Climate Change, Economic Growth, and Cooperative Management of Indus River Basin

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Introduction

Water flows through the three pillars of sustainable development – economic, social and environmental. Water resources, and the essential services they provide, are among the keys to achieving poverty reduction, inclusive growth, public health, food security, lives of dignity for all and long-lasting harmony with earth's essential ecosystems. Water issues have risen in prominence in recent years, reflecting growing understanding of water's centrality as well as the world's success in achieving the Millennium development Goal target of halving the proportion of people without sustainable access to safe drinking water. Water is inextricably linked to the development of all societies and cultures at the same time, this development also places considerable pressure on water resources — agriculture, energy and industry all have impacts on the use and governance of water.

The Indus river basin is one of the most depleted basins in the world (Sharma et al., 2010). During certain periods of the year, water even does not really reach the sea any more, making it a closed basin (Molle et al., 2010). Already today it faces large problems with respect to water resources. These will only become more challenging in the next decades, due to population growth, rapid urbanisation and industrialisation, environmental degradation, inefficient water use and poverty (economic water shortage), all aggravated by climate change. The supply of freshwater in several areas of the world is likely to be impacted negatively by climate change. Management of such water resources is more complex if they are shared by different countries, particularly if increases in water demand are also expected. Such is the case for the Indus river basin's water, which is the lifeblood of billions of people. The area covered by this basin exceeds 450,000 square miles and is spread across four countries - India (29%), Pakistan (63%), and China and Afghanistan (8%). While over 80% of the water is used for agriculture, it also supports power production, drinking water needs, industrial activities, and a multitude of ecosystem services. Moreover, perceived fair distribution of this water, both across countries and within states or provinces of a given country, is of paramount importance for regional political stability (Romshoo, 2012). Allocation of the water between the two main stakeholders, namely India and Pakistan, has been taking place since 1960 under the provisions of the Indus Water Treaty (IWT), brokered by the World Bank (http://siteresources.worldbank.org/INTSOUTHASIA /Resources/223497-1105737253588/IndusWatersTreaty1960.pdf). The treaty is often cited as a success story for transboundary sharing of river waters, as it has survived three wars, a persistent conflict on Kashmir, and generally turbulent political relations between India and Pakistan (Briscoe, 2010).

Over the last few years, many parts of India and Pakistan have been experiencing moderate to severe water shortages, more particularly the Indus basin regions, brought on by the simultaneous effects of population and agricultural growth, increased industrialization and urbanization, and of course the climate change. Different aspects of the water in the Indus basin have been the subject of several studies, e.g. hydrology and available water resources (Winiger et al., 2005; Archer, 2003; Immerzeel et al., 2010; Kaser et al., 2010), the impact of climate change on glaciers and the hydrological regime (Akhtar et al., 2008; Immerzeel et al., 2010; Tahir et al., 2011), agricultural water demands and productivity (Cai and Sharma, 2009, 2010), groundwater management (Kerr, 2009; Qureshi et al., 2009; Scott and Sharma, 2009; Shah et al., 2006), reservoir sedimentation (Khan and Tingsanchali, 2009), ecological flows and the Indus delta (Leichenko and Wescoat, 1993), water policy (Biswas, 1992; Miner et al., 2009; Shah et al., 2006, 2009; Sharma et al., 2010), water resources management (Archer et al., 2010; Qureshi et al., 2009) and modeling the agriculture-energy and/ or hydro-meteorology of IRB, Pakistan (Yang et al., 2016; Khan et al., 2014; Khalid et al., 2013). These studies have looked to issues either isolate or region specific and mostly from Pakistan area of the IRB. The trans-boundary nature of the issues and multi-sectoral perspective of Indus waters with hydrological and economic estimates from basin perspective are missing in these past research approaches.

Objectives, Model and Data Base

It is in this backdrop that the present approach is looking from macro angle covering whole of the Indus Basin in the study with multi-sectoral allocation and benefits from the Indus waters along with the sensitivities of trans-boundary issues and its impact on the sectors and across the borders. Our objective is to examine the likely impacts of this combination of factors on the Indus river basin's economy and to make some policy suggestions for improving the well-being of the region's population.

