

STIMSON

Environmental Security Program

VISITING FELLOWS REPORT

Bridging The Divide

TRANSBOUNDARY SCIENCE & POLICY
INTERACTION IN THE INDUS BASIN

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Foreword

The Stimson Center's *Bridging the Divide: Transboundary Science & Policy Interaction in the Indus Basin* is the ambitious outcome of Stimson's Indus Basin Science Policy Visiting Fellows project and the collaborative work of two exceptional researchers, Dr. Muhammad Jehanzeb Masud Cheema from the University of Faisalabad in Pakistan and Dr. Prakashkiran Pawar of The Energy and Resources Institute in India. Both India and Pakistan face common challenges managing their shared natural resources. With rapidly depleting groundwater, burgeoning population growth, and diminishing surface water flows, the Indus is swiftly becoming a "closed" basin—one where nearly all available water is allocated for existing use, with almost no capacity for future development. Left unaddressed, these issues could jeopardize water supplies, development objectives, and social welfare on both sides of the border, potentially fuelling tensions within and between countries. As both nations continue to grow in economic and political importance, strained resources at home remain one of their largest international obstacles.

With this problem in mind, the Stimson Center Environmental Security Program, with the support of the Richard Lounsbery Foundation, created the Indus Basin Science Policy Visiting Fellowship program for early-career Pakistani and Indian scientists to articulate specific strategies for joint research and knowledge building in the region. Dr. Cheema and Dr. Pawar were accordingly selected from among a competitive pool of researchers and promising young professionals from both countries, representing the next generation of water experts in the region. Hosted at the Stimson Center in Washington, D.C., the fellowship offered the two scientists opportunities to meet with analysts, managers, and policy experts from international research institutions, academia, NGOs, and the U.S. government; to conduct site visits to institutions and facilities both in the Washington area and in the Pacific Northwest; and also to work together to explore ideas for mutual cooperation and investigation to meet the emerging challenges facing the Indus.

The report that follows is a jointly-authored result of that collaborative experience. As one element of the project, the fellows also took it upon themselves to conduct a comprehensive literature review to analyze the existing state of both science and policy research in the region. This initial study was not a requirement of the fellowship, but rather a reflection of the fellows' initiative and their drive to make their collaboration as fruitful and relevant as possible. This phase of the project is documented in Part I of the *Bridging the Divide* publication.

As their final product, the researchers were tasked to formulate a proposal for a practical, cooperative research project that could be implemented by Indian and Pakistani scientists towards building a shared knowledge base for water resources management in the Indus Basin. During their time in-residence, Stimson facilitated meetings for the fellows to consult with hydrogeologists from NASA, discuss water treaty negotiation with the U.S. Geological Survey and Army Corps of Engineers, and to consider basin modelling approaches with those from top U.S. universities. Utilizing this expertise and with Stimson's guidance, the fellows developed a comprehensive project plan that designates specific research needs and data gaps to be addressed in the Indus. It identifies potential Indian and Pakistani scientists or institutions to participate in the project team and defines their contributions; sets down the research activities, methodology, and project timeline; and indicates the project's intended objectives and expected contributions to cooperative knowledge-building. Together, Part I and II of this publication look to guide and inform future international research efforts and serve as a framework towards a more responsive policy agenda.

The full value of the Indus Basin Science Policy Visiting Fellowship is not and could not be captured in a single report. Much of its success was defined by the professional development, friendship, and lessons-learned of the fellows themselves, a success we hope will grow with their continuing collaborations. Likewise, Stimson hopes that the influence of the researchers' fellowship will expand as the fellows reach out to and engage with decision-makers and the larger publics in India and Pakistan. The Stimson Center Environmental Security Program thanks the Lounsbery Foundation for the support which made this initiative possible. We tremendously valued the opportunity to work with Drs. Cheema and Pawar, and appreciate their dedication to collaboratively seek a more sustainable future for their region. Their findings and proposal presented here have the potential not only to improve science and policy frameworks within the Indus Basin, but to spark a greater conversation within research communities and between countries over the possibilities of peaceful, cooperative water policy solutions.

David Michel
Director & Senior Associate
Stimson Center Environmental Security Program

Executive Summary

Stagnant or decreasing agricultural productivity, increasing dependence on groundwater, high risk of climatic variability, enhancing industrialization, and unplanned and un-regularized urban growth are realities of the Indus River Basin. They have poised a variety of challenges for water resources governance, management, and use. Groundwater overdraft, food and nutritional security, decreased freshwater availability vis a vis escalating demand, and water pollution are major challenges and even greater threats. Water policies in the region thus call for a more holistic understanding of basin dynamics for the efficient management, equitable distribution, and sustainable use of scarce resources.

In this report, an attempt has been made to thoroughly review the knowledge base available in studying Indus Basin issues. Approximately 200 papers/reports were reviewed in which scientific and policy research in the Indus Basin were highlighted. Out of the total papers and reports, approximately 100 were found to be more related to scientific work, while the other 105 were focused on socioeconomic, regulatory, and policy issues. Their temporal and spatial scales have also been investigated in order to judge the applicability of the research to the transboundary context. Knowledge gaps and links between science and policy have also been explored. Each paper was weighted in order to assess the effectiveness and scope of these studies for transboundary, multidisciplinary, multi-expert, and comprehensive work, based upon a questionnaire of the studies. These research questions were based on the spatial and temporal extent of the study, number of experts and organizations involved and their origins, data sources, availability and quality issues, and the science and policy interlink considered in the study.

The scientific research carried out in the Basin has been focused on a variety of topics. However, through the review, it was revealed that there are three topics most on the radar screen of researchers. These are surface water, groundwater, and their conjunctive use. Forty-five percent of the total research reviewed was focused on these three aspects. In approximately 63% of the scientific research papers, only one subject was considered for analysis. It was also found that only 16% of the scientific studies focused on the TIB, while most (47%) focused solely on the Indus Basin in Pakistan or the Indus Basin in India. As far as temporal scale is concerned, 40% of the scientific research used more than ten years of data, while in 34%, less than two years of data was used. Interestingly, entire TIB studies constitute only 16% of the total scientific studies. Even within this 16%, only 6% used more than 10 years of data, while 7% used less than two years. The studies in which more than ten years of data was used were either at the global scale and include the TIB, or otherwise used previous reports/studies for analysis.

The review of the socioeconomic, regulatory, and policy papers revealed that about 30% considered the Indus Basin Treaty and 25.7% considered water resources in general. However, only one subject was considered for analysis in 42% of the total policy papers. Forty-one percent (43 papers) of the policy research studies were related to pure policy or Indus Treaty evaluation, for which the geographic scale of application is irrelevant. Out of the remaining 62 papers, 66% (41 papers) are about the individual Indian or Pakistani Indus basins, while merely 29% (18 papers) consider the transboundary basin. As far as data type is concerned, 53% (56 papers) of the total policy studies were data independent while 47% (49 papers) were data dependent. Out of the 49 data dependent papers, 42.9% (21 papers) used primary multi-year data and 16.3% (8 papers) used primary single-year data, while secondary data is used in 34.7% (17 papers). In 6.1% (3 papers), no distinct dataset is used for analysis.

It is important for scientific research to translate findings in terms of policy perspectives, and similarly, there should be a clear link between policy decisions and science. Such a linkage is rarely observed in the case of the Indus Basin. In order to gain information on how well the science and policy are linked in the research, questions regarding this aspect were included in the project questionnaires. It was found that there is currently no clear linkage between the scientific research and policy. Only 12% of the scientific studies tried to develop a linkage between data and policy, while 71% missed this important bridge. The rest of the scientific studies mentioned only that the scientific findings could be taken up by policymakers. The linkage in the policy research was even less than in the scientific case. In fact, in all of the policy research papers in which a scientific link was expected, only a few lines mention scientific data, and these completely miss conveying what type of scientific data is required for policymaking, what type of methodologies should be used to reduce bias in the data, which scientific phenomena may be creating considerable ambiguity for policymakers, and what range of variation of results is there in this information. As compared to scientific research papers, socioeconomic and policy research papers contain more narratives. Hence writers of these policy papers should articulate the scientific links more precisely, with special highlighted areas for further explanation.

Acronyms

amsl	Above Mean Sea Level
CCA	Canal Command Area
CWR	Crop Water Requirement
DEM	Digital Elevation Model
FAO	Food and Agriculture Organization
GRACE	Gravity Recovery and Climate Experiment
ha	Hectare
hr	Hour
IB	Indus Basin
IB-In	Indus Basin Indian Part
IB-Pk	Indus Basin Pakistani Part
IBIS	Indus Basin Irrigation System
ICIMOD	International Centre for Integrated Mountain Development
IRSA	Indus River System Authority
IWC	Indus Water Commission
IWT	Indus Waters Treaty
IWMI	International Water Management Institute
km ³	Cubic Kilometer
KPK	Khyber Pakhtunkhwa
mha	Million Hectares
PID	Provincial Irrigation Department
PMD	Pakistan Metrological Department
TIB	Transboundary Indus Basin
TIBA	Transboundary Indus Basin Aquifer
TRB	Transboundary River Basin
UIB	Upper Indus Basin
yr	Year

Transboundary Indus Basin Science Policy Review: Status, Methodologies, and Ways Forward

Introduction

Transboundary River Basins

Water is one of the most precious resources on earth, vital for human sustainability. The growing global population and unconstrained water resources utilization threaten spatial and temporal fresh water availability. The threat is more severe in regions with arid to semi-arid climate, and those with basin boundaries that do not coincide with political ones. Nearly half the world is situated in one of 276 transboundary river basins (TRB), which bear 40% of the world's population. These 276 international rivers generate 60% of global freshwater (De Stefano et al., 2012; Wolf and Giordano, 2002). The greatest number of these rivers are situated in Europe (68), followed by Africa (64), Asia (60), North America (46), and South America (38), as illustrated in Figure 1.

The transboundary nature of these river basins has resulted in acrimonious disputes over water. Any change in upstream water use can severely affect the downstream users, although they may be thousands of kilometers apart from each other. The effects of land and water use planning in one part of the basin are vital for the users in another part (e.g. Molden et al., 2001).

The TRBs in South Asia are not only providing for the food requirements of the region, but also for much of the world. There are three major TRBs: the Ganges, Indus, and Brahmaputra, that share the political borders of China, India, Pakistan, Afghanistan, Nepal, Bhutan, and Bangladesh. All of these countries have political differences with each other, which makes integrated water resources management more challenging. The Indus River Basin, shared between four Asian countries, is considered one such challenging example.

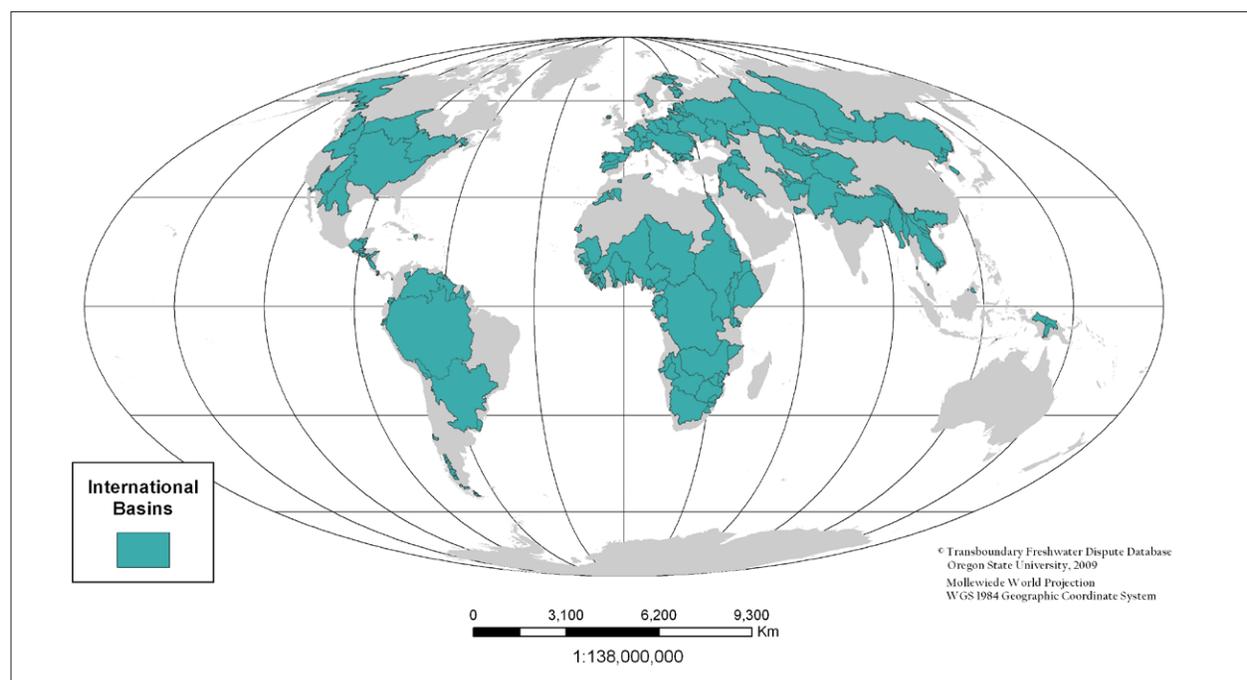


Figure 1: International river basin boundaries. Source: Oregon State University.

