Governing the
'Water Tower of Asia'

The Case for a System of Integrated Knowledge for the Hindu Kush Himalaya

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Dedicated to the memory of
Ghanshyam Raturi
1934-1997
Environmental Activist and Poet of Uttarakhand
Himalaya, India

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Abstract

Across the globe, the availability of freshwater, both for ecosystems conservation and for meeting people's needs, is facing a massive crisis. The same is true for the Hindu Kush Himalaya (HKH), or the "Water Tower of Asia". The HKH is the source of 10 large rivers of Asia, serving the water needs of 16 countries; at least 2 billion people live in these basins. Amidst such huge dependence of both human populations and ecosystems, complex governance challenges have emerged. Today the HKH is a hotspot for water crises and their impacts.

As early as in 1992, the idea of Integrated Water Resource Management (IWRM) has been proffered as a strategy for managing water resources in a holistic manner and thereby avoiding resource challenges from escalating into crises. IWRM has remained marginal in its utility, however. This report builds on existing knowledge about integrated governance and offers a framework for bringing IWRM closer to practice. Using the cases of the 10 HKH river basins, this study charts a framework for creating a System of Integrated Knowledge (SINK). The report outlines the steps in the process of integration of knowledge at three levels: primary, secondary, and tertiary. It underlines the need for capacity building for policymakers and practitioners in the governance of the HKH river basins.

"The Hindu Kush Himalaya is the source of 10 large rivers of Asia and serves the water needs of 16 countries; at least 2 billion people live in these basins. Today the region is a hotspot for emerging water crises."

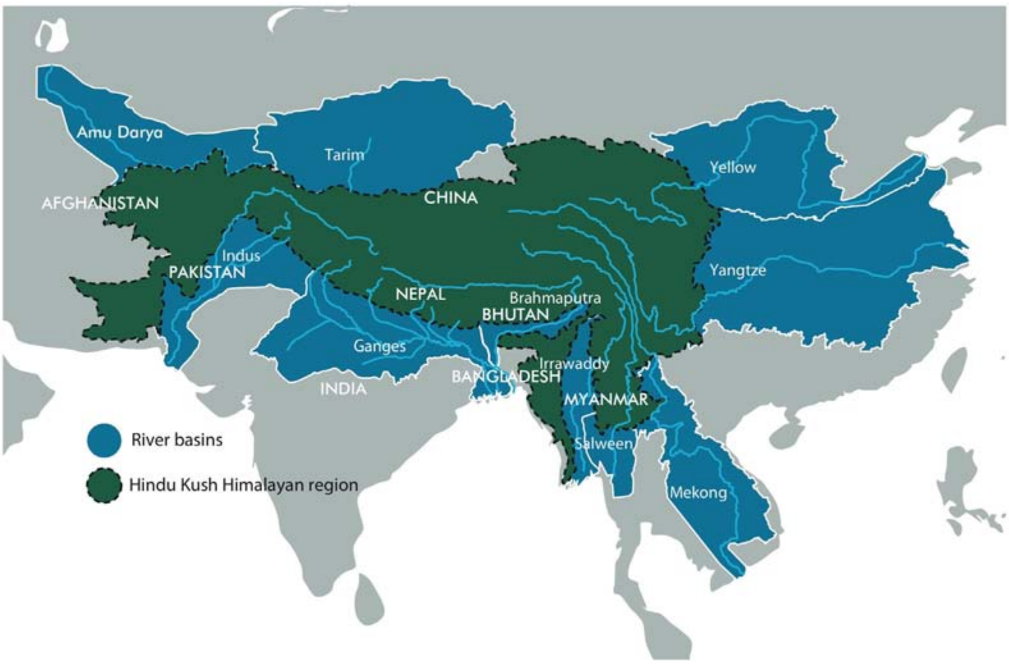
Introduction

Mountains play a role in the birth and growth of human civilisations. This role is particularly observed with respect to the flow of rivers originating from the mountains, thus earning for these mountains the name, "Water Towers of the World".[1] In the context of growing water scarcity and the challenges in governance of this resource, the rivers flowing out from the world's mountains are of global significance.[2] To respond to the challenge of a global water crisis, there is a need for a new approach to water governance replacing the present one which is based on a reductionist paradigm. This new approach will have to be based on holistic, inclusive and integrated knowledge.[3] The need for a shift has become more urgent in the context of the Sustainable

Development Goals (SDGs).[4] In 2021, the World Meteorological Organisation (WMO) stressed on the urgency of addressing the global water crisis, especially as the impacts of climate change are becoming starker.[5]

In Central and South Asia, the imperative is clear for the governance of the Hindu Kush Himalaya (HKH)—a mountain range that stretches 3,500 km and straddles eight countries – Afghanistan, Pakistan, India, Nepal, Bhutan, China, Myanmar, Bangladesh. The HKH is the origin of 10 large rivers in Asia that are crucial to the water needs of 16 countries in the region, including large ones such as China and India. For the sheer size of the HKH, and that of the population it serves, these mountains are known as the "Water Tower of Asia".[6] About 250 million people live within the HKH region itself. The 10 rivers originating in the range flow downstream to the vast plains of Asia and their deltas, serving the livelihood needs of cumulatively 2 billion people.[7] These river basins are: Yellow, Yangtze, Mekong, Salween, Irrawaddy, Brahmaputra, Ganges, Indus, Amu Darya, and Tarim (Figure 1). Their total area is 8.99 million sq. km, of which 2.79 million sq. km lie within the HKH region.[8] This picture of the duality of the uplands and the plains is important; Figure 1 shows their locations.

Figure 1: Basins of the HKH Rivers



Source: ICIMOD
Note: Areas outside the HKH region in light blue, and the HKH region in dark green.

Such dependence on the HKH, and the growing demands of freshwater in all the river basins of the HKH, necessitates that it be governed in an informed manner in order to mitigate potential disputes and environmental degradation. The challenge becomes even more acute amidst the impacts of global warming dictating the temporal and spatial availability of flows as well as extreme weather events.

In 1983, the International Centre for Integrated Mountain Development was established in Kathmandu, Nepal, to balance environmental preservation and the need for economic activities for poverty reduction in the region.[9] Some years later, following the work of the World Commission on Environment and Development and the Rio Earth Summit in 1992, the principles of "integrated development" and "sustainability" were declared to be intertwined to encompass ecological, social, and economic imperatives.

This report assumes the principle that nature organises itself in a systematic and integrated manner; it is the reductionism that has predominated contemporary governance paradigm that interrupts nature's systems. To overcome such reductionist thought, for instance for water resources, the imperative is for the creation of a knowledge system that integrates disciplinary knowledge to generate a holistic understanding. This new framework for integration of knowledge system is identified in this study as the System of Integrated Knowledge (SINK).

In the past several decades, integration of knowledge at various levels has been thought of, but the articulation of the steps for integration has not progressed to create any significant impact in practice. SINK provides a new paradigm for the governance of water systems. It draws on other disciplinary knowledge systems, including indigenous/local/traditional knowledge; the creation of new knowledge is taking place largely in specialised areas of research. A dynamic and symbiotic relationship between such realms of disciplinary knowledge will lead to the synthesis of specialised knowledge and the creation of integrated knowledge. Indeed, water governance experts should manage the integrated and inclusive knowledge through a model of a "knowledge pyramid": the most consolidated and synthesised knowledge is at the top–often characterised as wisdom. This is a complex process in need of greater attention that it has not received so far. As some observers have noted, the lack of dynamic and holistic systems thinking required for the generation of integrated knowledge on water resources is due to two reasons: First, the reward system in academic institutions tends to encourage "traditional" research as they are often easier to get published. Second, funding organisations tend to support projects that are practical and time-bound, rather than those that push for the development of integrated interdisciplinary frameworks which are inherently slower and more uncertain.[10]

In the case of the HKH region—with its environmental fragility, ecological complexity, and dense populations in the foothills and plains where poverty reduction is a priority—the range of integrated knowledge needed for water governance is wide and multi-disciplinary. Further, of the 10 HKH river basins, eight are shared by two or more countries; all the basins are also affected by provincial and sectoral trans-boundary governance challenges.

This report aims to articulate the fundamental aspects of a SINK specific to the HKH. It offers suggestions for a new approach to research and education processes that generate and use SINK and builds the capacity of professionals, political leaders, and policymakers involved in the governance of the HKH basins.

The rest of the monograph is structured as follows. Section 1 outlines a description of the fragile natural environment of the HKH and the atmospheric, geospheric, biospheric, and hydrospheric processes through which the streams and rivers are formed. Section 2 describes the concept of "integrated knowledge" and expands it to cover existing research from other parts of the world that have conceptualised and generated integrated knowledge in different governance domains. The third section then underlines the relevance of integrated knowledge in the governance challenges specific to the 10 HKH river basins. The last section offers a framework and systematic approach to the generation of diverse types of integrated knowledge as part of SINK. The aim is to guide in the design of research and education programmes for advancing SINK in practice in the HKH river basins.

The HKH Region and Its River Basins

The HKH region extends from Myanmar to Afghanistan, covering a distance of about 3,500 km[11] and encompassing 12 mountain ranges including Tien Shan, Kunlun Shan, Pamir, Hindu-Kush, Himalaya, Tanggula, and Hengduan Shan.[12]

Over millennia, the streams and rivers from the HKH region have extended vital ecosystem services to support life, in general, and in particular, the human communities residing within this mountain region. Of equal importance are the vast plains of Asia in the lower parts of the 10 HKH river basins.

In the downstream parts of these basins, millions of people depend on the waters from the HKH rivers for many purposes, among them: domestic use, agriculture, hydropower, and industry. These rivers are fed by rainfall runoff, melt water from snow and ice, and groundwater. The amounts of water from each of such sources vary across rivers, and depending on the location within each basin.[13] In view of the hydrological, social, cultural, ecological, historical, economic and political importance of the flows in the HKH rivers, their total run-off is recognised as regional assets with a global significance.

The demand for freshwater from these basins is growing rapidly, generating potentially challenging conditions for governance, albeit in different ways. These governance issues of some of the individual HKH river basins have been studied, mainly from the perspective and needs of individual countries. However, the totality of the challenges faced by the so-called "Water Tower of Asia" has not been adequately investigated. These existing studies have also not examined the flow in rivers and streams in the HKH basins in a precise manner.[14] This has become even more important amidst climate change, which is exacerbating the challenges to water security.

There are commonalities between the key governance challenges in the individual river basins, and an exchange of knowledge among the 10 river basins will be useful as a repository of HKH-specific knowledge. This underlines the importance of a holistic approach to the governance of all the HKH river basins as a unique asset. Thus, understanding the role of the basins of the 10 HKH rivers in water and food security in Asia is an important agenda for joint research and action in governance. However, there is a general lack of literature on this area, which prohibits making a comprehensive picture of all the HKH river basins.

This study contributes to filling that gap. The creation of a HKH-specific system of integrated knowledge of science and for their governance can be a starting point. While there are descriptions of these challenges in sustaining the HKH region,[15] a lot more work is needed for creating a holistic knowledge of science and for governance specific to the HKH region. In this monograph, the integration of the various ecosystems processes that lead minute precipitation of water or snow to form the flows in large rivers, itself exemplifies a process of integration of perception relevant for the analysis that will follow. Burrard and Hayden have given an early account of the HKH rivers from the point of geology and physical geography.[16] At the level of analysis of some of the basins with a reduced spatial coverage, several studies exist, including those by Jun and Xia, Tandon and Sinha, and Alley.[17, 18, 19, 20]

The total area of the HKH region covered in snow and ice is about 60,000 sq. km,[21] making it the world's "Third Pole". Other estimates say the Third Pole holds more than 100,000 sq. km of glacier.[22] The entire HKH region, and the Tibetan Plateau in particular, has an important influence on the precipitation patterns in the region. The Himalaya act as a buffer, creating unique geomorphological features and protecting the lush green southern slopes from the dry and arid winds coming from the north, and thus supporting a rich mosaic of biota and eco-regions.[23] The perennial flows of the HKH rivers are vital for water, food, and energy security in large parts of Asia; these rivers are regarded as nothing less than life-giving and sacred. The Yellow River and the Ganges (also known as Ganga), for example, are revered as 'Mother Rivers' in China and India, respectively.[24]

As mentioned earlier, some 2.5 billion people depend on the 10 HKH basins for their sustenance. These basins are therefore likely to face temporal scarcity and, meanwhile, there are governance challenges in water-sharing between the countries that straddle the basins. Historically, the 10 river basins have been studied and governed as individual basins, leaving a gap in evaluating the totality of the flows in the region. While each basin has its own unique characteristics in terms of meteorological, hydrological, political, and ecological features, they share similar governance challenges.

First, the overarching issue of global warming and related gaps in data affect all the basins. There is also the presence of the monsoon high flows, disputes over access to water in the post-monsoon, water-scarce period. Further, most streams and rivers cross boundaries – both political and sectoral, thereby intensifying the challenges of governance of transboundary river basins. For example, while the Yellow, Ganges and Indus River water managers must address water scarcity in their delta regions, the Yangtze and the Brahmaputra are faced with the summer monsoon high flows—including extreme flood events—and high rates of erosion and sedimentation. The Yangtze and the Ganges face growing industrial demands for water and river pollution; Amu Darya has challenges in governing newly emerged international trans-boundary situations that the Ganges, Brahmaputra and Indus have been facing since independence and partition of India in 1947. The Mekong and Brahmaputra face similar conflicts based on upstream hydropower generation and productivity concern of the downstream riparian ecosystems, especially fisheries. There are more of such common issues which can be the basis for an exchange of knowledge between all the HKH river basins. However, at present, there is limited exchange of knowledge on these issues. A framework of integrated knowledge base for river basin governance in the HKH region is seen as a useful common platform for addressing this task.

The cultural and economic dimensions of the *Himalaya*

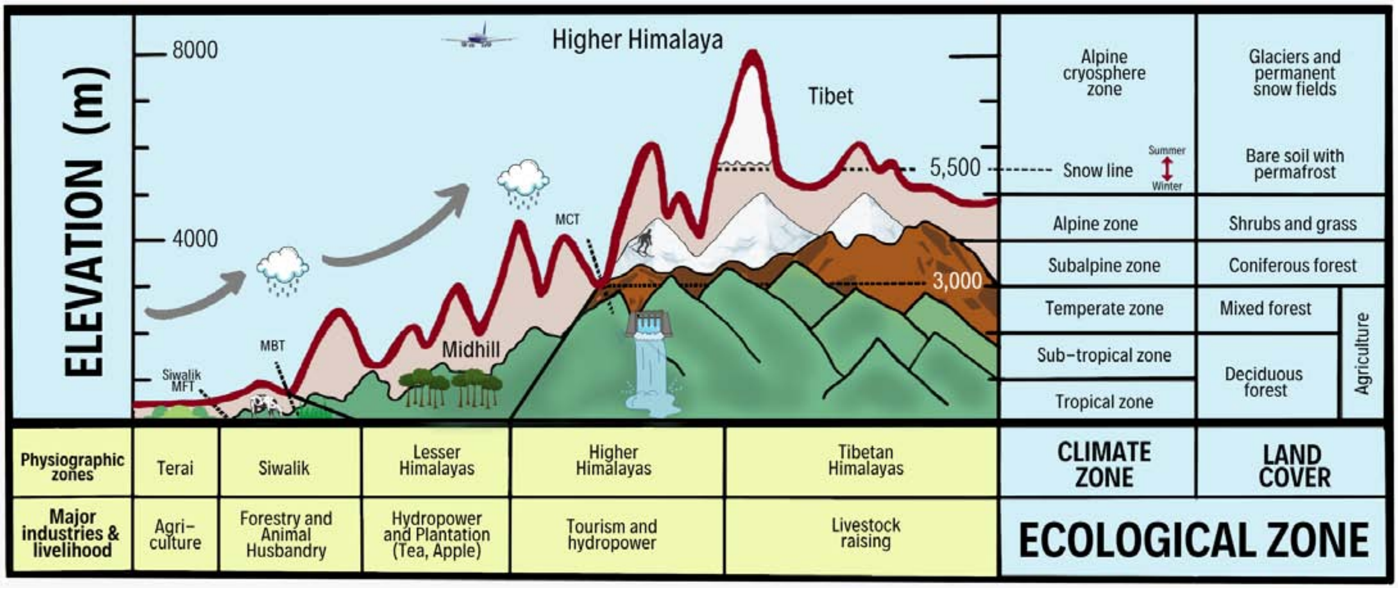
The earliest written reference to *Himalaya* is found in the oldest known scripture, the *Rig Veda*.[25] Translated from the original Sanskrit to English, *Himalaya* means "the abode of snow and ice". This is a clear hydro-meteorological description of the parts of the Himalayan range with elevation above the snow line. These parts are also characterised by steep slopes. Most of the features attributed to the Himalaya may also be applied to the whole of the HKH. The HKH region is rich in ethnic and cultural diversity, which provides social-anthropological importance; the same diversity can be a cause for potential conflicts over the products and services of the natural environment, including river flows.

People living in the Himalaya region consider the snow- and ice-clad mountains as the home of Buddhist and Hindu deities. These beliefs in the sacredness of the rivers have led to popular opposition to many large river-related engineering projects. For example, the Lepchas of Sikkim in North-East India have been protesting against hydro-electric projects on the ground that their land is sacred and should not be destroyed by infrastructure projects.[26]

The Himalaya have enchanted explorers, scholars, and artists from different parts of the world. In addition to storing large volumes of snow and ice, these areas above the snow line offer scope for biodiversity studies and mountaineering expeditions. Human settlements in these areas are sparse. Due to the vertical formation, seismic activities, anomalous precipitation of both snow and rain, the high Himalaya are naturally quite fragile. The snow and ice melts give rise to freshwater flows that generate streams and rivers that flow down to the lower parts of the mountains and the foothills.

The less spectacular but much more active economically and more densely populated parts of the Himalaya lie at altitudes below the Alpine Cryosphere zone.[27] In these regions, the slopes are less steep and the land is usually covered by meadows, forests and farms, with human settlements scattered across. Discharge from springs in these parts sustains the supply of water for drinking and ensures water security of the local people. The springs feed the stream flows, thus helping to maintain a base flow during the lean period, supporting irrigation of mountain farms, and promoting food security.[28] The groundwater potential at the foothills is large and adds to the base flows of the streams and rivers. These lower parts of the Himalaya have substantial economic activities such as pastoralism, forestry, mining, agri-horticulture, irrigated agriculture, and nature tourism.

Figure 2: Cross-profile of the Himalaya showing physiographic and climatic zones, land cover, and economic potential



Source: Authors' own, with assistance from former ORF intern, Sanjoli Johana Shah. Based on Nepal et al. (2018)

The geographical area of the HKH region can therefore be perceived as made of two parts separated by the Snow Line. In terms of the type of contributions to the total flows of water in the HKH rivers, the upper region dominates when the snow and ice melts are considered, while the lower region contributes rainfall run-off to the flows of rivers. Figure 2 presents a sectional view of the Himalaya and the monsoon-related atmospheric circulations. For the effective governance of the HKH region, knowledge that is based on the recognition of this distinction offers scope for maintaining easier upstream-downstream relations.

Mountain building, atmospheric circulations, and precipitation over the HKH region

Mountain Building

The HKH is a geologically young and active mountain region, constantly gaining height as a result of the continental drift of the Indian (or Gondwana) plate and its tectonic collision with the Asian continental plate. These plate movements have been going on for about 60 million years, resulting in the lifting of an old sea floor, known as the Tethys Sea, as a mountain. Thus, was formed the main Himalayan range and the lifting of the Tibet Plateau (See Figure 2). While the process of orogeny is much longer, most of the altitude gained by the Himalaya has occurred in the last 2 million years.[29] In the understanding of both the meteorology and hydrology of the HKH region, and, consequently the flows in the HKH river basins, this tectonic process and the uplift of the Tibet Plateau are significant. Valdiya,[30,31] Zurick,[32] Gansser,[33] and many others have given accounts of the geological evolution and uplift of the Himalayan range. Zurick has described the Himalayan uplift and landscape in the following words:

> *The summits and gorges, the long lines of undulating ridges, and the diverse terrain that we see as the actual mountains are merely the outer skin of a geological plate up to 75 kilometers thick that underlies the region. It is the movement of this crustal fragment during the past 60 million years, with the South Asia plate submerging beneath that of the Asian continent and lifting the oceanic crust of the ancient Tethys Sea along the way that has caused the mountains to form. They continue to grow because the Indian plate maintains its northward drift into Eurasia at a speed of movement today of about 2 cms per year.*[34]

The Himalaya proper has been described as extending over 2,400 km as an arc from the Indus bend around the summit Nanga Parvat (8125 m) in the north-west to the Brahmaputra (Yarlung Tsangpo) bend around Namchi Barwa (7756 m) in the southeast.[35] The highest point of the HKH region is located at 8,850 m and is still growing. It is called by various names, such as Sagarmatha (Nepali), Chomolungma (Tibetan). More recently it was given another name—Mount Everest.[36]

With all 14 peaks of the world taller than 8,000 m being located in the HKH region, the Himalaya form a wall whose altitude rarely goes below 5,500 m,[37] creating an obstacle to atmospheric circulations. As a result, the HKH region acts as a climate-maker, generating large precipitations from the South Asian Summer Monsoon (SASM), East Asian Summer Monsoon (EASM), and the Westerlies (See Figure 2 and Figure 3). The south aspect of the Himalayan Arc receives far more precipitation than the north, which exists as a vast arid/semi-arid rain shadow region. Annual average precipitation varies from 3,000 mm in the eastern Himalaya to 100 mm in the southern plain desert on the western side.[38]

The HKH region also has some deep gorges like those of river Siang/Dihang, and Kali Gandaki, the latter being the deepest gorge in the world.[39] The combination of the geologically young mountain, and the impact of intense Asian monsoons, makes the region environmentally fragile, ecologically complex, and prone to diverse natural hazards. In the words of Campbell:

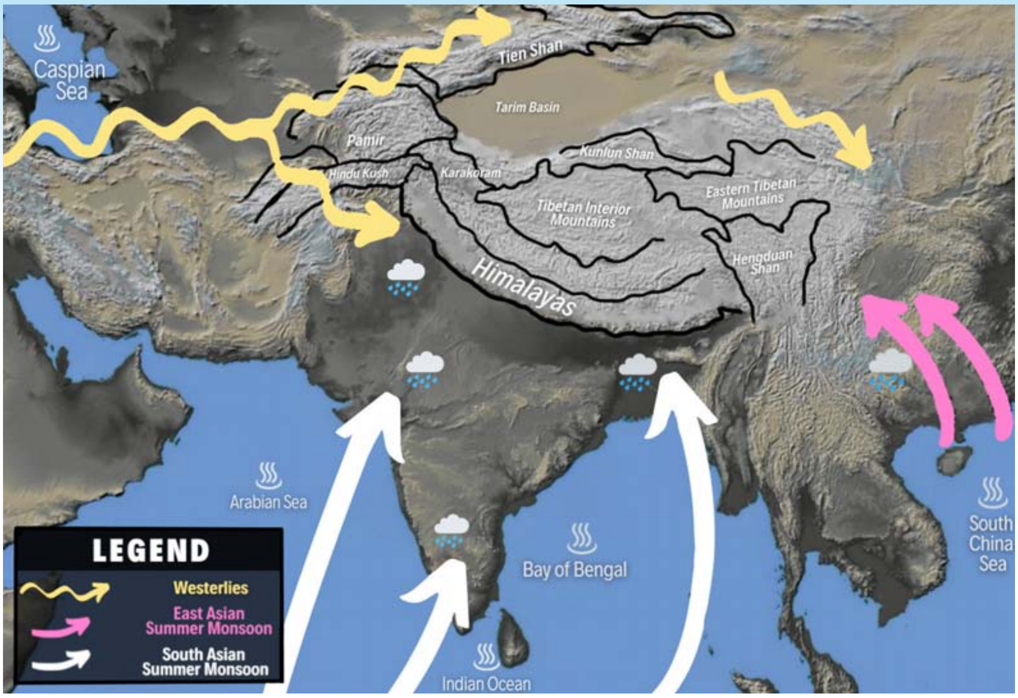
> *A spectacular and varied source of life in Asia, the Himalaya also buries its shares of humans. The moving tectonic plates that created the mountains, still erupt in massive earthquakes......Annually there are floods, glacial lake outbursts, landslides, avalanches and blizzards that can cause devastating damage to humans, their settlements and their livelihoods.*[40]

Owing to this environmental sensitivity, high biological diversity, and cultural diversity, along with the livelihood requirements of large populations, there is a perennial dilemma in identifying the proper approach to the prospects and limitations of human economic activities in the HKH region.[41] However, in spite of being prone to serious natural hazards, the lower half of the Himalaya is far more densely populated than other tall mountains, and thus, has to accommodate significant environmental impacts from human economic activities. When such activities are undertaken without the support of integrated ecological knowledge, the fragility of the ecosystem heightens.

Atmospheric circulations and precipitation over the HKH region

The HKH, including the Himalayan Arc and the Tibetan Plateau, significantly influences the precipitation patterns in the region and, thus, the nature of flows in the basins of the HKH rivers. This precipitation is mainly the result of the interaction of the mountains with the three significant atmospheric circulations (Refer to Figure 3 for the rest of the following description). The HKH divides the region into rain-rich (south aspect of the Himalaya and the eastern margin of the Qinghai-Tibet plateau, west of Pamir and Tien Shan mountains) and low rainfall areas (rain shadow along the north aspect of the Himalaya, the vast Tibet Plateau and the Taklamakan desert). A large part of the precipitation over the HKH region is predominantly rainfall from the two Summer Monsoons during June to September. In the winter months of November to February, the Westerly disturbances result in some precipitations mainly in the western parts of the region dominated by snowfall. Topography is key in modifying storm systems including the Westerly disturbances brought in by the synoptic westerlies below the 3,000-m mark. However, violent rainstorms can overcome this barrier and penetrate further into an otherwise arid region as it had happened in 2002.[42] The wind pattern is shown in Figure 3. These atmospheric circulations and the HKH are the generators of one of the most significant ecosystem processes related to water. The rainfall is varying across the length and breadth of the HKH region. For instance, it is as high as 4,000 mm in Pasighat in the east, while Kashgar in the Tarim basin may receive an annual precipitation less than 100 mm. The flow in the eastern rivers like Yellow, Yangtze, Mekong, Brahmaputra, and

Figure 3: The three main atmospheric circulations over the HKH



Source: ICIMOD (Modified by authors, with assistance from former ORF intern, Sanjoli Johana Shah.)[43]

Ganges are dominated by the rainfall component while Indus, Amu Darya, and Tarim carry a large contribution from snow and ice melts. This makes the rivers belonging to the two groups similar in certain hydrological aspects.

The landscape hydrology and the flows in HKH rivers

Originating from the high mountains, the HKH rivers flow through the foothills and the surrounding plains, interacting with the land and land cover, altering their hydrological features and eventually reach their confluence with the respective sea/ocean/wetlands. The land of the HKH performs a significant role in the shaping of the hydrological character of streams and rivers. The landscape creates conditions for stream flows, left after parts of the precipitation that constitutes evapotranspiration, recharge of the soil moisture and percolation to the groundwater aquifers. Based on the slope and the nature of the type of land cover, the HKH landscape performs regulating services on the surface run-off, thus shaping the hydrological identity of streams and rivers. The HKH landscape links the precipitation and the hydrological character of the streams and rivers emerging from the region. In the monsoon-fed areas a good part of such hydrological linkages can be described as regulating ecosystem services to the high flows – reducing the peak flows and delaying the runoff. In a similar manner, the storage of water in the snow and ice cover, also delays the runoff.[44]

There is no doubt that the HKH extracts from the atmosphere annually a very large volume of freshwater but that has yet to be accurately assessed. Nevertheless, this is a crucial intervention in the global water cycle.

The landcover of the HKH is also undergoing rapid changes, thus affecting the flows in the rivers. There are changes taking place in the land use and land cover of the HKH region.[45] The Regional Land Cover Monitoring System for the Hindu Kush Himalaya, an initiative of the ICIMOD would provide a more comprehensive picture.[46] Important changes include forest fragmentation, urban growth, and land degradation from mining. A wide area with diverse land use and land cover and affected by global warming and climate change, needs to be assessed by modelling exercises.[47] There are existing detailed accounts of the challenges in hydrological modelling of the HKH region.[48] The structural fragility of the Himalaya and the intensity of the monsoon precipitations generate an HKH-specific hydro-meteorological mosaic.[49]

An area extending from Shanghai in the east to Karachi in the west utilises the flows in the HKH river basins for human survival and economic activities. The Yangtze provides support to the huge industrial area surrounding Shanghai and irrigated agriculture makes the Ganges basin act as the grain basket of India.

The mountain landscape is also a climate maker at the micro-level, generating a grand mosaic of micro-climatic diversity. There are various factors creating this mosaic: altitude, aspect, slope, sunshine periods, and wind directions. Understanding this micro-climatic diversity—which is important for soil moisture and the localised agri-horti-pastoral economies—is necessary especially for the assessment of local water needs and endowments. The hydrological impacts of climate change on the flows in these river basins are an additional challenge for science and governance.[50,51]

Table 1 gives an overview of the basic features of the 10 HKH river basins.

Tables 1a and 1b: Key Features of the HKH River Basins

Rivers	Basin area (km^2)[52]	Percentage Contribution to total runoff Reference Period (1985-2014)[53]				Total estimated GDP Within HKH 16 (USD billion)[54]
		Glacier Melt	Snow Melt	Rainfall Runoff	Base Flow	
Amu Darya	268,280	4.4	74.4	5.4	15.8	37
Brahmaputra	400,182	1.8	13.2	62.1	22.8	168
Ganges	202,420	3.1	10.3	64.7	22.0	790
Indus	473,494	5.1	39.7	43.9	11.4	380
Irrawaddy	49,029	0.0	5.1	78.2	16.7	38
Mekong	110,678	0.3	7.4	55.1	37.2	160
Salween	119,377	1.4	14.7	55.7	28.3	23
Tarim (Interior East/Interior West)	1,081,663	1.1 / 5.8	20.2 / 28.4	49.7 / 44.4	29.0 / 21.4	70
Yangtze	687,150	0.2	5.5	71.0	23.3	1,981
Yellow	272,857	0.1	9.6	63.9	26.5	696

Rivers	Annual mean discharge (m^3/sec)[55]	Population (millions) in 2015[56]	Population density[57]	Water availability (m^3/ person/ year)[58]	% Of areas under above High Water Stress[59]	Number of dams[60]
Amu Darya	1,376	30.18	39	2,081	28%	3
Brahmaputra	21,261	68.07	182	5,656	-	27
Ganges	12,037	580.09	401	932	55%	795
Indus	5,533	42.87	165	978	62%	39
Irrawaddy	8,024	39.5[61]	79	7,742	-	N/A
Mekong	9,001	77.31	71	4963	-	1
Salween	1,494	17.88	88	7,876	-	N/A
Tarim (Interior East/Interior West)	1,262	11.37	7	4,933	37%	N/A
Yangtze	28,811	604.94	214	2,465	4%	26
Yellow	1,438	198.02	156	308	63%	8

Figure 4: The ten river basins of the Hindu Kush Himalaya

Source: ICIMOD

Endnotes

1 Jayanta Bandyopadhyay, "Water Towers of the World," *People and the Planet* (1996) (London)5 (1). https://lib.icimod.org/record/9922

2 Jayanta Bandyopadhyay et al. "Highland Waters: A Resource of Global Significance," in *Mountains of The World: A Global Priority*, ed. Bruno Messerli and Jack D. Ives (New York: Parthenon, 1997), 131–134.

3 Gro Harlem Brundtland, Foreword to *The Global Water Crisis: Addressing an Urgent Security Issue*, by Harriet Bigas et al. (Hamilton: UNU-INWEH, 2012), xi–xii.

