references, including *Bonell, M. and L. A. Bruijnzeel, editors. 2005.* Forest, Water and People in the Humid Tropics. Cambridge University Press; *D'Odorico et al. 2010*. Ecohydrology of Terrestrial Ecosystems. BioScience **60**:898-907; *Perret, Babel, and Yamsiri. 2010.* Resource efficiency and ecosystem services in rice production in Thailand's central plain: baseline research. Asian Institute of Technology (AIT) and CIRAD (UMR G-Eau) and *Zhang L, Nan Z, Xu Y, Li S (2016)* Hydrological Impacts of Land Use Change and Climate Variability in the Headwater Region of the Heihe River Basin, Northwest China. PLoS ONE 11(6): e0158394. doi:10.1371/journal.pone.0158394.

effluent (principally phosphorous and nitrogen). By preventing flow of these nutrients downstream, wetlands help reduce the risk of eutrophication (excess of nutrients) in rivers. Despite their importance, Asia has lost about 60% of its natural wetlands since 1970 [105], and its natural forests at a rate of 0.25 million hectares per year between 1990 and 2015.

There is increasing evidence on the importance of landscape management and their upstream-downstream implications to water-related infrastructure, rather than relying only on brick-and-mortar approaches. These natural-based solutions maximise nature's abilities and functions and are being increasingly mainstreamed into policy for water, risk mitigation, agriculture and irrigation, especially in terms of soil erosion, sediments and non-point source pollution (see Section in page 35), and to cities (see page 39), urban settlements, climate change [106].

The most notable example of transboundary nature investment in the Asia region is the Mekong WET programme (Cambodia, Lao PDR, Thailand and Viet Nam) which can inform investments in South East Asia. Mekong WET promotes several ecological actions to safeguard and restore agro-ecosystems, for example sustain and restore flow dynamics to floodplains; integrate mangroves and aquaculture ponds; avoid/regulate wetland drainage and pollution from soya and palm oil; safeguard and restore high mountain lakes, peatlands and floodplains to reduce droughts downstream; incorporate wetlands in urban planning, minimize encroachment on wetlands, rehabilitate wetlands in cities and their surrounding landscapes; re-wet petlands and cultivate only on small scale with crops adapted to wet soil conditions (paludiculture).

This section discusses some of the main nature-based investments in the Indus, Brahmaputra and Ganges basins. Most of them are basin-level rather than transboundary but the lessons are important to scale-up action.

Nature-based and agriculture: Investments in sustainable water ecosystems look at activities that affect water quality, quantity and regulation from ecosystems, for at demand and supply points. Investments include higher-value crops, improving surface-water irrigation productivity (e.g. Prek Thnot watershed in Cambodia).

Supporting existing and planned (grey) infrastructure: These investments in ecosystem management can be designed and implemented in combination with existing and planned infrastructure (e.g. pipes, canals, dams). Wetlands for example are used in some places in USA to reduce risks of flooding or drinking water contamination, as a buffer against human and technological errors for example caused by poor repair or lack of proper maintenance of the water infrastructure or failure of plant operators to respond to warning signs [107].

Nature-based solutions and disaster mitigation (see also early warning systems): Some ecosystems, like wetlands, can be managed to moderately help reduce the severity of some natural disasters, such as floods and storm surges. The latest evidence from research on ecosystems and migrations suggest that healthier ecosystems can help displacements to shocks (hurricanes, floods, earthquakes) become short-term and short-distance, with people returning to their homes when the ecosystems recover [108]. For example, healthy mangroves are better able to recover faster after events such as cyclones [109].

The economic values of flood control are important (e.g. estimated value of US$2.8 million/year at the That Luang wetland in Lao), and activities can help restore valuable economic ecosystems for coastal fishing communities. But the effectiveness of nature-based solutions can be limited. For example, mangroves play a limited role for areas exposed to tsunamis where engineering approaches such as sea walls and embarkments, higher ground shelters and warning centres are perceived as more effective in saving lives. Inland wetlands can be used alongside engineering structures and planning to better degree to mitigate moderate floods along urban areas – see below.