Transboundary Indus Basin

The Transboundary Indus Basin (TIB) is shared between Pakistan, India, Tibet (China), and Afghanistan. The total size of the basin is 1.12 million km², with an elevation range from 0 to 8600 m above mean sea level (a.m.s.l). Most of the basin area is shared by Pakistan and India (86% of total), while the rest is shared by Tibet (China) and Afghanistan. Irrigated agriculture is practiced in the TIB on around 26 million hectares (mha) of land and is considered vital to ensure the food security of the region. The lifeline and mainstay of irrigated agriculture in the TIB is the Indus River, which originates in the northern Himalayas' Mount Kailash in Tibet (China), at an altitude greater than 5,000 m. It traverses from east to west through India and longitudinally through Pakistan, ultimately flowing into the Indian Ocean to the south. The Indus is fed by 24 tributaries, with eight being major tributaries. The Jhelum, Chenab, Ravi, Sutlej and Beas Rivers are the major eastern tributaries, while the Kabul, Gomal, and Gilgit Rivers flow west and north, respectively (Figure 2; FAO, 2012b).

The Jhelum River originates in the upper end of the Kashmir Valley and joins the Chenab River near Trimmu Barrage in Pakistan. The origin of the Chenab is in the Himalayas, and it flows into the Indian states of Himachal Pradesh, Jammu, and Kashmir. Further down, the Chenab enters Pakistan upstream of the Marala Barrage. The Ravi River originates near the Kangra district of Himachal Pradesh and joins the Chenab in Pakistan. The Sutlej River arises from the lakes of Mansarover and Rakastal in the Tibetan Plateau at an elevation of about 4,570 m. The Sutlej joins the Chenab at Panjand (Pakistan). The Beas River originates in the Rohtang Pass in the Himalayas at an elevation of 4,000 m, and joins the Sutlej above Harike in India before entering into Pakistan. The Chenab then flows into the Indus above Guddu Barrage (Pakistan). The Gilgit River arises in the northern areas of Pakistan with its upper reaches mostly glaciated and covered with permanent snow. The Kabul River originates in the south-eastern slopes of the Hindu Kush range in northern Pakistan. It flows through the Chitral Valley of Pakistan and then enters Afghanistan to meet the Indus further down, above the Kalabagh Barrage near Attock in Pakistan (Singh and Jain, 2002; Thatte, 2008).

Transboundary Indus Basin Aquifer

The Transboundary Indus Basin is underlain by an extensive unconfined aquifer, most of which is shared between India and Pakistan, and underlays a surface area of 0.16 million km². The TIB Aquifer (TIBA) has large groundwater reserves with an annual replenishable potential of approximately 90 km³. A high recharge rate is found in the North, below the foothills of the Himalayas, and reduces towards the South (Figure 3; Laghari et al., 2012).

The aquifer is well developed, with an unconfined to semi-confined porous alluvial formation and the capacity to retain and transmit water as underground flow. Most of the groundwater flows from northeast to southwest in the basin, according to water table contour maps from 2004 (Chadha, 2008). The water retained in the aquifer is being used as an alternative source for irrigation. Inadequate and variable surface water supplies have forced farmers of both countries to use groundwater as a supplemental source, with an annual contribution of more than 50% of total irrigation requirements. Local and readily available groundwater makes groundwater irrigation more productive compared to surface water irrigation. Large numbers of irrigation wells have been added every year in both countries, which has resulted in a 20-30% increase in groundwater abstractions over the last 20 years (Qureshi et al., 2010b).



Figure 2: Location of reservoirs and barrages constructed on the Indus River and its tributaries. Source: FAO.

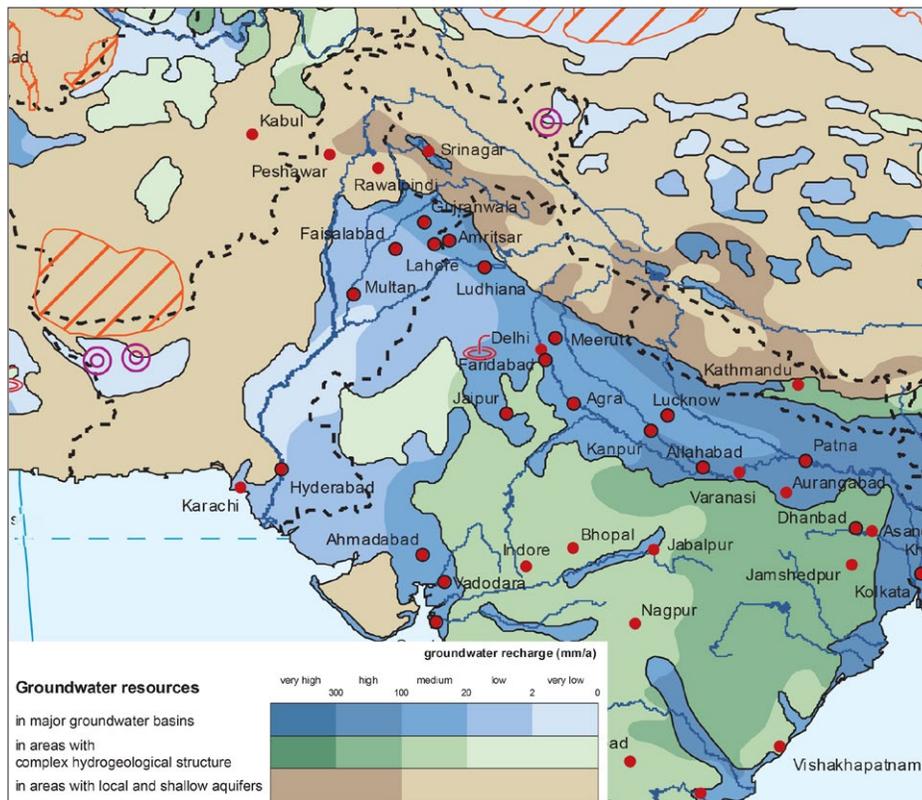


Figure 3: Transboundary Indus Basin Aquifer with annual recharge information (extracted from original.) Source: UNESCO. <http://www.whymap.org>.

Indus Waters Treaty

All water users are hydrologically connected in a river basin. Upstream water use has a direct effect on the downstream users, even thousands of kilometers away or in another country. By affecting water supplies, upstream water users can cause dramatic impacts on downstream water users and their environments. Such was the case at the time of united India's partition into India and Pakistan in 1947, which politically divided the Indus Basin.

Due to political differences and disagreement on water use between the two countries, various conflicts arose over water distribution on the rivers in the Indus Basin. India, being the upper riparian, diverted all flows from the northeast to southwest flowing rivers (called Eastern Rivers: the Ravi, the Beas, and the Sutlej) to meet its growing irrigation demand. Consequently, it created water scarcity and an environmental threat in parts of the basin previously fed by these rivers, mostly in eastern parts of Pakistan. The situation caused a continuous barrier to normalizing relationships between the two states.

To resolve these issues, water rights were defined under World Bank and United Nations auspices in 1960 by the signature of the Indus Waters Treaty (IWT) between India and Pakistan. Twelve articles with eight annexures, various sub-sections, and sub-annexures, are defined in the treaty. According to the IWT, the flows of the three main west-flowing rivers (the Indus, the Jhelum, and the Chenab) are available to Pakistan, while India has exclusive rights to the waters of rivers flowing east. Pakistan has unrestricted use of all the waters of the Western Rivers, which India has an obligation to let flow. India has the right to use runoff water from the Western Rivers for domestic use, non-consumptive use, agricultural use (as per IWT Annexure C), and hydropower (as per Annexure D). Before the treaty, there were irrigation

S. No.	Linking canal	Off-taking barrage	Linked rivers	Year constructed	Country	Length (km)
1	Upper Chenab	Marala	Chenab-Ravi	1912	Pakistan	142
2	Upper Jhelum	Mangla	Jhelum-Chenab	1915	Pakistan	142
3	Balloki-Sulemanki	Balloki	Ravi-Sutlej	1954	Pakistan	63
4	Marala-Ravi	Marala	Chenab-Ravi	1956	Pakistan	101
5	BRBD	Marala	Chenab-Ravi	1956	Pakistan	175
6	Trimmu-Sidhnai	Trimmu	Chenab-Ravi	1965	Pakistan	71
7	Sidhnai-Mailsi	Sidhnai	Ravi-Sutlej	1965	Pakistan	132
8	Mailsi-Bhawal	Sidhnai	Ravi-Sutlej	1965	Pakistan	16
9	Rasul-Qadirabad	Rasul	Jhelum-Chenab	1967	Pakistan	48
10	Qadirabad-Balloki	Qadirabad	Chenab-Ravi	1967	Pakistan	129
11	Chashma-Jhelum	Chashma	Indus-Jhelum	1970	Pakistan	101
12	Taunsa-Punjad	Taunsa	Indus-Chenab	1970	Pakistan	61
13	Madhopur-Beas	Madhopur	Ravi-Beas	1955	India	20
14	Beas-Sutlej	Pandoh	Beas-Sutlej	1977	India	37
15	Sutlej-Yamuna	Nangal	Sutlej-Yamuna	under construction	India	214
16	Sutlej-HaryanaAlwar	Ferozpur	Sutlej-Haryana & Alwar Districts (Ganges)	proposed	India	

Table 1: Linking canals constructed in the Indus Basin before and after IWT.
Sources: Thatte, 2008; Scott-Wilson, 2011.

canals feeding water from the Eastern Rivers in Pakistan. India paid 62.06 million pound sterling for the replacement work of these canals. The treaty states that, while flowing in Pakistan, any tributary in its natural course that joins the Satluj main stem and Ravi main stem after these rivers have finally crossed shall be available for unrestricted use by Pakistan. In addition to this, Pakistan has agricultural water-use rights to certain tributaries of the Eastern River Ravi, as per provisions of Annexure B. There was also a transition period from the 1st of April 1960 to the 31st of March 1970 when India had limitations on the agricultural use and storage of water, as well as an obligation to make deliveries, from the Eastern Rivers, according to provisions in Annexure H (Indus Waters Treaty, 1960).

A permanent Indus Water Commission (IWC) was established under the IWT Article VIII for smooth implementation of the treaty. The commission was to meet once a year, alternately in Pakistan and India. The functions of the IWC are to establish and maintain cooperative agreements for IWT implementation, provide a report at the end of each year, inspect the rivers once every five years, and settle disputes. The commission is also responsible for sharing data on agricultural use, hydro-electric power generation, water storage, and flows in the rivers. Under Article VI, both countries are supposed to share daily gauge and discharge data, reservoir extractions, canal withdrawals, and escapes.

The IWT was successfully implemented in the first few decades, and a number of reservoirs and a network of inter-river linking canals were constructed in the Indus Basin under the Indus Basin Settlement Plan (IBSP). The details of the linking canals along with their years of construction are provided in Table 1.

S.No	Reservoir	River	Country	Construction year
1	Mangla	Jhelum	Pakistan	1966
2	Chashma	Indus	Pakistan	1971
3	Tarbela	Indus	Pakistan	1976
4	Diamer-Basha	Indus	Pakistan	Under construction
5	Kurram tangi	Kurram	Pakistan	Under construction
6	Munda	Swat	Pakistan	Under construction
7	Bhakra	Sutlej	India	1963
8	Pong	Beas	India	1974
9	Pandoh	Beas	India	1977
10	Salal	Chenab	India	1995
11	Thein	Ravi	India	2001
12	Baglihar	Chenab	India	2004
13	NimooBazgo	Indus	India	Under construction
14	Chutak	Indus	India	Under construction

Table 2: Major reservoirs constructed in the Indus Basin. Source: Cheema, 2012.