4 UNESCO and UNESCO International Centre for Water Security and Sustainable Management, *Water security and the sustainable development goals*, Paris: UNESCO Publishing, 2012, https://digitallibrary.un.org/record/3807832?ln=en

5 World Meteorological Organisation, *2021 State of Climate Services: Water,* Geneva: WMO Publications, 2021, https://library.wmo.int/doc_num.php?explnum_id=10826

6 International Centre for Integrated Mountain Development, *Sustainable Mountain Development 1992, 2012, and Beyond,* by Madhav Karki, Kathmandu: ICIMOD, 2012, https://www.fao.org/fileadmin/user_upload/mountain_partnership/docs/HKH_FINAL_Regional_Report_HKH_29May_0.pdf

7 P Wester, A Mishra, A Mukherji and A B Shrestha, eds., *The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People. (Germany: Springer International Publishing, 2019) https://link.springer.com/book/10.1007%2F978-3-319-92288-1*

8 International Centre for Integrated Mountain Development, *Sustainable Mountain Development 1992, 2012, and Beyond*

9 N. S. Jodha, *A Framework for Integrated Mountain Development*, Kathmandu, ICIMOD, 1990, https://lib.icimod.org/record/25705/files/attachment_465.pdf?type=primary

10 Editorial, "Too much and not enough," *Nature Sustainability* 4, 659 (2021), https://doi.org/10.1038/s41893-021-00766-8

11 Santosh Nepal, Avash Pandey, Arun B. Shrestha, and Aditi Mukherji, *Revisiting Key Questions Regarding Upstream-Downstream Linkages of Land and Water Management in the Hindu Kush Himalaya (HKH) Region*, Kathmandu, ICIMOD, 2018, https://doi.org/10.53055/ICIMOD.739

12 ICIMOD, "The pulse of the planet," ICIMOD Website, https://www.icimod.org/who-we-are/the-pulse-of-the-planet/

13 A. B. Shrestha, N.K. Agrawal, B. Alfthan, S.R. Bajracharya, J. Maréchal, B van Oort, eds., *The Himalayan Climate and Water Atlas: Impact of climate change on water resources in five of Asia's major river basins*. (Kathmandu: ICIMOD, GRID-Arendal and CICERO, 2015). https://grid.cld.bz/The-Himalayan-Climate-and-Water-Atlas-Impact-of-Climate-Change-on-Water-Resources-in-five-of-Asia-s-Major-River-Basins

14 Richard Kattelmann," Uncertainty in Assessing Himalayan Water Resources," *Mountain Research and Development* Volume 7 No 3 (1987): 279-286

15 Jayanta Bandyopadhyay 'Securing the Himalayas as the Water Tower of Asia: An Environmental Perspective' *Asia Policy* 16 (2013) July:45-50.

16 Col. S.G. Burrard and H.H. Hayden, "A Sketch of the Geography and Geology of the Himalaya Mountains and Tibet," *Nature* 81 (1909): 424-425

17 Xia Jun and Y D Chen," Water problems and opportunities in the hydrological sciences in China," *Hydrological Sciences Journal* 46, no. 6, (2001) https://doi.org/10.1080/02626660109492885

18 S. K. Tandon and R Sinha, "The Ganga River: A Summary View of a Lage River of the Indian Sub-continent" in *The Indian Rivers*, ed. D.S. Singh (Singapore: Springer Hydrogeology, 2018), 61–73.

19 Kelly D Alley, 'Water Wealth and Energy in the Indian Himalayas' *The Silk Road* 10 (2012):136-145

20 Leendert Adriaan Bruijnzeel and Christiaan N. Bremmer, "*Highland-lowland interactions in the Ganges Brahmaputra river basin: a review of published literature" ICIMOD Occasional Paper No. 11* (1989)

21 International Centre for Integrated Mountain Development, *Sustainable Mountain Development 1992, 2012, and Beyond*

22 Yao et al.," Third Pole Environment (TPE)," *Environmental Development* 3, (2012) https://doi.org/10.1016/j.envdev.2012.04.002

23 International Centre for Integrated Mountain Development, *Sustainable Mountain Development 1992, 2012, and Beyond*

24 Jayanta Bandyopadhyay, "Restoration of Ecological Status of Himalayan Rivers in China and India: the Case of the Two Mother Rivers – the Yellow and the Ganges," in *Environmental Sustainability from the Himalayas to the Oceans: Struggles and Innovations in China and India,* ed. Shikui Dong, Jayanta Bandyopadhyay and Sanjay Chaturvedi (Switzerland: Springer, 2017):69-98

25 Rasoul B. Sorkhabi, "Historical Development of Himalayan Geology," *Journal of Geological Society of India 49* (1997): 89-108.

26 Kerry Little, "From the villages to the cities: the battlegrounds for Lepcha protests," Transforming Cultures eJournal 5, no. 1 (2010), https://doi.org/10.5130/tfc.v5i1.1579

27 "Revisiting Key Questions Regarding Upstream-Downstream Linkages of Land and Water Management in the Hidu Kush Himalaya (HKH) Region"

28 K. Mahamuni, D. Upasani, "Springs: a common source of a common resource." (paper presented
at the 13th Biennial conference of the international association for the study of the commons (IASC), Sustaining commons: sustaining our future, Hyderabad, India, January 10–14, 2011).

29 David Zurick, Julsun Pacheco, Basanta Shrestha and Birendra Bajracharya, *Atlas of the Himalaya, part 2, page 24*

30 K.S. Valdiya, "Evolution of the Himalaya" *Technophysics* 105(1984): 229-248.

31 K.S. Valdiya,"Emergence and evolution of Himalaya: reconstructing history in the light of recent studies" *Progress in Physical Geography: Earth and Environment* 26(2002):360-399

32 Zurick et al., *Atlas of the Himalaya*

33 Augusto Gansser, *Geology of the Himalayas (*London: Interscience Publishers, 1964)

34 Zurick et al., *Atlas of the Himalaya*

35 Zurick et al., *Atlas of the Himalaya*

36 Zurick et al., *Atlas of the Himalaya*

37 Harka Gurung, Introduction to *Atlas of the Himalaya, by* David Zurick, Julsun Pacheco, Basanta Shrestha and Birendra Bajracharya (Kathmandu: ICIMOD, 2005)

38 Shrestha et al., *The Himalayan Climate and Water Atlas: Impact of climate change on water resources in five of Asia's major river basins.*

39 Zurick et al., *Atlas of the Himalaya*

40 Gabriel Campbell, Foreword to *Atlas of the Himalaya, by* David Zurick, Julsun Pacheco, Basanta Shrestha and Birendra Bajracharya (Kathmandu: ICIMOD, 2005)

41 J D Ives and B Messerli, *The Himalayan Dilemma: Reconciling Development and Conservation* (London: Routledge, 1989)

42 Bodo Bookhagen et al., "Abnormal monsoon years and their control on erosion and sediment flux in the high, arid northwest Himalaya." *Earth and Planetary Science Letters* 231, no. 1-2 (2005), https://doi.org/10.1016/j.epsl.2004.11.014

43 International Centre for Integrated Mountain Development, *Sustainable Mountain Development 1992, 2012, and Beyond*

44 Aylward Bruce, Jayanta Bandyopadhyay and Juan-Carlos Belausteguigotia, (2005) "Freshwater Ecosystem Services" in *Ecosystems and Human Well-being: Policy Responses, Volume 3* ed. Kanchan Chopra, Rik Leemans, Pushpam Kumar, Henk Simons (Washington DC : Island Press, 2005), 216-255.

45 Uddin et al., "Regional Land Cover Monitoring System for Hindu Kush Himalaya." in *Earth Observation Science and Application for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region*, ed. B Bajracharya, R.B. Thapa and M.A. Matin (Cham: Springer, 2021), 103–125

46 ICIMOD, "Launch event: Regional Land Cover Monitoring System for the Hindu Kush Himalaya," YouTube video, January 04, 2022, https://www.youtube.com/watch?v=vu8XFuYepA8&t=30s

47 Uddin et al., "Regional Land Cover Monitoring System for Hindu Kush Himalaya."

48 Francesca et al., " Challenges and Uncertainties in Hydrological Modeling of Remote Hindu Kush-Karakoram-Himalayan (HKH) Basins: Suggestions for Calibration Strategies," *Mountain Research and Development* 32, no. 1 (2012), https://doi.org/10.1659/MRD-JOURNAL-D-11-00092.1

49 Francesca et al., “ Challenges and Uncertainties in Hydrological Modeling of Remote Hindu Kush-Karakoram-Himalayan (HKH) Basins: Suggestions for Calibration Strategies,”

50 Tonkin et al., “Prepare River ecosystems for an uncertain future” *Nature* 570 (2019):301-03. https://doi.org/10.1038/d41586-019-01877-1

51 International Centre for Integrated Mountain Development, *Sustainable Mountain Development 1992, 2012, and Beyond*

52 David J. Molden et al. “The Great Glacier and Snow-Dependent Rivers of Asia and Climate Change: Heading for Troubled Waters,” in *Water Security Under Climate Change. Water Resources Development and Management,* ed. A.K. Biswas and C. Tortajada C. (Singapore: Springer, 2022). https://doi.org/10.1007/978-981-16-5493-0_12

53 S. Khanal et al., “Variable 21st century climate change response for rivers in High Mountain Asia at seasonal to decadal time scales,” *Water Resources Research* 57, 5. https://doi.org/10.1029/2020WR029266

54 “No Water No Growth – Does Asia have enough water to develop?, September 2018”

55 Revisiting Key Questions Regarding Upstream-Downstream Linkages of Land and Water Management in the Hindu Kush Himalaya (HKH) Region”

56 “No Water No Growth – Does Asia have enough water to develop?, September 2018”

57 Revisiting Key Questions Regarding Upstream-Downstream Linkages of Land and Water Management in the Hindu Kush Himalaya (HKH) Region”

58 Revisiting Key Questions Regarding Upstream-Downstream Linkages of Land and Water Management in the Hindu Kush Himalaya (HKH) Region”

59 China Water Risk, *No Water No Growth – Does Asia have enough water to develop?, September 2018*, Hong Kong, China Water Risk, 2018 https://www.chinawaterrisk.org/wp-content/uploads/2018/09/CWR-Report-No-Water-No-Growth.pdf

60 Revisiting Key Questions Regarding Upstream-Downstream Linkages of Land and Water Management in the Hindu Kush Himalaya (HKH) Region”

61 Tarek Ketelsen, Luke Taylor, Mai Ky Vinh, Rory Hunter, Robyn Johnston, Shaoyu Liu, Kyaw Tint, Khin Ma Ma Gyi and Marisa Charles, *State of Knowledge: River Health in the Ayeyarwady*, Vientiane, CGIAR Research Program on Water, Land and Ecosystems, 2017, https://hdl.handle.net/10568/82968

Review of Literature

By the late 1950s and early 1960s, it was evident that decisions on the governance of the natural environment had become suboptimal, having been guided by an inadequate reductionist framework of knowledge. Scholars began to question this dominant view of an 'Economic Man' arriving at 'rational decisions'.[1] Thereby the emphasis was laid on the need to draw from a broader range of variables in research on decision-making and espousing the idea to draw from divergent fields of enquiry. This became critical for providing a spatial perspective on the governance of the natural environment with an initial, distinctive focus on the river basins.[2,3] In the 1970s, the term 'ecosystem perspective' started gaining prominence globally, creating an integration of many interrelated ecosystem processes.[4]

Scholars have elaborated on the approach towards the integration of the needs of the natural environment and of the human communities dependent on the related ecosystem services.[5] As a result of these initiatives, the integration of the full array of physical, biological, and socio-economic-cultural variables to address societal goals and ecosystem functions acquired a new brand in the term Integrated Water Resource Management (IWRM). a concept facilitated by the Global Water Partnership (GWP).[6]

The HKH region is in need of holistic governance that, in turn, depends on integrated knowledge or SINK. The present reductionist governance framework has reached a dead-end and new and more effective governance cannot happen without moving towards the integration of knowledge realms.

Geographers and behavioural researchers have long proposed that decisions related to the governance of the natural environment are largely based on the range of choices set by cultures and institutions, and not solely by that set by knowledge of the natural environment. The wisdom has long existed that such decisions are reductionist. For example, Herbert A. Simon postulated 'bounded rationality' and suggested that there are limits to humans' thinking and sub-optimal decision-making.[7] Wolpert built on Simon's idea by adding the suboptimal conditions of imperfect knowledge.[8] Meanwhile, White highlighted that decisions in resource management are based on the practical range of choices set by cultures and institutions and not by a theoretical range of choices offered only by the physical environment.[9]

The concept of IWRM and some disagreements

The integration of knowledge from a broader range of topics and variables in research is critical for providing a spatial perspective on the governance of the natural environment with an initial, distinctive focus on the river basins[10, 11] This was despite the dichotomy prevalent in the usage of the term back then – needs of the ecosystem (bio-geophysically-based) or needs of the humans who use the ecosystem services.[12] The integration of the full array of physical, biological, and socioeconomic-cultural variables to address societal goals and ecosystem functions through the widespread propagation of IWRM helped to overcome the dichotomies of the past.[13] Notwithstanding the acknowledgement, and frequent use of the objective of IWRM in policy documents, a SINK for the governance of water remains largely underdeveloped, in particular in the case of the HKH.

The IWRM construct has been criticised for being too broad[14] and for lacking in empirical evidence that supports its utility.[15] Critics also say that politics plays an integral role in decision-making for water governance.[16] More recently, it has been highlighted that

IWRM has become an end in itself rather than a means to address challenges of water governance holistically. It is often seen as a step to increase chances of donor support, thus closing the window on alternative thinking.[17]

In the context of the HKH, this limitation is perhaps best exemplified by the experiences gained from the implementation of IWRM in Nepal. Suhardiman et al. have noted that mere inclusion of IWRM principles does not ensure acceptance, more so if power relations exist among various ministries that hinder cooperation amongst them. Apart from this, the challenge of scaling up IWRM in Nepal from the local to higher levels remains, coupled with interpreting IWRM in a manner that suits best to continue fulfilling the sectoral mandates.[18] As a relatively new frontier of IWRM, Afghanistan echoes similar concerns. As a recommendation, Ahmadzai et al. suggest a creation of 'technical', 'non-affiliated' and 'empowered' working group at the centre to neutralise the struggle for power between line ministries for water sector reforms to enhance agricultural productivity.[19] Clearly, despite a long and illustrious history of arriving at an integrated approach like the IWRM, the concept remains weak owing to the dearth in an integrated knowledge system from which it can draw its functional strength and demonstrate tangible outcomes. To make the approach to the generation of SINK for the HKH river basins, a review and some understanding of work on the integration of knowledge will be useful.

Post-IWRM propositions for Integrated Knowledge

Integration is a conceptual process that can help policymakers arrive at solutions to complex problems that are non-linear. It encompasses all forms of interactions – between and among systems, actors, disciplines, jurisdictions, institutions, and sectors— and at a suitable spatial scale, like a river basin. The knowledge thus created from these interactions become instrumental in creating a repository of knowledge that is essential to advance holistic governance. This includes change in perception and capacity building of political leaders, policymakers and water professionals. Taking the initial step towards integration requires a synthesis of knowledge from diverse fields and disciplines.

A review of the thought processes on integration emerging globally will be useful as a background for generating a SINK for the HKH region. Based on a review of current research on an integrative approach to knowledge and its application, this report identifies four crucial components: an initial motivation for integration; a critical examination and assessment of processes and sub-processes that lead to the generation of integrated knowledge; an integrating factor that binds the elements together; and the scope to apply the knowledge to diverse and complex problems operating at varying temporal and spatial scales. A basis for the initial motivation is the recognition and development of a 'big idea' – an idea which is simple enough to provide a clarity of purpose to a varied community of researchers, while stimulating them intellectually.[20] The same can be extrapolated for an even wider community involving scientists, citizens, and government agencies.

The Water Framework Directive of the European Union (EU)[21] is an example of a regional instrument that uses available integrated knowledge while making it acceptable to diverse member countries. The motivation was primarily to ensure the health of the rivers in the region.[22]

It is also important to identify the efforts that lead to the creation of integrated knowledge. Integration is created at the interface between two or more elements of knowledge that are of a different kind. One way to understand this is to critically assess the interfaces shared between the three most important stakeholders that collectively shape the decisions on river basin governance and are also impacted by the problems of the river: civil society, service agencies, and scientists. A collective understanding and a partnership between science, society, and government agencies are imperative for co-managing complex realities.[23,24]

Integration of Knowledge on the Earth's Surface

For the governance of water systems, scientific knowledge itself needs to be interdisciplinary.[25] Paola et al. have argued that an understanding of the interwoven complex of physical, ecological, biological, geochemical and human dynamics would be critical for predicting the evolution of the natural world, such as the Earth's surface. Therefore, the need for the scientific community to work across disciplines towards the goal of developing a unified surface process science to provide a comprehensive and predictive understanding of the dynamics of Earth's surface.[26] As a starting point, they have focused on channels and channel networks that offer a natural organising template for environmental observation, modelling, and prediction through the interplay of physical, ecological, and geochemical variables. In other words, they suggest that the predictive study of channels and networks and their behaviour would be the integrating factor for knowledge in disciplines as diverse as hydrology, geomorphology, ocean and atmospheric science, geology, and ecology.

Despite a preliminary level of integration using earth system dynamics as a natural integrator of disciplines, the proposal by Paola et al. has been largely restricted to the quantitative tools and methods. The role of humans in predicting earth system dynamics such as channel behaviour and processes has been missing despite an iteration of stream restoration as a potential ‘motivation’. To that end, two other recent, interdisciplinary endeavours at a global scale deserve mention: the study of critical zones or the Earth’s thin living skin,[27] and that of planetary boundaries to find a “safe operating space for humanity.”[28] Both of these studies account for the human impact on the planet as is occurring in the present era and analyses water systems, amongst various other focal points. Despite evidence, however, there has been poor uptake of the recommendations and the connection with policy remains weak. This hints at other variables that might be important for making science work in a holistic manner, which is a priority for the HKH region.

For instance, it is common knowledge that human decisions and actions through the control and regulation of flows have detrimental impacts on environmental security in the long run. These actions are essentially guided by qualitative attributes such as attitudes, perceptions, and interests, hinting at an essential integration between the ‘quantitative’ and the ‘qualitative’. Many parts of the HKH region have been impacted by reductionist engineering without any concern for long-run costs to livelihood and ecosystem processes.[29] Projects for the augmentation of water supply, hydropower installations, and other impoundments involving disproportionate benefit-sharing from shared watercourses, and prevention of inundation in the floodplains through the construction of embankments—have all resulted in a myopic and hegemonic vision of development.

For instance, evidence shows that avulsions – a natural process by which flow diverts out of an established river channel into a new permanent course on the adjacent floodplain abandoning the former channel, are now engineered by humans in coastal deltas and inland alluvial fans.[30] Deforestation and human interventions in the upstream of avulsion sites create an increased inflow of sediments. This is compounded by the construction of levees and dams along the volatile stretches of the river that inhibit the natural deposition of these sediments in floodplains, thereby triggering avulsions.

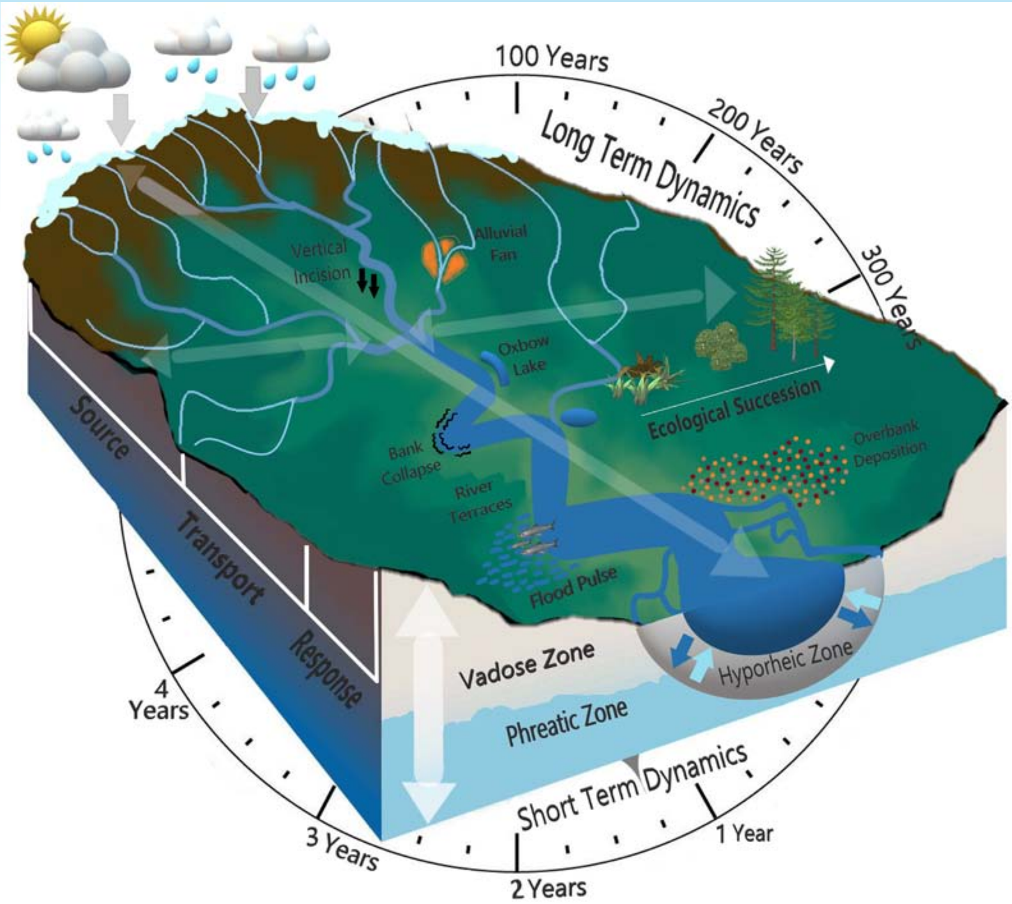
Integration of Knowledge and Perception of Flows in Rivers

Rivers do not just constitute volumes of water to be diverted for meeting human requirements. Flows are constituted by many elements, while they are quantified as volumes passing a point per unit time. Flows in rivers are constituted by water (including quality), energy, biodiversity, sediments, among others, in a synergetic relationship. Such a perception holds great importance for the HKH region.[31] The WEBS perspective is based on the integration of meteorology, water chemistry, hydrology, sedimentology, geomorphology, river engineering, economics, and other disciplines and knowledge realms. The four elements in WEBS are closely related with each other and changes in one affect the others. This comprehensive perception should further be complemented by creating a broader framework of scientific inquiry. By adopting generalisation and causal explanation,[32] the framework becomes inclusive to the social sciences and studies of ecological systems.[33] Aided by an interdisciplinary science to expose the larger spectrum of knowledge that is developed by learning together rather than in competition,[34] the three stakeholders mentioned earlier need to develop an adaptive and cooperative approach.

The interaction between rivers with the surrounding landscape, enabled through various kinds of flows to and from the channel, is also underrepresented in policy. This holds particularly true for the monsoon-dominated landscape of the HKH region. There is substantial contribution to flows from snow and glacial melts, thereby dictating the perennial nature of flow and their time-lags. The bulk of the water is derived from the South Asian Summer Monsoon (SASM) and East Asian Summer Monsoon (EASM), resulting in distinct, annual peaks in the hydrograph within a short and predictable time interval, during a specific period of the year. Thus, the geomorphic function of flows increases during this 'wet period', allowing high flows in the channels to erode, transport, and deposit sediments and biota. Over millennia, such actions have created the fertile floodplains and have provided various ecosystem services to humans including agriculture and fisheries.

In the present times, these floodplains house the burgeoning cities of Asia like Shanghai, Dhaka, Kolkata, Delhi, and Lahore, as well as extensive tracts of arable land. Thus, the nourishing high flows—or floods—are perceived an inconvenience to human interest in the floodplains.[35] An eco-hydrological perspective of floods would take into account the rainfall-runoff and surface-subsurface hydrologic linkages. The interactive pathways of river-floodplain ecosystems are of four types: lateral, longitudinal, vertical, and temporal (Figure 5).[36] The deliberate manipulation of rivers for enhancing certain functions such as water provision (diversion and supply), conveyance (navigation, hydropower generations) or limiting hazards (floods, bank erosion), have severely undermined the natural process of ecosystems. These processes result from a connected riverine system. Wohl has attempted to summarise river science through the perspective of flows being integral and espouses new approaches to river basin governances.[37]

Figure 5: The interactive pathways of river-floodplain ecosystems – lateral, longitudinal, vertical and temporal



Source- Modak and Ghosh (2021)[38]

Integration of Knowledge of Science, Society, and Governance

The examples given in the earlier sections of this report are from the physical world. Meanwhile, a framework has been provided for structuring the partnership between science, management, and society, wherein the scientist adopts a 'service to society' attitude and recognises their dual role of not just obtaining knowledge but also disseminating it within the society.[39] Similarly, the role of public agencies is also to not 'solve the problem' as experts through a regulatory, command-and-control approach. Rather, it should provide unbiased social services that will allow the community to engage the knowledge with the problem at hand and arrive at potential solutions. Key would be the employment of pragmatic tools to alter the patterns of resources use and move it to an agreed future distribution of costs and benefits through a participatory and inclusive process and without coercion. For its part, society needs to understand that transferring the responsibility of solving problems of resource governance to public agencies would not help. Moreover, absolving themselves from the fact that all the problems that are presently encountered deal with common property resource that inevitably warrants a cooperative approach, is also an impediment for effective governance.

Thus, a shift towards shared learning generated by 'communities of learning' would lead to the generation of integrated knowledge. Often, the term 'best available science' (BAS)[40] is used to engender involvement, credibility, awareness, trust, transparency, and communication amongst the stakeholders, thus acting as an effective integrator. Ryder et al. have laid out attributes that underpin BAS and identified issues of uncertainty and risk of an overt reliance on science that may lead to unexpected or inequitable outcomes.[41] They also emphasise communicating BAS to negate turbulent boundaries between cultures of science policy and governance, with the acknowledgement that the information may be subjected to diverse and contested interpretations.[42] Harmonising relations and co-creation of knowledge is critical to arrive at BAS that considers the integrated nature of water systems.

This report discusses some of the emerging initiatives in the generation of integrated knowledge. In the case of the HKH, for which the process of the generation and use of SINK is in a nascent stage, the idea of SINK may act as a push for research and education, which can in turn help achieve a more holistic form of governance.

The following section analyses the challenges of governance of the 10 HKH river basins. It explores the scope for applying SINK in the management of each of these basins, as well as ideas for cross-learning.

Endnotes

1 Justin Fox, "From "Economic Man" to Behavioural Economics," Harvard Business Review, May 2015, https://hbr.org/2015/05/from-economic-man-to-behavioral-economics

2 R. J. Chorley, and R. W. Kates, Introduction to *Introduction to Geographical Hydrology*, by R. J. Chorley (London: Methuen and Co., 1969).

3 G. F. White, "Contributions of geographical analysis to river basin development," *Geographical Journal* 129 (1963): 412-36.

4 Bruce P. Hooper, "Integrated water resources management and river basin governance," *Journal of Contemporary Water Research and Education* 126 (2003): 12-20.

5 Malin Falkenmark and Carl Folke, "How to bring ecological services into Integrated Water Resource Management." *AMBIO:; A Journal of the Human Environment* 29,6 (2000): https://doi.org/10.1579/0044-7447-29.6.351 .

6 Global Water Partnership, *Integrated Water Resources Management - TAC Background Paper No. 4*, 2000 https://www.gwp.org/globalassets/global/toolbox/publications/background-papers/04-integrated-water-resources-management-2000-english.pdf

7 H. A. Simon, *Models of Man: Social and Rational.* (New York: Wiley, 1957)

8 G.F. White, "Choice of use in resource management," *Natural Resources Journal* 1 (1961): 23-40.

9 J. Wolpert, "The decision process in spatial context." *Annals of the Association of American Geographers* 54 (1964): 537-558.

10 R.J. Chorley, R.W. Kates, Introduction to *Introduction to Geographical Hydrology*

11 G. F. White, "Contributions of geographical analysis to river basin development," *Geographical Journal* 129 (1963): 412-436.

12 Falkenmark, Malin, and Håkan Tropp, "Ecosystem Approach and Governance: Contrasting Interpretations." *Stockholm Water Front* 2 (2005): 4-5.

13 'Integrated Water Resources Management, 2000'

14 A. K. Biswas, "Integrated water resources management: A reassessment." Water International, 29 (2004): 248–256.

15 W. Medema et al., "From premise to practice: A critical assessment of integrated water resources management and adaptive management approaches in the water sector." *Ecology and Society* 13, 2 (2008): 29. http://www.ecologyandsociety.org/vol13/iss2/art29/

16 K.M. Jensen, "Viewpoint–swimming against the Current: Questioning development policyand practice." *Water Alternatives* 6, Issue 2 (2013): https://www.water-alternatives.org/index.php/all-abs/215-a6-2-12/file

17 Mark Giordano & Tushaar Shah, “From IWRM back to integrated water resources management,” *International Journal of Water Resources Development* Volume 30, Issue 3 (2014), https://doi.org/10.1080/07900627.2013.851521

18 Suhardiman, Diana, Floriane Clement, and Luna Bharati. “Integrated water resources management in Nepal: key stakeholders’ perceptions and lessons learned.” *International Journal of Water Resources Development* 31, no. 2 (2015), https://doi.org/10.1080/07900627.2015.1020999

19 Ahmadzai, Atal, Mujib Ahmad Azizi, and Khalid Behzad, *The impacts of water sector reforms on agricultural productivity in Afghanistan*, Kabul, Afghanistan Research and Evaluation Unit, 2017, https://www.researchgate.net/publication/331476178_The_Impacts_of_Water_Sector_Reforms_on_Agricultural_Productivity_in_Afghanistan/stats#fullTextFileContent

20 Graham E. Fogg and Eric M. LaBolle, “Motivation of synthesis, with an example on groundwater quality sustainability” *Water Resources Research* 42, 3 (2006), https://doi.org/10.1029/2005WR004372

21 Water Framework Directive, *Water Framework Directive. Journal reference OJL* 327 (2000): 1-73.

22 Gorazd Urbanič et al., “Back to Ecology: Reference Conditions as a Basis for Assessment, Restoration and Sustainable Management of Large Rivers,” *Water* 13, no. 18 (2021), https://doi.org/10.3390/w13182596

23 Donald Ludwig, “The era of management is over.” *Ecosystems* 4, no. 8 (2001): 758-764.

24 Kevin H. Rogers, and Charles M. Breen. “The ecology–policy interface.” *Frontiers in Ecology and the Environment* 1, no. 1 (2003): 50-50.

25 J. Bandyopadhyay, *Water, ecosystems and society: a confluence of disciplines* (SAGE Publications).

26 Chris Paola et al., “Toward a unified science of the Earth’s surface: Opportunities for synthesis among hydrology, geomorphology, geochemistry, and ecology.” *Water resources research* 42, no. 3 (2006) https://doi.org/10.1029/2005WR004336

27 P. Waldron, “Critical zone science comes of age,” *Eos, 101* (2020) https://doi.org/10.1029/2020EO148734

28 Johan Rockström et al., “Planetary boundaries: exploring the safe operating space for humanity.” *Ecology and society* 14, no. 2 (2009) http://www.ecologyandsociety.org/vol14/iss2/art32/

29 Jayanta Bandyopadhyay and Nilanjan Ghosh, “Holistic engineering and hydro-diplomacy in the Ganges-Brahmaputra-Meghna Basin,” *Economic and Political Weekly* (2009): 50-60.

30 F. Pearce, ”When the levees break.” *Science* 372, 6543 (2021) https://doi.org/10.1126/science.372.6543.676

31 Jayanta Bandyopadhyay, "Towards a Synergy-Based Approach to River Basin Governance", *Observer Research Foundation Issue Brief No. 308*, (2019) https://www.orfonline.org/research/towards-a-synergy-based-approach-to-river-basin-governance-54786/

32 Steward TA Pickett et al., *Ecological understanding: the nature of theory and the theory of nature* (Academic Press, 2010) https://doi.org/10.1016/B978-0-12-554522-8.X5001-8

33 Crawford S. Holling and Craig R. Allen. "Adaptive inference for distinguishing credible from incredible patterns in nature." *Ecosystems* 5, no. 4 (2002): 319-328.

34 Pickett et al., *Ecological understanding: the nature of theory and the theory of nature.*

35 Kersi S. Davar, John M. Henderson, and Brian C. Burrell, "Flood damage reduction." *Water international* 26, no. 2 (2001): 162-176.

36 Bandyopadhyay, *Water, ecosystems and society: a confluence of disciplines.*

37 Ellen Wohl, Sustaining River Ecosystems and Water Resources (Cham: Springer, 2018)

38 Sayanangshu Modak, & Surajit Ghosh, *Floods as agents of vitality: Reaffirming human-nature synergies*, Water Science Policy, 2021, https://dx.doi.org/10.53014/REHQ6535

39 Kevin H. Rogers, "The real river management challenge: integrating scientists, stakeholders and service agencies" *River Research and Applications* 22, 2 (2006), https://doi.org/10.1002/rra.910

40 T.B. Francis, K.A. Whittaker, V. Shandas, A. V. Mills, and J.K. Graybill, "Incorporating science into the environmental policy process: A case study from Washington State." *Ecology and Society* 10 (2005): 35–52.