The hydro-economic model we develop for this purpose is designed to capture overall net benefit from basin wide water utilized annually and to compute its net present value over a specified time period. The annual net benefit comes from water for used in agriculture, power production, and urban activities. Agricultural profits are generated from crop specific per acre water production functions (e.g., Jalota, et al, 2007), modified to include a water-use efficiency parameter. Unlike existing studies of the Indus river basin (e.g., Yang et al., 2016), this approach allows us to explicitly study the effects of adopting water conservation technologies or shifting to less water intensive crops. Water use in power production is taken to be non-consumptive. Net benefits in this sector depend on hydropower capacity, the increase of which is costly and may also be limited by other considerations. Urban water use is relatively modest now. It is assumed to increase exogenously over time with economic growth and population increases. Agricultural and urban water demands may also be met with use of groundwater, which is a common property resource. Declining groundwater stocks result in falling water tables and rising costs of extraction. Climate change influences river water supply that is to be allocated across regions and sectors in any given year, after accounting for any regulatory minimum flows. The overall goal of our dynamic optimization model is to maximize the aggregate present value of net benefits from this allocation of water resources. Possible control variables are surface water and groundwater used by each crop, choice of irrigation technology, land allocated to each crop, surface water allocated to each region, and investment in regional hydropower capacity.

The mathematical form of the Indus Economic Optimization Model (IEOM) is as under

Maximize $Z = \sum_{k=1}^{9}(\mathrm{Ag}) + \sum_{m=1}^{2}(\mathrm{Hp})$

Subject to:

- Agricultural land constraint
- Irrigation water withdrawal constraints and
- Hydropower generation capacity constraints

Where Z is the total net benefits (in billion USD), Ag is the net benefits from states/provinces in the basin from 1 to 9 and Hp is the benefits from hydropower generation from countries 1 and 2 (i.e., the main stakeholders, India and Pakistan).

The Model is run subject to current land under agriculture as a land constraint in each state/province. Likewise, surface water irrigation limits are put for every state/province as well as country based as per the Water accords and IWT allocations. The groundwater withdrawal caps are also made to put for bringing the resource at steady state. In case of hydropower sector, the existing infrastructure, ongoing projects and identified potential are put as constraints while doing sensitivity.

The data we use for parameters related to climate, economics, agriculture, hydropower, hydrology, and demographics is drawn from various private and public sources, such as the Intergovernmental Panel on Climate Change (http://www.ipcc-data.org/), Indiastat (www.indiastat.com), Jammu and Kashmir State Power Development Corporation (http://jkspdc.nic.in), Directorate of Economics & Statistics, J&K (http://ecostatjk.nic.in), and Pakistan Bureau of Statistics (www.pbs.gov.pk).

Profile of Indus Basin

The transboundary Indus river basin has a total area of 1.12 million km^2 distributed between Pakistan (47 percent), India (39 percent), China (8 percent) and Afghanistan (6 percent) (Table 1). The Indus river basin stretches from the Himalayan mountains in the north to the dry alluvial plains of Sindh province in Pakistan in the south and finally flows out into the Arabian Sea (Figure 1). In Pakistan, the Indus river basin covers around 520 000 km^2, or 65 percent of the territory, comprising the whole of the provinces of Punjab and Khyber Pakhtunkhwa and most of the territory of Sindh province and the eastern part of Balochistan. The drainage area lying in India is approximately 440 000 km^2, nearly 14 percent of the total area of the country, in the States of Jammu and Kashmir, Himachal Pradesh, Punjab, Rajasthan, Haryana and Chandigarh. Only about 14 percent of the total catchment area of the basin lies in China, covering just 1 percent of the area of the country, and Afghanistan, where it accounts for 11 percent of the country's area (Table 1). Very roughly, at least 300 million people are estimated to live in the Indus basin.