After signing the IWT, both governments started mega projects to efficiently utilize the Indus River System flows. These included construction of large dams, the Bhakra Dam (1963) on Sutlej River, the Mangla Dam (1966) on the Jhelum River, the Tarbela Dam (1976) on the Indus River, the Pong (1974) Dam on the Beas River, and the Baglihar Dam (2004) on the Chenab River. In Pakistan, construction of the large capacity, multi-purpose Diamer-Basha Dam on the Indus, about 315 km upstream of Tarbela Dam, was initiated and is expected to be completed in 2018. In India, Kishan Ganga, Nimoo Bazgo, and Chutak Dams are also noteworthy projects to mention. The locations of these various structures constructed after the IWT are shown in Figure 2, and details of the major reservoirs constructed in the Indus Basin are provided in Table 2.

The average annual flows of major rivers in the basin are provided in Table 3. These flows represent the pre-treaty (1922-61) and post-treaty (1985-2002 and 2007-2010) situations. The table shows decreasing flow trends for both west- and east-flowing rivers. The average flow of eastern rivers into Pakistan was reduced from historic levels by 75% and 92% during the years 1985-2002 and 2007-2010, respectively. Pakistan can utilize residual flows from these east-flowing rivers, but these flows are variable and available only during the monsoon season. About a 17% reduction from the historic average flow of the west-flowing rivers was observed during the 2007-10 period. Climate change and its variability may also cause a reduction in flow of the west-flowing rivers (Ahmad, 2009). The upstream interventions by both countries could be a significant cause of reduced flows as well.

The recent advancements on optimizing the use of water resources for irrigation, food, and energy, combined with climate change concerns, strongly demand a revisiting of the treaty. For example, the construction of new dams/hydropower projects by India is not deemed acceptable by Pakistan. The International Court of Justice has to be involved in various on-going projects to check whether the projects are violating the treaty or not. Moreover, the treaty is mainly focused on available surface water supplies without considering the transboundary aquifers under current climate change scenarios. The frequency of extreme events is expected to increase in the near future and provisions for flood water management strategies need immediate attention.

	River	Rim station	Average Annual Flow 1922-61 (km ³)	Average Annual Flow 1985-2002 (km ³)	Average Annual Flow 2007-10 (km ³)
West flowing rivers	Indus	Kalabagh	114.4	94.1	101.9
	Jhelum	Mangla	28.3	23.7	19.3
	Chenab	Marala	31.9	24.5	23.9
East flowing rivers	Ravi	Below Madhopur	8.6	4.0	1.1
	Sutlej	Below Ferozepur	17.2	2.2	0.8
	Total		200.4	148.5	147.0

Table 3: Average flows in major rivers of the Indus Basin before and after IWT. Sources: Khan, 1999; Government of Pakistan, 2011; IUCN, 2011.

A large number of research studies have been carried out on integrated water resources management in the Transboundary Indus Basin. Researchers from both India and Pakistan, as well as international researchers, are involved in studying issues in the basin. These include studies on a wide range of spatial and temporal scales, as well as of surface water and groundwater use, and of climate change impacts on water availability. However, these research studies still lack a fundamental link of how well the scientific knowledge on integrated water resources management can be translated into policy implications at the transboundary scale.

Indus Basin Science-Policy Review

The geopolitical nature of the basin has made the Indus a test case for scientists and policy analysts to efficiently manage resources. India and Pakistan, major beneficiaries, are facing tremendous pressure on their water resources due to an exponential increase in population and unconstrained water resource utilization. The situation is leading towards an alarming reduction in per capita water availability. Population shifts to cities and industrialization have become major competitors with the traditional water users in the agricultural sector. Changing climate and global warming threatens the spatial and temporal availability of freshwater resources. Changes in precipitation patterns and intensity are also being observed in the Upper Indus Basin, where most of the glaciers are located. In order to provide scientific answers to these issues, large research has been carried out by the scientific community that varies in space and time. The data used and methods applied also vary and depend upon the data availability.

In this report, an attempt has been made to thoroughly review the types of research and methodologies that have been carried out in studying Indus Basin issues. Their temporal and spatial scales have also been investigated in order to judge the applicability of the research to a transboundary context. The knowledge gaps and links between science and policy have also been explored.

For this purpose, a comprehensive review of the literature related to ‘Transboundary Indus Basin Science and Policy’ research was carried out. This research material has been referred to as ‘papers’ in general and they include peer-reviewed papers, non-reviewed research papers, working papers, conference papers, online discussion articles, project reports, and project summaries both at national and international levels. The research papers and reports with the key words of ‘Indus Basin’, ‘Transboundary Indus Basin’,

‘water resources management in the Indus Basin’, ‘climate change in the Indus Basin’, and similar terms, were randomly reviewed and downloaded from web search engines, especially from Google. Research papers published in proprietary journals were collected from different sources all over the world. Research material was majorly divided into two sections, namely science and policy. Interestingly, over 200 papers/reports were found in which scientific and policy research in the Indus Basin is highlighted. Out of the 205 total papers and reports, 100 were found to be more related with scientific work while the remaining 105 were focused on policy issues. These papers were classified and weighted according to questions relevant to transboundary Indus Basin research, including both science and policy parts.

In order to assess the effectiveness and scope of these studies, questionnaires for scientific and policy research were formulated and their options were determined and finalized based upon internal expert discussions. There were 11 questions for the science section and 10 questions for the policy section, while there were four options for the science section and five options for the policy section. The policy section had one additional option of ‘question not applicable’. The questionnaires can be seen in Annexures I & II. The research questions were based on the spatial and temporal extent of the study, number of experts and organizations involved and their origin, data sources, data availability and quality issues, and the science and policy interlinks. The findings are discussed in the respective science and policy sections.

Review of Scientific Research

The scientific research carried out in the basin has been focused on various different topics. However, through review, it was revealed that several topics are most on the radar screen of researchers, including surface water, groundwater, and their conjunctive use (Figure 4). Forty-five percent of the scientific research work has been focused on these three subjects. The quantification of climate change impacts on water resources (14%) and agriculture (14%) has also been given special attention in basin-scale studies. Some focus has, likewise, been given to glaciology related studies (9%), as climate change, especially in the Upper Indus Basin (UIB), has had adverse effects on the glaciers and can result in their retreat. Significant contributions are also seen in the fields of pollution (5%), water-related environmental issues, crop water use, hydropower, and socio-economy.

It can be presumed that scientists are aware of the fact that the availability of surface and groundwater can hamper agricultural activities in the basin. They are also responsive to the current climate change threats, glacier melts, and future water scarcity issues. With this in mind, only one subject was considered for analysis in most (63%) of the scientific studies carried out in the basin. Two to three subject areas were considered in 22% of the studies, and 8% integrated socioeconomics with the scientific research. Only 7% of studies touched on more than four areas in their analysis. Moreover, only one method was applied in the analysis/application for 49% of the studies. Two or more methods were tested in 44% of studies, including remote sensing, trend analysis, hydrological models, etc.

In order to carryout transboundary river basin management in an integrated manner, it should be expected that researchers adopt a multi-disciplinary approach, considering multi-faceted aspects of research and giving due importance to socioeconomic characteristics.

Another shortcoming in the scientific research is the lack of basin level integrated approaches for managing resources, meaning those that transcend political boundaries. It was rarely found that the spatial and temporal extents of the research were adequate for basin-scale integrated water management. The research focused on a basin scale had to compromise by using a long time series of data, especially for climate and flow data. Therefore, most of the studies were restricted to be carried out at regional or local scales where sufficient data could be made available.

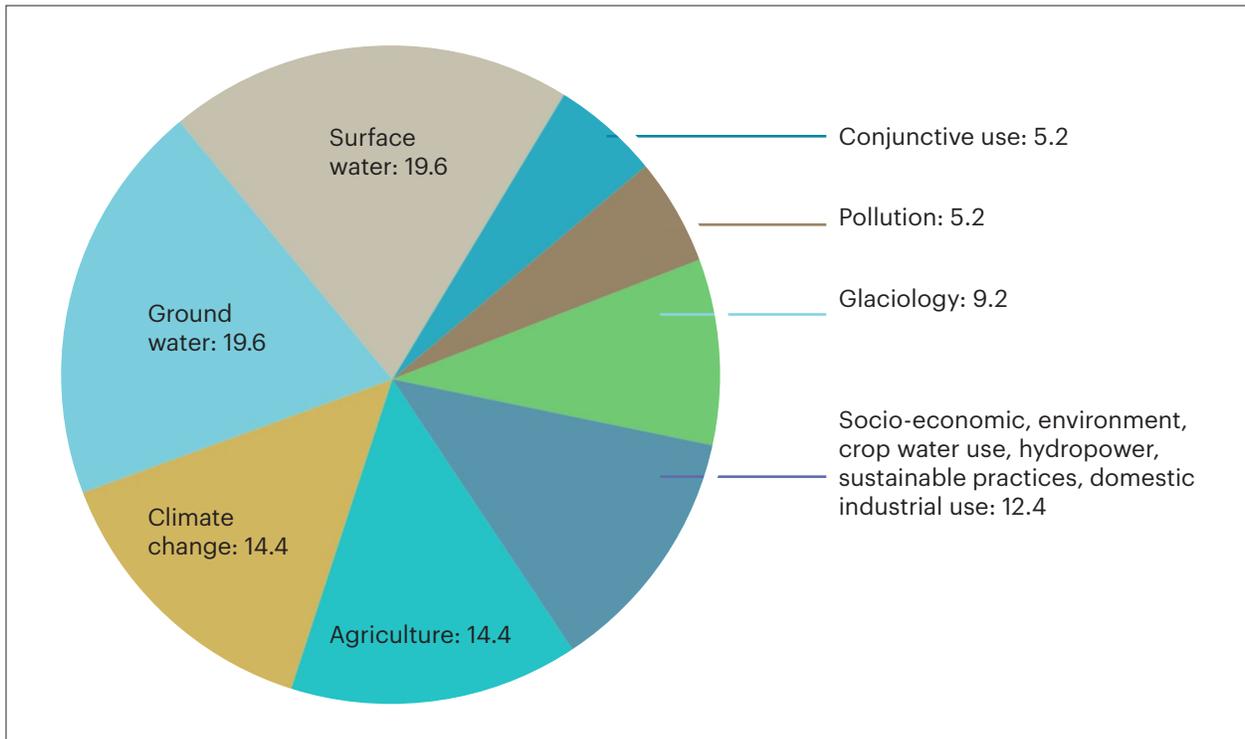


Figure 4: Classification of research carried out in the basin based on research focus.

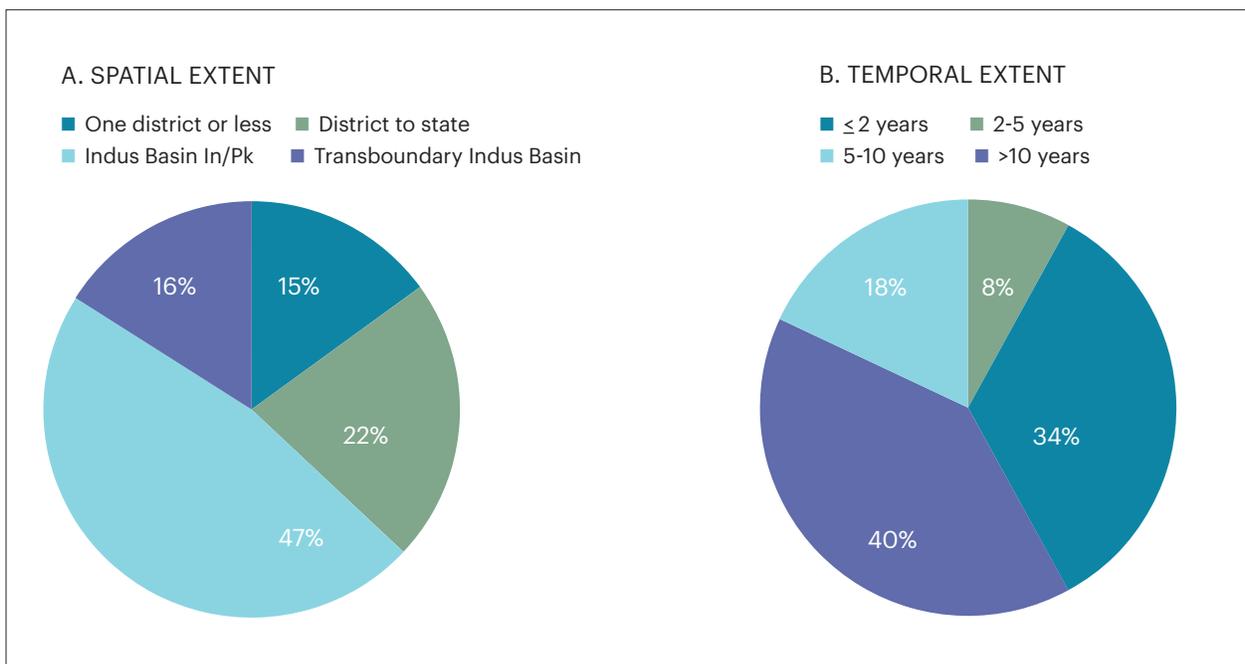


Figure 5: Spatial extent of study area (A) and duration of data used (B) in the studies carried out in the Indus Basin.