41 Darren S. Ryder et al., "Defining and using 'best available science': a policy conundrum for the management of aquatic ecosystems" Marine and Freshwater Research 61, 7 (2010), https://doi.org/10.1071/MF10113

42 Darren S. Ryder et al., "Defining and using 'best available science': a policy conundrum for the management of aquatic ecosystems"

The Ten HKH River Basins

This chapter describes the ten river basins in the HKH region with respect to the governance challenges they are facing and how integrated knowledge can be used to address them. The river basins will be described in a sequence starting from the Yellow and going clockwise up to the Tarim. Such a view of the entirety of the HKH landscape would be useful for the design of a governance framework that will be relevant to each basin, while being harmonised with the specificities of the HKH landscape as a whole.

1. Yellow River Basin

The Yellow River flows along the fringes of the Ordos Plateau at Bayin, Gansu Province.
(Photo: Getty Images/zhouyousifang)

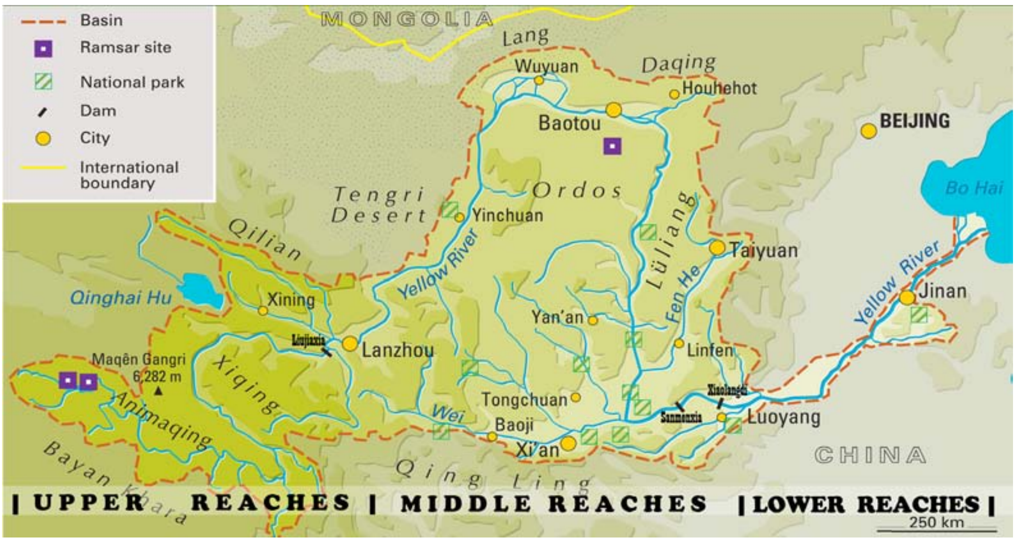
Physiography and Socio-Cultural Milieu

Known as 'China's pride' and the 'cradle of Chinese civilisation', the Yellow River or Huang He is arguably the most important in China. The river originates from the Bayan Har Mountains in the Tibet-Qinghai plateau and follows a 5464-km-long[1] generally eastward journey along a particularly circuitous route to the Bohai sea. At its loop, the river traverses the extensive Ordos (also known as Loess) Plateau which contains deposits of loamy soil from where the river acquires a large amount of silt and gets its distinctive yellow colour. Based on physiography, the entire river can be divided into three stretches – the upper reaches (its source region at 4500 masl to the Toudaoguai gauging station near Datong at 1000 masl); the middle reach (Toudaoguai to Huayuankou); and the lower reach (Huayuankou to the river's confluence with the Bohai Sea).

The current average annual precipitation in the basin is only 476 mm, rendering the basin largely arid and semi-arid. The bulk of the moisture is drawn through the East Asian Summer Monsoon (EASM) between July and October with a distinctive increase in rainfall as one moves downstream.[2,3] The average annual discharge of the yellow river is greater than 2100 m^3/s,[4] though other estimates have put it in the range of 1300 m^3/s to 1990 m^3/s,.[5,6,7] Historically, 70 percent of the sediment brought down by the river gets deposited in the North China Plain while the remainder enters the sea.[8] At present, it discharges roughly <0.2 X 10^8 tonnes/annum of suspended sediment into the sea[9] and contributes around 6 percent of the global sediment loads in the world's oceans.[10] To put these numbers in perspective, Yellow ranks 26th in the world in terms of drainage area, but it stands second only to the Amazon in terms of sediment delivery to the oceans.[11]

The sediments carried by the river has been instrumental in creating a fertile floodplain and a highly productive delta. The basin was home to the first-ever dynasty in northern China—the Xia dynasty, and has stood witness to the origin of dryland farming involving indigenous food grains like foxtail millet and broomcorn millet.[12] Since ancient times, civilisational progress in the basin has been closely associated with the ability to control the flow in the river system.[13] Today around 115 million people depend on the river,[14] spread across eight provinces and autonomous regions of China. Most of the population are settled in the lower reaches of the river, primarily in the two provinces of Henan and Shandong, where employment opportunities abound. The population density in the lower reaches of the river is also significantly higher at 750 people/sq. km compared to 35 and 39 in the middle and upper reaches, respectively.[15] As China has evolved from a dynasty-controlled kingdom to a people's republic, the dependence and use on the water of the Yellow has also increased manifold. Large dams for flood moderation, irrigation and hydropower generation are prioritised for nation-building, providing food security, and preventing damages due to natural hazards like floods.[16]

Figure 6: Map of the Yellow River Basin



Source: UNESCO (2011)[17] – modified by authors.

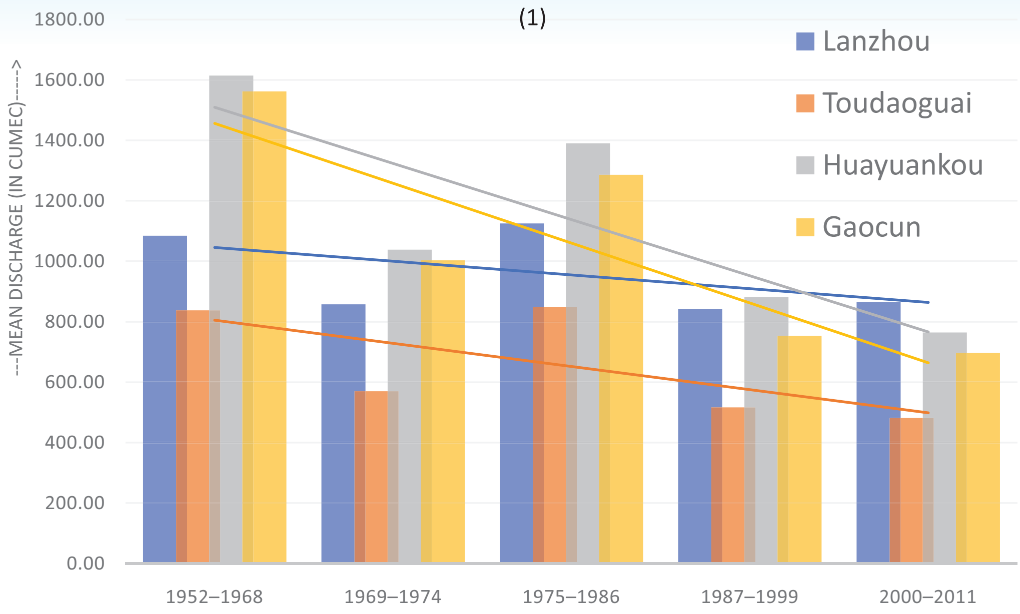
Challenges to Integrated Governance

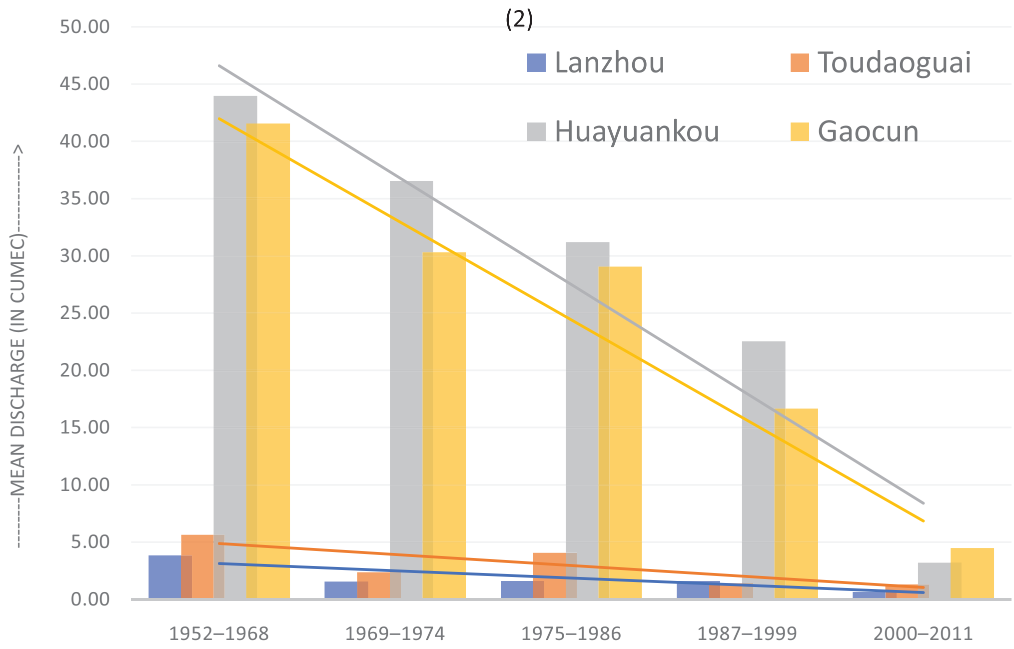
In the last five decades, China has undergone rapid economic growth due to the adoption of a liberalised economic system, greater links with international financial institutions, and an inflow of foreign direct investments. The growth, in turn, has fuelled industrialisation, agricultural intensification, and urbanisation in different parts of the basin.[18] Policies like the 'decentralised household responsibility system' of 1979 which held households responsible for the profits and losses of an enterprise have been crucial for the intensification of agriculture and ensuring food supply to an increasing population.[19] All these initiatives have propelled China to global-style modernity by bolstering the national economy. Little attention was paid to situate such plans and policies within the bio-geo-physical realities of the basin. Inherently disintegrated from the natural specificities of the basin, such policies have created a dichotomy between the ecological integrity of the basin and economic goals. Since 1972, channel dry-up events have been occurring in the delta due to water abstraction and stockpiling. In one of the most extreme of such cases, the channel remained dry for 226 days in 1997 within a stretch of 704 km upstream from the confluence of the river with the sea (See Figure 7).

Closely associated with reduced water quantity is the issue of declining water quality. According to various studies, this decline has been caused by saline irrigation return waters,[20] and organic pollutants from urban areas and heavy metals in untreated waste water produced from industrial operations.[21] The use of chemical fertilisers in the basin has continued to increase (to reach 70 percent within just a decade since 2005) and so has the construction of water infrastructure like wells, canals, and reservoirs to bring more land under irrigation. Indeed, irrigated area had increased by more than 800 percent between 1949 and 2000.[22]

The ancient wisdom of Great Yu (2200-2100 BC) suggesting "who so ever controls the Yellow River, controls China" continued to find relevance in rapidly modernising China. The water infrastructure primarily augments diverted flow and reduces the 'water-scarce' nature of the basin. However, water scarcity in the basin has remained a stubborn reality. The basin is endowed with only 430m^3 of water per capita. This is far lower than the threshold (1000m^3) of identifying a region as "water-scarce" and within the category of "absolute scarcity" (below 500 m^3).[23,24,25] Apart from the natural limiting factors of prevailing climatic and hydrological condition defining the skewed water availability over space and time, water demand has also risen from 12.2 X 10^9 m^3 in 1950 to 35.1 X 10^9 m^3 in 2008 resulting in a distinct decline in river flow.[26,27] Disintegration was all pervasive – from planning to execution, and across the entire length of the river – disregarding its continuity and the ecological processes vital for the sustenance of the ecosystem.

Figure 7: Mean water discharge (1) and sediment concentration (2) at four gauging stations (from upstream to downstream with Gaocun being the most downstream location) along the Yellow River within different periods.[28] **(Under Creative Commons)**





A supply-oriented paradigm based on structural interventions had guided water governance in the basin. This strategy has disturbed the ancient balance that was instrumental in shaping Chinese civilisation. In recent years, the use of water for irrigation in the upstream has created water scarcity in the downstream provinces like Shandong and Henan, which have a higher share of industrial production as compared to other provinces in the basin.[29] Water scarcity has also manifested into a sectoral competition for the allocation of water, with authorities generally giving preference to industrial and domestic users than for agriculture.[30] The river also has a long history of inundating its floodplain, causing casualties in the past. Despite floods causing momentary inconvenience and contributing to bountiful harvests for the rest of the year, China has a long tradition of carrying out technological and organisational innovations to contain the spread of the floodwaters, the pace and intensity of which had increased in recent years. This has contributed to the deterioration of the environment and destabilisation of the channel of the Yellow river.[31]

In a marked departure from a linear approach towards knowledge creation and application, the Yellow River Conservancy Commission (YRCC), established in 1946, was empowered by the Central Government in 1999 to manage and integrate water allocation in the entire basin for meeting social, economic and environmental needs. The basin-level institutional push also benefited from the synergistic association with a pre-existing policy called the Yellow River Water Allocation Scheme (1987). The scheme sought to balance demand and supply of water by setting a cap on abstraction at 37 billion m^3 for an average runoff of 58 billion m^3.

The efforts at flood control have various strategies for various sections of the river – soil erosion and sedimentation control measures in the Loess Plateau (upper stretch), constructing and operating large reservoirs like Sanmenxia and Xiaolangdi (middle stretch), and finally, the expansion of flood retention areas and the raising of existing levee structures (lower stretch). The use of science and technology such as satellite-based drought monitoring and flow forecasting to predict water run-off patterns, scale modelling and simulation, have been the hallmark of YRCC. Applied research for water and sediment regulation in Yellow River to effectively enlarge its flow capacity to prevent flooding have also been conducted.

The challenges in the basin remain three-fold: managing agricultural productivity and economic growth despite an apparent 'scarcity'; finding nature-based solutions and innovations for managing high sediment yield; and preventing natural hazards like floods, droughts and channel avulsion in the delta.

2. Yangtze River Basin

The Three Gorges Dam on the Yangtze River is a multi-function water-control system and also the world's largest hydroelectric facility.

(Photo: Getty Images/Xiaoyang Liu)

Physiography and Socio-Cultural Milieu

Political power in China has historically been concentrated in the Yellow River basin, and economic power was derived from the fertile agricultural plains drained by the Yangtze and its tributaries. Originating from the Tanggula Mountains in the Tibet-Qinghai plateau, Yangtze is the longest river of China (6300 km)[32] and also the largest in terms of basin area (1,722,193 km^2). Globally, Yangtze ranks fifth in terms of water discharge (900 km^3/year) and has a sediment load (470 Mt/year) comparable to some of the highest rivers in the world.[33] Most of the precipitation occurs between May to October and the moisture is supplied by the prevailing conditions of EASM. The percentage of glacial melt in the total flow is only 18 percent,[34] making the monthly mean discharge of the river extremely variable due to the pre-eminent role of the monsoon. Abundant and widespread rainfall in the basin has served as an important source of food grains since the beginning of the rule of large dynasties in China.

The conquest of Shu and Ba, now located within Sichuan province in the Upper Stretch, between 441 and 316 B.C., had provided the Qin dynasty with 'a new, highly productive grain basket'. This helped the dynasty conquer a larger territory in the third century.[35] Observers have said that in the two millennia since the initiation of the Qin dynasty, Yangtze has continued to mark the boundary between the kingdom and the empire by virtue of its sheer economic potential.

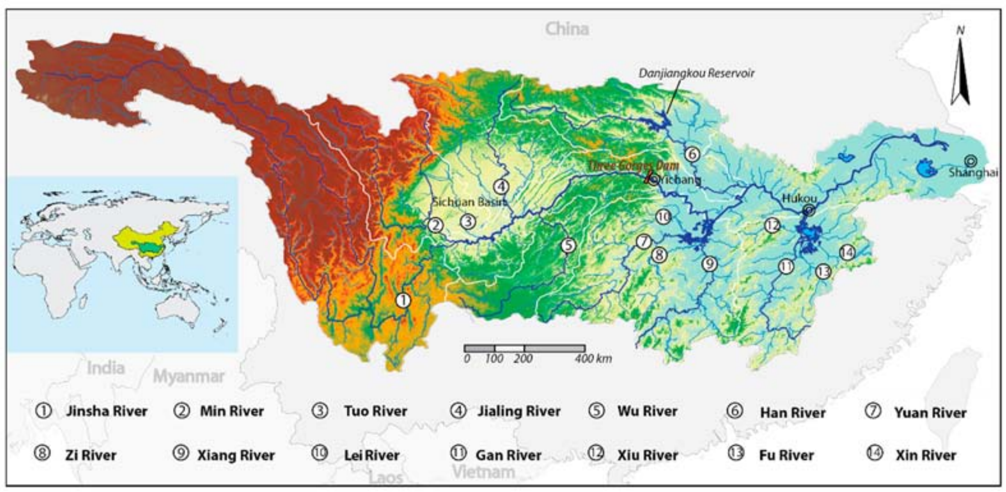
In terms of physiography, the basin can be divided into three parts: upper reach, middle reach, and lower reach. The upper reach is the longest and consists of high plateaus, mountains, river valleys, and large intermontane regions. From the source to Yichang—located in the downstream of the Three Gorges Dam (TGD), the variation of discharge in the upper stretch is minimal as deep inside the hinterland, the influence of monsoon is reduced.[36] The middle reach is often defined as the area between Yichang and Hukou (the outlet of the Poyang lake), though some extend it to Datong (which marks the limit of tidal influence). In contrast to the upper basin, the middle reach is characterised by extensive floodplains, large lakes, and hills. Agriculture is the main economic activity, supported by the presence of irrigation infrastructure around the large lakes like the Dongting, the Poyang, and the Jianghan. The lower reach of the river, meanwhile, consists of the basin downstream of Datong and until the estuary. This part of the basin consists of vast expanse of low plains that has undergone dramatic and rapid socioeconomic growth in the past few decades. The geographical endowments and the turn of events across history, have led to the development of three distinct regions within the basin that have their own economic and political centres of power: Chengdu and Chongqing for the Upper Yangtze; Wuhan, Changsha and Nanchang for the Middle Yangtze; and Suzhou, Hangzhou and Shanghai for the Lower Yangtze.

Between 1949 and 1976, under the leadership of Mao Zedong, China took various initiatives for expanding irrigation and food security in the basin while also initiating the survey and planning for constructing the TGD.[37] In the period after Mao, rivers of the Tibet-Qinghai plateau became even more important as the technology for harnessing the flows could be utilised. Gradually, in the 21st century, the demand for the ecological restoration of Yangtze as one of the 'mother rivers' of China gained prominence – leading to the declaration of an 'ecological civilisation' as a national objective in the 12th Five Year Plan document of China issued in 2011.[38]

Challenges to Integrated Governance

As with the Yellow, the Yangtze basin similarly suffers from the dominance of the constructionist paradigm that largely disregards natural systems and processes.

Figure 8: The Yangtze River Basin



Source: Xiankun et al.[39]

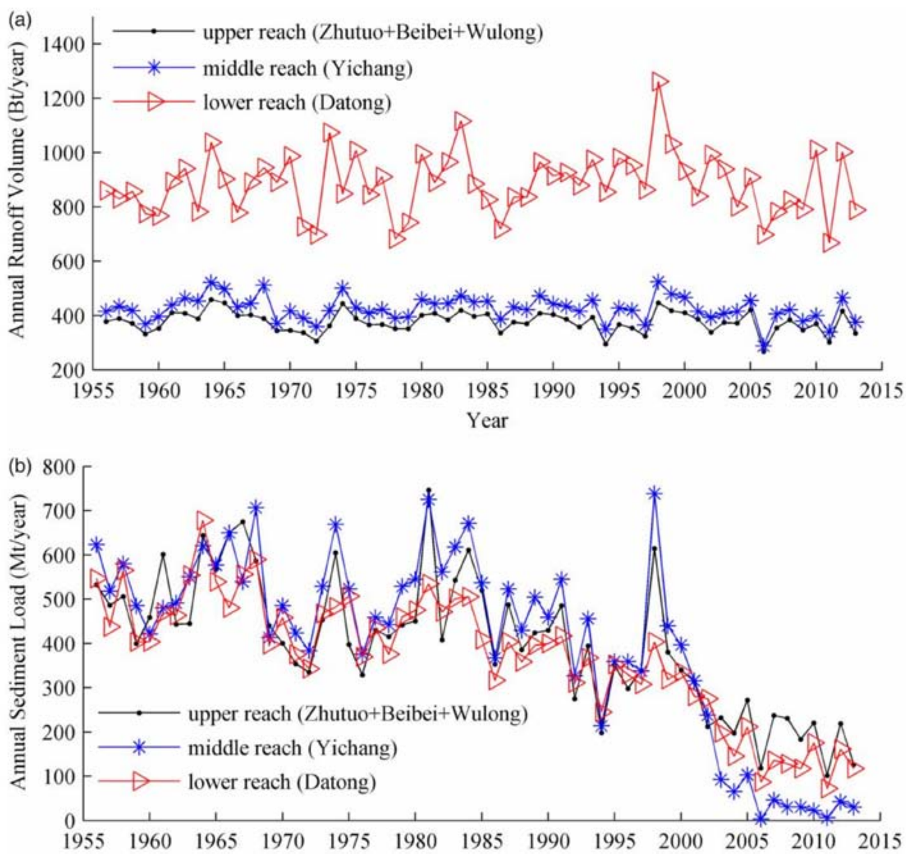
Perhaps the greatest tragedy in this oversight has been the extinction of the Baiji, or the Yangtze river dolphin that was endemic to the middle-lower Yangtze and neighbouring Qiantang River. In 2006, scientists declared the Baiji to be extinct, and they attributed the phenomenon to unsustainable by-catch by fishing communities, along with the degradation of its habitat.

The present challenges in the Yangtze basin are wide-ranging and pertain to the location along the river system from the headwaters to the estuary. The Upper Basin is plagued by issues of deforestation and reduced discharge in the tributaries. Despite being relatively less modified than the middle and lower stretches, some areas show a strong and acute degradation of forests. For example, the total forest cover in the Minjiang River basin has reduced from 1327 X 10^3 hectares in the 1960s to 467 X 10^3 hectares by the end of the century—a decline of nearly 65 percent. The Jianling and the Yalong rivers are also affected by deforestation of varying intensity.[40] In combination with the fact that agriculture is practiced on sloping land, the impact of soil erosion in the upper reaches of the Yangtze has also become a growing concern.

Since the middle of the last century, the construction of dams gained a firm footing in the Yangtze basin with around 50,000 dams being constructed for meeting increasing hydropower and irrigation water requirements.[41, 42] The construction of the TGD in 2006 was a monumental feat, still standing as the largest hydropower project in the world. It also led to widespread submergence of land in the Three Gorges Reservoir Region (TGRR) that extends to a distance of approximately 600 km upstream of Yichang.[43] In recent years, industrial and domestic wastewater releases in the TGRR have caused eutrophication,[44] even as toxic chemicals from abandoned factories, mines and garbage dumping sites have remained in the vicinity post-resettlement.[45]

After a prolonged period of accelerated dam construction in the entire basin and more than 19 years since the TGD started operating in a limited capacity, a substantial amount of literature has emerged on the impact of the large infrastructure construction on the river and its delta. Almost all of these analyses point to a steady decline in the sediment load (Ref. Fig. 9) and a progressively reducing supply of sediments to the delta. The sediment discharge in the Yangtze has dropped by almost 70 percent in the last four decades when measured at Datong – the most seaward gauging station upstream of which there is no tidal influence. The drop is more acute immediately after the TGD and at the end of the upper stretch, measured at Yichang gauging station – approximately 530 Mt/yr in the 1950s and 1960s to approximately 60 Mt/yr after 2003.[46]

Figure 9: Annual water and sediment load for the Yangtze River as measured at Datong, the farthest downstream gauging station, 1953–2008



Source: Yang et al.[47]

The diversion of water for meeting the increased water demand in the basin, and afforestation efforts in recent years, have also contributed to reduction in sediment discharge.[48]

This has not only resulted in the loss of ecosystem services of sediment-rich flows in the downstream regions, but has also created an additional problem of river bank erosion. In the first six years (2003-2008) of TGD's operation, the middle section of the river underwent sustained net erosion; 40 percent of the sediment remains trapped behind the TGD, causing the energised water to erode its banks.[49] The trapping of sediments behind the TGD has meant that the flow in the downstream has a reduced concentration of suspended sediments. The lowermost 565 km of the Yangtze has experienced excess riverbed erosion and the deepening of riverbed due to channel width reduction, backwater effects, tide and wave and in-channel sand mining.[50]

Even with such erosion activity, the net outfall of sediments into the East China Sea has continued to decline. This has caused a net decline in salt marsh accretion and net erosion in the subaqueous delta front.[51] The sediment inflow into Lake Dongting and Lake Poyang, both connected with the river, has also reduced,[52] as has the freshwater inflow in the middle and lower reaches during Autumn while increasing the inflow during Spring.[53] Closely linked with the operation of TGD, the impact of altered flow regimes on the river-lake ecosystem and their onnectedness needs to be explored further.

3. Mekong River Basin

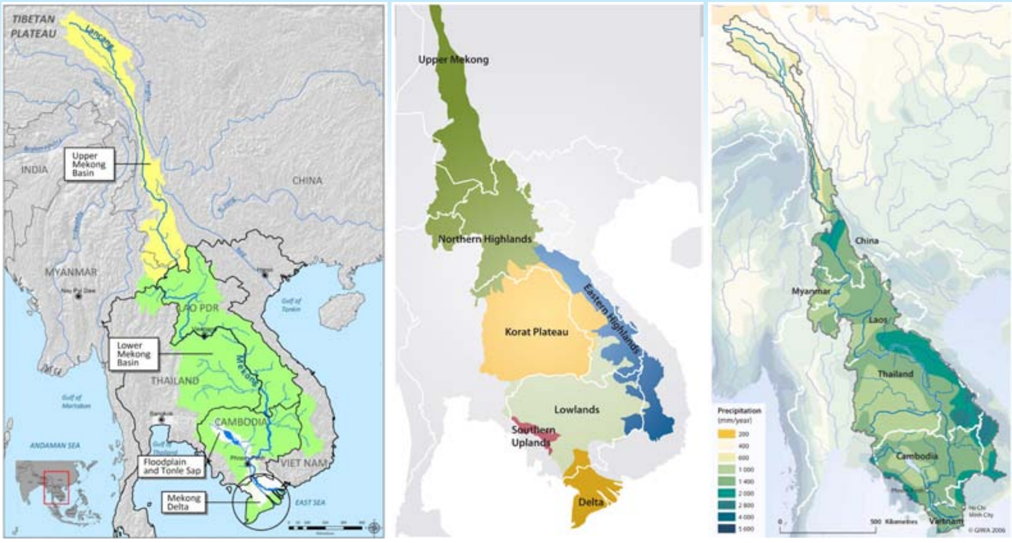
The fisheries industry based in the 'flood pulse' of the Mekong and its tributaries, employs millions in the lower Mekong countries, particularly Cambodia and Vietnam.
(Photo: Getty Images/sangkhomhungkhunthod)

Physiography and Socio-Cultural Milieu

The Mekong basin has supported successive human civilisations throughout history. The river itself has provided a passage for the movement of people, goods, and ideas since its birth. At present, the river supports the subsistence needs of more than 70 million people in six countries in South East Asia. It originates from the "three river source area" in the Sanjiangyuan National Nature Reserve, perched high in the Tibetan Plateau. The total length of the river is 4880km[54], draining a pan-shaped basin with an area of 795,000 km^2.[55] The annual mean discharge of the river into the South China Sea is approximately 475 km^3.[56]

The entire basin can be divided into six distinct physiographic regions: Lancang River Basin (Tibet and Yunnan); northern highlands (Southern Yunnan, Myanmar, Lao PDR, Northern Thailand and Vietnam); Korat Plateau (largely within Thailand); Eastern Highland (From Lao PDR through Vietnam); Lowlands (Cambodian floodplains and the delta region); and Southern Uplands (south-eastern Cambodia) (Ref. Fig 10).

Figure 10: Map of the Mekong basin, its physiography and precipitation

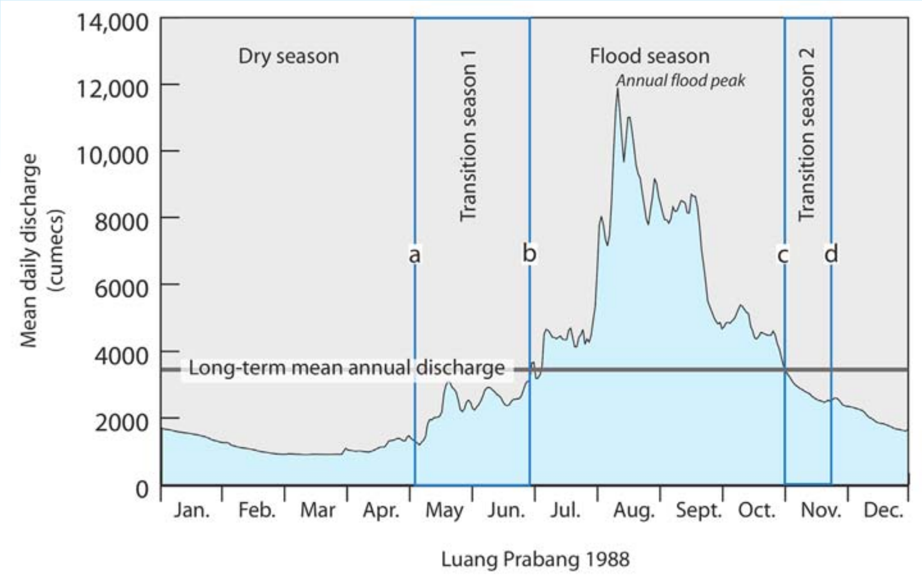


Source: Mekong River Commission[57, 58]

The bulk of the population is settled in the lower Mekong basin; population density – is 50 inhabitants/km² in the Upper Basin, and double that or 100 inhabitants/km² in the Lower Basin.[59] The higher mountains in the Tibetan plateau are permanently snow-covered with very little precipitation. However, immediately south of the plateau in China's Yunnan province, the climate is warmer and annual rainfall is as high as 1700 mm.[60] In the lower Mekong basin, rainfall can be even more significantly high, particularly in the northern and eastern parts (2000-4000+ mm); it decreases over the western basin and the lowlands.[61] The basin is mostly under forest cover. Farming is practiced either in the hill slopes as shifting cultivation, or in the valleys where wet rice is grown in areas where rainfall is high. The southern slopes of the Annamite Range consist of plantation estates.[62]

The river provides a safe and convenient transport route while the fertile floodplains of the Mekong support an agricultural and fisheries surplus that have been traded over the centuries.[63] In the 19th century, European powers were drawn to the region, and France was the first to establish its colonial presence in 1862 when it forced Vietnam to cede three of its provinces.[64] Subsequently, the French explorers followed the same route that was taken in 1644 by the Dutch merchant Geritt van Wuystoff to travel from the delta, up the Mekong, to Yunnan.[65]

Figure 11: Representative hydrograph of Mekong at Luang Prabang during 1988, showing the 4 distinct bio-hydrological seasons



Source: Mekong River Commission (2009)[66]

Apart from navigability, another important characteristic of this basin is that the bulk of the rainfall (85-90 percent) occur between June and October, mostly under the influence of SASM. This results in the discharge fluctuating throughout the seasonal calendar, oscillating between flood and recession pulse that has allowed the animal and plant species to adapt to this cycle of fluctuation. Hydrologists and biologists have identified four such distinct seasons in the annual hydrological cycle, each with its own attribute: end of dry season; end of transition season 1; end of flood season; and end of transition season 2 (Figure 11). The annual flood pulse provides a large and productive ecological system that enhances the floodplain river productivity by submerging terrestrial vegetation and also boosting the productivity through algal production in the warm, shallow and nutrient-rich waters of the floodplains.[67]

The effort to create a basin-wide organisation for the Mekong to deliberate on issues of mutual interest has had a chequered past that has run parallel to a history of shifting balance of power in the region. Initially, it was France who dominated the landscape, particularly in Vietnam, Thailand and Cambodia; Japan followed, during the Second World War, resulting in the expulsion of the western power. The new power balance eventually collapsed with the defeat of the Axis powers and the region witnessed a series of wars of independence. Subsequently, the lower Mekong basin became a frontline of the Cold War as the bipolar centres of power – the US and USSR—jostled for influence and assertion in the region.