Table 1: Country areas in the Indus river basin

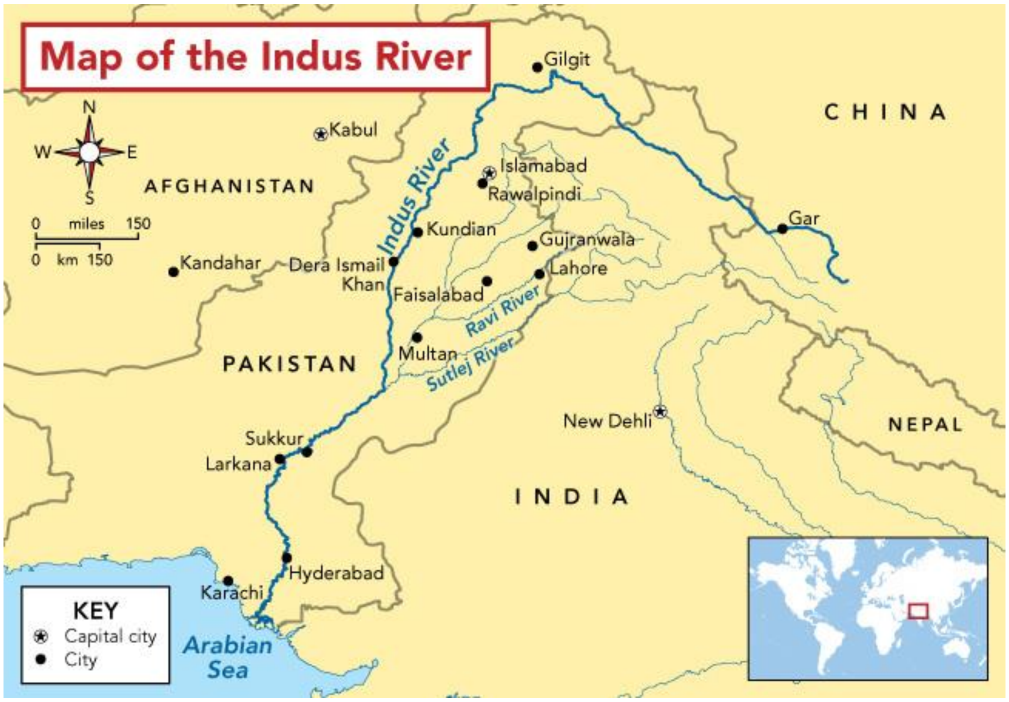
Basin	Area		Countries included	Area of country in basin (Km^2)	As % of total area of basin	As % of total area of country
	Km^2	% of Southeast Asia				
Indus	1120000	54	Pakistan	520000	47	65
			India	440000	39	14
			China	88000	8	1
			Afghanistan	72000	6	11

Source: FAO STAT

Climate is not uniform over the Indus river basin. It varies from subtropical arid and semiarid to temperate sub-humid on the plains of Sindh and Punjab provinces to alpine in the mountainous highlands of the north. Annual precipitation ranges between 100 and 500 mm in the lowlands to a maximum of 2000 mm on mountain slopes. Snowfall at higher altitudes (above 2500 m) accounts for most of the river runoff (Ojeh, 2006).

At the time of independence (1947), the boundary line between the two newly created independent countries i.e. India and Pakistan was drawn right across the Indus Basin, leaving

Figure1. Map of Indus and its tributaries



Source: www.google.com

Pakistan as the lower riparian. Moreover, two important irrigation head works, one at Madhopur on Ravi river and other at Ferozepur on Sutlej river, on which the irrigation canal supplies in Pakistan Punjab had been completely dependent, were left in the Indian territory. A dispute thus arose between two countries regarding the utilization of irrigation water from existing facilities. Negotiations held under the good offices of International Bank for Reconstruction and Development (World Bank), culminated in the signing of Indus Waters Treaty in 1960. The Treaty

Table 2. Indus Basin Statistics of India and Pakistan

Particulars	**India (Upper-riparian)**	**Pakistan (Lower-riparian)**
Length	1114 km	1708 miles
Basin area	321289 sq.km	252638 sq. miles
Average annual flow	73.31 BCM	173.63 BCM
Live storage capacity	6.57 BCM	15 MAF
Utilizable surface water	46 BCM	145 BCM
Basin Population (2011)	58.42 million	172 million
Per capita water availability (2010)	1255 cubic meter	1038 cubic meter
Estimated renewable groundwater supplies	27 km^3/yr	63 km^3/yr
Estimated total groundwater withdrawals	55 km^3/yr	52-63 km^3/yr