It is evident from Figure 5, that only 16% of studies in the review focused on the TIB, while most of the time (47%), the focus was on the Indus Basin in Pakistan or the Indus Basin in India only. This 47% is inclusive of research carried out on the Pakistani or Indian part of the Upper Indus Basin region. About 37% of the research studies were restricted to an area of one state or smaller.

As far as temporal scale is concerned, 40% of research used more than ten years of data, while 34% of studies used less than two years of data. Within the entire TIB studies, 6% of studies used more than ten years of data, while 7% of studies used less than two years of data. The studies in which more than ten years of data were used were either global-scale studies that also included the TIB, or they used previous reports/studies for analysis. It was also seen that the studies using less than two years of data were done by merely three to four researchers.

In fact, basic information on water flows, sources of water, and water demand is either missing or not easily available in the basin. There are also “classified datasets” on flow and climate that are restricted and not shared throughout the scientific community. The scarcity of spatial data required in carrying out water resources studies is, likewise, a major point for concern. For example, less than four weather stations are available in one 10,000 km² area of the basin, which is insufficient for basin-scale studies (Cheema and Bastiaanssen, 2012). Therefore, it can be seen that most research has been focused on the area of the basin where data is easily accessible, and for longer time series. It is strongly felt that there is a need to increase the density of observation stations as well as their frequency of data retrieval. A real-time observation system is also direly needed that can provide a continuous time series of data.

Currently data is made available through various national organizations that have a clear mandate to collect and provide data for research, but these mandates are hardly ever observed. There are, however, international organizations that collect data through satellites and other global data-sharing mechanisms. They make their datasets publically available through global data-sharing facilities and researchers rely on these organizations to acquire a wide range of datasets on climate, flows, snow cover, groundwater, etc. About 28% of the analyzed scientific studies used data from international agencies

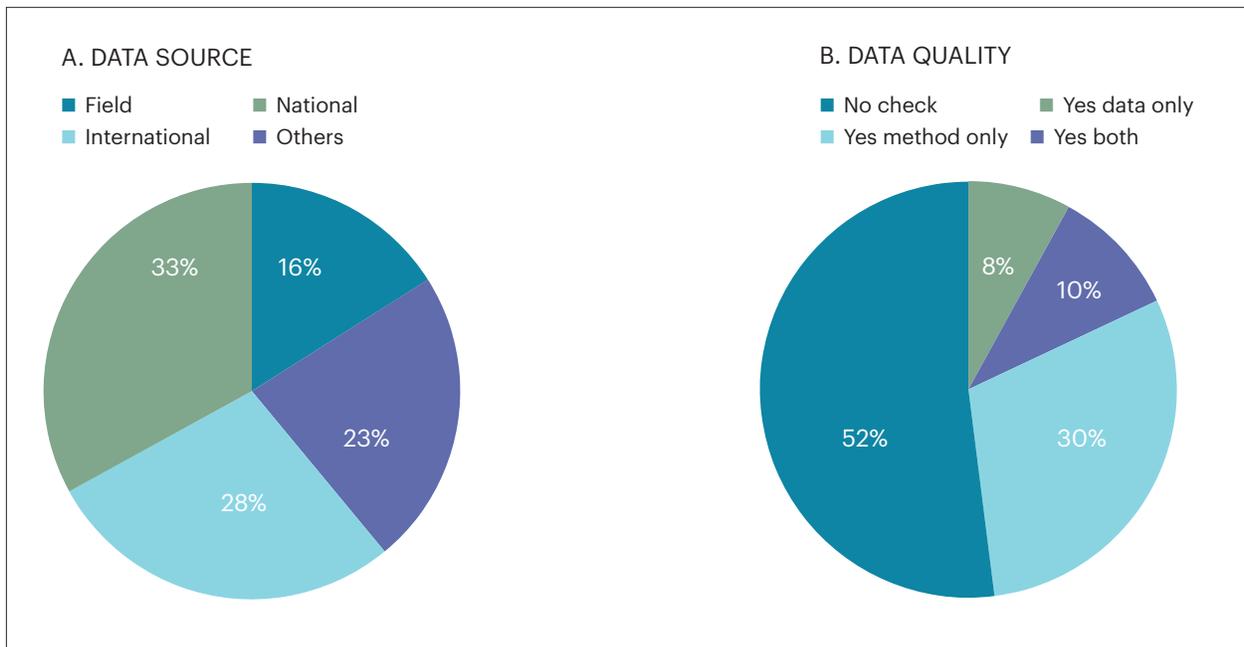


Figure 6: Data sources (A) and quality of data (B) used in the scientific studies.

(Figure 6a). However, the quality of such datasets is itself a point of major concern. Figure 6 (b) shows information regarding data quality checks applied prior to the analysis, or method validation done after such analysis. Referring to this figure, it is shown that 50% of studies were carried out without any data quality or method validation check. Only 10% of studies report anything about data quality and method validation.

It is also observed that most of the scientific research in the basin is carried out by four or less experts. About 87% of studies fall into this category, while only 12% of studies were carried out by five to ten experts. In only one study were 16 or more researchers involved. In most cases, the number of organizations/institutions involved in a study was two or less (78% of the total). Only 20% of studies involved three to five organizations and in only two cases did six to nine organizations jointly conduct a study.

Here we argued that if we want to do a comprehensive integrated water resources management study at a scale beyond political boundaries, we have to involve scientists with different expertise so that most of the issues can be handled efficiently. It is also felt in this review that to carryout Transboundary Indus Basin integrated water management studies, a reasonably long time series of data is required. In this connection, it is argued that importance should be given, with equal weight, to incorporating both top level project management and expertise in field data collection, analysis, and experience, into future research. This multi-disciplinary approach will allow scientific studies to be translated best into a policy framework.

Review of Policy Work

In this section, an effort is made to review the policy-related work done in the Indus Basin. Research papers in the policy section were randomly selected and classified according to their subject content. Figures 7 and 8 show these classifications.

Based on Figure 7, it can be concluded that 42% of the policy papers reviewed considered only one subject, while 32% papers considered two subjects. Thus, the papers considering two or fewer subjects constituted 74% of the sample and multi-disciplinary papers constituted 36%, out of which only 8% considered four or more subjects. The subjects of the sample papers, as displayed in Figure 8, reveal that the most papers (about 30%) considered the Indus Waters Treaty, followed by 25.7% of papers that considered water resources in general. It is also evident that only a few papers focused on groundwater (5.3%) and surface water (2.9%) resources individually. Fourteen-percent of policy papers incorporated socioeconomic factors in their evaluations. A considerable number of research papers (27.7%) had climate change, the environment, or sustainable practices as their main theme.

Table 4 gives the complete classification of policy research papers. Classification is based on nine questions, each with five options, and the table indicates the number of research papers in each category along with a percent value.

Out of a total 105 randomly selected policy-related research studies, 41% (43 papers) were an evaluation of rules, laws, or the legal meaning of words, situations, or phenomena, or an overall evaluation of the Indus Waters Treaty (IWT) of 1960 (Q. No.1). As these involve rules or legal obligations, they have the same applicability to all geographic areas, irrespective of size. Of the remaining 62 papers, 66% (41 papers) were exclusive to either the Indian Indus or Pakistani Indus river basins, and merely 29% (18 papers) were at the transboundary scale.

As far as data type is concerned, 53% of the total studies (56 papers) didn't need any data to support their findings, conclusions, or remarks (called data-independent here), while 47% of studies (49 papers) needed data to support their findings (called data-dependent here) (Q. No. 2). Out of the 49 data-

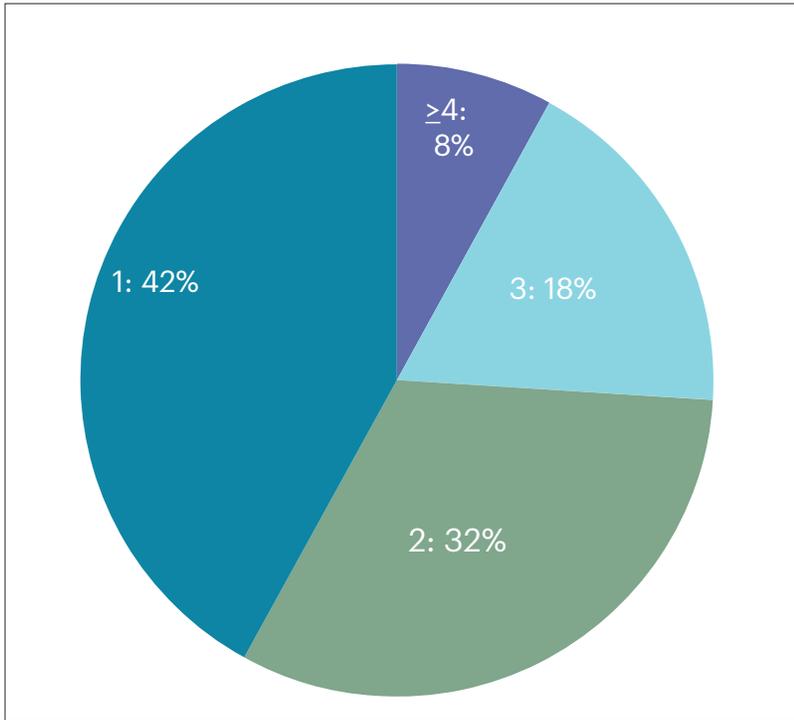


Figure 7: Classification of research papers based on subject numbers.

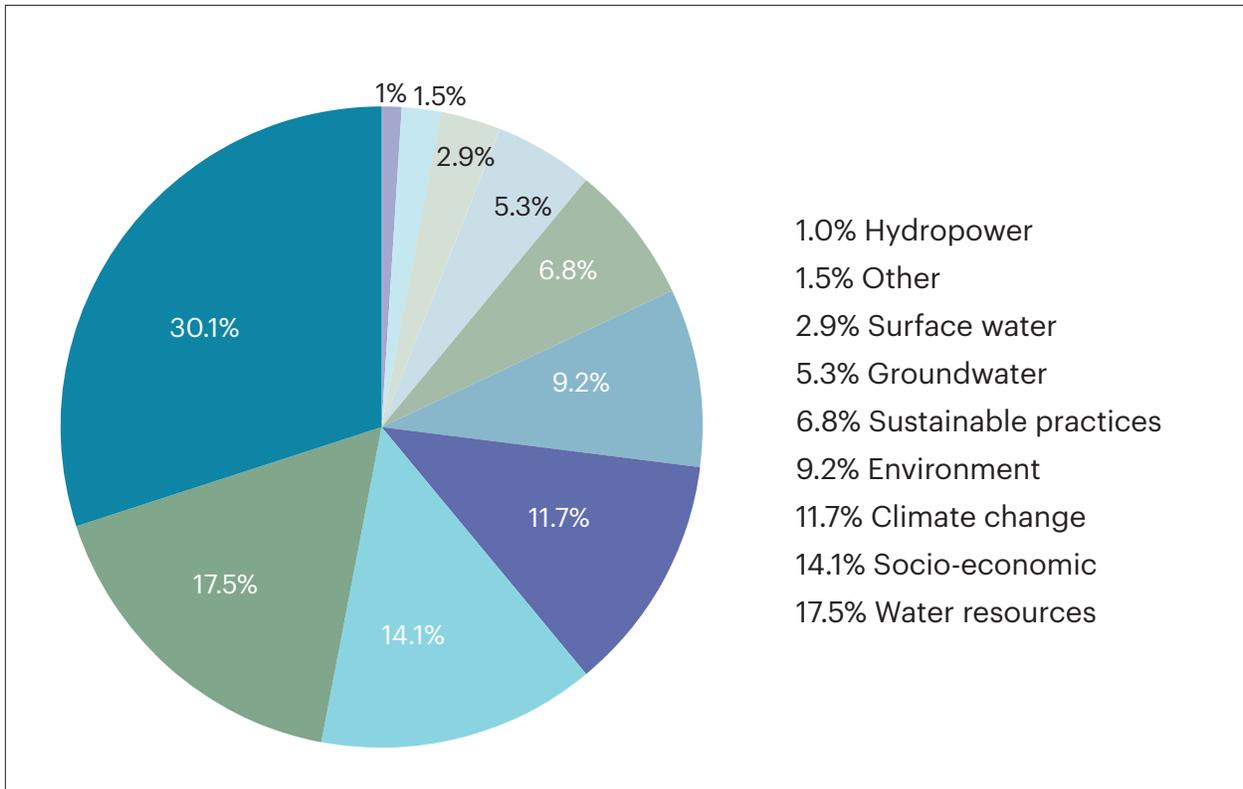


Figure 8: Classification of research papers based on subject numbers.

dependent papers, 21 papers (42.9 %) used primary multi-year data. In 17 papers (34.7%), secondary data was used for analysis. In 6% of the papers (3), data should have been used for support and analysis of the conclusions, but was not. Sixteen percent of the data-dependent papers (8) used either one- or two-year questionnaire surveys, reconnaissance surveys, interviews, etc. For data-independent research papers, the source of the data is a non-applicable question (Q. No.3, Option E). Hence, the total number of data independent papers and those with the source of data as “non-applicable” is the same. Similarly, the number of papers that used “primary multi-year data” and the number where the source was “multi-year actual” data, are also the same (Q. No.2, Option D).