The US particularly adopted a strategy of promoting economic development in the Lower Mekong Basin (LMB) to contain the spread of communism after Mao's takeover of China in 1949. The efforts crystallised with the formation of the Mekong Committee (MC) in 1957 to explore the possibilities of coordinated water resources development projects in the lower Mekong Basin.[a] After a series of successes and failures, the MC was disbanded in 1975, as Pathet Lao and Khmer Rouge gained power and the reunification of Vietnam got underway.[b] Throughout the Cold War, Vietnam received technical and financial support from the USSR for hydropower projects.[68] The erstwhile MC became the Interim Mekong Committee in 1978, and continued operating until the early 1990s when all the riparian states again felt the common need to utilise the Mekong's resources for rapid economic development. The international development actors had changed considerably and Asian Development Bank's (ADB) support for developing the "under-utilised" and "uncontrolled" river arose concurrently with the emergence of China as a global economic and political power.[69]

Challenges to Integrated Governance

Growing population and expanding economic interests in the basin have inflicted considerable costs on the environment, among them: permanent modification on the flow regime of mainstream Mekong; sediment trapping; loss of wetlands; and deterioration of riverine habitats. Most of these concerns have been the result of human activity, in particular, hydropower development. According to estimates, approximately 30,000 MW of hydropower can be generated in the four LMB countries; the Upper Basin also has the potential for hydropower generation. In the Yunnan part (China) within the basin, the total hydropower potential is estimated to be 23,000 MW. Thus, hydropower developments in the Lancang and Mekong mainstream, as well as those on its tributaries, is gaining momentum. Most of these are in Lao PDR (13,000 MW), Cambodia (2,200 MW) and Vietnam (2,000 MW).[70] This development has grown manifold in recent years. The Mekong was one of the least regulated of all the large river basins in 2008 with an active reservoir storage capacity capable of holding 2 percent of the annual discharge.

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a Until the early 1970s, a total of eight dams were constructed on the tributaries of the Mekong. Thailand became a large benefactor of the US's and World Bank's policies that emphasised electrification, and construction of roads, reservoirs and canals. The US was the largest non-riparian aid donor to the MC, contributing 37 percent of the total contribution during the committee's first ten years of operations.

b Khmer Rouge is the regime through which the Communist Party of Kampuchea (CPK) ruled Cambodia between 1975 and 1979. Pathet Lao was the left-oriented nationalist group in Laos that took control of the country in 1975.

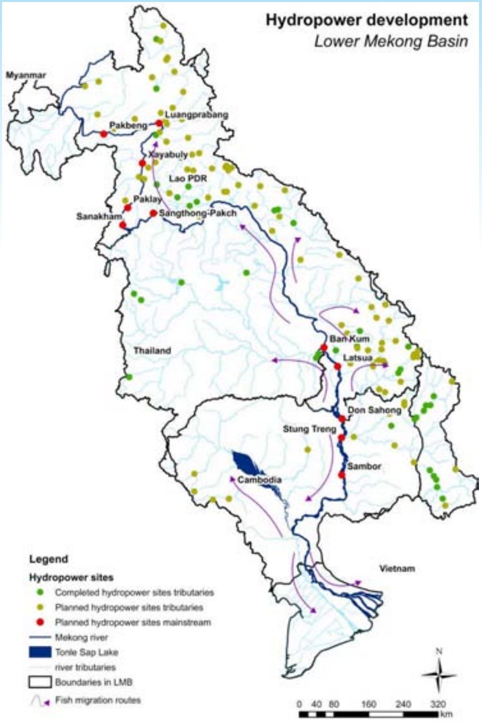
However, this is projected to increase to approximately 19 percent of the mean annual flow, including flood storage capabilities. These figures do not reflect the existing and planned storage of reservoirs being constructed in China.[71]

With hydropower, the debate seems to be centred around the loss of flood pulses, floodplain habitat and wetlands. The impacts of upper Mekong dams appear to have increased the dry season flows (41 - 74 percent above pre-dam averages in March-May),[72] the effect of which is noticed as far downstream as Kratie, Cambodia. During the beginning of the wet season, the maximum daily flow at Chiang Saen and Stung Treng may have been delayed by 22 days in 2010-2014 as compared to the 1960-1991 averages.[73] Another study has estimated that the frequency of floods exceeding 0.5-year recurrence intervals would reduce by 72 percent and 6 percent at Chiang Saen and Strung Treng in Cambodia, respectively.[74] The lower Mekong basin houses dams on the tributaries of the Mekong with integral powerhouses and large storage reservoirs. These have locally reduced the impact of seasonal flow variability in the tributaries but despite there being 11 dams on the Mekong mainstream, flow variability remains high since the dams can store only a few days of the river's mean annual inflow.[75]

A case in point is the Sekong, Sesan and Srepok (3S) tributaries that contributes 16-23 percent of the Mekong's annual flow. The tri-national watershed of these rivers is spread across Vietnam, Laos, and Cambodia, and it could see a general increase (63 percent) during dry season and decrease (22 percent) during the wet season. In a full development scenario (considering 41 dams) the annual daily maxima could be reduced by 36 percent and the annual daily minima increased by 168 percent.[76] Furthermore, dam operations are carried out for profit, employing 'hydropeaking strategies' to match the demand requirements—this has led to fluctuations over daily and weekly time scales (matching lower demand in the night and during the weekend).[77]

As such, the construction of hydropower infrastructure is affecting the river system in three principal ways: (i) decreasing the connectivity of the river system; (ii) altering the flow regime in the mainstream and its tributaries; and (iii) altering the physical and chemical attributes of the water. Free flowing stretches of the Mekong are extremely crucial for the migration of certain species of fish for spawning (Ref. Fig. 12).[78] The importance of fisheries in the delta region cannot be understated. For example, fisheries alone account for 16 percent of Cambodia's GDP, and employs over half the population of the country either full- or part-time.[79] Moreover, the entire harvest of fish in the Lower Mekong Basin accounts for 47-80 percent of the required protein intake for the residents of the region.

Figure 12: Hydropower Development in Lower Mekong



Source: IWMI

This dependency is more than that in any other major basin in the world.[80] However, in terms of sheer economic value, estimates of hydropower benefits (USD6 - USD32 billion) outweighs the damages to industry centred around fisheries (USD2 - USD13 billion).[81,82] However, in terms of the number of people employed in this industry and the food security that it provides for the poor, the loss of flood pulse and fish habitat is going to be immense.

Regional development centred around hydropower exploitation in the Mekong basin involves trade-offs with other provisioning and supporting services of the ecosystem – the most important of which is fisheries. Therefore, a holistic evaluation of hydropower projects is required, along with accounting for all its short-term and long-term costs. Such an evaluation needs to be interdisciplinary. Stakeholder involvement is also crucial at all stages of the projects, such that the benefits of hydropower projects are proportionately distributed. Often, such evaluations would involve transboundary cooperation. For instance, according to a study, it was found that for the first time in 28 years, the difference between the water that would naturally flow versus the observed data at Chiang Saen gauge (at the border between China and Thailand) had maximised in 2019, resulting in severe lack of water flowing from Upper Mekong during the wet season.[83] The general notion has been that the construction of dams with increasing reservoir capacity in China, and the Chinese government's effort to distribute energy production in the Mekong across the annual cycle, has contributed to the regulation of flow such that periods of high and low flow can be evenly distributed.[84]

The task seems to be cut out for the MRC is it endeavours to facilitate basin-wide cooperation, even as it tries to rope in China and Myanmar. In the most-recent Basin Development Strategy (BDS) articulated in the State of Basin Report 2018, the LMB countries have reiterated that the current water security issues can be addressed effectively only at the basin scale.[85] China and Myanmar interact with the LMB states through another multilateral institution called the Mekong-Lancang cooperation, which is seen as an institutional counter to MRC. Observers have called it an "institutional balancing strategy" by China against other initiatives like the US–Mekong Partnership (UMP), MRC, and Mekong–Japan Cooperation.[86] It has also been expressed that the Mekong-Lancang cooperation is primarily focused on hydropower development and other water-related infrastructure, despite having the strategy, "joint sustainable management of the river" in the agenda.[87] Even as there are differences in perception, an interdisciplinary and holistic assessment of hydropower should be a prerequisite for financing hydropower irrespective of the river basin institution through which it is routed.

4. and 5. Salween and Irrawaddy River Basins

The Salween river remains untapped and holds immense potential for hydropower generation.

(Photo: Getty Images/Michael Runkel/robertharding)

Home to the Irrawaddy dolphins, categorised by IUCN as a Vulnerable species, the Irrawaddy River is the lifeline of Myanmar and home to flood-recession agriculture.

(Photo: Getty Images/Stefan Malin / EyeEm)

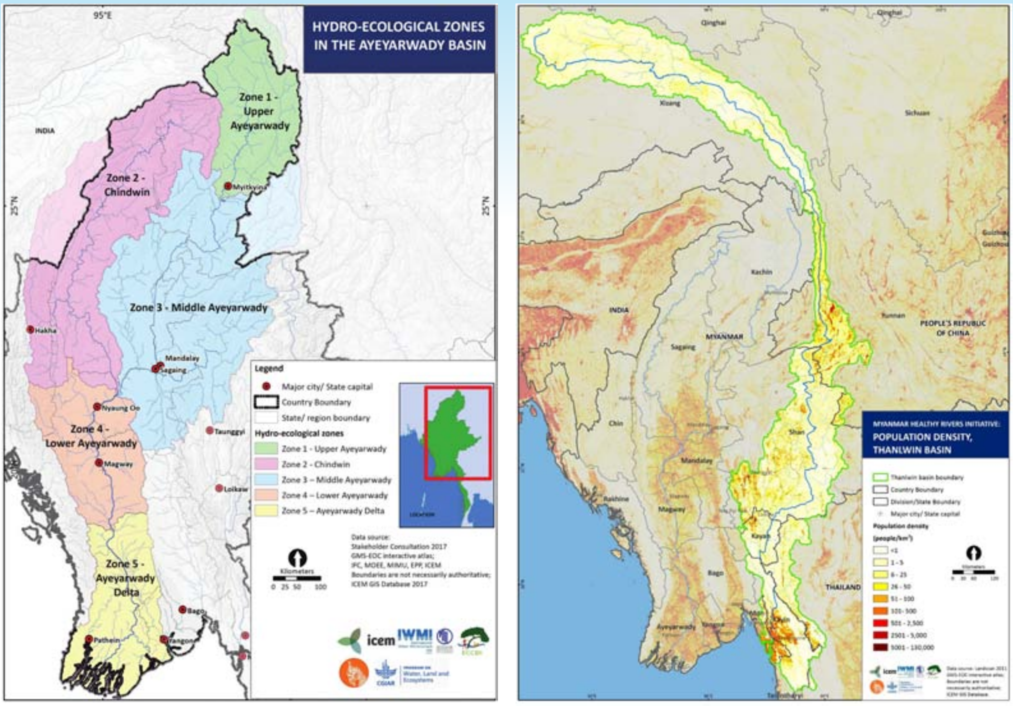
Physiography and Socio-Cultural Milieu

Located between the Mekong basin on the east and the Brahmaputra on the west, Salween and Irrawaddy are the other two major rivers in Southeast Asia apart from the Mekong, that originate from the HKH. These two river basins exhibit similar characteristics. Large stretches of the rivers and their tributaries continue to remain free-flowing.

The Salween (Upper Salween or Nu River in China, Thanlwin or Lower Salween in Myanmar and Thailand) is about 2800 km long and originates from the Tangula mountain on the Tibetan plateau at an altitude of over 4000 m. It runs parallel to the Lancang and the Yangtze through deep gorges in the north-west part of Yunnan province in China, before finally diverting to take a more southernly route to the Andaman Sea. The transnational basin spans across an area of 320,000 km^2, and is distributed among China (53 percent), Myanmar (42 percent), and Thailand (5 percent).[88] The agricultural tracts along the river are mainly confined to southwest Yunnan in China (upper stretch), South Shan State, as well as the coastal region of Kayan and Mon states in Myanmar and in the floodplains in Kayin state, Thailand. The population density corresponds to the location of these agricultural tracts, thereby highlighting the dependence of over 10 million people in the basin on agriculture. The climate of the basin is heavily influenced by the SASM between May to October, and by the northeast monsoon between November to April. It is also noteworthy that the annual precipitation in the basin is extremely varied, with stretches of the midstream receiving around 1200 mm of rainfall while the rainfall on the coastal areas can be as much as 4000 mm to 5000 mm. The Salween discharges an average flow of 1650m^3/s into the sea.[89]

Due to a mountainous terrain with marked decline in gradient and availability of glacier-fed perennial flows, the upper part of the Nu-Salween holds great hydropower potential. Plans for hydropower projects on the Nu River were made over 20 years ago, in 1995. China integrated hydropower development in the basin with regional development by linking it with the Western Region Development Strategy (2000 – 2020). This long-term strategy also includes the "West East Power Transfer" (WEPT) plan that envisages the construction of large dams in Southwest China. These dams will generate energy for the Southeastern seaboard, where there is large demand, particularly for industries.[90] The Lower Salween has witnessed many incidents of displacement, and civil and armed conflicts since 1948. To this day, political instability prevails in the northern and eastern Shan state, and conflicts continue between ethnic armed organisations, Myanmar armed forces, and a diverse range of militia.[91] These have impeded the construction of structures on rivers and investments in the natural resources sector.

Figure 13: Ayeyarwady/Irrawaddyy and Thanlwin/Salween Basin Maps



Source: IWMI

The Irrawaddy River is the most important river in Myanmar and almost the entire river basin, of about 4000 km[2], is located inside Myanmar (91 percent) while the remaining areas extend to China (5 percent) in the north and to India (4 percent) in the west. Irrawaddy is fed by two tributaries in its upper reaches: the N'Mai (originating in Tibet, China), and the Mali River (originating in Northern Kachin state, Myanmar). Precipitation in the basin is highly influenced by the SASM with a distinct wet season, the precipitation varying between different locations: 500 mm in the Central Dry Zone and 4000 mm in the north-western parts and in the delta. Based on the hydrological regime, the basin can be divided into five regions – Upper Irrawaddy, Chindwin, Middle Irrawaddy, Lower Irrawaddy, and the Irrawaddy delta. Due to the highly seasonal nature of rainfall, the basin experiences a distinct flood pulse the can be traced as it moves downstream.[92]

The total length of the river is 2170 km and in the middle and lower reaches, the river creates floodplains before finally branching into a nine-armed delta and discharging annual water flow of about 400 km[3] to the Andaman Sea. Irrawaddy is also heavily silt-laden, carrying 261 to 364 million tonnes of sediments per year, making it the 5th largest river to be doing so.[93] The river has historically served as an important route of communication and trade since the land was not possible to penetrate. This exchange also involved items as varied as Kachin costumes from the tip of the country to bamboo mats that were being sent from the delta.

The river has also witnessed a number of landmark events in Myanmar's history like the Bamar's choosing the Irrawaddy basin as the site of the Bagan dynasty, and subsequently the river being used for sailing deep inside the hinterland in a mighty flotilla for annexing new territories. It was also the passage used by King Thibaw and his queen Supayalatt's when they went into exile in India after Myanmar's loss to Britain in the late 19th century.[94]

Challenges to Integrated Governance

The Salween is a relatively quiet territory at present. Proponents of large dams frame their narratives around the idea of "development"–i.e., that dams will promote regional connectivity, industrialisation, electrification, and ultimately, poverty reduction. This continues to be contested by other stakeholders, who underline the negative consequences of large dams. These include human rights violations, and various social and environmental costs.[c,95]

Amidst contrasting opinions about the benefits and negative impacts of large dams, certain factual considerations exist. For one, the populations within the Salween and Irrawaddy basins have grown, contributing to agricultural expansion and change in land-use in certain areas such as Yunnan (China), the Moei river subbasin (Myanmar, Thailand), and the areas around the Lake Inle.[96]

The consequences are already emerging: increased logging, reduction in forest cover, and expansion of plantations. This is true particularly in the Shan and Kayin states of Myanmar.[97] Similarly, the mining sector also holds great promise for economic prosperity. However, it also involves various environmental costs. So far, the impact of unregulated mining—such as pollution of waterways—has been localised; one example is the pollution of Inle Lake due to open-cut coal mining.[98] The impact will heighten once these activities operate at scale. Different scenarios may thus emerge in the future – ranging from unregulated development and fragmented sovereignty, to recognising the river as commons and developing it sustainably for ensuring social justice.[99]

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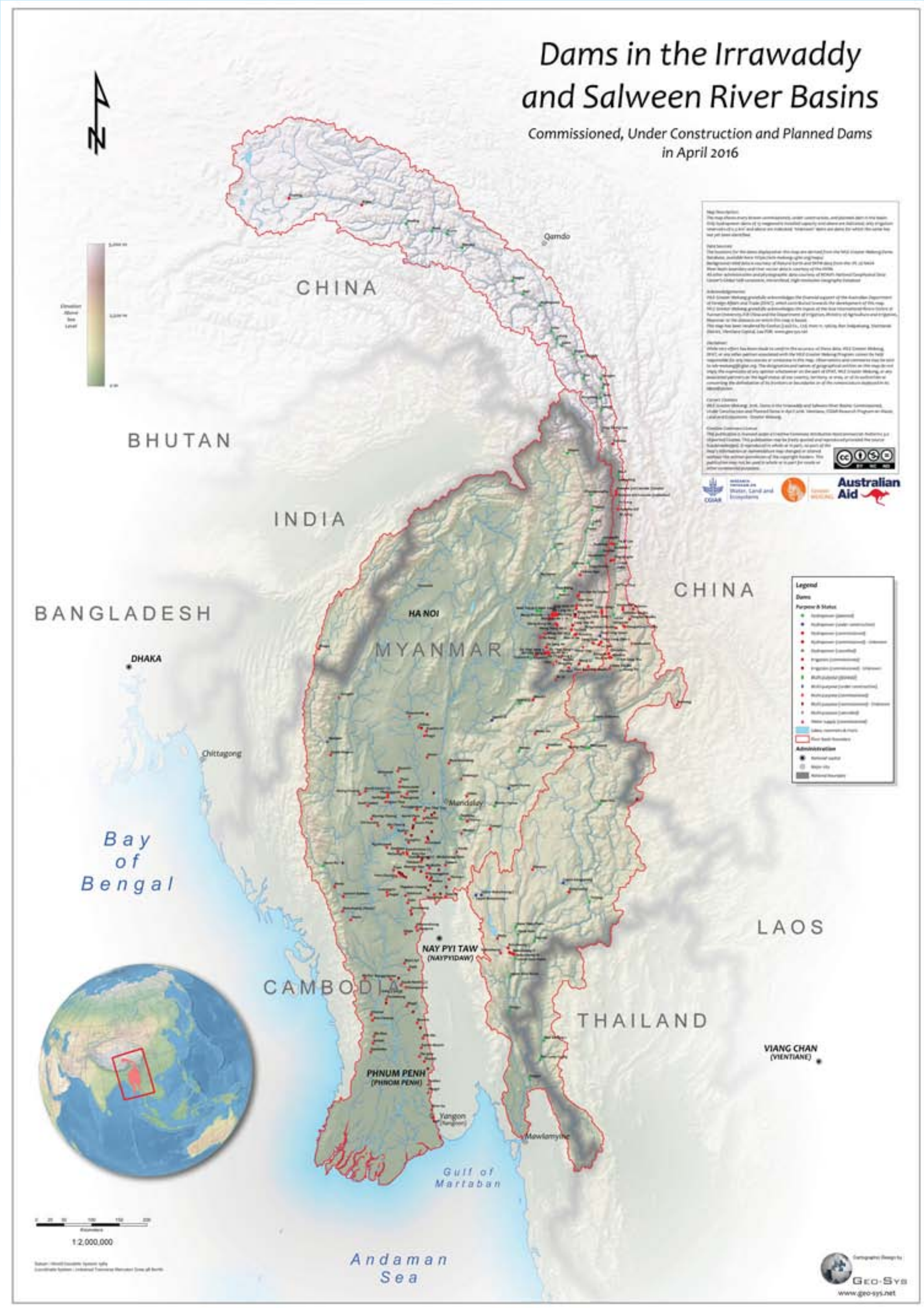
c The environmental costs may include decline in fisheries, reduction in forest cover and productivity, decline in soil fertility and water availability for flood recession farming, river bank erosion, salinity ingression in the deltas amongst others. Human rights related concerns are mostly associated with involuntary displacement of populations and their rehabilitation.

Figure 14: Dams in the Irrawaddy and Salween Basins



Source: CGIAR Research Programme on Water, Land and Ecosystems.[100]

The Irrawaddy basin is also undergoing transformations at a localised scale. These may escalate into potential governance challenges in the near future if not addressed in an integrated manner. For now, the population growth in the basin has been slower than expected since the last census of Myanmar in 1983. This is possibly due to conflict-induced displacement of people or emigration in search of better income opportunities. Despite this, the use of water has continued to expand, particularly driven by an extension in irrigation services since the 1980s under a planned initiative of the government. The government has plans to expand the irrigation coverage, with a focus on facilitating the cultivation of summer paddy.[101]

Similarly, hydropower generation features prominently in Myanmar's strategy for meeting its demand for power. At present, there are 14 existing projects of 10 MW capacity or greater on the tributaries of the Irrawaddy with a combined capacity of 2100 MW but Myanmar plans to bolster the production of hydropower further.[102] A large share of this energy will be transmitted to the urban centres in the basin. Six out of Myanmar's 10 largest cities are located in the Irrawaddy basin, including Yangon and Mandalay.[103] Urban water infrastructures are already under stress. Unplanned growth in an already neglected services delivery landscape is contributing to localised pollution in the form of solid waste and sewage water discharge. These will have ramifications in the downstream regions. As with the Salween basin, the Irrawaddy too may see an expansion in mining-related activities which could contribute to land degradation and lead to declining water quality.

Many of the issues discussed in this section are expected to occur if the normal trajectory of economic growth were to be followed in the basins at the cost of the natural environment. Any deviation from the business-as-usual scenario will necessitate actions that are commensurate with the needs of the times while reflecting the lessons from similar landscapes in monsoon-driven Asia. The imperative is for management plans that will harmonise the aspirations of the people in Salween and Irrawaddy basins with the needs of the environment. The same plans should also consider the threats of climate change. The following points outline the essential elements of a management plan for Salween and Irrawaddy. These two basins represent the last frontiers of water resources development in all of the ten HKH river basins.

1. Initiate a participatory process of development that is bottom-up and representative of the people's aspirations. This holds especially true for Myanmar that has a large number of ethnic groups in a conflict-affected and politically volatile landscape. SINK for the river basins will essentially draw from the local epistemologies and provide the basis for integration across the horizontal existence of varied social and ethnic groups as well as their linkages with the vertical tiers of administration.

2. The hydropower potential of both these basins is a highly lucrative agenda that is only beginning to reveal itself as Myanmar and China initiate regional development in their respective parts of the basin by harnessing the power of flows. Often, there is strong collaboration on that front as Table 2 would indicate. There is strong transboundary financial linkage with regard to developing the capacity of hydropower in an immensely endowed but financially weak Myanmar and supplying it to markets located outside its borders. However, as evident from previous instances in the shared HKH landscape like the Mekong, the development of hydropower entails critical trade-offs with other sectors with ramifications on the social and environmental make of the project-affected areas and regions in the downstream. These linkages to be analysed and understood better while creating a repository of information for participative decision-making.

Table 2: Planned dams on the Salween River mainstream in Myanmar[104]

Project	Location	Reported capacity (MW)	Developers	Power market	Status
Hatgyi	Karen State	1,365	Sinohydro (PowerChina), EGATi (Thai), MOEE (Myanmar), International Group of Entrepreneurs (IGE) (Myanmar)	Thailand	Joint Venture Agreement, Memorandum of Agreement (24 April 2010)
Dagwin	Karen State/ Mae Hong Son Province	729	EGATi	Thailand	Cancelled
Weigyi	Karen State/ Mae Hong Son Province	4,540	EGATi	Thailand	Cancelled
Ywathit	Karenni State (approx. 45 km upstream of Thai border)	4,000	China Datang Overseas Investment Co., Ltd., PowerChina, MOEE, Shwe Taung Group	Reportedly China	Memorandum of Agreement (18 January 2011)
Mong Ton (previously Tasang)	Shan State	7,110	CTGC, Sinohydro, China Southern Power Grid, EGATi, MOEE, IGE	Thailand	Memorandum of Understanding (10 November 2010)
Nongpha	Shan State	1,200	HydroChina (PowerChina) MOEE, IGE	China	Memorandum of Agreement (22 May 2014)
Kunlong	Shan State	1,400	Hanergy Holding Group, PowerChina, MOEE, Gold Water Resources (Asia World)	China	Memorandum of Agreement (21 May 2014)

6. Brahmaputra River Basin

River crossing in the wide Brahmaputra is often a perilous activity, especially during the monsoon season when the river gets flooded.
(Photo: Getty Images/Andrea Pistolesi)

Physiography and Socio-Cultural Milieu

The Brahmaputra is intertwined in the cultural milieu of India's North East Region (NER) and the immediate neighbouring countries of Bhutan and Tibet, where it is also considered sacred. The river system is a lifeline of Assam, whose people benefit from the flows of the river owing to wide and flat floodplains, abundant water, and a favourable climatic regime. In recent decades, both India and China, two of the largest riparian nations of the Brahmaputra, have turned their attention to the basin for the promotion of hydropower.

The Brahmaputra originates from the Angsi glacier near Mount Kailash in the Tibet Autonomous Region (TAR). In TAR, it is known as the Yarlung Tsangpo. It follows a peculiar course and travels in an easterly direction for nearly 1100 km out of its total length of 2880 km through a largely rugged and arid landscape. Thereafter, it takes a spectacular bend, cuts a deep gorge and enters India through the Upper Siang district of Arunachal Pradesh. For much of history, very little was known about the course of the Yarlung-Brahmaputra due to its inaccessibility for both geographical and political reasons.[105] As it bends, it also transitions from the rain-shadow north aspect of the Himalaya to the rainfall-rich south aspect of the range. It is known as Siang or Dihang in Arunachal Pradesh. Thereafter, it is joined by two other rivers – Lohit and Dibang near the town of Sadiya in Upper Assam— following which, the combined flow is known as the Brahmaputra.

This also marks the beginning of the fertile Brahmaputra valley and its inland delta, where the bulk of the population reside and engage in agriculture and other livelihood activities like fishing. In this stretch, the Brahmaputra is joined by numerous tributaries from Subansiri to Teesta. As the river enters Bangladesh downstream of Dhubri in Assam, it becomes Jamuna, which merges with the Ganges near Gualondo to form the Padma river. At this confluence the Brahmaputra basin comes to an end. The large and widespread rainfall south of the Himalaya generates a large volume of sediments and adequate flows to transport these sediments, making the Brahmaputra one of the most sediment-laden rivers of the world. The high discharge is caused by annual precipitation (both snow and rain) in excess of 3000 mm/year.[106] The estimates for average annual sediment load at Bahadurabad range between 540 Mt/yr[107] and 721 Mt/yr[108].

The total drainage area of the basin is 580,000 km^2, distributed across four nations – China (50.5 percent), India (33.6 percent), Bangladesh (8.1 percent), and Bhutan (7.8 percent).[109] The entire basin can be divided into three physiographic zones: the Tibetan Plateau, with elevation of above 3500 masl, the Himalayan belt with elevations in the range of 3500-100 masl, and finally, the lowland floodplains.[110] Most of the rainfall (60 - 70 percent) is received during the monsoon period, and only a minuscule part of it is tapped for irrigation. Eleven percent of the entire basin area is cultivated for agriculture, while only 20 percent of the area is irrigated.[111]

Historically, the Brahmaputra valley has been immensely productive with its annual cycle of flooding. People learnt to co-exist with the high-flows of the river, minimising the losses and reaping the benefits once the flood waters receded. Bamboo was also extensively used in building houses and embankments, among others.[112] In recent years, however, there has been a distinctive shift towards urbanisation. Floods are increasingly become a nuisance, particularly in the Brahmaputra valley of Assam and downstream Bangladesh. Both regions are undergoing land use change and the expansion of river infrastructure. These hold the potential to directly impact sediment flow and other hydrological conditions.[113,114]

Figure 15: The Basin Map[115]

Challenges to Integrated Governance

The Brahmaputra basin presents a formidable challenge in the form of regular, intense monsoon precipitations and resultant floods in the middle and lower reaches of the river. Additionally, as a product of the meteorological and physiographic situation of the basin, variation of flows in the river and the high sediment load cause morphological changes to the river in the form of bank erosion and frequent shifting of river channels. Bank erosion is a particular concern in parts of Upper and Lower Assam despite the initiation of anti-erosion measures. During the period of June to September, under the influence of SASM, flood flows are generated when the discharge in the river increases phenomenally as the river widens and the braided channels coalesce. The annual average flood discharge is 48,160 cumecs.[116,117] The Brahmaputra valley of Assam is particularly susceptible to flood damage, with 3.2 million hectares or 40 percent of its land surface area being flood-prone. While the occurrence of floods is a natural phenomenon, anthropogenic interventions like massive deforestation, intense land-use pressure, high population growth along with structural measures like embankments have aggravated the situation over the years.[118]

The other challenge in the basin stems from the proposed transfer of water from the Brahmaputra sub-basin to the Ganga sub-basin as part of India's larger project of interlinking of rivers. If this plan is executed, it could have serious implications on the flow of Jamuna, that could result in diplomatic friction between India and Bangladesh. Whitehead et al. (2015) caution that in a future climate-scenario of increased variability and enhanced uncertainty of both monsoon high flows and low flows, water diversions upstream of the Ganga-Brahmaputra-Meghna delta could further threaten the flows in the river systems and the ecological process in the delta that are dependent on these flows.[119] Indeed, transboundary frictions already exist due to an impasse between India and Bangladesh over the sharing of Teesta waters, a Himalayan tributary to the Jamuna.[120,121,122] It is imperative for both countries to look critically at the trade-offs involved and consider the various facets of social and economic feasibility of river interlinking projects, along with environmental security.[123]

Table 3: A basin snapshot[124]

Country	Drainage area (10^3 km^2)	% of area of basin	Arable land (km^2)	Population (million) (1999)	Hydropower potential (10^3 MW)	% Of basin's total hydropower potential
China	293	51.1	n/a	2	110	53.4
(Tibet) Bhutan	38.4	6.7	2,956	0.635	30	14.6
India	195	34.0	55,000	31	66	32
Bangladesh	47	8.2	36,000	47	0	0
Total	573.4	100	93,956	80	206	100

Finally, the flurry of hydropower projects in the eastern Himalaya and in Tibet and Bhutan needs to be analysed closely to understand the net benefits in the short and long term. Observers have often argued that the habitat loss and alterations to the ecosystem due to inundation and changes to the flow regime have been overlooked in impact assessments. Further, large poor populations are often excluded from the decision-making process.[125] As mentioned earlier, the basin is a shared one and most of the issues pertaining to floods, bank erosion, and shifting of courses, or anticipated concerns around hydropower projects and water diversion, manifest at a transboundary level. For instance, China has been sharing flood-period data with India and Bangladesh, the efficacy of which is considered misplaced.[126] Similarly, the construction of a dam at the great bend of the Brahmaputra also raises various concerns in India[127] as the country has also expedited its own dam construction on the Siang.[128]

The Brahmaputra river remains largely free-flowing. The longitudinal connectivity of the mainstream Brahmaputra remains intact despite the existing and proposed structures in its headwaters – the Lohit, Dibang, Siang, and Subansiri, as well as those on many of its tributaries. However, the landscape has already undergone large-scale transformation. Salkia, in a biographical sketch of the river, notes how the 'manicured' landscapes of tea plantations initiated by the British companies during the colonial era interrupted the connections between the river, the floodplain, and highlands through massive forest clearance in the uplands of Assam, increased human settlements, and enhanced road and river traffic. Thereafter, the jute began to symbolise the imperial conquest of the floodplains of Brahmaputra. It also necessitated the state to prioritise on construction of embankments to protect the plants from long spells of submergence once India gained independence.[129] At present, the needs for embankments have grown for protecting not only agricultural land but also the urban quarters and other expanding areas of economic interest in the floodplains.