Sources (India): Central Water Commission, India 2010; WAPDA, Pakistan 2011; Pakistan Economic Survey 2010-2011; AQUASTAT Survey 2011 fixed and delimited the rights and obligations of India and Pakistan in relation to each other, concerning the use of the waters of the Indus System of Rivers. The treaty divides the Indus Basin system between India and Pakistan by allocating three eastern rivers of the basin, namely the Ravi, Beas and Sutlej to India and the three western rivers — the Indus, Chenab and Jhelum — to Pakistan. The Treaty obliges both India and Pakistan to not interfere in the waters of the rivers allocated to the other side except for the limit specified for Agricultural Use, Domestic Use and Non-Consumptive Use. India was also given the right to generate hydroelectricity on waters of the western rivers through run-of-the river projects.

Agriculture and water resource development

Indus basin is one of the fertile lands on the earth and has grown over the centuries through Indus Valley Civilization. The research and development in agriculture and farmer supportive policies by the governments of both countries during the 1960s with advent of green revolution technology generated surpluses of food from the basin to feed other areas. This in turn brought prosperity to the farmers, which opened doors of welfare for the future of the community. There was expansion of irrigation infrastructure and maximum utilization of Indus waters during the seventies and eighties. Along with surface water, groundwater was also exploited for irrigation and in nineties; groundwater development surpassed surface water irrigation in most productive areas of Indus Basin (Indian Punjab, Haryana, Pakistan Punjab). Highly subsidized energy supply for groundwater draft in India and relatively in Pakistan made unsustainable groundwater exploitation with falling water tables and mounting energy subsidy bill to government exchequer, apart from creating groundwater externalities to farmer through well failures as well as huge investments and environmental externality.

The surface water apportionment was made by the states/provinces of the both riparian countries after the signing of Indus Water Treaty for the optimal allocation of water among the riparian states in both countries through hectic and long deliberations. There have been water disputes with regard to allocation share among the states/provinces within the countries as well as

Table 3. Water Allocation across states/Provinces in India and Pakistan from Indus river basin

Country/State/Province	Geographical area (Million hectares)	Cultivated area (Million hectares)	Water allocated (MAF)
INDIA			**34.34**
Punjab	5.03	4.16	14.54
Haryana	4.37	3.52	3.82
Rajasthan	34.27	18.34	8.6
Himachal Pradesh	4.55	0.54	
Jammu & Kashmir	3.78	0.73	0.65
PAKISTAN			**117**
Punjab	20.63	16.52	55.94
Sindh	14.09	3.22	48.76
Khyber-Pakhtunkhwa	10.17	1.89	5.78
Balochistan	34.72	0.93	3.87

Source: Land use statistics and Water Apportionment Accords of India and Pakistan on building of dams and water infrastructure projects by lower riparian provinces. The geographical area, agriculture area and surface water allocation from the Indus Basin rivers across the states/provinces is depicted in Table 3. In India, whole of the Punjab, Himachal Pradesh and Jammu and Kashmir area fall under Indus basin, while as, 70% of Haryana and 32% of Rajasthan come under the basin. On the other side in Pakistan, it covers whole of Punjab, Sindh, most of the Khyber-Pakhtunkhwa and lesser area of Balochistan province. The water allocation from the eastern rivers (Ravi, Beas and Sutlej) in India and western rivers (Indus Main, Jhelum and Chenab) in Pakistan among the riparian states/provinces was based on their historical use and surplus water (in case of eastern rivers) from these rivers as well as re-organization of states (Punjab and Haryana in India).