Figure 9 shows in detail the number of experts involved in the sampled studies. Studies at an international scale that consider a multi-faceted, basic need like water require the participation of many organizations with multiple experts. But this graph shows that 66% of total papers involved three experts or fewer. Only about 21% of the papers involved five or more researchers. Similarly, referring to Table 4, Q. No. 5, we can see that more than 54% of research was carried out by individual organizations and about 88% by groups of three or fewer organizations. Seven percent of the studies were carried out by five or more organizations. The involvement of more organizations ensures data availability, data quality, better analysis, and mutually agreed upon results, in addition to numerous other benefits.

In 42% of the sampled Indus Basin policy studies (see Table 4, Q. No. 6) international organizations were in the lead role. If the percentage of studies led by one or more international organizations is added to those led by a team of both national and international groups, it becomes apparent that they constitute 81.4% of total studies. Fewer than 19% of the studies had a national (Indian or Pakistani) group acting as the leader of the research.

Q. No.	Sub/Option	A	B	C	D	% of Subtotal (A+B+C+D)	E: % of Total, 105 (E)
1	Scale	3.2 (2)	1.6 (1)	66.1 (41)	29.0 (18)	100 (62)	41.0 (43)
2	Data Type	6.1 (3)	34.7 (17)	16.3 (8)	42.9 (21)	100 (49)	53.3 (56)
3	Data Source	24.5 (12)	16.3 (8)	16.3 (8)	42.9 (21)	100 (49)	53.3 (56)
4	Experts	34.7 (33)	31.6 (30)	12.6 (12)	21.1 (21)	100 (95)	9.5 (10)
5	Orgs.	54.1 (53)	33.7 (33)	5.1 (5)	7.1 (7)	100 (98)	6.7 (7)
6	Lead Role	18.6 (19)	42.2 (43)	27.5 (28)	11.8 (12)	100 (102)	2.9 (3)
7	S-E & Survey	13.3 (12)	23.3 (21)	43.3 (39)	20.0 (18)	100 (90)	14.3 (15)
8	Method	7.6 (8)	25.7 (27)	39.0 (41)	27.6 (29)	100 (105)	0.0 (0)
9	Science link	15.2 (16)	76.2 (80)	8.6 (9)	0.0 (0)	100 (105)	0.0 (0)

Table 4: Percentage and number of research papers classified in different options.

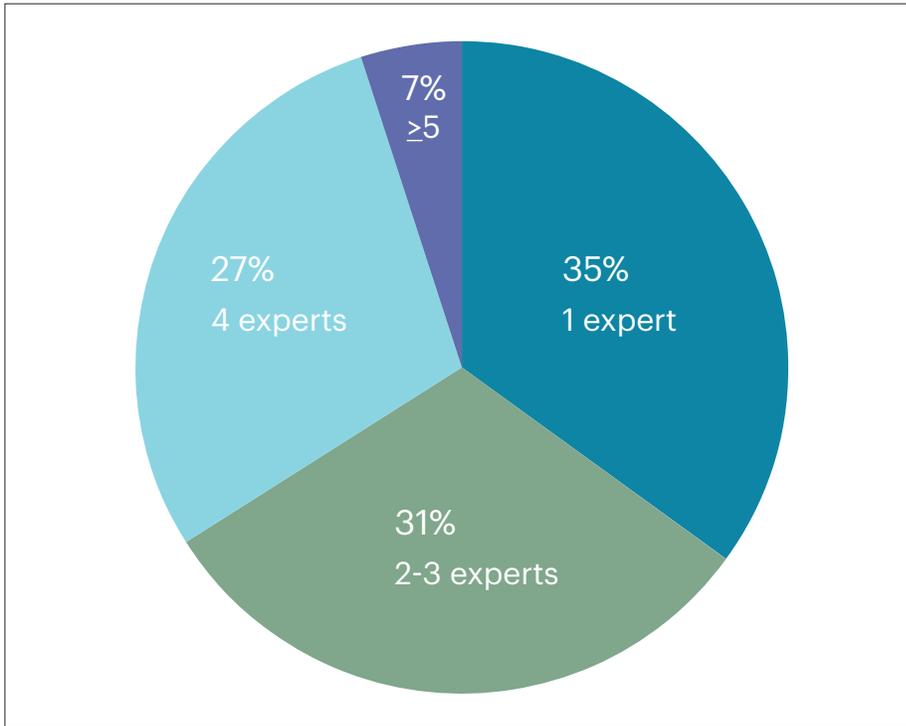


Figure 9: Number of experts involved in the study.

One factor in the success of a research project is whether it brings about socioeconomic change in society. Hence socioeconomic evaluation has become an integral and important part of research. Most of the time socioeconomic conditions are evaluated using indicators, which in turn can be assessed using different techniques like participatory tools, meetings, focus group discussions, expert evaluations, interviews, questionnaires, etc. Most of these techniques can be applied through surveys, so socioeconomic evaluations and relevant surveys should be considered important parts of an ideal study. Special attention was paid to looking for these two components in the research papers, which is in addition to the theoretical evaluation of rules, laws, or overall IWT evaluation papers. Question No. 7 in Table No. 4 gives the details of this classification. It can be seen from this row that actual surveys involving two or more subjects was the favored option of policy studies (63.3% of total), while 86.7% of the studies included some kind of survey. There were very few studies that excluded the survey but still addressed sociology or economic factors.

Science-Policy and Policy-Science Linkage

It is important for scientific research to translate its findings in terms of policy perspectives. Similarly, policy work should be clearly linked to hard science. Such a linkage is rarely observed in the body of research in the Indus Basin. In order to get information on how well the science and policy are linked with one another, questions regarding this link were included in the questionnaires.

Currently there is no clear linkage to be found between science and policy research in the Indus basin. Only 12% of scientific studies have tried to develop a linkage between data and policy, while 71% of scientific studies missed this important point (Figure 11). The rest of the studies only exhibit expectations that the scientific findings may be taken up by policymakers.

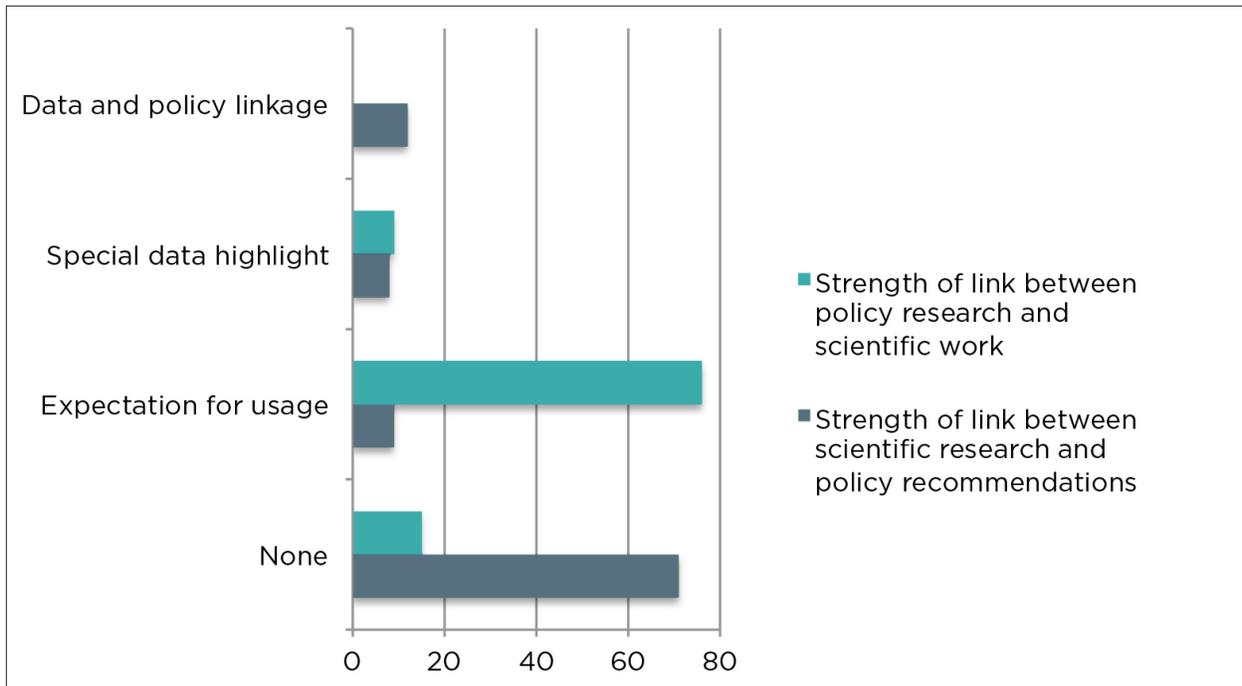


Figure 10: Linkage between the work of the scientific and policy communities.

The linkage between policy research and science is even weaker than that of scientific research to policy (Figure 11). In fact, the analysis indicates that there are no complete linkages between policy research and scientists. The policy-related research has not tried to bring scientists on board when making recommendations to any significant degree. For the sound application of scientific research, coordination is needed between science and policy work to improve understanding and to incorporate the underlying scientific issues into policy. Such a linkage is hardly found in the case of research carried out in the Indus Basin, and there is a dire need to strengthen these linkages so that scientific results can be properly implemented by policymakers.

Emerging Threats for Indus Basin Science and Policy

Extensive review of the literature regarding the subject revealed that depending upon the jurisdiction of the project, time and resource availability, basic professional knowledge, experience, and focus of the study, various authors have identified different pressing issues and concerns. We have selected some of the representative comments that are relevant to the transboundary-scale Indus River System study and blended them with our experience and knowledge.

The scientific studies carried out in the basin have focused on various emerging issues regarding water resources and their management with a transboundary perspective. However, their limited spatial and temporal focus discloses the fact that the availability of a well-distributed and trustworthy knowledge base on various hydrological and policy aspects of the basin is still a distinct goal to achieve. Likewise, a major threat to the food security and environmental sustainability of the basin is climate change, which can have adverse effects on both science and policy decisions.

A trend of rising temperatures has been observed in the northern parts of the basin, which mostly have snow and glaciated areas. The glaciers are retreating at a rapid pace and a 2.15% approximate reduction

in snow cover has been observed in the upper Indus Basin during the past decades. Some glaciers are receding at an even higher pace, such as 46 mm/day/year in the case of some Himalayan glaciers (Mukhopadhyay, 2012; Thayyen and Gergan, 2010). This reduced snowpack affects the river flows, as contributions of glacial melt and snowmelt to annual river flows can be over 50% and vary annually (ICIMOD, 2012). Such effects were evident in 2014, when a sudden temperature drop in the Upper Indus led to a significant drop in river flow into Pakistan over a 72 hour period. The decreased snow melt threatened to pose up to 40% cuts to provincial water shares from Tarbela Dam, a large regional dam mostly fed through snow melt water, in order to conserve supplies for Rabi (winter) crops (Kiani, 2014). Rainfall variability over the past few decades, in terms of both intensity and spatial coverage, has also been observed. These rainfall fluctuations in water-producing zones affect the total river flows and decrease availability in water consuming areas.