Urban cities and nature-based solution: “sponge-cities”: The concept of ‘sponge city’ was introduced and implemented in China, initially as a response to flooding. It relies on a mix of urban planning policies, designs and legal frameworks to mainstream urban water management to collect, store and treat rainwater. Actions include pumps, storage tanks, wetlands, bioretention ponds, permeable pavements. China is leading scaling up of sponge cities, but some examples also exist in South East Asia. The International Water Management Institute (IWMI) has been exploring the benefits of urban wetlands in cities like Hyderabad and Kolkata, where activities not only help manage flood but also supports thousands of fishing people. Colombo in Sri Lanka seeks to be one of the first Ramsar-accredited wetland cities [110]. Peri-urban wetlands are important as sources of food for expanding cities, providing jobs for thousands of people (e.g. in Karhera, India [111]).

Basin management to improve water delivery: For many years ICIMOD has been leading research on water security in the Hindu Kush-Himalayan region. Their studies show the potential of using different forms of natural storage systems in the cryosphere (e.g. snow, ice, glacial lakes) and the biosphere (e.g. soil moisture, groundwater aquifers, rivers and wetlands). While most of the benefits of these management will be felt at the basin level (rather than transboundary) [112], investments in hydroelectric basis will have impacts on energy security for the region ([13] -see also Energy Section on page 26), and more scientific information is needed to understand and monitor the transboundary aquifers of the Indus, Ganges and Brahmputra basins [112]. Several initiatives in the HKH region are piloting various forms of incentives for ecosystem services to promote better land management [113] and incentives to promote water buffering through recharge, retention and reuse e.g. in Saurashtra, Gujarat [104]. However, the scales remain small to make much of an impact in the larger basin.

Natural water-based ecosystems benefit millions of people especially vulnerable farmers with little access to alternatives. Investments that help improve the condition of wetlands and low-lying floodplains can have many benefits for local people. More than a billion people in the world depend on wetlands for their livelihood and are at the heart of smallholder farming, combining rice and fish production. In the Lower Mekong area, for example, the value of inland fisheries is about US$3 billion per year [114]. Low-lying habitats are particularly important in Bangladesh, with 80% of its territory Bangladesh located at the confluence of the Ganges, Brahmaputra and Meghan rivers, and have an elevation that ranges between 1-4 masl. The coastal regions cover 30% of the cultivable land in Bangladesh. About 13 million people in Bangladesh (80% are lower income) depend on fishing, much of it from wetlands, ponds and rivers [77, 115, 116]. Investments in rehabilitation of the wetland around Kolkata in India helped over 32,000 people by securing food and access to cleaner water [110]. The common property nature of many of these wetlands and marshes provide are in effect a safety net for rural people when crops fail, providing access to fishing, hunting, and non-timber forest products, especially at the rural frontier where poor communities who depend on wild resources and biodiversity, and can offer a pathway out of poverty for many [111].

Many of these water-based ecosystems are at risk – potentially affecting millions of people. Resource degradation disproportionately affect poorer people, who do not have resources to migrate to less exposed sites [108]. Any nature-based solution that does not take into account poor and vulnerable people and their lack of power risks making these groups worse off after interventions [117].

Water, nature-based solutions and gender: Rural women's household responsibilities (including boys and girls) are more water-intensive than rural men, e.g. fetching water for domestic use and/or watering household gardens [73, 74] yet women have little power over water decisions. Bottom-up approaches need to 'permeate upwards', rather than trickle down, to ensure inclusivity [39] especially given that these agreements will have to be implemented through local, national and regional organisations. Direct action needs to happen to support the participation of more women as technical specialists working in the field, e.g. capacity building to equip women to perform technical functions and as brokers of information, rather than their more 'traditional' roles linked to community health or contribution to rural communities, [40] in peace and security talks.

Upstream land management may offer limited benefits in terms of flooding downstream. It is important however to understand the hydrological dynamics involved in big rivers. According to Priya et al [22], steep, high altitude Himalayan slopes mean that land use management (often technically feasible in many less challenging catchments) is unlikely to help to manage floods and sediments. As such, India/Bangladesh are unlikely to be able to attenuate flood events, or sediment flows through investing in better upstream land use. Various hydrologist [118, 119] have highlighted this before, in relation to the disparities between public perception and scientific evidence relating to the causes of floods, their impacts, and the benefits of mitigation measures:

> *"It is believed that this disparity may have resulted not only in the wastage of development funds (possibly to the extent of tens of billions of dollars per year) on unachievable targets, but also in the unwarranted blame of upland communities whose practices have generally had only marginal impacts on downstream flooding". [118, 120]*

This said, there is strong evidence suggesting that land management affecting soil structure can have more localised impacts in terms of flood control. For example, soil sealing from roads and city infrastructure undermine soil hydrology, resulting in the loss of infiltration and converting precipitation directly into overland flow [121]. When coupled with poor drainage and sewer systems this often results in flooding. Conservation agriculture that minimizes soil disturbance (zero tillage) is often found to improve drainage and water-holing capacity [106].