Table 4. Permissible storage limit to India on Western Rivers and agriculture use

<table>
<tr><th>River Systems</th><th>General storage capacity (MAF)</th><th>Power storage capacity (MAF)</th><th>Flood storage capacity (MAF)</th><th>Irrigated cropped area (acres)</th></tr>
<tr><td>Indus</td><td>0.25</td><td>0.15</td><td>Nil</td><td>70,000</td></tr>
<tr><td>Jhelum</td><td>0.50</td><td>0.25</td><td>0.75</td><td rowspan="2">4,00,000</td></tr>
<tr><td>Jhelum Main</td><td>Nil</td><td>Nil</td><td>As provided in Para 9, Annexure E of IWT</td></tr>
<tr><td>Chenab</td><td>0.50</td><td>0.60</td><td>Nil</td><td rowspan="2">2,31,000</td></tr>
<tr><td>Chenab Main</td><td>Nil</td><td>0.60</td><td>Nil</td></tr>
<tr><td>Total</td><td>1.25</td><td>1.6</td><td>0.75+Annex E of IWT</td><td>7,01,000</td></tr>
</table>

Source: Indus Water Commission and IWT draft

India has limited rights of water use on Western Rivers (allocated to Pakistan) for agricultural purposes and run-of-the-river hydropower projects in the state of Jammu and Kashmir as depicted in Table 4. The permissible use rights on western rivers by India is the bone of contention between the two countries with respect to water infrastructure projects which India plans to build for hydropower, irrigation and flood control.

Modeling outcomes

We calibrated our model using the information on crops grown; area, yield and water use for each of the states/provinces along with costs and returns from these crops on per unit basis and then carried out simulations under alternative water use to maximize the net benefits. Water allocation across countries and states/provinces is taken to be constrained by terms of the prevailing IWT and water allocations accords, respectively. Control variables are used one at a time and in different combinations. The ratio of groundwater use in some states (Indian Punjab, Haryana, Pakistan Punjab and Sindh) is much higher than the surface water use, though; more than 70% of recharge to groundwater is from surface water sources and rainfall, but needs heavy capital investment and energy for its extraction. The results of the model are presented in Table 5.

As per the present cropping pattern, the net benefits from agriculture in Indian part of the Indus basin is USD 6.73 billion with water use of 86.71 BCM. The major share comes from Punjab state, followed by Haryana and Jammu and Kashmir (J&K). Rajasthan is the largest state of India with almost four times more geographical area than Punjab, however, a meagre area of 98,3023 hectares are irrigated by the IGNP project carved out of the eastern rivers of the Indus basin. The

Punjab state in India has a relatively higher water allocation (17.93 BCM) from the eastern rivers, apart from drawing more than 34 BCM from groundwater to sustain its booming agrarian economy. However, this region along with the neighboring Haryana state is the most groundwater over-exploited regions of the India with unsustainable groundwater exploitation rates. Highly subsidized electricity to farm sector and very nominal surface water charges are the main reason

Table 5. Net benefits and water use in agriculture in Indus Basin states

Country/ State/ Province	Present Scenario		Optimal allocation		Steady state groundwater use	
	Net benefits (Billion USD)	Water use (BCM)	Net benefits (Billion USD)	Water use (BCM)	Net benefits (Billion USD)	Water use (BCM)
INDIA	**6.73**	**86.71**	**8.63**	**110.6**	**7.83**	**59.13**
Punjab	2.72	46.77	3.01	53.07	2.80	28.89
Haryana	1.82	25.51	1.98	40.25	1.58	17.73
Rajasthan	0.43	7.40	0.59	11.78	0.40	7.01
Himachal Pradesh	0.49	3.05	1.07	2.08	-	-
J&K	1.27	3.98	1.98	3.42	-	-
PAKISTAN	**6.28**	**142.33**	**8.29**	**157.55**	**6.91**	**131.80**
Punjab	3.87	63.93	4.87	62.5	4.35	57.45
Sindh	1.15	53.2	1.76	64.35	1.02	48
KPK	0.85	17.35	0.98	19.35	-	-
Balochistan	0.41	7.85	0.68	11.35	0.56	7.0

Source: Authors own computations by applying Model

for low water use efficiency of the farms. It is reported that farmers in Punjab region of India are using more than actual water needed for crops, particularly in rice and wheat, which are high water consumptive crops (Karam Singh, 2012; Srivastava et al., 2015; Kaur et al., 2015). More than 90% of the total cropped area in Indian Punjab is dominated by rice-wheat crop rotation system at the expense of unsustainable water use of 44.19 BCM out of the total 46.77 BCM, thereby accounting 94.5% of the total water use share of the state. Price support and better procurement for the crops by the government along with almost free energy for groundwater draft make farmers to go for these crops. The net benefits increases by 28% when model is run based on crop profitability in both summer and winter season with no water use cap. So obviously, it chooses rice and wheat for the two seasons exclusively in Punjab and apple fruit crop in J&K and Himachal Pradesh. Haryana state follows the same crop choice as Punjab with no water constraint. When water cap is put in model to bring the groundwater into steady state position, the land allocated to high water consumptive crops decline and net benefits also reduce but are relatively higher than the status quo position.