It is projected that by 2025 the water inflow reduction in the Indus River System will be 32%, which would result in a regional food shortage of 70 million tons (Qureshi, A.S., 2011). This would also exert huge pressures on already depleting groundwater storage. According to one study, groundwater losses from the basin totaled approximately 10 km³ per year between 2002 and 2008, resulting in significant drops in local groundwater tables. Future scenarios indicate that such depletion will likely continue, as groundwater currently accounts for 48% of all basin water withdrawals (Tiwari, et al., 2009; FAO, 2012b). This continuous abstraction without sufficient recharge can adversely affect the groundwater flow paths. The groundwater in the Indus flows naturally from the northeastern to southwestern part of the basin. A change in flow may severely affect the already degraded environment in the middle parts of the basin, including Rajasthan state and eastern parts of Punjab province. The overexploitation of groundwater is also causing secondary salinization, at the added cost of the energy needed to abstract it. Moreover, the reduced surface flows are a consistent environmental threat to flora, fauna, and aquatic life, especially in the lower Indus Basin.

Reduced water availability in conjunction with rising population has resulted in converting the basin to a water scarce region. Per capita water availability has reached 1000 m³ /yr. The population rise and urbanization is also affecting land use patterns by reducing agricultural lands and mounting pressure for increased food production on available land. By 2050, the Indus will be able to effectively feed 26 million fewer people than it does today, even as the population is predicted to expand. Traditional agricultural practices and poor land/water management, without consideration for integrated approaches, will not be able to meet future demand. The land and water productivity of various staple crops is highly variable. In the case of rice, the land and water productivity vary between 2.6 t/ha to 6.18 t/ha and 0.20 kg/m³ to 2.04 kg/m³, respectively, in the region (Immerzeel et al., 2010; Cai et al., 2010).

The lack or limited interaction between the scientific and policy communities is also a potential threat to the sustainability of the basin. Scientific findings have to be translated into policy implications in a way that is rarely achieved today. As most of the policy and socioeconomic studies have given top priority to the modernization of water management institutions, increased multi-dimensional participation is needed for public involvement in government programs at all levels, training and capacity building of field operation staff and farmers, agricultural policy re-orientation (with respect to irrigation, water-use efficiency, and infrastructure development), and multi-faceted efforts for climate change science, resilience, and adaptation. All studies dealing with an evaluation of the 'Indus Waters Treaty of 1960' argue for a revision of the treaty, justified by numerous supporting reasons. Some of these reasons, as well as main evolving threats for major concern in the basin, have been given as follows:

Climate Change

The Himalayan glaciers feed many of Asia's major rivers, including the Indus, Ganges, and Brahmaputra, which make them 'Asian Water Towers'. Their retreat and disappearance would threaten the water supplies on which millions of people in neighboring nations depend, including those in India and Pakistan. Hence climate change concerns should be a top priority. The areas of richest biodiversity and ecosystem services are in developing countries, where they are relied upon by billions of people to meet basic needs. Therefore, the relationship between livelihoods, sustainability of these areas, and climate change impacts on them is an integrated embodiment of the subject. It is predicted that climate change will result in increased water availability in the short term, but that water availability in long term will decrease. Sustainability of the currently favored rice-wheat cropping system, in its present form, is questionable. Agriculture in the Indus Basin area is the major sector for economics and employment in this region. Hence developing alternate cropping patterns with the common consensus of government and society is of prime importance. It is our experience that the region is characterized by a hierarchical society with a low literacy rate, but with a tremendous enthusiasm to absorb new technology and gain higher productivity. Agricultural policy reorientation should be done while keeping these facts in mind.

Findings like the widespread expansion of glaciers in contrast to a worldwide decline of mountain glaciers in central Karakoram, or the decrease in monsoon temperatures, have made the future impacts of climate change in the Upper Indus and associated flows downstream very uncertain. The unavailability of good-quality long-term data that can support reliable modeling and validation, coupled with challenging topography, has made climate analyses difficult. Conceptual snowmelt runoff models have proven useful for estimating discharge from remote mountain basins, including those spanning the various ranges of the Himalaya. However, these models have limited ability to address characteristic components of water disputes, such as diversions, storage, and withholding. Climate change-proof water management planning necessitates the building of water storage structures in convenient locations to provide additional flood control and emergency water supplies.

The great floods of August 2010 in Pakistan, or more recently of June 2013, involved multiday cloudbursts in North Indian states, a result of climate change-induced altered rainfalls, the effects of which were enhanced due to national development decisions integrally linked to unplanned growth and the social geography of the region. The devastating 2010 floods caused economic damages of approximately \$10 billion to Pakistan, and the June 2013 floods led the central government of India to spend about \$48 million alone on compensation for the families of those who had died (Ali, 2013; BBC News Service report, 2013). In the Indus Basin, monsoonal rains are the most important flood-causing factor, followed by the size, shape, and land-use of the catchments and the conveyance capacity of the corresponding streams. The constant threat of flooding, and socioeconomic pressure to develop these regions, calls for combined action from both countries. Long-term co-operative solutions may lift huge economic burdens from both nations. Discussion on the merits, demerits, and provisions for the design aspects of proposed major irrigation projects in the Indus Basin, in light of siltation and waterlogging problems, is also inevitable.

There is a need for joint, impartial research that would provide alternative approaches to address the present and future challenges emanating from the Indus Waters Treaty. Formation of an Indus Waters Experts Group might be a good starting point. This group should have multi-disciplinary, multi-organization researchers, and a mix of governmental and non-governmental sector specialists.

Sustainable Development: Population, Social, and Economic Aspects

There is a need for persistent effort, at the governmental and non-governmental level, to bring all stakeholders and interest groups to a common platform in order to facilitate better understanding of each other's concerns, clear any misgivings, and ultimately build a consensus on how to address the real, emerging issues related to the smooth implementation of the Indus Waters Treaty. Indus water disputes used to be a product of territorial changes. Today they are largely the product of a decrease in water flow, changes in demography and population, as well as usage issues resulting from increased irrigation and the need for drinking water. Efforts, which essentially include cultural and social paradigm shifts, that will help the country evolve to a modern society should be encouraged. The modernization of irrigation structures, encouragement of farmer training and capacity building, and the effective use of information communication technology are some of these suggested strategies. Agriculture related strategies, like assessing the relative social and economic value of surface and groundwater irrigation, delaying rice transplanting and short duration rice varieties, and farmer training for conjunctive irrigation, are important. Decreasing water resource availability and the misuse of water in irrigation result in highly confusing situations. Excess irrigation additionally results in waterlogging and salinization. Accordingly, estimates of losses due to salinization in Pakistan are 28,000 to 40,000 ha of land and about US \$230 million of revenue per year (Aslam and Prathapar, 2006). Better coordination between national and state governments, with context-specific modifications to achieve the larger goal of effective localized water management, is of paramount importance.

Pressure of Performance

Strong national will at the political and administrative levels is required to implement standard global practices, including water availability prediction, real-time water withdrawal monitoring and data sharing, and trading of unused water allocations. Beyond water conflict in the Indus Basin, building inter-provincial trust is of prime importance. There is enough water in the Indus Basin to provide for the livelihoods of its residents, provided that water is managed efficiently, distributed equitably, and monitored jointly. Water-use efficiency should be the main aim of every water consuming sector. In this regard, hydronomic zones hold potential as a tool to better understand complex water interactions within river basins, isolate similar areas within basins, and help develop water management strategies better tailored to different conditions within basins. Dialogues for addressing such transboundary surface and groundwater management, managing water as a resource, and developing trust, demand a great paradigm shift in the mindset of the people. As groundwater management requires a higher degree of user involvement than surface water development, top-down control-and-command measures will not work, and actions should be initiated from and with public participation. Based on our previous experience with the conflict over time, quantity from the hydrological side, coupled with governance, institutional, and economic considerations from the societal one, remain major arenas for concern.

Outcomes

Major Areas

Based on an extensive review of the literature on the Indus Basin, identifying emerging threats and utilizing prior experience, the following major areas have been identified for special focus in future studies on the TIB in order to encourage efficient and effective water resources management:

- a) Integrated water resources management at a basin scale, beyond political boundaries
- b) Climate change and its threats to water availability and food security in the transboundary context

- c) Sustainable surface and groundwater use, and rainwater harvesting/aquifer recharge techniques
- d) Exploration of hydropower potential
- e) Water-saving technologies
- f) Critical review of the 'Indus Waters Treaty of 1960', connected to the current socioeconomic constraints and opportunities, and considering future climate change and surface/groundwater development
- g) Bringing consensus into the science-policy dialogue

Methods

An integrated, holistic methodology to international river basin management is needed in which the basin is accepted as the logical unit of operation. A multi-sector, integrated system, complemented by information sharing, transparency, and wide participation, is therefore best suited to encompass all of these elements. Such an integrated system approach to evaluating the interaction between the hydrological processes in the mountains, river flow generation, water retention in reservoirs, groundwater pumping, and agricultural water use in the Indus Basin is largely lacking. In the past, most scientific modeling research concentrated on the sections of the basin with well-established databases. These studies are valuable to test hypotheses and to construct local-scale hydrological knowledge, however, a complete understanding of the hydrological processes can only be obtained if the research is focused on establishing a solid basis for solving real-life problems for the entire basin.

Therefore, the future research on the basin should not be based on a single methodology. It should be based on a multi-disciplinary approach that can adopt ground measurements, remote sensing, hydrological models, trend analysis, and scenario development into the program of study. The socioeconomic and policy perspectives should also be linked to the hydrological ones. For this purpose, a number of experts with different scientific and policy backgrounds, as well as from both national and international organizations, should be involved to handle the complexity of the basin-scale studies.

To ensure successful long-term implementation and realization of the Indus Waters Treaty, robust socioeconomic understanding is required. Presently such information is available at varied scales and selected parameters only. Use of participatory appraisal techniques ensuring stakeholder involvement at all levels is suggested as a best implementation practice.

Data

A major obstacle in carrying out such multi-disciplinary research for transboundary water resources management is the unavailability or inaccessibility of fundamental information on water flows, sources of water, and water demand. The information sharing mechanism, availability of data for the general public, and real-time data monitoring between riparian states remain some of the major concerns about the current Indus Waters Treaty signed in 1960. The information that is available is not shared with independent researchers, which restricts them from carrying out effective water management studies or plans.

Various regional and global organizations have provided access to shared data sets, but this access has been limited. It was found that the acquisition of long-term data series is difficult and involves a series of bureaucratic permissions. Accessibility is also hampered by the fragmented structure of governmental institutions designated with various water management roles and tasks. Due to the lack of coordination and institutional problems, the data collected by these departments is of little use for transboundary water resources management and decision-making.

For this purpose, a dense, automated monitoring network is recommended that would provide information on climate, surface flows, and groundwater variations in a real-time environment. Moreover, there is a need to strengthen institutions so that they have enough resources to make shared datasets publically available. The use of satellite products can also provide an alternative source of data for water resources management. These datasets are normally free from political bias, and moderate-resolution datasets are publically available, though efforts are needed to make fine-resolution satellite data available at a lower/minimal cost to researchers.

A ground-truthing mechanism is also recommended to carry out validation of the products made available through satellites.

Policy Requirements and Related Science Applications

Water is regarded in many cultures as a sacred resource or as a divinity in and of itself. It is an integral part of geography, ecology, society, history, and culture. Water is an essential life-supporting substance, which is required for varied uses like economic activities, navigation, and municipal use. Understanding water in all its complexity must form the bedrock on which ‘water governance’ rests. The term ‘water governance’ encompasses a wide range of issues, including water policy, water management, water sharing, water rights, conflicts, social justice and equity, conservation, sustainability, and so on, almost all of which involve legal questions (Iyer, S., 2010). Major questions to highlight here are of the ownership of water and of its distribution between neighboring countries. Regulation of water use in the interest of equity, social justice, harmony, and sustainability should be the desired goal.