Planners are increasingly realising that integrating the natural infrastructures such as thriving wetlands, managed floodplains, banks lined with trees and grasses, will bring potential benefits to communities. The lateral spread of water during high flows would rejuvenate the land and managing the occurrence of floods in the floodplains, which is anyway inevitable, would reduce the human exposure to them and limit or eliminate the losses incurred. This is also identified in the Integrated Flood Management (IFM) approach that is being promoted through the Associated Programme on Flood Management (APFM)— a joint initiative of the World Meteorological Organisation and Global Water Partnership. The IFM shifts focus from traditional flood protection to creating solutions that are flood-resilient, and also considers the challenges posed by anthropogenic factors along with a changing climate. In order to implement IFM successfully in the Brahmaputra basin, all stakeholders will have to be included—the government agencies and departments, civil society and researchers, sector-specific stakeholders and the public at large. Their interactions would give shape to the process of finding lasting solutions to the challenges imposed by floods and river bank erosion on the development of the basin while integrating all stakeholders toward a single cause. Similarly, the integration of ecology, economics and engineering, along with societal aspects like the distribution of benefits and costs will feed to the creation of integrated knowledge necessary for arriving at decisions on hydropower projects. Thus, the Brahmaputra basin illustrates a potential arena for the application of SINK particularly for managing flood even as hydropower development and water diversion catches on, creating further problems of disintegrated and linear thinking.[130]

7. Ganges River Basin

The Ganga has enormous religious and cultural significance; it is also one of the most polluted rivers in the world.
(Photo: Getty Images/Artur Debat)

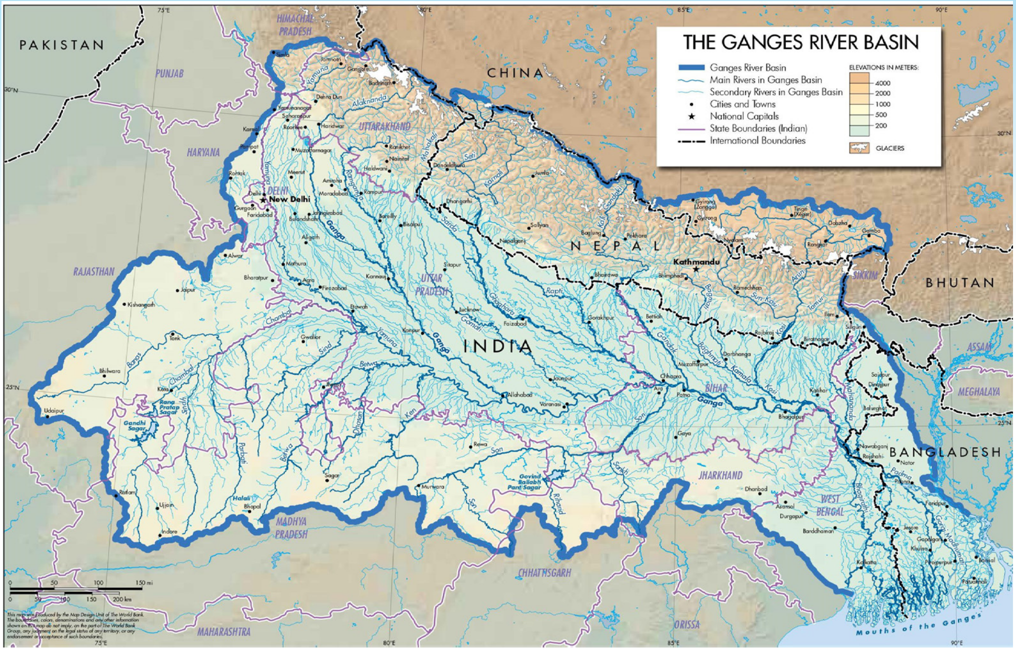
Physiography and Socio-Cultural Milieu

Revered as Mother River by a large section of the population in South Asia, the Ganges was declared in 2008 by then Indian Prime Minister Manmohan Singh as the country's national river. The basin contains vast swathes of arable land and was the power centre of South Asia's ancient kingdoms. The Ganges originates from the Gaumukh glacier, on the southern slope of the Himalaya and traverses a slow journey before bifurcating into two distributaries – the Bhagirathi Hooghly in West Bengal of India and the Ganges/Padma river that enters Bangladesh. The Ganges/Padma mainstream then merges with the Jamuna (as the Brahmaputra is known in Bangladesh) near Goalondo. Throughout its course, it is fed by a number of tributaries, many of which originate in the Himalaya, such as the Sarda (Mahakali), Karnali, Rapti, Gandaki, Baghmati, and Kosi. At least two of these rivers – the Ghaghara(Karnali) and the Kosi—have their catchments distributed across three countries (i.e., China, Nepal, and India.) The glacial melt contribution of the basin is low, accounting for only 9 percent of the total flow.[131] The bulk of the flow is generated by the SASM over a distinct wet season (June to September). Approximately 70 to 80 percent of the total rainfall occurs during this period. The average annual rainfall in the basin varies between 400 – 2000 mm.[132] The mean annual discharge of the Ganges is 12,037m^3/s,[133] with very high seasonal fluctuations in the flow. The water availability in the basin is also spatially skewed, with a general trend of water scarcity in the direction of west to east, and water abundance, south to north.

Overall, the flows in the river system supports a densely populated region of 401persons/ km^2, the highest of all the HKH basins.[134] Around 70 percent of its area is devoted to agriculture.[135] The bulk of the population reside in the fertile Gangetic plains whose history of occupation dates back to the Vedic times (or the second half of first millennium BC). The Indo-Aryans had crossed the Indus to settle in the fertile region between the Yamuna and the Ganges.[136] The 6th century BC witnessed these settlements slowly emerging as powerful states known as the Mahajanapadas. The flat and fertile floodplains of the Ganges and its tributaries provided the ideal conditions for the agriculture-based economies of all subsequent kingdoms in the subcontinent– the Mauryas, the Guptas, the Sultans of Delhi, Mughals, and finally the British rulers.[137] The earliest evidence of large-scale construction for diverting water can be traced to the Yamuna irrigation canal in the 14th century AD, followed by the Mughals constructing various run-of-the-river systems.[138]

After the Mughals, the British East India Co. consolidated the large-scale interventions to harness the waters of the river systems. The Upper Ganges Canal was constructed for providing irrigation to the fertile and densely populated region between the Ganges and the Yamuna.[139] Construction of embankments to restrict floodwaters from damaging croplands also became an accepted norm during this period.[140] In recent times, rapidly increasing population and a corresponding growth in water use, high rates of industrialisation, and urbanisation have put constraints on sustainable development of the basin. India, after independence from the British, continued with this trend and gave priority to large-scale engineering interventions in the rivers originating from the Himalaya. The Farakka barrage was commissioned in 1975 to resuscitate the Kolkata Port. During this period, popular protests erupted against large river projects on the issue of inadequate rehabilitation of the displaced people and the ecological risks associated with large dams.[141]

Figure 16: The Ganges Basin



Source: Sadoff et al. (2013)[142]

Challenges to Integrated Governance

The spatially and temporally skewed distribution of rainfall has meant that the precipitation is concentrated within a few months of the year – causing monsoon high flows. Flood management becomes a formidable challenge in the Ganges basin, particularly in its middle and lower reaches, since the exposure to the seasonal inundation has increased manifold due to extensive land-use change over the decades. Consequently, the damage to life and property has also increased as has the flood-prone area in one of the affected states—Bihar. The construction of embankments has often exacerbated the crisis by providing a sense of security that is not ecologically informed and thus encouraging further expansion of land-intensive economic activities in the protected areas. This has resulted in catastrophic floods at the occasional but inevitable instances of a breach in embankment. The embankments have also created the additional problem of waterlogging in the stretches they protect.

The current situation of embankments and flood prevention is such that during the rainy season, the people in the supposedly 'protected' areas live in constant fear of being displaced by a breach. At the same time, those living in-between embankments do not fear breaches, as these help in making the high-water level recede.[143, 144, 145, 146] The World

Bank estimated the average annual loss for the entire basin at USD 630 million in 2016.[147] Almost 96 percent of this loss is concentrated in just two India states – Bihar and Uttar Pradesh.[148] Upstream water storage is an attractive proposition to control the spate of flooding but research indicates that it could, at best, reduce the intensity of flooding.[149,150]

Monsoons and the resultant high flows in the river system are a key ingredient for the ecological integrity of the whole basin. They allow for the geomorphic actions within river corridors – generation of sediments, their transportation and deposition, recharge of aquifers and water bodies, and help enhance the productivity of land in a landscape that is still closely integrated with the natural system. The integration between the economy, ecology and society needs to be rewired to create harmony and balance preferably at a river basin or large watershed scale to respect the natural process of integration. In the present arrangement, human populations remain dependent on the ecosystem services provided by fluvial systems. However, economies have developed at the cost of the natural environment – in a manner that exploits the flows in an unsustainable manner, thereby harming the ecosystem. Therefore, river science and engineering will have to be integrated with the understanding of sediment dynamics, geomorphic processes, and socio-ecological considerations.

It is imperative that monsoon high flows be accommodated in planning and management of water resources at the basin scale, considering future climate scenarios. Indeed, flood pulse is intrinsic to the ecological character of the Ganges River basin. Any intervention that disrupts the longitudinal connectivity and moderates the flow, particularly the flood pulse, should be informed by a detailed knowledge of economic, societal, political, and scalar consequences of such interventions. Key would be a judicious mix of structural and non-structural measures, along with an adaptive management through initiatives like 'floodplain zoning', 'controlled flooding', and increased natural water storage (green water).

During the lean season, the flow in the rivers reduce considerably, indicating pollution. Getting the river to acceptable standards has been a constant challenge over the years, and efforts to improve the water quality can be traced to the Ganga Action Plan (GAP) launched in 1985. The initiative sought to restore the river's water quality to the 'bathing class' as stipulated by CPCB. According to the government's own assessment, GAP has met with limited success: while the Dissolved Oxygen and the Bio-chemical Oxygen Demand (BOD) has shown discernible improvement, the high levels of coliform have remained a concern.[151] Independent assessments have also revealed other concerns, such as the stretch from Kanpur to Patna on the mainstream, and the one from Nabadwip to Diamond Harbour on the Bhagirathi-Hooghly (a distributary).

Figure 17: Water quality standard according to selected parameters across stations from upstream to downstream in 2019 – Pre-COVID-19 (Left to Right)[152]

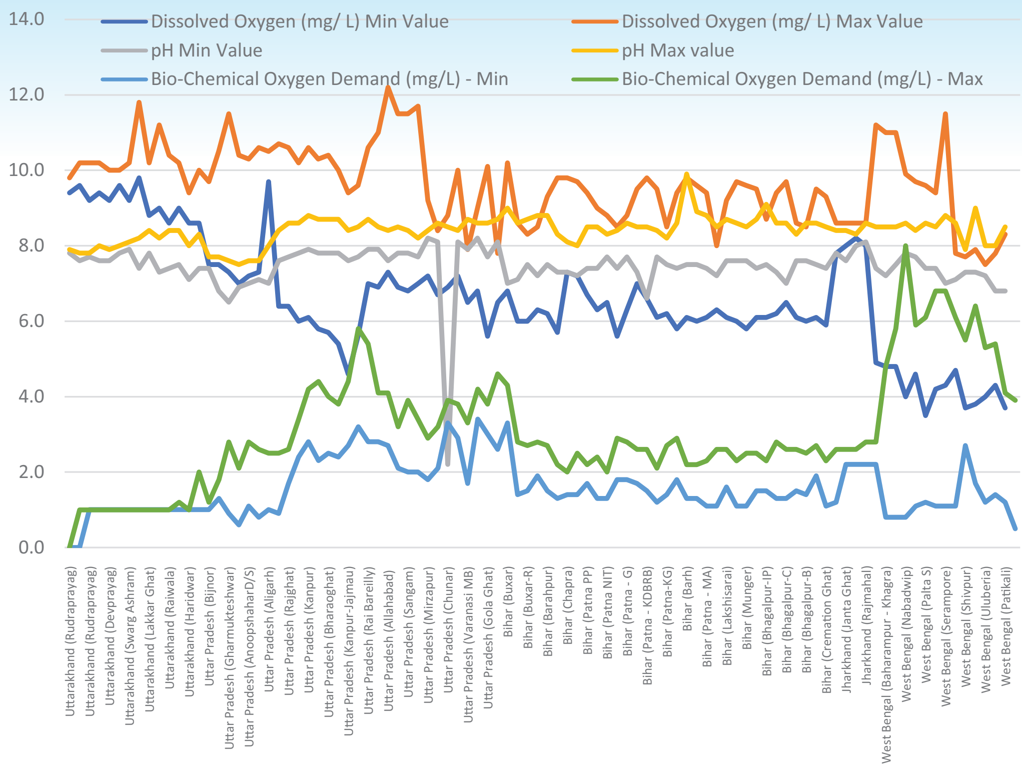
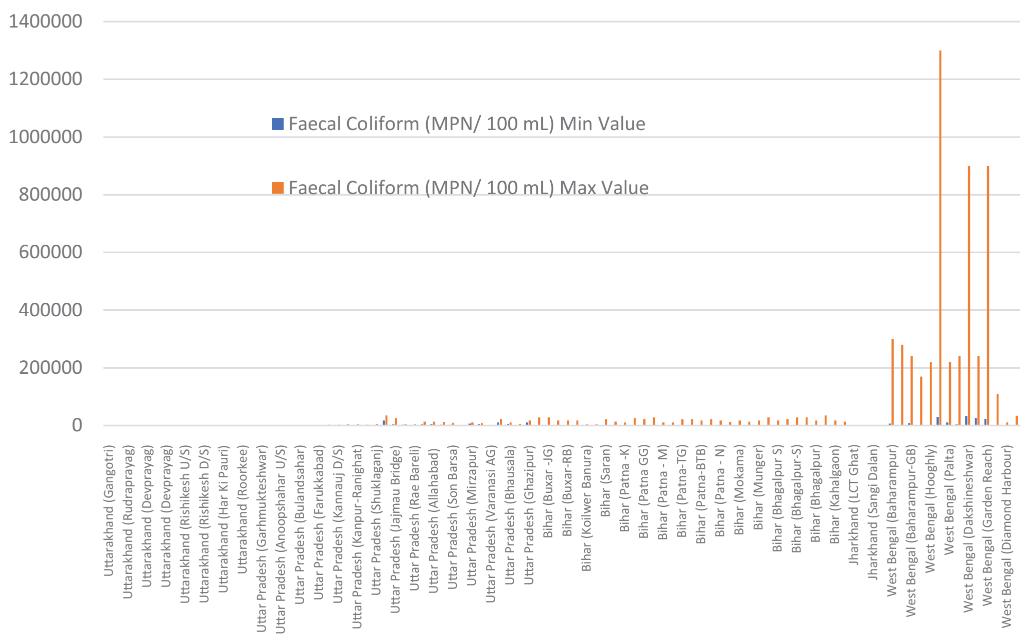


Figure 18: Faecal Coliform across stations from upstream to downstream (Left to Right) in 2019[153]



BOD and coliform levels are high, and experts attribute this to untreated wastewater from the cities flowing into the river (Ref. to Fig. 17 and Fig. 18).[154] To be sure, the faecal coliform content is high throughout the entire stretch—at Devprayag, for instance, where the Bhagirathi and the Alaknanda meet to form the Ganges, it is 100 times more than the acceptable limit. This further increases to 1000 times or more than the acceptable limit near urban centres located in the downstream, like in Kanpur.[155]

The challenge of maintaining good water quality standard is a multidimensional one. According to a team of experts from the Indian Institute of Technology (IIT), the critical weakness in GAP was the straightjacketed approach of sewage collection, conveyance, and treatment. Little heed was paid to other direct and indirect factors like crematories on the banks, and non-point sources of pollution or even flow diversions affecting the river's dilution capacity. The same experts have also pointed to the lack of a clear policy-legal and institutional framework, leaving multiple institutions, each with its own discretionary roles, to manage the basin—this has resulted in lack of synchronisation and proliferation of ambiguities.[156] Thus, the challenge of curbing pollution would require composite knowledge borrowed from behavioural sciences, regulatory practices, wastewater management, hydrology, water chemistry, and riverine ecology. There is a need to draw from a repository of SINK that is well-suited to the Ganga, as well as from the shared experiences in other basins like the Yellow.

As mentioned earlier, the water quality in the river deteriorates as soon as the flow in the river system diminishes after the monsoon season. Concomitant with it is the abstraction of water from the mainstream to meet the water requirements for irrigation. Even in cases where water is not used for consumptive purposes such as for generating hydropower, the water is withheld behind structures. This not only aggravates the crisis of water pollution but also leads to severe fragmentation of the river and its channels, and additionally traps sediments that would otherwise flow downstream. Further, a reduced influx of year-round freshwater increases the salinity in the distributaries of the Ganges within the estuarine zone, impacting aquatic life and the mangroves.[157] At least two aquatic species that have suffered the most due to human-induced alterations in natural flows and flow regimes are the Gangetic Dolphin and the Hilsa or *Tenualosa ilisha*.[158]

The absence of integrated thought across temporal and spatial scales is apparent in current interventions. These interventions assumed the short-term gains, without any concern for the long-term costs. Ghosh and Bandyopadhyay (2020) have analysed the challenges of water governance in the basin with regard to certain key interventions, both proposed and executed—such as the Farakka Barrage, the interlinking of rivers, and an eroding Sundarban delta.[159] They identified key areas of knowledge gap with regard to an institutional void, ecohydrological knowledge on surface water systems, social dimensions of water systems and local governance, impact of climate change, and flood management, among others.[160] The role of SINK in filling such gaps cannot be overemphasised.

8. Indus River Basin

An intricate network of canals facilitates surface water irrigation for a bountiful harvest as seen in Punjab, Pakistan.
(Photo: Getty Images/Amir Mukhtar)

Physiography and Socio-Cultural Milieu

India and Pakistan have been cooperating on issues related to the mutually beneficial sharing of the waters in the Indus River basin. There is large-scale agricultural production in the basin, which meets the growing requirements for food grains of the burgeoning population of the two countries spread beyond the basin borders. The Indus River basin comprises 1.12 million km^2 [161] and is shared between China, India, Pakistan and Afghanistan; the basin has around 178 million inhabitants.[162] It is home to two of the highest mountain ranges in the world – the Himalaya to the east, and the Karakoram to the north, and is bound by the Suleiman and Kirthar ranges from the west. The high-mountain ranges protect the plains from the freezing continental winds of the north, while also acting as a barrier to avert the monsoon rains from escaping to Central Asia. Annual precipitation varies from 100mm to 500mm in the plains to a maximum of 2000mm on the slopes of the mountains, snowfall being a regular occurrence at altitudes above 2500m. The precipitation generates a mean annual flow of 5,533 cumecs with a high degree of perenniality; glacial melt contribution to the total flow of the Indus is up to 50 percent.[163] Some 69 percent of the flow originates from India; Pakistan contributes 19 percent; and Afghanistan and China together provide 12 percent.[164] The Indus River has two main tributaries – the Kabul River on the right bank and the Panjnad on its left bank.[165] Physiographically, the basin can be divided into two parts: the upper basin comprising of the mountainous regions and the lower basin that has the alluvial plains, formed by the deposition of the Indus and its tributaries and constituting highly productive agricultural land.

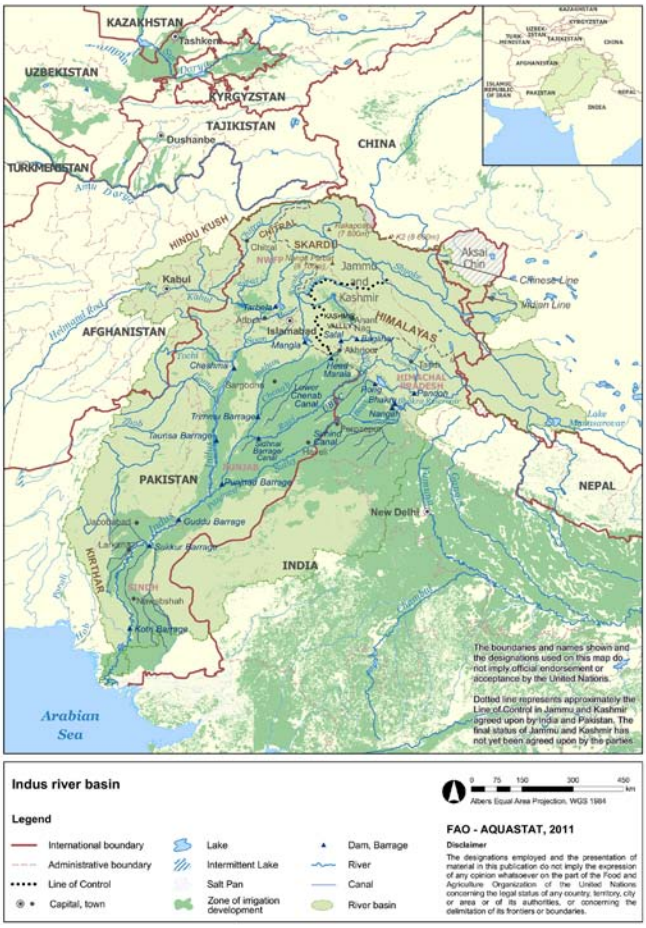
The Indus Basin was home to one of the earliest civilisations in the world – the Indus Valley Civilisation which emerged some 4,000 years ago. This riverine civilisation harnessed the river spills during seasonal floods to emerge as an agricultural and trading powerhouse.[166] The basin's first canal system was constructed by the Mughal emperors almost 600 years ago,[167] serving the twin purposes of irrigating the fields and providing water for the gardens and fountains of the Mughal palaces and forts in present-day Lahore.[168] The existing network of canals has its roots in the annexation and consolidation of Punjab by the British in 1849. The British embarked on an 'agricultural colonisation' by establishing an extensive system of weirs and barrages. Plots of land from these newly irrigated tracts were awarded to the former troops of the Punjab army in exchange for their loyalty to the British crown.

The system was immensely useful for the British as the Punjabi immigrants not only improved the productivity of the land, but also transformed canal management into a valuable source of taxes for the colonial rulers. The British also introduced the *warabandi* system of irrigation through the Irrigation Act of 1873—it continues to this day at the provincial level in Pakistan. Subsequently, the Triple Canal Project of 1915 that connected the Jhelum, Chenab and Ravi rivers with the extensive network of irrigation and the Sutlej Valley Project of 1933 further extended the scope of irrigation.[169]

The irrigation system that was originally conceived for the entire lower basin stood divided between India and Pakistan in 1947. This paved the way for the landmark Indus Waters Treaty in 1960, formulated and enforced under the aegis of the World Bank. Under this treaty, the western rivers (Indus, Chenab, and Jhelum), comprising 70 percent of the water in the basin, were allocated to Pakistan for unrestricted use. India was given exclusive rights to the three eastern rivers of the basin – the Ravi, Beas, and Sutlej.[170] Moreover, the Indus Basin Project (IBP) was initiated in Pakistan at the behest of the World Bank. The two main components of the IBP were constructing storage reservoirs on Jhelum and Indus rivers, and inter-river link canals.

This was done to mitigate the impact of India diverting the waters of the three eastern rivers, and to improve agricultural production.[171] India also embarked on a series of large multipurpose projects during the first five-year plan (1951-56), one of which was the Bhakra Nangal Project. The subsequent five-year plans emphasised expanding the irrigation network and including groundwater for irrigation water supply.

Figure 19: The Indus Basin



Source: FAO[172]

Challenges to Integrated Governance

Agriculture is among the human activities in the Indus basin that consume the most water resources. Many of the challenges in water governance pertain to the manner in which agriculture is practiced in the basin. Important produce like cotton, sugarcane, and wheat are all water-intensive and their continuing viability, particularly in Pakistan, is a matter of concern. Compounding the challenge are other issues like low efficiency of irrigation, poor regulation of water use, lack of modern technology, and pressing power shortages.[173] Moreover, the proliferation of bore wells has meant that it is not only surface water that is increasingly being used for irrigation, but also groundwater. This coincided with the beginning of the Green Revolution in the early 1960s, resulting in a steady decline in quantity and quality of groundwater.[174]

In the Sindh province of Pakistan, salinity ingression is a significant problem which the government attempted to solve with the Salinity Control and Reclamation Project (SCARP), launched in the 1950s. High-capacity tube wells were installed to pump non-saline groundwater into the canals and flush out salt from the root zones of plants, and into the drains. However, the lack of regulation meant that the salt-water balance was tipped back to its natural state as a result of over-extraction of groundwater.[175]

Apart from the unsustainable use of groundwater, another issue of concern is regarding the future of the Indus Waters Treaty (IWT) of 1960. Since the treaty came into force, various technological developments have made certain provisions of the treaty obsolete. This has led to varied interpretations of such treaty provisions, thereby resulting in tensions between India and Pakistan. For example, in 2005, following India's construction of the Baglihar hydroelectric plant on the Chenab River, differences arose between the two countries regarding the spillways of the reservoir. For the first time since the treaty became operational, the Permanent Indus Commission could not resolve the dispute.[176] There is a need therefore, for the treaty to be updated and be made more adaptive and consultative rather than adhering to rigid structures. The future might also witness an emerging trade-off between Pakistan constructing more storage structures, on one hand, and on the other, maintaining environmental flows in the Indus to sustain the deltaic ecosystem and address salinity ingression in coastal Pakistan. Pakistan is planning to implement a number of multi-purpose projects to improve irrigation coverage, generate additional hydropower, and control floods.[177] The treaty will likely require a review as basin states grapple with issues that have emerged only after the treaty was promulgated. The role of SINK is crucial in making the treaty more relevant and representative of the aspirations of the future generations.

Irrigated agriculture in the Indus basin exemplifies the nexus between food, water, and energy. There is a need, therefore, for integration across sectors and scales.[178] In their analysis of the institutions and planning of irrigated agriculture, Shahid et al (2019) note the sharp geographical and jurisdictional divide between Pakistani Punjab's Agriculture and Irrigation departments. They note that the planning for irrigation and agriculture in the province has historically been a tussle between departments and hierarchical tiers. Moreover, department officials often make a distinction between planning, management, and operational functions, with each department having its own definition of "integration".

The result is fragmented planning even at the local provincial level. The present analysis proposes that the meso scale be reimagined as the boundary spanning scale. It would allow planning to cater to particular socioecological variations within that zone, while including farmers' voices in the design and planning stages and connecting them to the macro, provincial tier for information dissemination. Thus, planning can be a dynamic, cross-sectoral process – happening simultaneously at multiple levels, such as the provincial and district/division or circle/zone.[179] Such innovations will depend on the generation and application of integrated knowledge that would complement the shift of the government policies in both parts of Punjab in India and Pakistan towards IWRM.

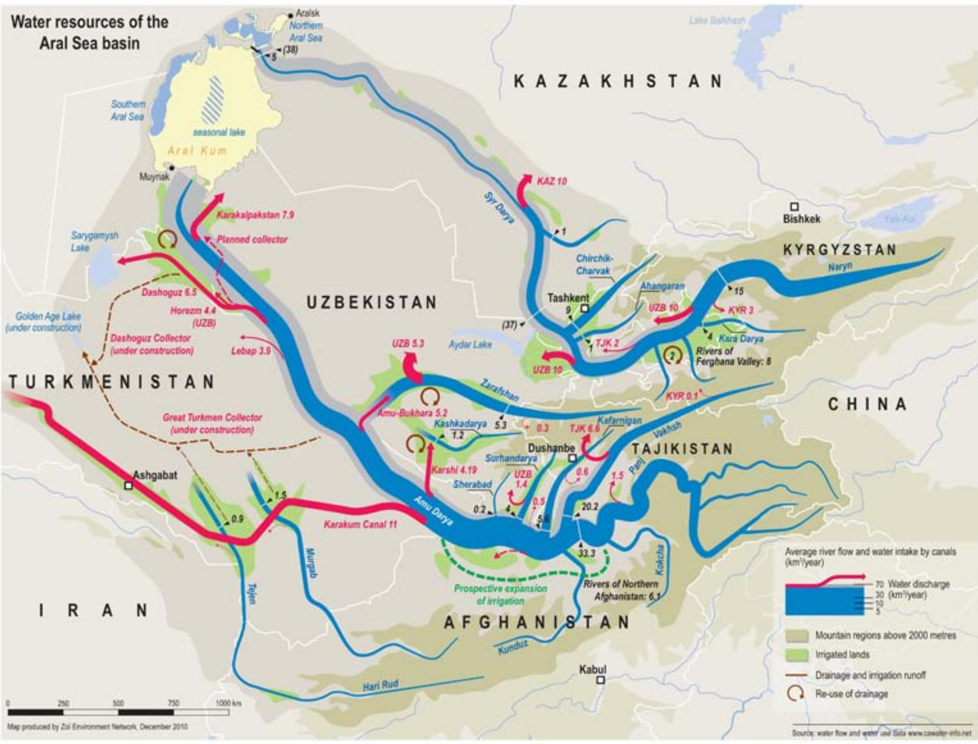
9. Amu Darya Basin

Boats that had remained stranded due to the shrinking of the Aral Sea as seen at Moynaq, Uzbekistan, Central Asia.
(Photo: Getty Images/Eddie Gerald)

Physiography and Socio-Cultural Milieu

With a length of 2540 km,[180] Amu Darya is the longest river in Central Asia and it has played a pivotal role in shaping the political and socio-economic landscape of the arid and landlocked region which was part of the ancient Silk Route. In recent times, the river has featured prominently in the global environmental debate as a prime example of an environmental disaster caused by human activities—i.e., the diversion of water from the river, eventually contributing to the shrinking of the Aral Sea. Amu Darya is formed by the confluence of two rivers – the Vaksh and the Panj—[181] contributing on average 54 km^3 of water per year, which is more than 80 percent of the main Amu Darya flow. It is also a transnational river that is shared by Tajikistan, Kyrgyzstan, and Afghanistan (upstream riparian) and Turkmenistan and Uzbekistan (downstream riparian). There are various estimates of the catchment area—between 465,000 km^2 to 612,000 km^2,[182] while the ICIMOD reports the basin area to be 534,739 km^2. The greater Amu Darya basin, which includes areas hydrographically[183] connected to the basin, is 1,300,000 km^2 and includes a larger part of Turkmenistan and Uzbekistan, along with a small part of Iran.

Figure 20: The Amu Darya and Syr Darya Basin



Source: UNEP[184]

The physiography of the basin comprises of three distinct zones: the mountains, the arid plain, and the delta. The mountainous part consists of the Pamir-Alai, the Tien Shan, and the Northern slopes of the Hindu Kush range. The average annual precipitation ranges from 800 to 1600 mm/year in the mountains of the east. The resulting flow, along with favourable soil and temperature, facilitate the cultivation of crops in the plains near water channels and in the floodplains. This zone also covers the deserts of Karakum and Kyzylkum within the arid Turan plain. A striking feature of this zone is the presence of a number of oases that were the centres of human activity in the earlier eras and are presently irrigated through large installations. Finally, the delta region is where the Amu Darya once drained into the Aral Sea. In the lower reaches of the Amu Darya, mean annual precipitation is less than 100mm, while evaporation exceeds 1500mm.[185, 186]

The Amu Darya basin had a role in the Cold War, as present-day Kyrgyzstan, Tajikistan, Kazakhstan, and Uzbekistan were all part of the erstwhile Soviet Union. In 1946 the *Frontier Agreement between Afghanistan and the USSR* was signed, and was followed by the establishment of a joint commission to discuss water-related issues. The commission codified a water allocation regime that allotted 9 BCM of the Panj river flow to Afghanistan, and the rest to the Soviet Union.[187, 188]

Table 4: Water Resource-related data of the Aral Sea Basin (in general) and Amu Darya (in particular)

Country	Mean Annual Runoff contribution to Amu Darya (km³/year)
Kyrgyzstan	1.93
Tajikistan	*59.45
Turkmenistan	0.68
Uzbekistan	4.70
Afghanistan	11.70

**Includes 3.09 km³ of Zeravshan river*

Country	Basin area of Amu Darya as percentage of the total area of the country	Aral Sea Basin (Amu Darya, Syr Darya and Tedzhen-Murghab basin)			
		Area Equipped for Irrigation (AEI) (in million ha)	As % of total	Area Actually Irrigated (AAI) (in million ha)	AAI as % of AEI
Afghanistan	25.4	1.30	13	0.77	59
Kazakhstan	*NA	1.30	13	0.83	64
Kyrgyzstan	3.9	0.42	4	0.42	100
Tajikistan	88.0	0.74	8	0.67	91
Turkmenistan	73.7	1.80	19	1.80	100
Uzbekistan	81.5	4.20	43	3.70	88
Total Aral Sea Basin Area		9.76	100	8.19	84

**NA is not available*

Source – Aquastat FAO.