Pakistan has a net benefit of 6.28 billion USD as per the present cropping pattern with 142.33 BCM of water use. Pakistan has relatively more area under Indus Irrigation system than India but due to lower yields, higher cost of production because of relatively low level of support by federal government in terms of market support prices, procurement policy and energy and fertilizer subsidy in comparison to farmers of India, get lesser net benefits despite having more area and water. The net benefits increase by 32% when model is run based on crop profitability.

The crop choices and area allocation varies across the provinces when model is run with water constraint (Table 5).

The climate change is likely to pose serious challenges to continued agricultural growth in the region. The predicted declines in river flows may be countered to some degree with changes in cropping patterns. Increases in water efficiency resulting from adoption of conservationist irrigation methods will sustain the future of agriculture in the basin. Given the prevailing low surface water prices and common property related failure of groundwater markets, appropriate financial incentives and other institutional measures to promote water conservation are going to make huge difference. Sustainable management of the basin's surface water and groundwater resources will motivate increasingly stringent water use. Maintaining or enhancing agricultural productivity in the face of such limits is likely to require newer seed varieties or other kinds of technological change in production methods, for which public policy support is desirable. In order to sustain the groundwater resource of the Indus basin, energy supply to farm sector should be metered and subsidy component on energy should be switched to water saving technologies for crop production, apart from price support and procurement policy shift from water consumptive crops such as rice, wheat to less water consumptive-high value crops.

Hydropower, Flood control and Future Cooperation

Indus basin across the border have a hydropower potential of 1,00,320 MW with 60% in Pakistan and 40% in India out of which more than 75% (75,554 MW) is identified and only 24% is harnessed till now with 20,645 MW under construction which will make upto 45% of potential. Pakistan has a huge potential gap to be harvested for hydro-energy projects on western rivers of Indus (Table 6). There is a potential of 20,000 MW of hydropower generation on Indian side of Jammu and Kashmir on western rivers allocated to Pakistan with permissible limits for run-of–the–river hydropower projects. Till now, meagre 17% is harvested with more 10% under construction. India has plans to utilize the waters of western rivers to its full capacity in norms as laid down by the treaty, however, Pakistan has serious apprehensions with regard to Indian projects.

Table 6. Hydropower generation and potential in Indus Basin

Particulars	**India**	**Pakistan**	**Total**
Hydropower Potential	40,320	60,000	1,00,320
Identified capacity (MW)	33,832	41,722	75,554
Hydropower installed capacity (MW)	16,653	7,264	23,917
Capacity under construction (MW)	6,560	14,085	20,645
Potential for development (MW)	17,107	38,651	55,758

Source: CEA, 2015; TERI, 2015; WAPDA, 2016

Our simulated increases in hydropower capacity lead to higher net benefits and should not provoke any objections from downstream riparian regions under our assumption that water use for such purposes is non-consumptive. Interestingly, however, the IWT does not take this view (i.e., it regards water used to generate hydropower as consumptive), suggesting that greater political goodwill needs to be established before potential benefits from additional hydropower are realized in practice. Also, some down-sides to hydropower have emerged since the treaty was signed in 1960. Adverse environmental and social impacts of storage related river projects were either not known then, or were not given the attention that they would surely claim now and in the future. There may be considerable scope for additional future cooperation as well. For example, arrangements could be made for sharing of hydrological data, for carrying out joint research related to climate change, and for establishment of early warning systems to mitigate flood damages. Much of this could be achieved by strengthening or modifying some of the existing provisions of the IWT, such as Article VI "Exchange of Data" and Article VII "Future Cooperation" and by exploring options to enhance the advisory capacities of the Permanent Indus Commission (IWT draft, 1960). The economic value of the Indus basin waters is likely be a lot higher with cooperation in all such areas.

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