Most of the socioeconomic, regulatory, and policy research reviewed here highlights the clear divide between science and policy issues in Indus Basin studies. The fact is the same for scientific research. The inter-dependability of science and policy should be very high, which in turn demands a smooth flow of scientific information into desired regulatory and policy actions, as well as requirements regarding scientific knowhow for regulatory and policy formation. The situation in the Indus River Basin has reached a stage which necessitates comprehensive, holistic dialogue between scientists, policymakers, and stakeholders in order to identify and prioritize scientific projects and relevant policy actions.

Action Roadmap

According to a statement by Al Gore, former vice-president of the U.S. and environmental advocate, “We should be ready for an unforeseen event that may or may not occur”. Therefore, preparing ourselves against the threat of climate change is key to basin sustainability issues. To achieve this goal:

- A comprehensive knowledge base is required on various hydrological processes, without political interference
- A complete revisit of the treaty is also needed that not only includes current climate change threats but also strengthens data-sharing on climate, groundwater, and surface water conditions
- The United Nations’ draft law on transboundary aquifers should be included in the treaty

To achieve these goals, the following action roadmap is suggested:

1. Formation of executive committees for science, policy, and governmental administration
2. Identification of the comprehensive science and policy requirements of the region
3. Unification of scientific facts and policy issues of the region, and the transformation of them into easy messages for the general public
4. Formulation of Public Hearing Committees
5. Public hearings for a sufficiently-long duration and at an appropriate time
6. Execution of identified science-policy projects
7. Training, capacity building, and awareness generation activities
8. Presentation of results to the governmental administration committees
9. Review of the facts, figures, and relevant expectations of both countries
10. Negotiation and finalization of treaty terms

Annexes

Annex I

Questionnaire developed to assess spatio-temporal coverage and scope of the research carried out by various researchers in the Transboundary Indus Basin:

1. What is the spatial extent of area under study/analysis/application?
 - a. Less than one district
 - b. More than one district to one state
 - c. Indus Basin Indian or Pakistani part (also include upper Indus Basin)
 - d. Whole Transboundary Indus Basin

2. What is the temporal extent of study/analysis/application (duration of data used)?
 - a. Less than or equal to two years
 - b. From two to five years
 - c. From five to ten years
 - d. More than ten years

3. What is the source of data used in the analysis?
 - a. Field
 - b. National organizations
 - c. International organizations
 - d. Others

4. Is the data quality checked or method validated?
 - a. No (neither data nor method)
 - b. Yes (data only)
 - c. Yes (method only)
 - d. Yes (both data and method)

5. How many experts were involved in the study?
 - a. Four or less
 - b. Five to ten
 - c. Eleven to fifteen
 - d. Sixteen and above

6. How many institutions/organizations were involved in the research?
 - a. Two or less
 - b. Three to five
 - c. Six to nine
 - d. Ten and above

7. Where is the organization/institution in the lead role based?
 - a. National (India or Pakistan)
 - b. International or both national
 - c. National and international
 - d. International more than one and national

8. What subject is emphasized in the study under consideration/application/analysis?
 - a. Any one (agriculture, livestock, groundwater, surface water, pollution, other environmental factor, economics, society, climate change, crop water use, etc.)
 - b. Two to three
 - c. Two to three including socioeconomics
 - d. Four or more

9. What is the methodology adopted for analysis/application?
 - a. Any one (remote sensing, hydrological methods, trend analysis [temperature/precipitation/flows], modeling scenario [mathematical/statistical/simulation/climate], etc.)
 - b. Two to three
 - c. Two to three including social or economic benefits or both
 - d. Four or more

10. Does the scientific research link policy? Clarity of policy message?
 - a. No
 - b. If yes, then just expectations
 - c. Special data highlight for policy
 - d. Data and policy linkage

11. How can the research paper/report be classified based on various research aspects?
 - a. Agriculture
 - b. Horticulture
 - c. Cash crops
 - d. Livestock
 - e. Groundwater
 - f. Surface water
 - g. Conjunctive use
 - h. Environment (multiple)
 - i. Pollution
 - j. Climate change (multiple)
 - k. Glaciology
 - l. Domestic/industrial/other uses
 - m. Soil
 - n. Socioeconomic
 - o. Sustainable practices
 - p. Hydropower
 - q. Crop water use

Annex II

Questions on Policy

1. Area of socioeconomic study/survey/analysis?
 - a. Less than one district
 - b. More than one district to one state
 - c. Indus Indian part or Indus Pakistani part
 - d. Whole Indus Basin
 - e. Not applicable (treaty or pure policy study)

2. Type of data used for analysis?
 - a. No data used
 - b. Secondary data used
 - c. Primary (actual) single year data used
 - d. Primary multiyear data
 - e. Not applicable

3. What is the source of data?
 - a. National
 - b. International
 - c. Actual/Survey/ Consult (single year)
 - d. Multi-year actual
 - e. Not applicable

4. Number of experts involved in the study?
 - a. One
 - b. Two to three
 - c. Four
 - d. Five and above
 - e. Not applicable

5. Number of institutions involved?
 - a. One
 - b. Two to three
 - c. Four
 - d. Five and above
 - e. Not applicable

6. Location of organization in the lead role?
 - a. National (India or Pakistan)
 - b. International or both national
 - c. National & international
 - d. International more than one and national
 - e. Not applicable

7. Subject under consideration/application/analysis?
 - a. Any one (social, economics, etc., excluding survey)
 - b. Any one (social, economics, etc., including survey)
 - c. Two including survey
 - d. Three or more including survey
 - e. Not applicable

8. Application/Analysis methodology
 - a. Review
 - b. Review and analysis of secondary data
 - c. Review and analysis of actual survey
 - d. Review, analysis, and synthesis of experience and survey

9. Policy research linking science? Clarity of scientific message?
 - a. No
 - b. If yes, then just expectations
 - c. Special data highlight for science
 - d. Clear policy and data linkage

10. Classification of research paper
 - a. Social
 - b. Economic
 - c. Socioeconomic
 - d. Groundwater
 - e. Surface water
 - f. Conjunctive use
 - g. Environmental (multiple)
 - h. Climate change (multiple)
 - i. Sustainable practices
 - j. Hydropower
 - k. Policy critique
 - l. Other

Transboundary Indus Basin: Scientific Knowledge Gaps and Policy Shortfalls

Integrated Modeling Framework for Assessment of Water, Environmental, Sustainability, and Socioeconomic Linkages Under Current Climatic Change Scenarios

Introduction

The agricultural sector has expanded enormously over the past five decades, enhancing its production to meet world food and fiber demand. Today, irrigated agriculture is practiced worldwide on about 324 million hectares of land, including that in Pakistan, India, Bangladesh, China, and the U.S., and produces about 40% of global agricultural outputs (FAO, 2012a, Turrall et al., 2011). Most of the irrigated agriculture in Pakistan and India is concentrated in the plains of the Indus-Gangetic basins, and makes up 90% of all agriculture in the Indus specifically. The Indus Basin is mainly shared between these two countries (86%) and fed through the River Indus and its major tributaries (Kabul, Jhelum, Chenab, Ravi, Sutlej, and Beas). The area encompassed by the basin is approximately 1.12 million km², with 47% in Pakistan and 39% in India (Yu et al., 2013; FAO, 2012b).

The mainstay of flows in the Indus and its tributaries is snow melt from upstream glaciers of the Himalayan, Karakoram, and Hindu Kush ranges. Total glaciated area in the basin is approximately 21,000 km². The flows available from snow melt contribute up to 80% of the total, while the rest is contributed from rainfall. More than 200 km³ of flows are available in the rivers annually (Yu et al., 2013; Sharma et al., 2008). The water flows in the rivers are regulated through reservoirs constructed on the major rivers, built after the signing of the Indus Waters Treaty of 1960 over the rights to river water between India and Pakistan. Eight major reservoirs (three in Pakistan and five in India) are currently utilized for hydro-power generation and irrigation supplies, while the construction of new reservoirs is also in progress (Figure 1).

The water releases from these reservoirs are controlled by a series of barrages downstream that diverts available water to 26 million hectares (mha) of agricultural land in the basin. Irrigated agriculture uses 93% of total diverted water resources, while the rest is used in urban and industrial sectors (FAO, 2012b). Surface water availability varies depending upon the season. The lack of reliable surface water supplies and erratic rainfall have forced farmers to augment their water supplies by means of groundwater extraction. As a result, large numbers of tubewells have been installed on both sides of the basin to extract groundwater. A significant percentage of irrigated area is totally dependent on groundwater alone, while a larger part uses it in conjunction with surface water supplies, otherwise known as 'conjunctive use'. Therefore, management of irrigation water is important and directly related to poverty reduction, as the agriculture sector makes up 22% of the GDP of Pakistan and nearly 40% of its work force, most of which resides in rural areas (FAO, 2012b).

The present population of the basin is approximately 300 million people, of which about 61% lives in Pakistan and 35% in India. One estimate projects that by 2050 this population will grow to as many as 383 million people (FAO, 2012b; Leghari et al., 2012). Rapid growth and associated settlement have already significantly increased the water demand for human and industrial consumption, and thus the

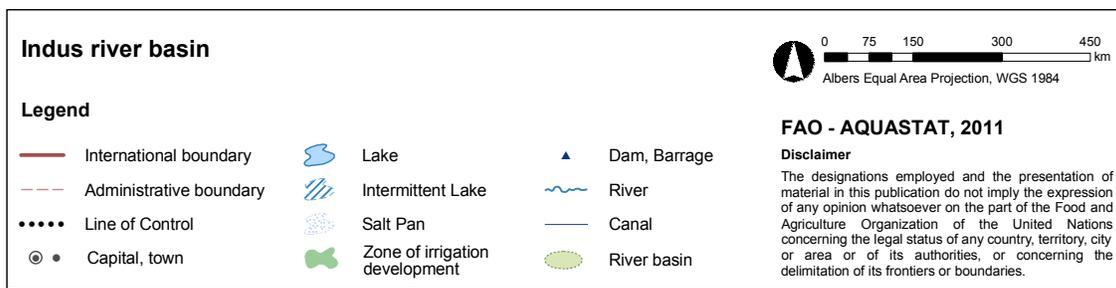


Figure 11: Location of reservoirs and barrages constructed on the Indus River and its tributaries. Source: FAO.

Summary of Major Transboundary Indus Basin River System Characteristics

Total area (km ²)	1,120,000
Glaciated area (km ²)	21,000
Irrigated area (km ²)	263,000
Population (no., million)	300
Major tributaries (no.)	8
Large dams (no.)	9
Reservoirs under-construction (no.)	5
Barrages (no.)	19
Link canals (no.)	16
Tubewells (no., million)	1
Total water availability (km ³)	287
Groundwater abstractions (km ³)	143.5

Sources: FAO, 2012b; Yu et al., 2013; Thatte, 2008; Scott-Wilson, 2011; Cheema, 2012; Sharma et al., 2008.

competition over irrigation water for agriculture has increased manifold. This growing population and reduced water availability has led to the categorization of the Indus Basin as a “water scarce” basin, according to World Business Council of Sustainable Development (WBCSD) and their definition of renewable internal annual freshwater availability (Finley et al., 2008). Water availability in Pakistan declined from 3,385 m³ per annum per capita in 1977 to 1,396 m³ in 2011, while India went from 2,930 m³ to 1,539 m³ over the same period. The reduction in water availability directly influences crop production and hence can adversely affect the food security of the region (FAO, 2012c).

Socioeconomic Development and Demands

Stagnant or decreasing agricultural productivity, increasing dependence on groundwater, high risk of climatic variability, enhancing industrialization, and unplanned and un-regularized urban growth are some of the realities of the Indus River Basin. These pose a variety of challenges for water resources governance, management, and use. Groundwater overdraft, food and nutritional security, decreased fresh water availability vis-à-vis escalating demand, and water pollution are major challenges and even greater threats for the environmental security and peace of the region. Water policies in the region thus need to include a more holistic understanding of the issues for the efficient management, equitable distribution, and sustainable use of scarce resources.