At that time, the prevalent view was that hydropower generation and agricultural production were the two core areas of socio-economic advancement. Water was used mainly for growing cotton, wheat and paddy, but the irrigation methods were inefficient.[189] The Karakum Canal, a product of Soviet engineering, conveys water (500m^3/sec) from the middle reach of the Amu Darya to the remote desert areas of Turkmenistan. As a result, the annual inflow into the Aral Sea reduced from 56 BCM in 1960 to null in 1985,[190] and 3.5 in 2000.[191] Towards the end of Soviet rule in Central Asia, irrigation alone accounted for nearly 90 percent of the total water use from the Amu Darya.[192] This meant that most of the riparian nations like Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, were using more than 90 percent of the total water just for irrigation.[193]

Challenges to Integrated Governance

Following the disintegration of the Soviet Union, the downstream riparian states like Turkmenistan, Uzbekistan, and Kazakhstan—who were then still utilising generous allocations of water—quickly realised that they needed to reduce their dependency on water from the upstream riparians. The economies of these downstream nations were still heavily dependent on water for irrigation and therefore, securing the water flows became integral to national security. This necessitated the signing of the Almaty Agreement in 1992 that established a framework to resolve water disputes. It also set the water allocation levels between the five states at Soviet-era quantities, until a new water allocation agreement was reached.

This was followed by the creation of regional water-centric institutions between 1992 and 1995, including the Interstate Commission for Water Cooperation (ICWC), the Amu Darya and Syr Darya basin management organisations, Interstate Council on the Aral Sea Basin (ICAS), International Fund for the Aral Sea (IFAS), and Sustainable Development Commission (SDC). Further, the Aral Sea Basin Program (ASBP), which is a consortium of international organisations like UNDP, UNEP, the World Bank, and the EU, was initiated in 1994. It tried to provide long-term solutions for some of the basin's wide-ranging problems through the implementation of various programs. A revision of the Aral Sea management framework structure was also carried out subsequent to the initiation of ASBP. Both these initiatives have been important in improving cooperation between the basin members.[194]

Some bilateral and multilateral agreements were also signed by the Amu Darya basin states. For example, in a barter agreement, Tajikistan exports 3.4 billion kWh (worth approximately USD170 million) of hydroelectric power to Uzbekistan in exchange for 3 billion kWh (USD130 million) of electricity that has been generated from natural gas.

Another improvisation has been the allocation of 0.15 BCM/year of Amu Darya water to Kyrgyzstan by ICWC to alleviate some of the demands of Kyrgyzstan in the neighbouring Syr Darya basin.[195] However, the ecological health of the Amu Darya delta in particular, and the conservation of Western Sea region of the Aral Sea in general, remain ambiguous.

The restoration of this region would require an inflow of 11–25 km^3/year, with at least 5–11 km^3 of freshwater. Uzbekistan has been proactive in taking steps to bring more water through collector-drainage network. This project has resulted in an increase in fish capture.[196] However, flows are likely to further decrease as Afghanistan could start using more than 2km^3 (of the total allocated 9km^3 of water), while the annual flow of the Panj river is 19km^3. Thus, the total outflow of the Panj into the Amu Darya will radically decrease if the Afghan government starts developing agriculture in the country's northern regions.[197]

Moreover, there is no immediate shift in sight away from water-intensive cotton production as it remains key role in the basket of export commodities from the region. In 2005, Central Asia accounted for 6.5 percent of the world's total production of cotton and contributed 15 percent of overall cotton exports.[198] Thus, the widely held view that Central Asia is a water-scarce region is questionable; the more accurate assessment would be that the region is unable to use water in a sustainable manner. This is the reason why social, environmental and economic aspects of water management need to be linked with participation and good governance.[199] Such process can be aided by a new system of knowledge.

10. Tarim River Basin

The flooded Tarim River in Xinjiang province, flowing past the Taklamakan Desert with a thin buffer of riparian vegetation.
(Photo: Getty Images/ViewStock)

Physiography and Socio-Cultural Milieu

The Tarim— whose name means "unbridled horse" and "field" in the local Uyghur language—is the longest inland river in China. Some of its tributaries are transboundary and originate outside China, such as Kyrgyzstan. The basin has been experiencing water scarcity for a long time, even as its strategic location gave it an important place in the ancient silk route. The physiography of the basin explains why water scarcity prevails in the region. The basin is bound by the Pamir, Karakoram in the west, which creates a rain shadow. Further, the Tien Shan mountains in the north, and the Kunlun Shan along with the Altun mountains in the south, strengthen the rain-shadow effect, creating a bowl-shaped basin with one side open. The Tarim is 1321-km long and flows along the northern edge of the basin, in a west-to-east direction.[200] The total stretch of the river is 2437km – from the Yarkand Laskaimu river to the tail-end of Taitema lake. The Tarim basin consists of nine river basins: Hotan, Yarkand, Aksu, Kaidu-Kongque, Kashgar, Cherchen, Dina, Weigan, Kuche, and Keriya. Of these nine, only the Aksu, Hotan, Yarkand and Kaidu-Kongquehe have flows that meet the mainstream of Tarim.[201]

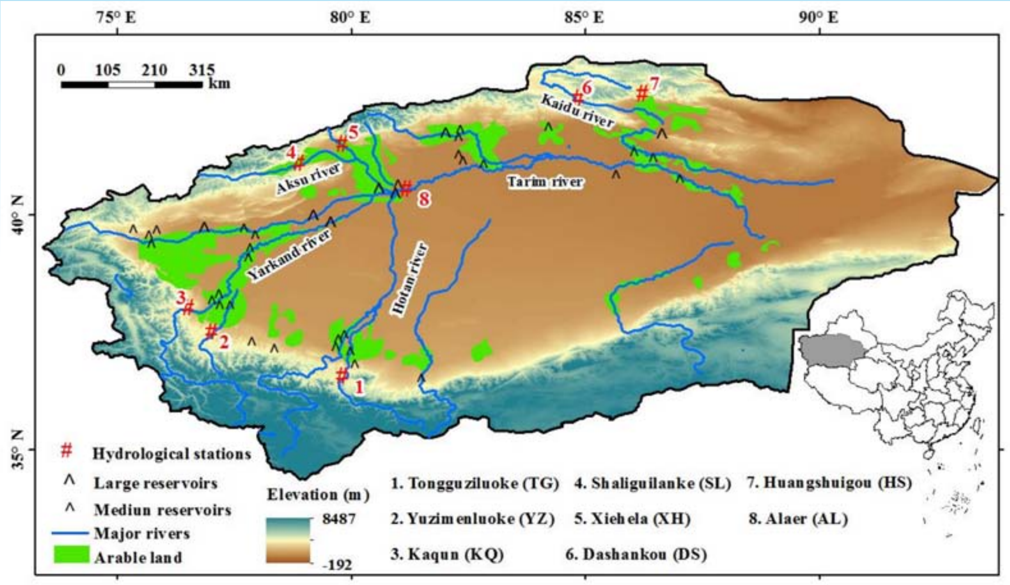
Administratively, the basin is almost entirely located in the Xinjiang Autonomous Region of China. Due to its location in the extreme Northwest, the climate is predominantly continental, with extremely low precipitation. The high-altitude mountains help in intercepting water vapour, allowing precipitation in the mountains and the immediate foothills. Annual rainfall in the Tian Shan mountains is between 400mm and 600mm.

It can reach up to 800mm in the Pamirs. In terms of rainfall, three distinct zones can be identified – the mountainous area has an uneven distribution ranging between 200mm and 500mm, the edges of the basin receive 50~80 mm, while the interior, central portion receive 17.4–25.0 mm. More than 80 percent of the total annual precipitation falls between May and September.[202]

According to China's Second Glacial Inventory, the Tarim Basin holds 34 percent of China's glaciated areas and 41 percent of total volume.[203] The headwaters of the Tarim river are supplied by snow melt and glacier melt, that form the bulk of the flow in the mainstream – snow melt being a dominant source during the springtime, and glacier melt during the summer when temperatures in high mountains begin to rise. The basin also receives maximum rainfall during the two months of July and August. As such, three-quarters of the annual run-off are concentrated in the summer season, which has traditionally led to flooding of river banks and back swamps, thereby replenishing groundwater and sustaining the growth of natural vegetation along a defined corridor.[204] A large part of the basin consists of the Taklakamakan desert, which is the world's second largest mobile desert. The lower reach of the river is 458-km-long and extends from Qiala to Taitema lake, which was earlier referred to as the 'Green Corridor' for the vegetation communities that were present in a 5-10 km zone around the river.[205]

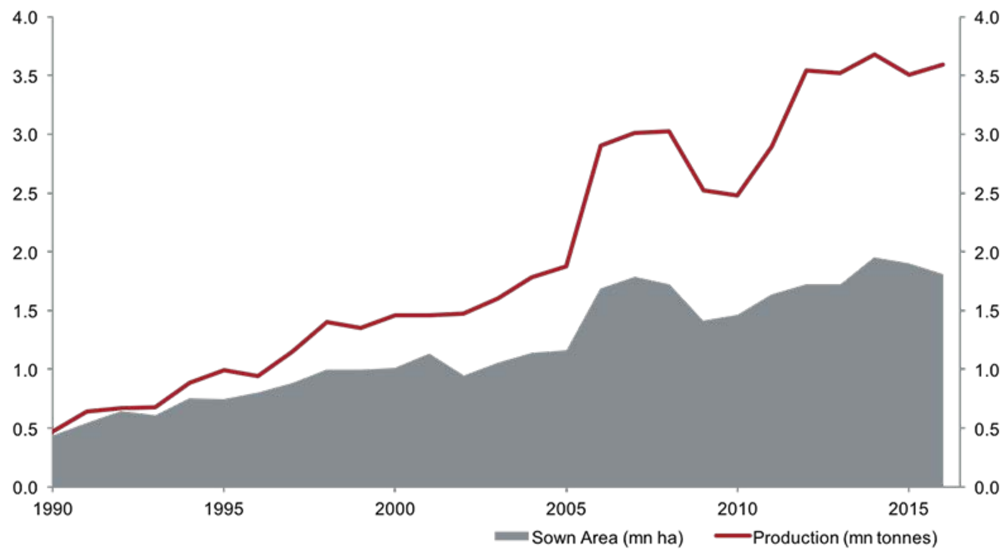
For much of the region's history, irrigated agriculture was concentrated in the oases along the foothills of the mountains, such as the Kuche, Kashgar, and Hotan. However, this changed considerably after 1949 as fallow land began to get converted to arable land and cotton replaced wheat as the most important crop in Xinjiang after 1978.[206] The scarcity of water has impeded overall socio-economic development in the region. The agriculture sector is the largest water consumer, utilising up to 95 percent of Xinjiang's water resources. Cotton, the main commercial crop of the region, uses the bulk of this irrigation water, and accounts for nearly one-third of Xinjiang's total sown area. In terms of production, cotton from Xinjiang represented 78.6 percent of China's total production in 2016[207] and has continued to expand over the years (Ref. Fig 22). However, being the largest producer of cotton in China, Xinjiang suffers from resource competition from various consumer groups of water. This issue has manifested into an upstream-downstream conflict as increasing demand for higher percentage of cotton that is produced in the upstream, coupled with increasing population pressure, poses ecological challenges for the downstream cotton farms.[208]

Figure 21: Tarim River Basin



Source: (Sun, et al. 2018)[209]

Figure 22: Cotton Production in Xinjiang (1990-2016)



Source: China Water Risk based on NBSC data

Challenges to Integrated Governance

Water resources management in the basin faces an apparent and direct sectoral conflict between water utilisation for economic growth, and the ecological needs of river flow. In the upper and middle reaches of the Tarim river, the consumption of water has increased to 13.10 × 108 m^3 and 26.69 × 108 m^3 in the 1990s, from 12.59 × 108 m^3 and 23.23 × 108 m^3 in the 1950s. Concomitantly, the volume of water arriving at the lower reaches of the river reduced from 13.53 × 108 m^3 in the 1950s to 2.67 × 108 m^3 in the 1990s. This has resulted in the drying up of the watercourse in the last 320 km.[210]

Since the 1950s, the reduction of downstream flow has resulted in significant loss of riparian vegetation. The condition has been so severe that even the most characteristic *Populus euphratica* forest, known for being tenacious and selectively wilting its prosperous branches and leaves to preserve its main trunk forest to withstand water scarcity, had started dying. This has caused the green corridor of riparian vegetation along the river to shrink as the sea of sand from the neighbouring area quickly began swallowing the land. Reduced flow in the downstream also contributed to the drying up of two terminal lakes of the Tarim—Lake Taitema and Lop-nur. Taitema Lake was Tarim's tail lake until the construction of the Daxihaizi reservoir in 1972. Since then, the lower reaches of the Tarim have remained dry until 2000, when water from the Daxihaizi Reservoir began to deliver water to the stretches downstream.[211] The bulk of the water is being diverted to facilitate irrigation. For instance, water consumption in the irrigated areas of the basins of headwaters of Tarim—the Aksu, the Yarkand, and the Hotan, had increased to 155 × 108 m^3 in 2000 from 51 × 108 m^3 in the 1950s.[212]

Considering the worsening ecological conditions, the State Council of China established the Tarim River Basin Management Bureau in 1992. This marked a new phase in the management of water resources in the basin, with the Bureau receiving a clear mandate to coordinate and manage efforts on the ecological protection of the basin. Soon after, in 1997, the Tarim River Basin Water Resources Management Regulation was issued.

Two World Bank projects helped facilitate the process, as did the Chinese government by investing 10.7 billion CNY to the regulation scheme from 2002 to 2009.[213] The Tarim River Regulation Scheme started with the following four objectives:

1. Enhance irrigation efficiency and introduce water-saving irrigation techniques, primarily through the introduction and expansion of drip irrigation.
2. Restrict agriculture to the field area of 1998, coinciding with the end of the first Tarim Basin Project.

3. Construct water reservoirs in the mountains, for example along the headwaters of the Aksu river in the Tian Shan straddling China and Kyrgyzstan, and decommissioning reservoirs in the lowlands. The latter was for preventing water losses through evaporation.
4. Allow water to flow downstream, thereby rejuvenating the lower reaches and restoring the riparian ecosystem. This was done by connecting the Kenqi River to the lower reaches of Tarim by constructing two channels that had started diverting water in 2002. Moreover, dykes were constructed along the middle reaches by 2004 to funnel the water to the main course and away from the several distributaries within the inland delta.[214, 215, 216]

Furthermore, a two-stage quota system was devised by 2005. It was based on the estimates that under average conditions (50-percent probability), the inflow of water to the Tarim is 3.42 km/annum from Aksu River, 0.90 from Hotan River, and 0.33 from Yarkant River; 0.45 would be released from Kaidu-Konqi river into the Tarim lower reaches. This quota is dynamic and accounts for low water inflow conditions (90-percent probability) where lesser volumes of water would be released to the Tarim river. Water allocation quotas also exist between the Aksu Prefecture and the Xinjiang Production and Construction Corps along the Aksu river, as well as between different sectors in the upper, middle, and lower reaches of the Tarim River (Ref. Fig. 23).[217,218]

Despite the elaborate plans, however, the amount of water released at Aral and constituting the combined flow of the three headwaters has not met the proposed quota since 1989. By the end of the Tarim Basin Project II in 2005, the quota established by the Tarim Basin Water Resource Commission for each prefecture was exceeded by 20 percent.[219] As a result, the date for following the new quota was postponed from 2005 to a later time that is yet to be defined. The reason for this is primarily the inability of the bureau in controlling the water withdrawal along the Aksu river. Moreover, the inaccuracy of forecast on the basis of which an allocation plan for the following period is to be based, has also offered little confidence. Finally, the quotas are set yearly and not monthly, which often allows the users to manipulate the withdrawal across the annual cycle to meet their irrigation demand requirement during the water-scarce spring and summer seasons while still keeping to the annual quota. Needless to say, this serves little to the cause of ecosystems' requirement of flows during the water-scarce months. However, at the root of this prolonged crisis is the continuation of cotton production that seems to be aligned with a larger policy thrust of allowing and even facilitating Xinjiang as a hub for cotton production.[220]

Figure 23: Long-term Average Water Inflow from the Aksu, Yarkant and Hotan Rivers into the Tarim and Planned Water Allocation along the Tarim River (km³/a)[d]

Source: Author's own based on Map from Wikimedia Commons and based on Thevs et al. (2014)[221]

The government has initiated certain target-oriented cotton price reforms in Xinjiang Uyghur Autonomous Region. Under this initiative, the government had instituted reforms, such as lifting price controls on the production and marketing of cotton and providing bigger subsidies to protect the interests of cotton farmers.[222] This contrasts with the price policy instruments, such as Contracted Purchasing Scheme (CPS), that was operational in 1999. Under the policy, the Chinese government gave cotton farmers an advance payment guarantee price between 20 percent and 25 percent, thereby reducing the impact of prevailing market prices. Farmers were mandated to sign an undertaking stating that they would supply the government with a specific quota of their cotton output.[223]

In light of these facts, the water governance challenge is between two sectors: agriculture and the environment. The lower reaches of the Tarim need the continuous diversions of water from the upper stream—this strategy was started in the 2000s. It is extremely crucial for recharging the aquifer and restoring the vegetation zone.[224]

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d The codes are I: irrigation and industry, E: environmental flow, O: oil exploitation. A–B: Tarim upper reaches, B–C: middle reaches, C–D: upper section of lower reaches, D and below: lower reaches. At Qala (C), on average 0.46 km3/a are transferred from the Kenqi River into the Tarim.

Despite an elaborate basin-wide plan, there are certain flaws in all its aspects– in its design, operation, and the enforcement of rules. As also seen in the earlier discussion, the long-term plan needs to incentivise irrigation communities to shift from water-intensive cotton to less water-intensive crops that are more suited to the regional conditions. Needless to say, harmony and consensus needs to be created across regional water users for irrigation. Planning needs to be done by bringing them on-board while advocating ecological security and environmental security, and their importance in facilitating intergenerational equity. Integration of knowledge is a prerequisite, not only for generating evidence but also actively shaping the process of integrated planning for the entire river basin.

Table 5: A Snapshot of the HKH Basins

River Basin	Degree of Integration Achieved				Key Governance Challenges
	Minimal	Basic	Effective	Advanced	
Yellow	■	■	■		Water scarcity, declining water quality, hydrological extremes
Yangtze	■	■	■		Integrity of riverine ecosystems, impact of large hydropower, floods
Mekong	■	■			Impact of hydropower, institutions for transboundary governance
Salween	■				Largely free-flowing, key challenges could be impact of hydropower and sectoral competition for water.
Irrawaddy	■				
Brahmaputra	■				Floods and shifting channels, impact of hydropower, institutions for transboundary governance
Ganga	■		■		Hydrological extremes, declining water quality, upstream-downstream connectivity, institutions for transboundary governance
Indus	■		■		Sectoral competition for water, water-energy-food nexus, institutions for transboundary governance
Amu Darya	■				Water scarcity, integrity of ecosystems, integrity of riverine ecosystems
Tarim	■	■	■		Water scarcity, sectoral competition for water, integrity of riverine ecosystems

Endnotes

1 Sun Feng,"The Great Yellow River Integrated River Basin Management" (International Conference on Transboundary River Basin Management, Thailand, May, 2012.

2 Robert J. Hijmans et al.,"Very high resolution interpolated climate surfaces for global land areas," *International Journal of Climatology* 25, Issue 15 (2005), https://doi.org/10.1002/joc.1276

3 Deming Zhao, Claudia Kuenzer, Congbin Fu, and Wolfgang Wagner,"Evaluation of the ERS Scatterometer-Derived Soil Water Index to Monitor Water Availability and Precipitation Distribution at Three Different Scales in China." *Journal Of Hydrometeorology 9* (2008): 549-562.

4 Brierley John, Gary, Xilai Li, Carola Cullum, and Jay Gao. 2016. "Introduction: Landscape and Ecosystem Diversity in the Yellow River Source Zone." In *Landscape and Ecosystem Diversity, Dynamics and Management in the Yellow River Source Zone*, by Gary Brierley John, Xilai Li, Carola Cullum and Jay Gao, 1-34. Springer, Cham.

5 Nakul Chettri, Arun B. Shrestha, Yan Zhaoli, Birendra Bajracharya, Eklabya Sharma, and Hua Ouyang, "Real world protection for the "Third Pole" and its people." in *Protection of the three poles*, ed. Falk Huettmann (Tokyo: Springer, 2012), 113-133

6 Feng,"The Great Yellow River Integrated River Basin Management"

7 Guobin Fu et al., "Hydro-climatic trends of the Yellow River Basin for the last 50 years," *Climate Change* 65 (2004), https://doi.org/10.1023/B:CLIM.0000037491.95395.bb

8 Mei'e Ren, "Sediment discharge of the Yellow River, China: past, present and future—a synthesis." *Acta Oceanologica Sinica* 34 (2015), https://doi.org/10.1007/s13131-015-0619-6

9 Mei'e Ren,"Sediment discharge of the Yellow River, China: past, present and future—a synthesis."

10 Houjie Wang et al., "Stepwise decreases of the Huanghe (Yellow River) sediment load (1950–2005): Impacts of climate change and human activities.," *Global and Planetary Change* 57 (2007), https://doi.org/10.1016/j.gloplacha.2007.01.003

11 Brierley John, Introduction to *Landscape and, Ecosystem Diversity in the Yellow River Source Zone*

12 Zhijun Zhao, "New Archaeobotanic Data for the Study of the Origins of Agriculture in China." *Current Anthropology 52* (2011): S295-S306.

13 Jayanta Bandyopadhyay. "Restoration of Ecological Status of Himalayan Rivers in China and India: The Case of the Two Mother Rivers - The Yellow and the Ganges," in *Environmental Sustainability from the Himalayas to the Oceans*, ed. Shikui Dzong, Jayanta Bandyopadhyay, Sanjay Chaturvedi (Springer International Publishing, 2017). 69-98

14 Sun Feng," The Great Yellow River Integrated River Basin Management"

15 Christian Wohlfart et al.,"Social–ecological challenges in the Yellow River basin (China): a review." *Environmental Earth Science* 75, 1066 (2016) https://doi.org/10.1007/s12665-016-5864-2

16 Christian Wohlfart et al.,"Social–ecological challenges in the Yellow River basin (China): a review."

17 UNESCO and IRTCES, *Sediment Issues & Sediment Management in Large River Basins Interim Case Study Synthesis Report, 2011*, Beijing, International Hydrological Programme UNESCO, 2011, http://isi.irtces.org/isi/rootfiles/2017/07/04/1496391629465963-1498713525773654.pdf

18 Clem Tisdell et al., "Economic reform and openness in China: China's development policies in the last 30 years," *Economic Analysis and Policy 39* (2009), https://doi.org/10.1016/S0313-5926(09)50021-5

19 Feng Kaiwen, "A Study on the outline history of the household responsibility system in rural China since 1949: The organizations, institutions, and their changes." *African and Asian Studies* 3, no. 3-4 (2004): 219-244.

20 Jingsheng Chen et al., "The response of river water quality and quantity to the development of irrigated agriculture in the last 4 decades in the Yellow River Basin, China." *Water resources research* 39, no. 3 (2003), https://doi.org/10.1029/2001WR001234

21 Yi-ping Chen et al., "Sustainable development in the Yellow River Basin: Issues and strategies." *Journal of Cleaner Production* 263 (2020), https://doi.org/10.1016/j.jclepro.2020.121223

22 Christian Wohlfart et al.,"Social–ecological challenges in the Yellow River basin (China): a review."

23 Malin Falkenmark and CG Widstrand, "Population and Water Resources: A Delicate Balance." *Population bulletin* 47, 3 (1992): 1-36.

24 Ximing Cai et al.,"Optional water development strategies for the Yellow River Basin: balancing agricultural and ecological water demands," *Water Resources Research* 40, no. 8 (2004). http://dx.doi.org/10.1029/2003WR002488

25 Claudia Ringler et al., "Yellow River basin: living with scarcity." *Water International* 35, no. 5 (2010), https://doi.org/10.1080/02508060.2010.509857

26 Cai et al., "Optional water development strategies for the Yellow River Basin: balancing agricultural and ecological water demands."

27 Claudia et al. "Yellow River basin: living with scarcity."

28 Guangju Zhao et al., "Temporal variation of streamflow, sediment load and their relationship in the Yellow River Basin, China." *PLoS One* 9, no. 3 (2014), https://doi.org/10.1371/journal.pone.0091048

29 Wohlfart et al."Social–ecological challenges in the Yellow River basin (China): a review."

30 Bryan Lohmar, Jinxia Wang, Scott Rozelle, Jikun Huang, and David Dawe, *China's agricultural water policy reforms: increasing investment, resolving conflicts, and*

revising incentives, Washington DC, U.S. Department of Agriculture, 2003, https://www.ers.usda.gov/webdocs/publications/42495/30867_aib782_002.pdf?v=0

31 Yunzhen Chen et al., "Socio-economic impacts on flooding: A 4000-year history of the Yellow River, China." *Ambio* 41, no. 7 (2012), https://doi.org/10.1007/s13280-012-0290-5

32 S. L. Yang et al, "50,000 dams later: erosion of the Yangtze River and its delta." *Global and Planetary Change* 75, Issues 1-2 (2011) https://doi.org/10.1016/j.gloplacha.2010.09.006

33 J. D. Milliman and K.L. Farnsworth, *River Discharge to the Coastal Ocean: A Global* (Cambridge: Cambridge University Press, 2011)

34 Mats Eriksson, JianChu Xu, Arun Shrestha B., Ramesh Vaidya A., Nepal Santosh, and Klas Sandström, 2009. *The changing Himalayas: impact of climate change on water resources and livelihoods in the greater Himalayas,* Kathmandu, International centre for integrated mountain development (ICIMOD), 2009, https://doi.org/10.53055/ICIMOD.516

35 E. L. Shaughnessy and M Loewe, *The Cambridge history of ancient China: from the origins of civilization to 221 BC.* (Cambridge University Press, 1999).

36 X. Chen, Y. Zong, E. Zhang, J. Xu, and S. Li, "Human impacts on the Changjiang (Yangtze) River basin, China, with special reference to the impacts on the dry season water discharges into the sea." *Geomorphology* 41, 2-3 (2001): 111-123.

37 Jayanta Bandyopadhyay, "Restoration of ecological status of Himalayan rivers in China and India: The case of the two mother rivers—The Yellow and the Ganges." In *Environmental Sustainability from the Himalayas to the Oceans*, ed. Shikui Dong, Jayanta Bandyopadhyay and Sanjay Chaturvedi (Cham: Springer, 2017), 69-98.

38 Bandyopadhyay, "Restoration of ecological status of Himalayan rivers in China and India: The case of the two mother rivers—The Yellow and the Ganges."

39 Yang Xiankun, Xixi Lu, Lishan Ran, and Paolo Tarolli. "Geomorphometric Assessment of the Impacts of Dam Construction on River Disconnectivity and Flow Regulation in the Yangtze Basin." *Sustainability* 11, 12 (2019) https://doi.org/10.3390/su11123427

40 Chen, "Human impacts on the Changjiang (Yangtze) River basin, China, with special reference to the impacts on the dry season water discharges into the sea."

41 Yang "50,000 dams later: erosion of the Yangtze River and its delta."

42 J.Z. Pan and J. He, "Large dams in China: A fifty-year review (In Chinese)." *China Water Power Press.* (2000)

43 Kaifeng Li, Cheng Zhu, Li Wu, and Linyan Huang. "Problems caused by the Three Gorges Dam construction in the Yangtze River basin: a review." *Environmental Reviews* 21, 3 (2013) https://doi.org/10.1139/er-2012-0051

44 J. Zhang, Z. F. Zhang, S. M. Liu, Y. Wu, H. Xiong, and H. T. Chen,"Human impacts on the large world rivers: Would the Changjiang (Yangtze River) be an illustration?" *Global Biogeochemical Cycles*13, 4 (1999): 1099-1105.

45 L. Ye, Y. Xu, X. Han, and Q. Cai, " Daily dynamics of nutrients and chlorophyll a

during a spring phytoplankton bloom in Xiangxi Bay of the Three Gorges Reservoir." *Journal of Freshwater Ecology* 21,2 (2006) https://doi.org/10.1080/02705060.2006.9665001

46 Yang et al., "50,000 dams later: erosion of the Yangtze River and its delta."

47 Yang, "50,000 dams later: erosion of the Yangtze River and its delta"

48 S. L. Yang et al., "Decline of Yangtze River water and sediment discharge: Impact from natural and anthropogenic changes." *Scientific Reports* 5, 12581 (2015) https://doi.org/10.1038/srep12581

49 Yang, "50,000 dams later: erosion of the Yangtze River and its delta"

50 Zheng et al., "Riverbed erosion of the final 565 kilometers of the Yangtze River (Changjiang) following construction of the Three Gorges Dam." *Scientific reports* 8, 11917 (2018), https://doi.org/10.1038/s41598-018-30441-6

51 Yang et al.,"50,000 dams later: erosion of the Yangtze River and its delta."

52 Zhou et al., "Impacts of Three Gorges Reservoir on the sedimentation regimes in the downstream-linked two largest Chinese freshwater lakes." *Scientific reports* 6, 35396 (2016), https://doi.org/10.1038/srep35396

53 Bing Gao et al., "Impact of the Three Gorges Dam on flow regime in the middle and lower Yangtze River." *Quaternary International* 304, 5 (2013) https://doi.org/10.1016/j.quaint.2012.11.023

54 Avijit, Gupta and S.C Liew, "The Mekong from satellite imagery: A quick look at a large river." *Geomorphology* 85, 3-4 (2007) https://doi.org/10.1016/j.geomorph.2006.03.036

55 MRC, *State of the Basin Report, 2003*. Phnom Penh, Mekong River Commission, 2003, http://www.mekonginfo.org/assets/midocs/0001489-inland-waters-state-of-the-basin-report-2003.pdf

56 W. Botkosal, "Establishment of local river basin organization to promote water governance." (paper at Conference on new thinking on water governance, Singapore, National University of Singapore, 2009)

57 Mekong River Commission for Sustainable Development https://www.mrcmekong.org/

58 UNEP, Global International Waters Assessment Regional assessment 55 Mekong River, June 2006, Kalmar, University of Kalmar, 2006, https://www.unep.org/resources/report/global-international-waters-assessment-mekong-river-giwa-regional-assessment-55

59 UNEP, *Global International Water Assessment, 2006,* Kalmar, University of Kalmar, 2006. http://wedocs.unep.org/bitstream/handle/20.500.11822/8761/GIWA_regional_assessment_55_Meekong_river.pdf?sequence=3&isAllowed=y.