Summary

Nature-based investments can be cost-effective in improving water management and retention. Nature investments, or 'green infrastructure' is often combined with success to reduce risk in grey infrastructure (e.g. watershed management and hydropower), and are increasingly promoted in cities both for water, food security and recreational values. Healthy ecosystems show higher resilience to shocks and are extremely important for millions of poor people who depend on them for their livelihoods. These interventions however are more likely to generate benefits at local level or mid-level basin than transboundary. However, they will be vital strategies to ensure inclusion and delivery of benefits at the very local level.

Multilevel linkages: section summary

	Transboundary	National	Poverty/ gender
Nature-based investments	There is a direct link from local to transboundary: any transboundary water agreement will have to be locally implemented.	NBS are often good complements to grey infrastructure (roads, bridges) and can involve local communities. Most nature-based interventions will have impacts at local level which will be diluted at transboundary level. But	Actions that support resilience and asset building of vulnerable communities will have good impacts on poverty. But needs to take into account initial distribution of assets and power otherwise interventions will exacerbate existing poverty.

Are water allocations in the Indus basin sub-optimal?

The main remit for this report has been to analyse the transboundary nature of water management linked to economic growth. This section explores this issue, briefly, with respect to water use within Pakistan. This is not a comprehensive overview of the topic but describes the interaction between land and water use which has developed over many years of investment under colonial, military and democratic governments.

Water for irrigation in Pakistan

- *Allocation is not based on water availability. Water prices are very low, leading to overuse and not allowing for cost-recovery. Water rights are intrinsically liked to property rights, with direct impacts on poverty.*

Almost 80% of Pakistan's agricultural land is irrigated and this consumes more than 90% of water withdrawal in the country. Any attempt to manage water more efficiently needs to specifically address its use in cultivation. In the large-scale irrigation schemes, less than 50% of the water extracted from the river reaches farms, due to leakage, although in many cases this aquifer recharge is re-harvested through tube wells and some also through return flows in areas where salinization is not an issue.

Government does not "allocate" any water as such. It builds water infrastructure that delivers variable water volumes to farmers along the irrigation canals. The amount of water that any farmer uses is not fixed or measured. Indeed, in many areas, surface flooding is commonly a wasteful irrigation method (compared to drip irrigation for example). In addition, farmers sink private tube wells into the aquifer.

Water prices

The only tangible policy levers that government has at present to effect anything resembling an "allocation" is to intervene in the cost of water fees (known as *abiana*) and the pricing/subsidy for different agricultural products in ways that could incentivise farmers to select less water consuming crops.

Pakistan has a long history of this kind of intervention, although in the past it has not clearly served to reduce water consumption. For example, the average water fees for rice and cotton remained almost the same for many years, although rice consumes 60% more water than cotton [122]. Choices may be made on the basis of export markets, value chains (e.g. cotton) or providing food for urban populations at reasonable prices and represent political choices through intervening in the market rather than decisions based on water availability.

The annual irrigation fee per hectare (*abiana*) is currently extremely low, forming only 3% of farmers input costs [123] and does not reflect the real cost of maintaining the water supply (see Table 6). Revenue from *abiana* declined from 2010-2014, even as O&M costs increased [124].

Table 6. Operation and maintenance cost, and abiana *collected in Pakistan (2010-2014) [124]*

Year	PKR (millions)		Deficit
	O&M costs	*Abiana*	
2010	8,597	1,882	
2011	7,662	1,609	-376.13%
2012	9,637	1,660	-480.64%
2013	10,230	1,301	-686.31%
2014	11,346	1,121	-912.19%

The average annual *abiana* collection rate remained (2012) at 60% of the assessed amount, which leads to a Rs. 1.2 billion loss annually at national level. Canal irrigation system in Pakistan is financially unsustainable as it recovers only an average of 24% of its annual O&M costs, imposing an annual subsidy of Rs. 5.4 billion at national level (2012). In Sindh, water fees remained unchanged for 10 years (2000-2010) even as productivity and markets evolved. The average selling price of privately supplied tube well water (2016) is about Rs.300 per hour, for an installed capacity of one cubic foot per second. This charge is four times more than what a farmer, relying entirely on government supplied canal water, pays for the same volume [123]. Overall it appears that there is no financial or other incentive framework to drive down agricultural water consumption.