60 "State of the Basin Report 2003"

61 Gupta and Liew,"The Mekong from satellite imagery: A quick look at a large river"

62 Gupta and Liew,"The Mekong from satellite imagery: A quick look at a large river"

63 Ian C. Campbell, Introduction to The Mekong : biophysical environment of an

international river basin, by Ian C. Campbell, 1-2. (New York: Academic Press, 2009) 1-2

64 D. G. E. Hall, *A History of South-East Asia* (London: Macmillan Education, 1981).

65 Higham, Charles. 2001. *The Civilization of Angkor*. London: Weidenfeld and Nicholson.

66 Mekong River Commission, *The Flow of the Mekong, November 2009*, Vientiane, Mekong River Commission, 2009, https://www.mrcmekong.org/assets/Publications/report-management-develop/MRC-IM-No2-the-flow-of-the-mekong.pdf

67 Campbell, Introduction to *The Mekong : biophysical environment of an international river basin*

68 Molle, François, Tira Foran, and Philippe Floch, Introduction: Changing Waterscapes in the Mekong Region – Historical Background and Context to *Contested waterscapes in the Mekong Region : hydropower, livelihoods, and governance*, by François Molle, Tira Foran and Mira Käkönen (London: Earthscan, 2009), 1-13

69 Chris Sneddon and Coleen Fox "Rethinking transboundary waters: A critical hydropolitics of the Mekong basin." *Political Geography 25, 2* (2006) https://doi.org/10.1016/j.polgeo.2005.11.002

70 FAO, Mekong Basin, Website Report in AQUASTAT Website, https://www.fao.org/3/CA2135EN/ca2135en.pdf

71 J. S Hecht et al.,"Hydropower dams of the Mekong River basin: A review of their hydrological impacts." *Journal of hydrology* 568 (2018), https://doi.org/10.1016/j.jhydrol.2018.10.045

72 T.A. Räsänen, "Observed river discharge changes due to hydropower operations in the Upper Mekong basin." *Journal of Hydrology* 545 (2017), https://doi.org/10.1016/j.jhydrol.2016.12.023

73 D. Li, D. Long, J. Zhao, H. Lu, and Y. Hong, "Observed changes in flow regimes in the Mekong River basin." *Journal of Hydrology* 551 (2017), https://doi.org/10.1016/j.jhydrol.2017.05.061

74 W. Wang et al.,"Dam construction in Lancang-Mekong River Basin could mitigate future flood risk from warming-induced intensified rainfall." *Geophysical Research Letters* 44, 20 (2017) https://doi.org/10.1002/2017GL075037

75 Hecht et al. "Hydropower dams of the Mekong River basin: A review of their hydrological impacts."

76 Hecht et al."Hydropower dams of the Mekong River basin: A review of their hydrological impacts."

77 A.B. Wyatt and I.G. Baird,"Transboundary impact assessment in the Sesan River Basin: The case of the Yali Falls Dam." *International Journal of Water Resource Development* 23, 3 (2007) https://doi.org/10.1080/07900620701400443

78 Z. Hogan "Long distance migration and marine habitation in the tropical Asian catfish, Pangasius krempfi." *Journal of Fish Biology* 71, 3 (2007) https://doi.org/10.1111/j.1095-8649.2007.01549.x

79 N. van Zalinge, N., P. Degen, C. Pongsri, S. Nuov, J. Jensen, N. V. Hao, and X Choulamany, *The Mekong river System, Proceedings of the second international symposium on the management of large rivers for fisheries,* Phnom Penh, Food and Agricultural Organisation of the United Nations and The Mekong River Commission, https://www.fao.org/3/ad525e/ad525e0l.htm

80 K. G. Hortle, *Consumption and the yield of fish and other aquatic animals from the Lower Mekong Basin.*" Vientiane, Mekong River Commission, 2007, https://www.mrcmekong.org/assets/Publications/technical/tech-No16-consumption-n-yield-of-fish.pdf

81 Mekong River Commission, *Assessment of basin-wide development scenarios - Main report,* Vientiane, Mekong River Commission, 2011 https://tile.loc.gov/storage-services/service/gdc/gdcovop/2013341124/2013341124.pdf

82 A. Intralawan, D. Wood, R. Frankel, R. Costanza, and I. Kubiszewski, "Tradeoff analysis between electricity generation and ecosystem services in the Lower Mekong basin." *Ecosystem Services – 30*, A (2018), https://doi.org/10.1016/j.ecoser.2018.01.007

83 Alan Basist and Claude Williams, *Monitoring the Quantity of Water Flowing Through the Mekong Basin Through Natural (unimpeded) Conditions*, Bangkok, Sustainable Infrastructure Partnership, 2020, https://www.pactworld.org/library/monitoring-quantity-water-flowing-through-upper-mekong-basin-under-natural-unimpeded

84 "Monitoring the Quantity of Water Flowing Through the Mekong Basin Through Natural (unimpeded) Conditions"

85 MRC, *State of the Basin Report, 2018*. Phnom Penh, Mekong River Commission, 2018, https://data.opendevelopmentmekong.net/dataset/6425d177-5d41-43a5-8589-cf05576d50a6/resource/dc89dedc-f864-4a76-9506-bd980dc972c7/download/sobr-v8_final-for-web.pdf

86 Sovinda Po, & Christopher Primiano, C. B., "Explaining China's Lancang–Mekong cooperation as an institutional balancing strategy: Dragon guarding the water." *Australian Journal of International Affairs*, *75*, 3 (2021)

87 Sebastian Biba, "China's 'old' and 'new' Mekong River politics: The Lancang–Mekong Cooperation from a comparative benefit-sharing perspective." *Water International*, *43, 5* (2018) https://doi.org/10.1080/02508060.2018.1474610

88 FAO, Salween Basin, Website Report in AQUASTAT Website, https://www.fao.org/documents/card/en/c/CA2134EN/

89 Darrin Magee and Shawn Kelley, "Damming the Salween River." In *Contested Waterscapes in the Mekong Region*, ed. Francois Molle, Tira Foran and Mira Kakonen (Routledge, 2012), 137-162

90 Darrin Magee, "Powershed Politics: Yunnan Hydropower under Great Western Development," The China Quaterly 185 (2006), https://doi.org/10.1017/S0305741006000038

91 J. Buchanan, *Militias in Myanmar*, Yangon, The Asia Foundation, 2016, https://

asiafoundation.org/wp-content/uploads/2016/07/Militias-in-Myanmar.pdf

92 Hydro-Informatics Centre, *Ayeyarwady State of the Basin Assessment (SOBA) 2017: Synthesis Report, Volume 1, December 2017*, Yangon, National Water Resources Committee, 2017, https://www.airbm.org/wp-content/uploads/2018/03/SOBA-Synthesis-Report-Volume-1_low_res.pdf

93 CGIAR, "Irrawaddy River Basin," WLE CGIAR Website , https://wle-mekong.cgiar.org/changes/where-we-work/irrawaddy-river-basin/

94 Aung Si Hein, "The Ayeyarwady River: The Heart of Myanmar," *Today Myanmar,* Oct 13, 2016, https://medium.com/@todaymyanmar/the-ayeyarwady-river-the-heart-of-myanmar-15872ad3172c

95 Carl Middleton, Alec Scott, and Vanessa Lamb. "Hydropower politics and conflict on the Salween River." in *Knowing the Salween River: Resource politics of a contested transboundary river*, ed. Carl Middleton and Vanessa Lamb (Cham: Springer, 2019): 27.

96 Johnston, Robyn M., Matthew P. McCartney, Shaoyu Liu, Tarek Ketelsen, Luke Taylor, Mai Ky Vinh, Ko Ko Gyi Mehm, Theiant Aung, and Khin Ma Ma Gyi, *State of knowledge: River health in the Salween*, Vientiane, CGIAR, 2017, https://hdl.handle.net/10568/82969

97 "State of knowledge: River health in the Salween"

98 PYO (Pa-Oh Youth Organization), *Poison clouds: Lessons from Burma's largest coal project in Tigyit*, Myanmar, PYO, 2020 https://www.burmalibrary.org/en/poison-clouds-lessons-from-burmas-largest-coal-project-at-tigyit

99 Chayan Vaddhanaphuti, Khin Maung Lwin, Nang Shining, Pianporn Deetes, R. Edward Grumbine. "Hydropower politics and conflict on the Salween River." in *Knowing the Salween River: Resource politics of a contested transboundary river*, ed. Carl Middleton and Vanessa Lamb (Cham: Springer, 2019): 279-303.

100 CGIAR Research Programme on Water, Land and Ecosystems, "Dams in the Irrawaddy and Salween River Basins: Commissioned, Under Construction and Planned Dams in April 2016," WLE Greater Mekong, https://hdl.handle.net/10568/83002

101 Ketelsen, T., L. Taylor, R. Hunter, R. Johnston, M. Charles, Mai Ky Vinh, Shaoyu Liu, Tint Kyaw, and Ma Ma Gyi Khin, *State of knowledge: River health in the Ayeyarwady*, Vientiane, CGIAR, 2017, https://hdl.handle.net/10568/82968

102 ICEM (International Centre for Environmental Management), *Developing a Strategic Environmental Assessment (SEA) of the Hydropower Sector in Myanmar*. Hanoi, ICIEM, 2017, http://hdl.handle.net/10986/31256

103 "State of knowledge: River health in the Ayeyarwady."

104 Middleton, "Hydropower politics and conflict on the Salween River."

105 Jules Stewart, "The Pundits: Surveying the Frontiers of India in the Great Game." *Asian Affairs* 48, 1 (2017), https://doi.org/10.1080/03068374.2016.1267440

106 Mukund P. Rao et al., "Seven centuries of reconstructed Brahmaputra River discharge

demonstrate underestimated high discharge and flood hazard frequency." *Nature communications* 11, no. 1 (2020), https://doi.org/10.1038/s41467-020-19795-6

107 John D. Milliman and James PM Syvitski. "Geomorphic/tectonic control of sediment discharge to the ocean: the importance of small mountainous rivers." *The journal of Geology* 100, no. 5 (1992): 525-544.

108 Mohammad Rezwanul Islam et al.,"The Ganges and Brahmaputra Rivers in Bangladesh: basin denudation and sedimentation," Hydrological Process 13, 17 (1999), https://doi.org/10.1002/(SICI)1099-1085(19991215)13:17%3C2907::AID-HYP906%3E3.0.CO;2-E

109 Walter Immerzeel, "Historical trends and future predictions of climate variability in the Brahmaputra basin" *International Journal of Climatology* 28, 2 (2007), https://doi.org/10.1002/joc.1528

110 A. K. Gain et al., "Impact of climate change on the stream flow of the lower Brahmaputra: trends in high and low flows based on discharge-weighted ensemble modelling." *Hydrology and Earth System Sciences* 15, 5 (2011), https://doi.org/10.5194/hess-15-1537-2011

111 Md. Shahriar Parvez and Geoffrey M. Henebry, "Assessing the impacts of climate and land use and land cover change on the freshwater availability in the Brahmaputra River basin." *Journal of Hydrology: Regional Studies* 3 (2015), https://doi.org/10.1016/j.ejrh.2014.09.003

112 Dinesh Kumar Mishra, "Living with Floods: People's Perspective." *Economic and Political Weekly* 36, 29 (2001), https://www.jstor.org/stable/4410885

113 J.N. Sarma, "Fluvial process and morphology of the Brahmaputra River in Assam, India." *Geomorphology* 70, 3–4 (2005), https://doi.org/10.1016/j.geomorph.2005.02.007

114 Patrick A. Ray et al.," Room for improvement: hydroclimatic challenges to poverty-reducing development of the Brahmaputra River basin." *Environmental Science & Policy* 54, https://doi.org/10.1016/j.envsci.2015.06.015

115 Ganesh Pangare, Bushra Nishat, Xiawei Liao and Halla Maher Qaddumi, eds., *The Restless River* (Washington: World Bank Publications, 2021), chap. 2, http://hdl.handle.net/10986/36258

116 D. C. Goswami and P. J. Das, "The Brahmaputra River, India: the eco-hydrological context of water use in one of world's most unique river systems" *Ecologist Asia* 11, 1 (2003), pp 9 -11

117 D. C. Goswami*, Himalayan Catchment and the Hydrologic Regime of Brahmaputra River, India: Selected Case Studies* (2001)

118 Nilanjan Ghosh and Jayanta Bandyopadhyay, "Governance of the Brahmaputra sub-basin: exploring the enabling conditions," in *Complexity of Transboundary Water Conflicts: Enabling Conditions for Negotiating Contingent Resolutions*, ed. Enamul Choudhury, Shafiqul Islam, Lawrence Susskind (London: Anthem Press 2018), 99-128.

119 P G Whitehead et al., "Impact of climate change and socio-economic scenarios on flow

and water quality of the Ganges, Brahmaputra and Meghna (GBM) river systems: low flow and flood statistics," Environmental Science Processes and Impacts 17, 6 (2015), https://doi.org/10.1039/c4em00619d

120 Sayanangshu Modak, "The Teesta Quagmire: India's missed opportunity?" *South Asian Voices,* November 10, 2020, https://southasianvoices.org/the-teesta-quagmire-indias-missed-opportunity/

121 Md. Arfanuzzaman and Qazi Kholiquzzaman Ahmad,"Assessing the regional food insecurity in Bangladesh due to irrigation water shortage in the Teesta catchment area." *Water Policy* 18, 2 (2016), https://doi.org/10.2166/wp.2015.072

122 Md Fakrul Islam,"The Teesta River and its basin area." In *Water Use and Poverty Reduction*, ed. Md. Fakrul Islam (Tokyo: Springer, 2016) 13-43.

123 Jayanta Bandyopadhyay and Shama Perveen, "The interlinking of Indian rivers: Questions on the scientific, economic and environmental dimensions of the proposal." *Interlinking of Rivers in India: Issues and Concerns* 53 (2008) https://www.soas.ac.uk/water/publications/papers/file38403.pdf

124 Muhammad Mizanur Rahaman and Olli Varis. "Integrated water management of the Brahmaputra basin: Perspectives and hope for regional development." *Natural Resources Forum* 33, 1 (2009), https://doi.org/10.1111/j.1477-8947.2009.01209.x

125 Ghosh and Bandyopadhyay, "Governance of the Brahmaputra sub-basin: exploring the enabling conditions"

126 Nilanjan Ghosh, Jayanta Bandyopadhyay, and Sayanangshu Modak, "China-India Data Sharing for Early Flood Warning in the Brahmaputra: A Critique", *Observer Research Foundation Issue Brief No. 328* (2019), https://www.orfonline.org/research/china-india-data-sharing-for-early-flood-warning-in-the-brahmaputra-58330/

127 Sutirtho Patranobis and Rezaul H Laskar, "China defends dam on Brahmaputra, India hits back" *Hindustan Times, December 04, 2020* https://www.hindustantimes.com/india-news/china-defends-dam-on-brahmaputra-india-hits-back/story-Z9fTogaquykvrYVXhgxbfK.html

128 Sayanangshu Modak, "Spotlight on planet's largest hydropower project by China on Yarlung/Brahmaputra" *Observer Research Foundation,* December 12, 2020, https://www.orfonline.org/expert-speak/spotlight-on-planets-largest-hydropower-project-by-china-on-yarlungbrahmaputra/

129 Arupjyoti Saikia, *The Unquiet River: A Biography of the Brahmaputra*. (Oxford University Press, 2019)

130 Jayanta Bandyopadhyay, "Interdisciplinary Governnace of the Transboundary Brahmaputra River System" in *The Restless River*, ed. Ganesh Pangare, Bushra Nishat, Xiawei Liao and Halla Maher Qaddumi (Washington: World Bank Publications, 2021), 368-371

131 "The changing Himalayas: impact of climate change on water resources and livelihoods in the greater Himalayas."

132 Ministry of Water Resources, Ganga Basin Report Version 2.0, Ministry of Water

Resources, Government of India, 2014. https://indiawris.gov.in/downloads/Ganga%20Basin.pdf

133 “The changing Himalayas: impact of climate change on water resources and livelihoods in the greater Himalayas.”

134 “The changing Himalayas: impact of climate change on water resources and livelihoods in the greater Himalayas.”

135 Ashok Swain (2018). “The Ganges River Water Sharing Agreement Between Bangladesh and India: In Search of New Mechanisms to Meet New Challenges.” In *Complexity of Transboundary Water Conflicts: Enabling Conditions for Negotiating Contingent Resolutions,* ed. Enamul Choudhury, Shafiqul Islam and Lawrence Susskind (London: Anthem Press, 2018), 129-144

136 Dwijendra Narayan Jha and D. N. Jha, *Ancient India: In Historical Outline* (Manohar Publishers & Distributors, 1998),

137 Sudipta Sen, *Ganges: The many pasts of an Indian river* (Yale University Press, 2019)

138 John Briscoe and Ravinder PS Malik. *India’s water economy: bracing for a turbulent future* (New Delhi: Oxford University Press, 2006)

139 Bandyopadhyay “Restoration of ecological status of Himalayan rivers in China and India: The case of the two mother rivers—The Yellow and the Ganges.”

140 Preeti Kapuria and Sayanangshu Modak. “An Eco-Hydrological Perspective to Monsoon High Flows in the Ganga-Padma System: Imperatives for Flood Management.” *ORF Occasional Paper* 214 (2019), https://www.orfonline.org/research/eco-hydrological-perspective-monsoon-high-flows-ganga-padma-system-imperatives-flood-management-55944/

141 Bandyopadhyay, “Restoration of ecological status of Himalayan rivers in China and India: The case of the two mother rivers—The Yellow and the Ganges.”

142 Sadoff et al., “Ten fundamental questions for water resources development in the Ganges: myths and realities” Water Policy 15, S1 (2013), https://doi.org/10.2166/wp.2013.006

143 Dinesh Kumar Mishra, “The Bihar flood story.” *Economic and Political Weekly* 32, 35 (1997): 2206-2217. http://www.jstor.org/stable/4405794

144 Mishra, Dinesh Kumar. “Living with Floods: People’s Perspective.” *Economic and Political Weekly* 36, 29 (2001): 2756-2761. http://www.jstor.org/stable/4410885.

145 Dinesh Kumar Mishra,”Bihar floods: the inevitable has happened.” *Economic and Political Weekly* 43, 36 (2008): 8-12. https://www.jstor.org/stable/40277917

146 Dinesh Kumar Mishra, *Trapped! Between the devil and deep Waters* (Dehra Dun: Peoples’ Science Institute, 2008)

147 Satya Priya, William Young, Thomas Hopson, and Ankit Avasthi, *Flood Risk Assessment and Forecasting for the Ganges-Brahmaputra-Meghna River Basins.* Washington, DC: World Bank, 2017 *https://openknowledge.worldbank.org/handle/10986/28574*

148 "Flood Risk Assessment and Forecasting for the Ganges-Brahmaputra-Meghna River Basins"

149 World Bank, *Ganges Strategic Basin assessment: a discussion of regional opportunities and risks,* Washington DC, The World Bank, 2014, *https://openknowledge.worldbank.org/handle/10986/24092*

150 Jayanta Bandyopadhyay and Dipak Gyawali, "Himalayan water resources: ecological and political aspects of management." *Mountain Research and Development* 14, 1 (1994) https://doi.org/10.2307/3673735

151 National River Conservation Directorate, *Status Paper on River Ganga: State of Environment and Water Quality*, 2009, https://knowindia.gov.in/assets/doc/status-paper-ganga.pdf

152 National Water Quality Monitoring Programme, in the Water Quality Database, http://www.cpcbenvis.nic.in/water_quality_data.html . ENVIS

153 National Water Quality Monitoring Programme, in the Water Quality Database, http://www.cpcbenvis.nic.in/water_quality_data.html . ENVIS

154 R. C. Trivedi, "Water quality of the Ganga River–an overview." *Aquatic Ecosystem Health & Management* 13, 4 (2010) https://doi.org/10.1080/14634988.2010.528740

155 Vinod Tare. "Managing and Sanctifying Water Bodies." In *Water Governance: Challenges and Prospects*, ed. A Singh, D. Saha and A. Tyagi (Singapore: Springer, 2019) 67-85

156 Indian Institute of Technology, *SWOT Analysis of Ganga Action Plan*, https://nmcg.nic.in/writereaddata/fileupload/50_006GEN.pdf

157 Sayanangshu Modak, "Towards an Ecosystems Approach to Fisheries Management Along the Bengal Coast," *ORF Occasional Paper No. 323* (2021) https://www.orfonline.org/research/towards-an-ecosystems-approach-to-fisheries-management-along-the-bengal-coast/

158 Mahesh Rangarajan, *Nature without borders* (Orient Black Swan, 2014).

159 Nilanjan Ghosh and Jayanta Bandyopadhyay, "Governing the Ganges and Brahmaputra: Beyond Reductionist Hydrology," *ORF Occasional Paper No. 273* (2020) https://www.orfonline.org/research/governing-the-ganges-and-brahmaputra-beyond-reductionist-hydrology/

160 Nilanjan Ghosh and Jayanta Bandyopadhyay, "Governing the Ganges and Brahmaputra: Beyond Reductionist Hydrology"

161 FAO, Indus Rive Basin, Website Report in AQUASTAT Website, https://www.fao.org/aquastat/en/countries-and-basins/transboundary-river-basins/indus

162 "The changing Himalayas: impact of climate change on water resources and livelihoods in the greater Himalayas"

163 "The changing Himalayas: impact of climate change on water resources and livelihoods in the greater Himalayas"

164 A. N. Khosla, "Development of the Indus River System: An Engineering Approach" *India Quarterly: A Journal of International Affairs* (1958), https://doi.org/10.1177%

2F097492845801400301

165 The Panjnad is the combined flow of five main rivers – the Jhelum and Chenab as western rivers (the grouping also includes the Indus), along with the Ravi, Beas and Sutlej (known as the eastern rivers).

166 Shane Mountjoy, *The Indus River (Rivers in World History)* (Broomall: Chelsea House, 2005)

167 David Gilmartin, “Scientific Empire and Imperial Science: Colonialism and Irrigation Technology in the Indus Basin” The Journal of Asian Studies 53, 4 (1994), https://doi.org/10.2307/2059236

168 Aloys Arthur Michel, *The Indus Rivers: a Study of the Effects of Partition* (New Haven: Yale University Press, 1967)

169 Condon et al., “Challenge and response in the Indus Basin”, *Water Policy* 16, S1 (2014), https://doi.org/10.2166/wp.2014.004

170 Condon et al., “Challenge and response in the Indus Basin”

171 Daanish Mustafa, *Hydropolitics in Pakistan’s Indus Basin*, Washington DC: US Institute of Peace, 2010, https://www.usip.org/sites/default/files/resources/SR261%20-%20Hydropolitics_in_Pakistan’s%20_Indus_Basin.pdf

172 FAO, Indus Rive Basin, Website Report in AQUASTAT Website, https://www.fao.org/aquastat/en/countries-and-basins/transboundary-river-basins/indus

173 John Briscoe and Usman Qamar, *Pakistan’s Water Economy: Running Dry*, Washington DC, World Bank Group, 2028, http://hdl.handle.net/10986/11746

174 Rodell et al., “Satellite-based estimates of groundwater depletion in India” Nature 460 (2009), https://doi.org/10.1038/nature08238

175 Condon et al., “Challenge and response in the Indus Basin”

176 Aquapedia Case Study Database, “Baglihar Hydroelectric Plant- Issue between Pakistan and India,” Aquapedia, http://aquapedia.waterdiplomacy.org/wiki/index.php?title=Baglihar_Hydroelectric_Plant_-_Issue_between_Pakistan_and_India&oldid=8307

177 Condon et al., “Challenge and response in the Indus Basin”

178 Madhav Bahadur Karki et al., “Enhancing Knowledge Management and Adaptation Capacity for Integrated Management of Water Resources in the Indus River Basin. In: Mountain Research and Development,” *Mountain Research and Development* 31,3 (2011), https://doi.org/10.1659/MRD-JOURNAL-D-11-00017.1 1

179 Ayesha Shahid, Afreen Siddiqi, and James L. Wescoat Jr. “Integrated Irrigation and Agriculture Planning in Punjab: Toward a Multiscale, Multisector Framework.” In *Indus River Basin*, ed. Sadiq I. Khan and Thomas E. Adams III (Elsevier, 2019), 389-415.

180 If measured from the source of its two head streams – the Panj river that originates from Afghanistan and Tajikistan, and the Vaksh river that originates in Kyrgyzstan. If measured from the confluence of Panj and Vaksh from the point where it becomes Amu Darya, the length is 1415km.

181 Panj is formed by the confluence of Wakhan river (originating in Afghanistan) and Pamir river (originating in Tajikistan

182 United Nations Environment Programme, GRID-Arendal, Zoi Environment Network, *Environment and security in the Amu Darya Basin*, 2011, Nairobi, UNEP, 2011 https://wedocs.unep.org/20.500.11822/7517

183 Major Irrigation canals, collectors; rivers, aquifers and springs related to the basin but not discharging to the main Amu Darya River.

184 United Nations Environment Programme, GRID-Arendal, Zoi Environment Network, *Environment and security in the Amu Darya Basin*, 2011, Nairobi, UNEP, 2011 https://wedocs.unep.org/20.500.11822/7517

185 Syed S. Kirmani and Guy J. Le Moigne, *Fostering riparian cooperation in international river basins : the World Bank at its best in development diplomacy*, Washington DC, World Bank Group, 1997, https://www.google.co.in/books/edition/Fostering_Riparian_Cooperation_in_Intern/AwOa9z7c_joC?hl=en&gbpv=1&printsec=frontcover

186 "Environment and security in the Amu Darya Basin"

187 Ahmad Masood and Wasiq Mahwash, *Water Resource Development in Northern Afghanistan and its implications for Amu Darya Basin*, Washington DC, World Bank Group, 2004, http://hdl.handle.net/10986/14939

188 Valery Votrin, "Transboundary Water Disputes in Central Asia: Using Indicators of Water Conflict in Identifying Water Conflict Potential" (thesis, Vrije Universiteit Brussel, 2003)

189 Sergei Vinogradov and Vance P.E. Langford, "Managing transboundary water resources in the Aral Sea Basin: in search of a solution," *International Journal of Global Environmental Issues* 1, no. 3/4 (2001), https://www.internationalwaterlaw.org/bibliography/IJGEI/07ijgenvl2001v1n34vinogradov.pdf

190 Erika Weinthal, *State Making and Environmental Cooperation* (Cambridge and London: MIT Press, 2002)

191 Ariel Dinar et al., "Understanding Transboundary Water Conflict, Negotiation and Cooperation – Case Study 4: The Aral Sea Basin" *World Scientific Series on Environment and Energy Economics and Policy* Vol 3 (2007) https://doi.org/10.1142/9789812790934_0015

192 Victor Dukhovny, Vadim Sokolov, Bakhtier Mukhamadiew "Integrated Water Resource Management in the Aral Sea Basin: Science, Policy and Practice," in *Hydrology and Water Law-Bridging the Gap*, ed. J. Wallace and P. Wouters (London: IWA Publishing, 2006)

193 United Nations Development Programme, United Nations Environment Programme, The World Bank, World Resources Institute, *World Resources 2002-2004: Decisions for the Earth: Balance, Voice, and Power*, Washington DC, World Resources Institute, 2003, https://files.wri.org/d8/s3fs-public/pdf/wr2002_fullreport.pdf

194 Dinar et al. "Understanding Transboundary Water Conflict, Negotiation and Cooperation – Case Study 4: The Aral Sea Basin"

195 G. Heltzer, “Stalemate in the Aral Sea Basin: Will Kyrgyzstan’s new water law bring the downstream nations back to the multilateral bargaining table? ,” *Georgetown International Environmental Law Review* 15 (2003): 291-320.

196 FAO, Aral Sea Basin, Website Report in AQUASTAT Website, https://www.fao.org/3/CA2139EN/ca2139en.pdf

197 A. Favre and GM Kamal, *Watershed atlas of Afghanistan* (Kabul: Afghanistan Information Management Service, Food and Agricultural Organisation, 2004), pp. 104–107.

198 International Crisis Group, *The Curse of Cotton: Central Asia’s Destructive Monoculture*, Bishkek/Brussels, International Crisis Group Asia Report, 2005, https://d2071andvip0wj.cloudfront.net/93-the-curse-of-cotton-central-asia-s-destructive-monoculture.pdf

199 Olli Varis and Muhammad Mizanur Rahaman. “The Aral Sea keeps drying out but is central asia short of water?” *Central Asian Waters: Social, economic, environmental and governnace puzzle,* ed. Olli Varis and Muhammad Mizanur Rahaman (Espoo: Helsinki University of Technology, 2008), 3-10.

200 Hou et al., “Response to environmental flows in the Lower Tarim River, Xinjiang, China: An ecological interpretation of water-table dynamics” *Journal of Environmental Management* 83, 4 (2007), https://doi.org/10.1016/j.jenvman.2006.07.006

201 Yaning Chen, *Water Resources Research in Northwest China* (Dordrecht: Springer, 2014), https://doi.org/10.1007/978-94-017-8017-9

202 Jianhua Xu, Yaning Chen, Weihong Li “‘The Nonlinear Hydro-climatic Process: A Case Study of the Tarim Headwaters, NW China,” in *Water Resources research in Northwest China*, ed. Yaning Chen (Dordrecht: Springer, 2014), 289–310.

203 Feng Hu,”5 Facts About the Tarim River”, China Water Risk, October, 2017 https://www.chinawaterrisk.org/resources/analysis-reviews/5-facts-about-the-tarim-river/

204 Y. D. Song et al., *Research on water resources and ecology of Tarim River, China* (Urumqi: Xinjiang People’s Press China, 2000) pp 481.

205 Hou et al., “Response to environmental flows in the Lower Tarim River, Xinjiang, China: An ecological interpretation of water-table dynamics”

206 H. Hsu and Fred Gale. “Regional shifts in China’s cotton production and use.” *Cotton and wool Situation and Outlook* 11 (2001): 19-25.

207 Feng Hu,”5 Facts About the Tarim River”

208 Kusi Appiah et al. “Cotton Production, Land Use Change and Resource Competition in the Aksu-Tarim River Basin, Xinjiang, China”, *Quarterly Journal of International Agriculture* 53, 3 (2014), http://dx.doi.org/10.22004/ag.econ.195737

209 Low flow regimes of the Tarim River Basin, China: Probabilistic Behaviour, Causes and Implications,” Water 10, no. 4 (2018), https://doi.org/10.3390/w10040470

210 Chen Yaning et al. “Ecological impacts of water resources utilization in the Tarim River Basin of China.” *(Proceedings of Symposium HS3006 at IUGG2007, Perugia,*

July 200) https://iahs.info/uploads/dms/14086.33-236-243-29-32-YANING-CHEN.pdf

211 Chen, *Water Resources Research in Northwest China*

212 Yaning et al. "Ecological impacts of water resources utilization in the Tarim River Basin of China."

213 Niels Thevs,"Water scarcity and allocation in the Tarim Basin: decision structures and adaptations on the local level." *Journal of Current Chinese Affairs* 40, 3 (2011), https://doi.org/10.1177%2F186810261104000305

214 Xiangmin Zhu, Liuyi Wu, Omarjan Obul, and Ärkin Habibulla, "The Regulation of the Tarim River System," in *Watershed and Floodplain Management along the Tarim River in China's Arid Northwest*, ed. Thomas Hoppe, Birgit Kleinschmit, Bruce Roberts, Niels Thevs, and Ümüt Halik (Aachen: Shaker Press, 2006), 77–90

215 Niels Thevs et al., "Structure, Reproduction and Flood-induced Dynamics of Riparian Tugai Forests at the Tarim River in Xinjiang, NW China," *Forestry*, 81,1 (2008) https://doi.org/10.1093/forestry/cpm043

216 Niels Thevs et al., "Vegetation and Vegetation Dynamics in the Tarim River Floodplain of Continental-arid Xinjiang, NW China", *Phytocoenologia*, 38, 1-2 https://doi.org/10.1127/0340-269X/2008/0038-0065

217 Niels Thevs et al., "Water allocation and water consumption of irrigated agriculture and natural vegetation in the Aksu-Tarim river basin, Xinjiang, China." *Journal of Arid Environments* 112, A (2015) https://doi.org/10.1016/j.jaridenv.2014.05.028

218 Thevs, Niels. "Water scarcity and allocation in the Tarim Basin: decision structures and adaptations on the local level."

219 World Bank, *Project Performance Assessment Report People's Republic of China: Second Less Plateau Watershed Rehabilitation Project (loan 4477 & credit 3222) and Xiaolangdi Multipurpose Project I & II (loans 3727 & 4200) and Tarim Basin II Project (loan 4341 & credit 3093)*, Washington: World Bank, 2007, https://ieg.worldbankgroup.org/sites/default/files/Data/reports/PPAR-41122-P003562-China_Loess_Xiaolangdi_Tarim.pdf

220 Thevs, Niels. "Water scarcity and allocation in the Tarim Basin: decision structures and adaptations on the local level."

221 Niels Thevs et al., "Water allocation and water consumption of irrigated agriculture and natural vegetation in the Aksu-Tarim river basin, Xinjiang, China."

222 Qin Zhongchun, *Xinjiang's Experience in Promoting Target-Oriented Cotton Price Reform*, Washington DC, Research Department of Rural Economy, DRC, 2019, http://en.drc.gov.cn/2019-05/14/content_37468775.htm

223 Kusi Appiah et al. "Cotton Production, Land Use Change and Resource Competition in the Aksu-Tarim River Basin, Xinjiang, China"

224 Huang and Pang, "Changes in groundwater induced by water diversion in the Lower Tarim River, Xinjiang Uygur, NW China: Evidence from environmental isotopes and water chemistry," Journal of Hydrology 387, 3-4 (2010), https://doi.org/10.1016/j.jhydrol.2010.04.007

The Case for a System of Integrated Knowledge (SINK)

The first three chapters of this report have highlighted the multi-dimensional and multi-scalar challenges in the governance of the ten HKH river basins. Governance is aimed at sustaining human activities that are socio-economically and culturally acceptable while ensuring the stability and rehabilitation of ecosystem processes. Ensuring such a balance is concomitant upon an approach that is supported by a holistic knowledge base—this would be the outcome of using a System of Integrated Knowledge (SINK), an overview of which was discussed in an earlier section of this monograph.