The proper economic pricing of water and the societal purpose for which it is used has long been the subject of political debate, as is the precise breakdown of what percentage of costs (capital + O&M) should be borne by government vs costs borne directly by farmers (*abiana*). The historical irrigation strategy has been built on supply side approaches – increasing water supply, with little effort put into cost recovery or designing a governance system within the irrigation schemes that brings together land and water governance in a single policy. Yet, globally, this is now seen as key to managing water scarcity in a context where food demand is likely to rise by 20-30 per cent in the next 25 years, and water availability will remain stable, or in places decline due to climate change [125].

Poverty, land insecurity and water

As the USAID assessment of the sector states,

> *"ownership of irrigated land in the Indus Valley is highly concentrated. Between 20% and 40% of rural households are reported to be landless or near-landless. They either lease or sharecrop land when they can or work as laborers on and off farms; many are raising stall-fed livestock. Poverty is highly correlated with landlessness and is seen as contributing to political and social instability. Repeated government attempts to address inequality of access to land and tenure insecurity have largely failed to transform the system. Tenants and sharecroppers have little incentive to invest in sustainable production practices. Insecure land tenure, coupled with poor water policy and management, have led to increasing degradation of land. Undervaluing the water supply has led to waterlogging and inefficient water-use in some areas while poor water distribution has caused lack of water in other areas, lowering the profitability of land and the incentive to invest in complementary inputs. Enactment of a comprehensive legal framework for establishing more equitable access to property and more transparent land administration could, many analysts believe, contribute to both political and economic development objectives" [126]*

Land and water governance reform need to go hand in hand, as water is vital to the productivity of land, yet water is highly scarce and the system of allocation is inflexible.Water and land reform could allow government to properly “allocate” water to different users and to play its role as manager of the national water resource on behalf of the people, and for the common good. However, to do this effectively during periods of water scarcity also requires consideration of how to remove or reduce allocations for particular actors and with what compensation, if any.

It is politically straightforward to build additional supply – few actors are against such an approach. However, removal of water, or reduction of allocations, can quickly become a toxic political issue. In other water scarce countries (eg Australia, Mexico) facing similar issues, the government has turned to the market [127].

By offering secure water rights to individual actors, these can then be traded between users to generate the highest economic return without government intervention. “Allocation” then becomes market based (with a strong regulator) rather than rent or politically motivated. During recent droughts in California for example a major purchase of irrigation water occurred from rural areas (holding legal water rights) to cities (for drinking and industrial supply) when drinking water reservoirs reached critically low levels.

Some authors suggest that too many institutions (as many as 18) have been created to manage and develop water in Pakistan. This is one reason why recent efforts to formulate water policy may have failed, as different institutions look at policy issues from their own vantage point. A key relationship is the effective policy coordination between the ministries in charge of agriculture and water/irrigation that often seem to operate independently [123]. Recent developments by the Punjab Province’s planning department requiring the agriculture, infrastructure and energy sectors to undertake an environment and climate assessment of all investments is a step forward, but is still addressed investment by investment, rather than a strategic assessment of the cumulative implications for water availability and drought and flood resilience in the Province.

Summary

Review of the existing literature reflects that there is no obvious strategy to allocate water within countries and even less at transboundary level. It also demonstrates that irrigation is highly inefficient but is currently the greatest consumer of water.

A review of Pakistan irrigation sector presents a picture of distribution mostly according to political pressures than water availability, and very suboptimal prices that limit any cost-recovery and potential investment. As cities grow so do their demand for water and their footprint in pollution and waste, which is showing signals of potential future hostpot for crisis (e.g. Lahore). There is even less of a strategy when it comes to transfer of sediments that move with water. Models show that accumulation of sediments are a useful tool to combat rising sea levels but better management systems are required to tackle the negative affects on reservoir storage and waterways without preventing flows to the coast.

In conclusion, the demand side management policy framework that would allow more flexible allocation of scarce water to different sectoral users within Pakistan is almost non-existent. Within a context of transboundary management, maximising water efficiency with available flows within Pakistan must be central to any future strategy, with policy interventions being measured as to their effectiveness in incentivising and achieving higher ‘crop per drop’ productivity.

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