This chapter outlines a process for creating a framework for research, education and communication programmes for creating a new community of professionals and policymakers who are better equipped for initiating and sustaining new governance processes. Such a process of knowledge creation will enable professionals and policymakers to go beyond a reductionist discipline and delve into other knowledge entities, including indigenous and traditional knowledge, to generate integrated knowledge.

Three basic realms for integrated knowledge

The process leading to the generation of SINK will involve a careful integration of relevant and related knowledge entities identified for their utility in addressing specific governance objectives. These governance objectives are in turn driven by current and emerging governance challenges across scales. There are three broad knowledge realms that can serve as a basis and a starting point for varied types of integration. The categories are based on the ease of interaction of disciplinary knowledge entities to generate integrated knowledge: knowledge of Natural Sciences; knowledge of Social Sciences; and the Knowledge of Stakeholders relevant for the governance challenge at hand, e.g., indigenous and local knowledge. Further, eight core challenges in the governance of HKH river basins are identified, in addition to the overarching challenge of Climate Change. These will serve as pointers for the framing of a subsequent, higher-level integration. (Such integrations are elaborated in section 4.2.) A number of such partially integrated knowledge entities would be related as part of a system, awaiting further degrees of integration, thus forming a SINK.

Integration of Diverse HKH Specific knowledge in Natural Sciences

The HKH river basins have historically been governed using a reductionist paradigm of natural science and engineering. An integrated knowledge framework overcomes the limitations of reductionism. A starting point could be the integration of disciplines that are closely related. For example, in all the HKH river basins, the science of meteorology and hydrology have largely remained separated by disciplinary and institutional barriers. Yet, the flow of water from the level of precipitation from the atmosphere to stream flows on the terrestrial surface of the Earth requires the integration of these two branches of science. In the case of the HKH where the monsoon precipitations are dominant, such an integration is even more important for activities such as the mitigation of damages caused by summer monsoon high flows. The integration of meteorology, land use and land cover studies, slope hydrology, hydro-geology, and irrigation, among other knowledge systems, is essential for generating a holistic view of river basin governance.

An important integration is related to the understanding of flows in rivers beyond the limited description as a transit of a specific volume of water per unit time at a given location. The synergetic perspective of WEBS as described earlier identifies many constituents beyond plain water. In addition to the chemical composition of the flowing water—energy, biodiversity, and sediments, as well as economics, are identified with the flows. Such an integration of knowledge available from various disciplines can result in a fundamental change in the engineering design and framework for assessment and decision-making for all human interventions into the flows of HKH rivers.

Integration of Diverse HKH Specific Elements in Social Sciences

The present framework for the governance of river basins is almost exclusively dominated by engineering backed by narrow economic analyses. Absent in such a framework are the involvement of local knowledge, cultures, practices, and popular perceptions of rivers, the scope of informal mountain economies, the ethnic mosaic of the HKH and related rich indigenous and local knowledge, as well as an understanding of the historical and political and economic contexts. All of these are important for holistic governance and yet are neglected in the design of integrated river basin governance.

As a result, opposition to engineering projects is often branded as "anti-development". In some parts of the HKH, where the local communities revere the high mountain rivers, engineers claim that hydropower development, for example, is "pro-people". An integrated knowledge of the social sciences can help create a new paradigm for governance.

Another example is the impact of reductionist governance and the single-minded pursuit of economic growth, on the informal local economies, which are pushed to the margins and not allowed to thrive. To arrive at holistic governance, these marginalised knowledge constituents within the social sciences need to be integrated and taken up as areas of collaborative research and education for river basin governance.

Integration of Knowledge of Stakeholders

The two processes of integration described above belong to the domains of both, formal knowledge that is nurtured in the formal institutions of research and education, and informal knowledge that exists with traditional social institutions such as Pani Panchayats in India and Guthi in Nepal. They also relate to the part of the stakeholders in the governance of river basin who are trained in the formal education system. As far as the HKH basins are concerned, stakeholders will include the United Nations (UN), multilateral financial institutions (MFI) such as the World Bank, and other international agencies. They use formal knowledge systems but also organise diplomatic negotiations and agreements where informal knowledge may prove to be a necessary input. For instance, Ghosh and Gyawali (2021) have identified a role for the European Union (EU) in improving water governance in the Himalaya through knowledge-transfer and facilitating constructive engagement between contending social solidarities like hydrocracies, market players, and activists.[1] Cooperation on water at the global level has a rich history which can be useful in addressing the HKH region as a whole.[2] Among the stakeholders, there are others who are local to the concerned region, and have limited exposure to the formal knowledge systems. They have been using the flows in the river basins through local and indigenous governance practices, based mainly on long-term observations and traditional best practices. Plenty of examples are available of such production systems based on local practices and initiatives of natural resource conservation. Among the stakeholders are NGOs that campaign in favour of the informal knowledge systems and institutions.

Local knowledge has many applications, for example: fishing practices based on breeding cycles, crop choices based on sustainable use of available water, rainwater harvesting, and watershed-based use of flows. Unlike the formal knowledge entities, informal knowledge as applied, have local origins, and therefore are highly diverse and adaptive.[3] Yet, for the larger participation of stakeholders in the governance process, what is needed is due recognition and assessment of informal knowledge. In the formation of integrated knowledge for governance, a process for internalising informal knowledge of those stakeholders who do not function within the formal knowledge system, has to be kept open. This makes the task of integration rather different as it poses the required association of knowledge entities from diverse cultural bases among whom finding a common point of contact could be difficult due to stark differences in worldviews, languages, and cultures.

Primary and secondary integration

The process of integration of knowledge is seen as comprising three levels: primary, secondary, and tertiary (Ref. Fig. 24). At the primary level, the process of integration would involve interactions among knowledge entities within the umbrella of the three foundational realms – of natural sciences, social sciences, and the knowledge of stakeholders. This would entail an interdisciplinary understanding of river basin governance through the integration of knowledge within natural sciences and engineering, as well as social sciences. Such an integration is achievable, as it takes place within well-set realms of natural sciences and social sciences.

Moving to a less formal scenario of knowledge, an understanding of the natural phenomena based on empirical evidence from both observations and experimentation to explain the natural world, is important for governance. Finally, the integration of experiential knowledge of various diverse stakeholders needs to develop through shared learning generated by 'communities of learning' as against the insular functioning of 'isolated groups'. (Ref. Section 2.5).

Based on the primary integration, the secondary integration would connect the three knowledge realms. Such an integration, in a more holistic framework, is useful for arriving at an agreement on best available science, with the assumption that any information from the natural and/or social sciences may be subjected to diverse and contested interpretations by different stakeholders. This integration may thus involve any two realms or all three together to address a specific challenge in governance of HKH river basins. At each stage of the levels of integration of knowledge, research and education activities are needed to advance the capacity of the professionals involved in governance. The following paragraphs use the case of the Indus basin to illustrate.

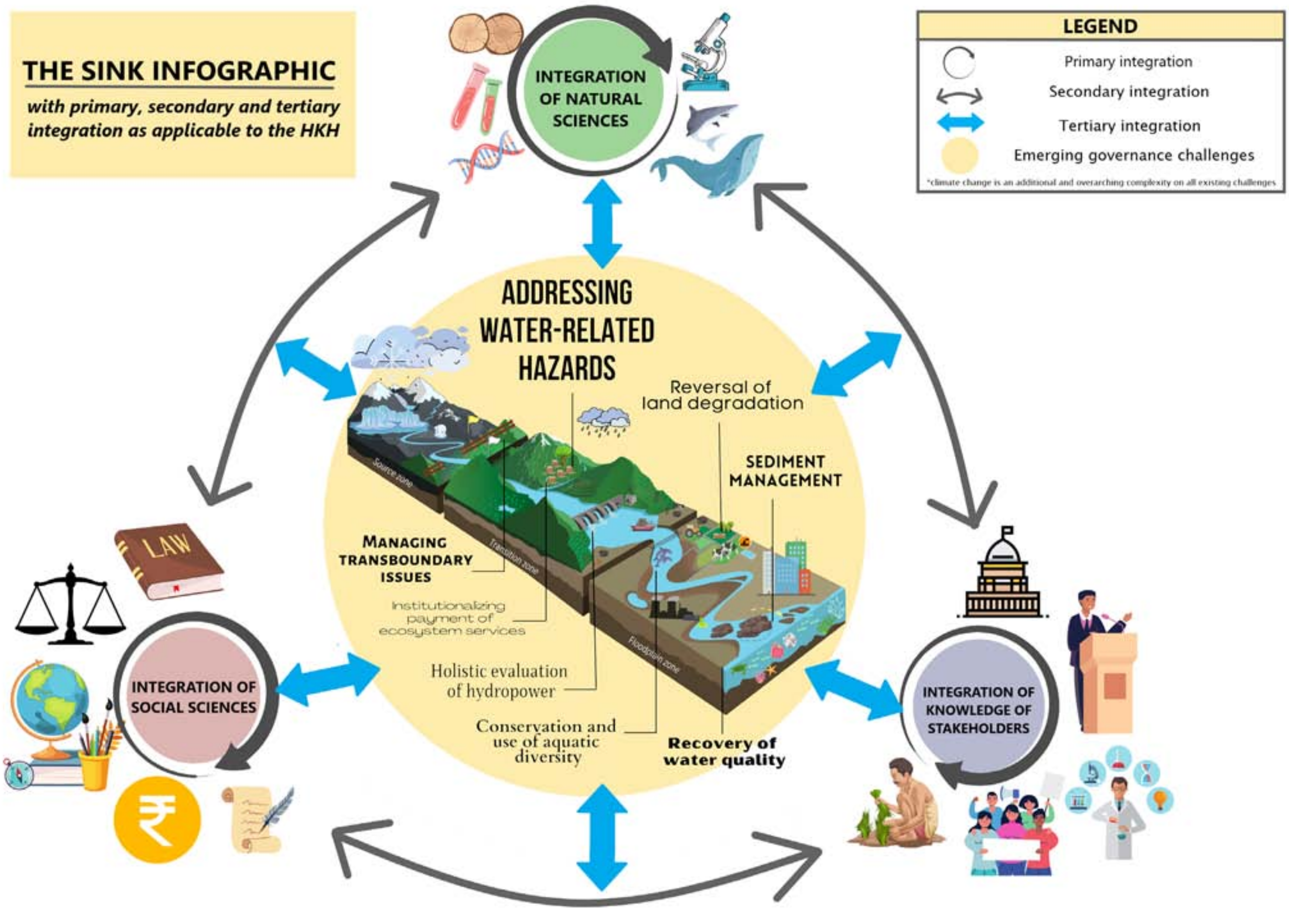
The idea of conjunctive use of groundwater and surface water in the Indus basin is not new and studies on the optimisation of their conjunctive use can be traced to the 1970s.[4,5,6,7,8] However, the trend of water use has been largely mono-directional, with the active promotion of groundwater extraction in the 1960s and 1970s that matched pace with the green revolution that was unfolding at that time. In the present times, conjunctive use of water has regained importance in the Indus basin as a planned intervention across the length of canals. This is to counter the twin challenges of rising water tables due to assured supply, and resultant application of surface water at the head ends and increasing salinity in the tail-ends due to high dependence on groundwater.[9]

The interaction between groundwater and surface water needs to be taken into account and the integration of natural sciences is critical for understanding and arriving at a holistic water budget reflecting a primary level of integration. Planning for the conjunctive use of surface and groundwater would require combining the responsibilities for the management of surface and groundwater. It may also require groups of water users to forego part of their long-standing surface water entitlements for the larger purpose of water and food security through the facilitation of conjunctive use. It would require a secondary integration between the understanding of natural processes associated with the surface water groundwater continuum, and the communication of such processes to various stakeholders while also taking into account their understanding and perception of issues. Lastly, inadequate understanding of the linkages between water, energy, and food and the crafting of policies to incentivise the use of electric tube wells and the rise of unregulated groundwater market indicates reductionist governance.

Thus, the secondary integration would remain partial for this particular governance concern if laws were not designed in accordance with social and economic realities of the transboundary agrarian landscape of Punjab and Sind, thereby also indicating integration of Social Sciences within the ambit of secondary integration. Another form of integration that will be crucial is that between hydrological boundaries of the river system and political boundaries of the provinces and nation states that is the requirement of the integrated river basin management and IWRM at basin scale.

The process of primary integration is more straightforward, as it depends on the integration of knowledge entities that have some near-relations to one another. The secondary integration is more complex and difficult as it integrates knowledge entities that are diverse and distantly related. The tertiary integration again brings all concerned knowledge entities closer as it relates to addressing specific governance challenges.

Figure 24: The SINK Diagram



(Authors' own, with assistance from former ORF intern, Sanjoli Johana Shah.)

Tertiary integration

This stage is for applying the integrated knowledge to address specific governance concerns, and it involves a mutual exchange of knowledge. The first is when the knowledge created after primary and secondary integration is applied to current and emerging governance challenges. This, in turn, will create experiential as well as experienced learning that will act as feedback to fine-tune the integrations at the lower levels. It will also provide a direction for the creation of frontier knowledge which will get added to the repository of foundational knowledge. This interlinked exchange of knowledge is identified in this work as the System of Integrated Knowledge (SINK). In order for tertiary integration to be started in a limited scale, some of the current and emerging governance challenges are being suggested for use. From the analysis of individual river basins, a generalisation is made to identify some of the present or emerging governance challenges in the HKH basins. This is an initial step for the application of SINK. Indeed, this report aims to pave the way for other research and education institutions working on the HKH region to advance and strengthen this framework of SINK for the HKH.

Current and emerging governance challenges in the HKH basins

This section outlines the most important governance challenges that are relevant across the HKH basins. Each of these can be the basis for starting transdisciplinary research and academic and non-academic education programmes to advance SINK. The framework can help create a new agenda for research and education on the three levels of integration (primary, secondary, and tertiary) for capacity building of professionals involved in the governance of the HKH basins.

Addressing water-related hazards

Meteorological and hydrological extremes are integral features of the entire HKH region that are being aggravated due to climate change and regional climate variability. Seasonal high flows from intense monsoon rainfall or high snowfall from westerlies occur regularly in the HKH. The engineering responses have been guided by the objective of structural interventions. Other forms of hazards include water scarcity and changes in the temporal distribution and intensity of precipitation. If the process of SINK management is applied, an alternative framework for addressing water-related hazards would be generated. Otherwise, extreme events may be described simply as "outliers".

The Yangtze basin provides rich experience regarding the formulation and implementation of some such steps of integration of knowledge in the case of governance of flows, including floods. The need for a paradigm change in the basins like of the Yellow and Yangtze has also been reiterated during the turn of the century.[10] Severe flooding in the Yangtze basin in 1998 provoked deep introspection, particularly when it was realised that neither the precipitation in the catchment nor the floodwater discharge from the upper basin had exceeded the historical maximum.[11] Yet, the water level in the middle and lower reaches were much higher than the historical maximum. This apparent mismatch was primarily attributed to human activities involving land-use change, and structural interventions like levees. The Chinese government then issued a certain ”32-character policy” in the same year, seeking to reduce the risk of damage due to floods by advancing integration of knowledge for working with nature rather than fighting it. Analysts have outlined four key areas of intervention: (a) increasing forest coverage; (b) restoring floodplains by decommissioning embankments and increasing floodwater retention capacity in the floodplains; (c) resettling farmers by building new townships and providing them with jobs instead of subsidies; and (d) strengthening other levees and dredging riverbeds.[12] This encapsulates the ‘best available science’ for flood risk management. It was further supplemented by the creation of a cross-sectoral National Development and Reform Commission (NDRC) that developed an integrated knowledge base to implement the intervention mentioned above.

Sediment management

Sediment is a notable constituent of flows in all the HKH rivers especially in the Ganga basin. It is fundamental to the creation of floodplains and deltas of river basins, and for replenishment of nutrients of the land and supporting the primary productivity of estuarine and coastal areas. The sediment yield from the HKH is high due to the intense monsoon and the fragility of the mountain landmass. However, as mentioned earlier, sediments have largely been seen as a problem in the effective delivery of operations in water engineering. The construction of dams and embankments have often constrained the delivery of sediments to the floodplains and deltas. From the Yellow, to the Yangtze, Mekong, Brahmaputra and the Ganges, the HKH region is rife with such instances. Lack of integrated thought across temporal and spatial scales is apparent in the manner that these interventions are executed. These are based on short-term gains without a strategy for addressing the ecological roles of the sediment. An alternative approach based on an integrated perception of flows can make the interventions ecologically sustainable. Recent interventions in the Yellow river basin, a heavily sediment-laden river, provide clues for the potential of SINK.

The strategy for flood moderation in the Yellow river basin is closely linked with efforts at managing sedimentation. These include altering the microtopography through the construction of check dams and the creation of level terraces. To improve the interception of precipitation and infiltration rate, vegetation restoration either by selective tree planting or by closing the parcel of land and allowing natural recovery of vegetation, were implemented. The 'Grain for Green' programme is one such attempt. The combined effect of withdrawal of water and flood moderation through levees has resulted in reducing the sediment load of the Yellow River. Another key innovation has been the change in design and operation of dams. The outlet of Sanmenxia has been reconstructed to allow flood flows to pass through the reservoir without significant sediment detention.

Further, changes in dam operations by storing clear water during the non-flood season and discharging turbid water during the non-flood season have allowed the transport capacity of the flow to flush out and carry the sediments.[13] In general for the HKH river basins, sediment management will be greatly facilitated by integration of knowledge of hydrology, sedimentology, geomorphology, mountain farming, and river engineering. This will bring fundamental changes in the method for environmental impact assessment of storage structures.

Conservation and use of aquatic diversity

Plagued by declining water quality, river fragmentation and alterations of the natural flow regimes, the spectacular freshwater and estuarine ecosystem diversity as well as related biodiversity of the HKH rivers stand threatened. The decline of the charismatic river dolphins in the Indus, Ganges, Irrawaddy, Mekong and the Yangtze is proof of this decline. These HKH rivers are some of the last remaining habitats of freshwater dolphins in the world. As a keystone species of the aquatic world, it indicates the poor health of aquatic ecosystems that also threatens various commercially important species like the anadromous hilsa shad (Tenualosa ilisha) in India and Bangladesh. One of the key reasons for the decline in the catch of Hilsa is the loss of the depth of flowing water during the non-monsoonal months owing to flow regulations and diversions, construction of barrages that restrict the upstream migration of schools of fish, and increased riverine pollution.[14] These impacts are rooted in the practice of disjointed and reductionist framework of river basin governance.

Thus, the application of SINK would be aimed at halting the degradation and rehabilitating the ecological status of the hydrological or biological continuum and replicating the natural processes essential for the sustenance of aquatic ecosystems and biodiversity. For instance, the ecological parameters should guide the process of restoration of the HKH rivers. The design of structures, its operations and the economic uses of flows should not take away from the ecological requirement of flows. Emphasising on an ecological continuum between the Yangtze estuary, its watershed and the adjacent coastal habitats, Zhang emphasised interdisciplinarity and the application of knowledge system continuum to decision-making processes through the integration of science into decision making.[15] Needless to say, realising interdisciplinarity, integration between river stretches and preserving the hydrological and biological continuum by replicating the gradient of physical conditions under natural flow conditions, would all require transboundary cooperation across jurisdictions and sectors. The integration of knowledge is important in this task. Knowledge entities like hydrology, zoology, botany, ecology, economics, law, and culture need to be integrated for addressing this governance challenge.

Recovery of water quality

The Ganges, the Yellow and the Yangtze basins all point to a certain correlation between an increase in industrial activity, generation of effluents along with the expansion of urban areas, all leading to a steady rise in the discharge of untreated wastewater into the river flows. The result is deteriorating water quality. However, such a linear relation between these two sets is not a given, as more of the river basins seek to industrialise and transition from agrarian economies to urban-industrial ones. The non-linear relation and the role of SINK can be best illustrated with the example of the Ganga basin. The challenge of maintaining a good water quality standard in the Ganga and its tributaries, is a multidimensional one. According to a team of experts from a consortium of seven Indian Institute of Technology (IIT), the critical weakness in Indian government's flagship program – Ganga Action Plan (GAP)—was the straightjacketed approach of sewage collection, conveyance, and treatment. Other direct and indirect factors were ignored, including the crematories on the banks and non-point sources of pollution or even flow diversions affecting dilution capacity of the river.

At the same time, it may be incorrect to transplant the argument 'bathing' in these rivers be ceased; this fails to consider the cultural context in the Ganges, where 'human-contact uses' are paramount to the river's religious and cultural role. Moreover, there is a lack of clear policy-legal and institutional framework, leaving multiple institutions to play their own discretionary roles and thereby resulting in ambiguities.[16]

The need is to draw from a repository of SINK that is well suited to the Ganges, and the shared experiences from other HKH basins like the Yellow. The multidimensional challenge calls for a multidimensional approach and an integrated framework are the only way forward. This makes a good case for an integration of disciplines such as water chemistry, human behaviour, and administration.

Trans-boundary cooperation and conflict resolution

Transboundary issues are often understood as those involving shared flows across international boundaries. However, this classical geostrategic definition of 'transboundary waters' is part of the whole complexity of managing water among competing users and jurisdictions. Issues that involve crossing of boundaries such as federal, provincial, village, privately-owned land boundaries at the subnational level as well as the sectoral boundaries broadly between industry, agriculture, natural environment, and urban areas, for the allocation of water.[17, 18] In the absence of an agreement or a treaty like the one on the Indus, between India and Pakistan, transboundary issues related to flows can become extremely complex as seen in the case of Amu Darya.

When all the HKH basins are considered, the Mekong River Commission (MRC) exists as one of the time-tested platforms for regional cooperation. The commission draws its power and mandate from the 1995 Mekong Agreement signed by Cambodia, Lao PDR, Thailand and Vietnam. Soon after, China and Myanmar also became dialogue partners in 1996 and China began to extend provision of hydrological data – initially during the flood seasons starting in 2008 and, thereafter, for the entire year since 2013. MRC recently prepared a Basin Development Strategy (BDS) 2021-2030 from the perspective of the Lower Mekong Basin countries. In the BDS, it has been explicitly mentioned that the current water security issues can be addressed effectively only at the basin scale, thereby requiring the involvement of China and Myanmar through another multilateral institution called the Mekong-Lancang cooperation of which all the six basin countries are members. With varying degrees of success in regional integration, the creation of a basin-wide institution utilising a cross-cutting and robust system of an indicator framework underscores the utility of SINK. In such cases, integration of river engineering with economics, politics, and diplomacy, can be the starting point for shaping SINK.

The hydropower dilemma

The advantages of altitude and good precipitation combine as large hydro-power potential in most parts of the HKH. In the broader framework, variability of rainfall and discharge is often treated as an obstacle to planning. The creation of water storage infrastructure is seen by engineers as the only way to moderate the various kinds of variability, thereby allowing nations sharing the HKH river basins to utilise the hydraulic gradient that the mountains provide. The proliferation of hydropower projects in the ecologically fragile, tectonically active, and disaster-prone landscape of the HKH has been growing rapidly as countries begin to acquire the technological and financial means to harness the power latent in the HKH rivers. However, in the case of Mekong for example, variability is an integral part of the hydro-meteorological regime to which the humans and the natural systems were well attuned. In the recent past, this has been destabilised.

The development of hydropower is not just disrupting the longitudinal connectivity of the river but also reducing the variability of flows; this creates new concerns. Owing to the fact that the basin is shared by six countries, hydropower development in the upstream, particularly in China, has led to concerns in the downstream countries. According to a study in 2020, for the first time in 28 years, the difference between the water that would naturally flow versus the observed data at Chiang Saen gauge (at the border of China and Thailand) had peaked in 2019, resulting in severe lack of water flowing from Upper Mekong during the wet season. The general notion has been that the construction of dams with increasing reservoir capacity in China and the Chinese government's effort to distribute energy production in the Mekong across the annual cycle has contributed to the regulation of flow such that periods of high and low flow can be evenly distributed. Construction of dams on the HKH rivers is a common challenge in the governance of the HKH basins. Integration of knowledge from hydrology, sedimentology, ecological economics, and river engineering, can shape a SINK that will be key to addressing this important challenge.

Promotion of desired land use and economic activities

All the 10 HKH river basins are experiencing rapid growth in population and economic activities. These activities have led to changes in land use and land cover, creating an impact on the flow characteristics in the rivers and altering the performance of engineering projects. The desired land cover will be decided by what is seen as the main and sustainable product of land in the HKH basins. Traditional economic concepts and institutions for land use considers forestry, agri-horticulture or ranching as profitable and therefore desirable. However, with global water scarcity worsening, and the HKH being a major instrument for the conversion of atmospheric water into flows in ten largest rivers of Asia, it is time to consider water as one of the main products of land use in the HKH region. Here the application of the concept of SINK could play an important role in the identification of desirable land use and land cover.

The issue of desirable land use and land cover is a complex one which may need drastic changes in laws on land management, very different from what mountain farmers have so far been used to. The mountain communities are important stakeholders in the question of changing land use and land cover. Such a transition is challenging and will depend on in-depth research and capacity building that will need integration of knowledge of forestry, farming, soil conservation, economics, ecology, and sociology.

Institutional process for adoption of Payment for Ecosystem Services

All the HKH river basins are clearly divided in two parts when water governance is considered. The upland parts mainly generate the flows in the rivers, while the lower parts involving the floodplains and the deltas mainly make economic uses of the flows. If pre-emptive steps of governance are not taken, such relations carry the potential for conflicts between upstream and downstream areas as demand grows with time. In order to integrate this duality into a holistic governance process and avoid any conflicts, a system for the upstream areas receiving negotiated amounts of payment for opportunity costs related to ensuring water flows to the downstream areas has been widely thought of in the recent times.

This method has come to be known as the Payment for Ecosystem Services (PES) or Rewarding Upland Communities for their Environmental Services (RUPES). This concept is applicable on all exports of ecosystem products but has become a symbol for trans-boundary cooperation on water flows. In the future decades, it is probable that all the HKH river basins will need governance interventions to address challenges of this nature. The process for the evaluation of estimating the exchanges is not simple and SINK can play a crucial role in making related assessments and describing the exchanges. There are already such governance steps existing in some of the HKH basins. In Amu Darya basin, for example, payment to the upstream areas is offered in kind, as energy in the form of fossil fuel. In the case of the Yellow river, governmental subsidies were provided to improve water use efficiency in the upstream areas, so that flow to the downstream areas were restored. However, preparations for arriving at innovations in governance steps for such a relation of exchange in all the HKH basins are a definite priority. This problem needs rigorous research, initially. Once the research part is done, the task for evolving an appropriate integrated institutional structure will make it functional.

Endnotes

1 Farwa Aamer, Nilanjan Ghosh, Dipak Gyawali, Tugba Evrim Maden, Hamza Shareef Hasan, Jenniver Sehring, Dinara Ziganshina, *International Hydro-diplomacy: Building and Strengthening Regional Institutions for Water Conflict Prevention – Pre-conference study 2021*, Konrad-Adenauer-Stiftung and The Stimson Center, 2021, https://www.stimson.org/wp-content/uploads/2021/11/Final-study_Web-preview.pdf

2 Zafar Adeel, Sirodjidin Aslov, Josefina Maestu, Olcay Unver, Water Cooperation: Views on progress and the way forward, Hamilton, United Nations University Institute for Water, Environment and Health, 2015, http://rem-main.rem.sfu.ca/papers/adeel/2015_-_Water_Cooperation_Brief_%28WEB_VERSION%29.pdf

3 Ministry of Science, Technology and Environment, Government of Nepal o Indigenous Research: Indigenous and Local Knowledge and Practices for Climate Resilience in Nepal, Mainstreaming Climate Change Risk Management in Development, by Madhav Karki et al., Kathmandu: 2015, https://www.cbd.int/financial/micro/nepal-resilience.pdf

4 Mohammad Talib Chaudhary, “Conjunctive Use of Indus Basin Waters-Pakistan: A General Summary of Ph. D. Dissertation - No. 30” (PhD dissertation, Department of Civil Engineering, Colorado State University, 1973)

5 Mohammad T. Chaudhary, John W. Labadie, Warren A. Hall, and Maurice L. Albertson,”Optimal conjunctive use model for Indus basin,” *Journal of the Hydraulics Division* 100, 5 (1974): 667-687.

6 Reza Maknoon and Stephen J. Burges, “Conjunctive use of ground and surface water.” *Journal-American Water Works Association* 70, 8 (1978): 419-424.

7 K. N. Duggal “Conjunctive use of surface water and groundwater--an optimization approach.” (proceedings of the International Seminar on Development and Management of Groundwater Resources, November 5-20, 1979, School of Hydrology, University of Roorkee, Roorkee, UP, India, 1980)

8 Karki et al.,“Enhancing Knowledge Management and Adaptation Capacity for Integrated Management of Water Resources in the Indus River Basin,”

9 Abdul Nasir Laghari, Davy Vanham, and Wolfgang Rauch,” The Indus basin in the framework of current and future water resources management.” *Hydrology and Earth System Sciences* 16, 4 (2012) https://doi.org/10.5194/hess-16-1063-2012

10 Wang Shucheng, *Resource-Oriented Water Management: Towards Harmonious Coexistence between Man and Nature* (Beijing: China WaterPower Press, 2002)

11 Yongqiang Zong and Xiqing Chen, “The 1998 flood on the Yangtze, China.” *Natural Hazards* 22, 2 (2000), https://doi.org/10.1023/A:1008119805106

12 Jammie Pittock and Ming Xu, *Controlling Yangtze River Floods: A New Approach*, Washington DC, World Resources Report, 2011, https://www.researchgate.net/publication/258844942_World_Resources_Report_Case_Study_Controlling_Yangtze_River_floods_A_new_approach

13 Guangqian Wang et al. "Sedimentation problems and management strategies of Sanmenxia reservoir, yellow river, China." *Water Resources Research* 41, 9 (2005), https://doi.org/10.1029/2004WR003919

14 Sayanangshu Modak, "Towards an Ecosystems Approach to Fisheries Management Along the Bengal Coast"

15 Jing Zhang, *Ecological continuum from the Changjiang (Yangtze River) watersheds to the East China Sea continental margin* (Springer International Publishing, 2015)

16 Indian Institute of Technology, *SWOT Analysis of Ganga Action Plan*, IIT, 2011, https://nmcg.nic.in/writereaddata/fileupload/50_006GEN.pdf

17 H. L. Beach et al., *Transboundary Freshwater Dispute Resolution: Theory, Practice, and Annotated References.* (New York: United Nations University Press, 2000)

18 Nilanjan Ghosh, "Challenges to Environmental Security in the Context of India-Bangladesh Trans-boundary Water Relations", *Decision (Springer)*, 42, 2 (2015) https://doi.org/10.1007/s40622-015-0082-4

Conclusion

This report is ORF's attempt to outline a step forward for the articulation of one aspect of integrated water resource management or IWRM—this is the creation of integrated knowledge for promoting the holistic governance of the ten river basins around the Hindu Kush Himalaya mountain range. The following points summarise this report's recommendations for the path towards such a framework.

1. **Nurturing human resources with multidisciplinary knowledge.** Dedicated professionals with an understanding of the utility of interdisciplinary and transdisciplinary thinking will be paramount for achieving

integration at the primary and secondary levels of SINK. These professionals will guide the practitioners such as policymakers, designers, engineers, bureaucrats, as well as the local communities that directly derive their lives and livelihoods from the basins. Therefore, these professionals will also have to participate in creating policy priorities and advocating new strategies for reaching the tertiary level of integration.

2. **Sensitising policymakers.** In order for the partially-integrated interdisciplinary knowledge to cross the threshold of secondary integration and get applied to governance challenges and achieve tertiary integration, policymakers will have to be sensitised regarding the utility of SINK. This will provide them with the impetus to shift from the Business as Usual (BAU) scenario of governance, one that has been proven to be ecologically unsustainable and socioeconomically unacceptable. Therefore, the capacity of policymakers will have to be enhanced so they can perceive, think and act with due consideration to SINK.

3. **Developing higher-education-level curricula.** In addition to the creation of dedicated professionals, the utilisation of SINK should also be extended to the community of students in traditional departments pursuing specialised disciplines. This can be done by providing an opportunity for students to join courses of their choice from other disciplines or through the creation of exclusive interdisciplinary programs. Over time, this can lead to the building of a community of university graduates who are sensitised to the utility of SINK in addressing current and emerging challenges of river basin governance.

The overall imperative is for stakeholders to establish a system of integrated knowledge and enlarge its sphere of influence as the guiding perspective for the holistic governance of the HKH river basins.

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