India and Pakistan are two emerging economies (Table 1) that, while evolving above the developing country threshold, still face many problems. Poverty, overpopulation, sanitation, and education are some of the major challenges facing the region. Agriculture serves as the backbone of the local economies and water is the key input for food production. Agriculture also depends upon the timely monsoon and a sufficient amount of annual rainfall. To overcome the uncertainty and vagaries of the monsoon, farmers resort to various methods of irrigation. Irrigated agriculture is the biggest consumer of water in the world. About 70% of the world’s freshwater is used for agriculture (FAO, 2012c). Sustainable water use for food production, human consumption, and industry are currently prime challenges. Water scarcity and stiff competition for water between different sectors have resulted in reduced water availability

	Pakistan	India
Population (million – 2013)	182.1	1252.0
GDP (billion US \$ – 2013) Gross National Income Per Capita (US \$ – 2013)	236.6	1877.0
Gross National Income Per Capita (US \$ – 2013)	1380	1570
Irrigated land as % of total agricultural land (2010)	75.98	35.19

Source: World Bank, 2013.

for irrigation. This is true at the global level, but has more tangible consequences at the regional scale. Climate change is another looming problem that may create a higher level of threat to water resources. Hence, the production of food, fiber, fuel, and other industrial inputs with less water availability will be a major challenge for both rainfed and irrigated agriculture. Water-use efficiency might take the lion's share towards solving problems in this region.

Problem Statement

The Transboundary Indus Basin (TIB) is an example of complex hydrology coupled with strained hydro-political relationships between riparian countries. The basin acts as the bread basket for more than a billion people in the region. The growing population demands more food, but agricultural lands are shrinking due to peri-urban expansions. At the same time, the basin is facing serious challenges of physical water shortages and lower water/land productivity. This water scarcity is being experienced by both the industrial and agricultural sectors. Irrigated agriculture is suffering the most, as 93% of water in the basin is consumed by this sector alone. The combination of these factors means that by 2050 the Indus will be able to effectively feed 26 million fewer people than it does today (FAO, 2013b; Immerzeel et al., 2010).

The water shortage is linked with the water flow availability in the rivers. These flows are generated from snow melts and glacial melts, as well as upstream rainfalls. During the last few decades, trends of rising temperatures associated with climate change have been observed in the upper Indus Basin (UIB), which is mostly comprised of snow and glaciated areas. The glaciers are retreating at a rapid pace and a 2.15% reduction in snow cover has been observed from 1992 to 2010. Some glaciers are receding at an even faster pace, for example 15.6 m per year in the case of Dokriani glacier in the Himalayan range. In an assessment of ten major basins in the Asia-Pacific region, the Indus is considered the most vulnerable to water scarcity under current conditions (Mukhopadhyay, 2012; Varis et al., 2012). While it is predicted that climate change will result in increased water availability in the short-term, water availability in the long-term is predicted to decrease. The sustainability of irrigated agriculture in its current form is questionable. It is a major component of the economy and employment in the region, and therefore, alternate ways of farming and best management practices need to be introduced, with the common consensus of government and society.

There is also a dire need to increase water and land productivity so that irrigated agriculture can meet the challenges of current climate change and withstand threats to food security and environmental sustainability. However, the unavailability of long-term, good quality data that can support reliable modeling and validation, coupled with challenging topography, has made this analyses complex. The unavailability of data due to limited gauging stations and available data-sharing issues between the riparian countries is making the job of scientists more difficult. Some datasets are termed as “classified” and are not accessible to researchers at all. Conceptual snowmelt runoff models have proven useful

for estimating discharge from remote mountain basins, including those spanning the various ranges of the Himalayas. However, these models limit the ability of policy decisions to address characteristic components of water disputes, such as diversions, storage, aquifer abstractions, and withholdings.

The reduced surface water flows have also exerted huge pressures on the already depleting groundwater storage. Groundwater is currently being abstracted for irrigation without consideration for its sustainability. According to one study, groundwater losses from the basin totaled approximately 10 km³ per year between 2002 and 2008 (Tiwari, et al, 2009). In the future, this may further increase. Continuous abstraction without sufficient recharge can adversely affect the groundwater flow paths. Groundwater flows naturally from the northeastern to the southwestern part of the basin. Negative groundwater flux can change flows, thus degrading the environment in the middle parts of the basin, including Rajasthan state and eastern parts of Punjab province. This over-exploitation of groundwater is also causing secondary salinization at the enhanced cost of the energy needed to abstract it. Unfortunately, there is no comprehensive database available of spatial and temporal groundwater abstraction information that takes into account the transboundary aquifer's sustainability. Therefore, it is important to check the localized abstractions, as well as map depletion hot spots in an integrated manner, so that over-abstraction in one part of the basin does not affect the natural flows to another.

The lack or limited interaction between the science and policy communities is a point to consider in maintaining the sustainability of the basin. Scientific findings have to be translated towards policy implications in a way that is rarely currently achieved. As most policy and socioeconomic studies have given top priority to the modernization of water management institutions, there is an increased need for multi-dimensional participation of the public in government programs at all levels. This includes the training and capacity building of field operation staff and farmers, agricultural policy re-orientation (with respect to irrigation, water-use efficiency, and infrastructure development), and multi-faceted efforts for climate change science, resilience, and adaptation. Therefore, strategies like the modernization of irrigation systems, the encouragement of farmers with training and capacity building, and the effective use of information technology for communication are required.

There is also a need for joint, impartial, and integrated research to provide alternative approaches to present and future challenges emanating from the Transboundary Indus Basin. Formation of an Indus Waters Experts Group would be a good starting point. This group could have a multi-disciplinary, multi-organizational mix of governmental and non-governmental sector specialists.

An integrated, holistic approach to transboundary river basin management is also needed, in which the basin is accepted as the logical unit of operation. A multi-sectoral, integrated system, complemented by information sharing, transparency, and wide participation, is therefore best suited to encompass all of these elements. Such an integrated system for the evaluation of interactions between the hydrological processes in the mountains, river flow generation, water retention in reservoirs, groundwater pumping, and agricultural water use in the Indus Basin is largely lacking and should be investigated.

Summary of Major Problems

- Accelerated water scarcity
- Threat of climate change
- Fragmented and non-accessible data
- Low water and land productivity due to conventional irrigated agriculture
- Groundwater over-exploitation
- Lack of linkages between science and policy

Supporting Science-Policy Evidence

This project formulation is based upon a detailed investigation of the science and policy research that has already been carried out in the basin. An attempt has been made to thoroughly review the knowledge base available in previous studies of Indus Basin issues. Approximately two hundred papers/reports were found in which scientific and policy research in the Indus Basin are highlighted. Out of the total number of papers and reports, about one hundred were found to be more related to scientific work, while the other one-hundred-and-five are more focused on socioeconomic, regulatory, and policy issues. Their temporal and spatial scales have been investigated in order to judge the applicability of the research to a transboundary context. The knowledge gaps and links between science and policy have also been explored. As part of the review, each paper was weighted, in order to assess the effectiveness and scope of these studies for transboundary, multidisciplinary, multi-expert, and comprehensive applications, using a questionnaire with specific criteria. The questions addressed the spatial and temporal extent of the study, number of experts and organizations involved and their origins, data sources and availability of these data sources, quality issues, and science and policy interlinks.

The scientific research carried out in the basin has been focused on a variety of topics. However, through the review, it was revealed that the three topics that most appear on the radar screen of researchers are surface water, groundwater, and their conjunctive use. Forty-five percent of the total research reviewed was focused on these three aspects. In approximately 63% of the scientific research papers, only one subject was considered for analysis. It was also found that only 16% of the scientific studies focused on the TIB, while most (47%) focused solely on the Indus Basin in Pakistan or the Indus Basin in India. As far as temporal scale is concerned, 40% of the scientific research used more than ten years of data, while 34% used less than two years. Interestingly, TIB-wide studies constituted only 16% of the total scientific studies. Within this 16%, only 6% used more than 10 years of data, while 7% used less than two years. The studies in which more than ten years of data was used were either at the global-scale and included the TIB, or otherwise used previous reports/studies for analysis.

The review of the socioeconomic, regulatory, and policy papers revealed that about 30% of them consider the Indus Basin treaty and approximately 25.7% consider water resources in general. However, only one subject is considered in 42% of the policy papers. Forty-one percent (43 papers) of policy research studies were related to pure policy matters or Indus treaty evaluation, for which the geographic scale of application is irrelevant. Out of the remaining 62 papers, 66% (41 papers) are about the individual Indian or Pakistani Indus basins, while merely 29% (18 papers) consider the transboundary basin. As far as data type is concerned, 53% (56 papers) of the policy studies were data independent and 47% (49 papers) were data dependent. Out of the 49 data dependent papers, 42.9% (21 papers) used primary multi-year data and 16.3% (8 papers) used primary single year data, while secondary data is used in 34.7% (17 papers). In 6.1% (3 papers), no distinct dataset was used for the analysis.

It is important for scientific research to translate findings in terms of policy perspectives, and similarly, there should be a clear link between policy decisions and science. Such a linkage is rarely observed in the case of the Indus Basin. In order to gain information on how well the science and policy are linked in the research, questions regarding links between them were included in the questionnaire. It was found that there is currently no clear linkage between the science and policy research. Only 12% of the scientific studies tried to develop a linkage between data and policy, while 71% missed this important bridge. The rest of the scientific studies mention only that the scientific findings can be taken up by policymakers. The linkage between policy research and scientists is even less than what was observed in the scientific case. In fact, in all the policy research papers in which a scientific link was expected, while

they often mention a few lines about the scientific data, they completely miss conveying what type of scientific data is required for policymaking, what types of methodologies should be used to reduce bias in the data, which scientific phenomena are creating considerable ambiguity for policymakers, and what range of variation of results is present. As compared to scientific research papers, socioeconomic and policy research papers contain more narratives. Hence writers of these policy papers should articulate the scientific links to policymaking more precisely, with special highlights for further explanation.

Suggested Action Road Map

Integrated water resources management at the transboundary level requires a broader framework. This framework should be smart enough to provide reliable information on water resources in riparian countries to their policymakers and water managers. This will enable all stakeholders (the policymakers, water specialists, and farmers) to consider proper water resources management in an integrated manner and carry out comprehensive conjunctive water use plans. It is expected that this information will be accepted by the riparian countries as well as the provinces/states. The suggested action plan is as follows:

- Development of a comprehensive knowledge base (temporally and spatially consistent) on various hydrological processes without political interference
- Formulation of an integrated model framework that will be smart enough to establish relationships between land-use, anthropogenic activities, climate, and socioeconomics, and provide policy guidelines
- Exploration of alternative irrigation scenarios to improve water/land productivity in view of the changing climate
- Investigation of the temporal and spatial extent of groundwater exploitation, considering transboundary perspectives and the development of retrofit measures

To achieve the suggested action plan, the following roadmap is recommended:

- Formation of executive committees for science, policy, and governmental administration
- Identification of the scientific research, socioeconomic investigations, regulatory, and policy requirements of the region
- Unification of the scientific facts and policy issues, and their transformation into easy messages for the general public
- Formulation of public hearing committees
- Public hearings of a sufficient duration, at an appropriate time
- Execution of identified science-policy projects
- Training, capacity building, and awareness generation activities
- Presentation of results to governmental administration committees
- Review of facts, figures, and relevant expectations of riparian countries
- Negotiation and finalization of terms

Consistent with the action road map, the following projects can be employed to address specific emerging issues in the Transboundary Indus Basin.

A. Estimating the Potential of Changing Water-Intensive Cropping Patterns in the Indus River Basin System to an Environmentally Sustainable, Economically Beneficial, Less Water-Intensive Crop Mix, and Its Policy Requirements

Methodology

Figure 12 broadly represents the methodology for assessment of sustainable crop mix which can be divided into four major sections:

I. Ex-ante Spatial Analysis

Environmental sustainability in relation to local geomorphology and demographic set-up is an important factor. Geographic Information Systems (GIS) is one of the valuable tools that has tremendous capability to combine these diverse factors at a spatial scale. Hence using this tool, several regionally important environmental criteria, like soil-type, topography, and runoff (an indicator of rainfall and land-use); geomorphological factors, like distance to surface water; market access factors; demographic factors, like population density; and labor availability in relation to irrigation technology, like pump irrigation, canal irrigation, and pressurized irrigation, will be analyzed. All the criteria to be used in the ex-ante analysis will be decided based upon expert consultation, and with local and literature surveys. This will form the basic sustainability analysis and will be carried out for each gridded pixel under the study area.

II. Bio-Physical Modeling

The Soil and Water Assessment Tool (SWAT) model was jointly developed by the USDA Agricultural Research Service (USDA-ARS) and the Texas A&M Agricultural Research lab. It is a river basin-scale physical model that uses specific information on weather, soil properties, topography, vegetation, and land management practices to directly model physical processes associated with water movement, sediment movement, crop growth, etc. The model simulates the quality and quantity of surface as well as groundwater, and predicts the environmental impact on land management practices, climate change,

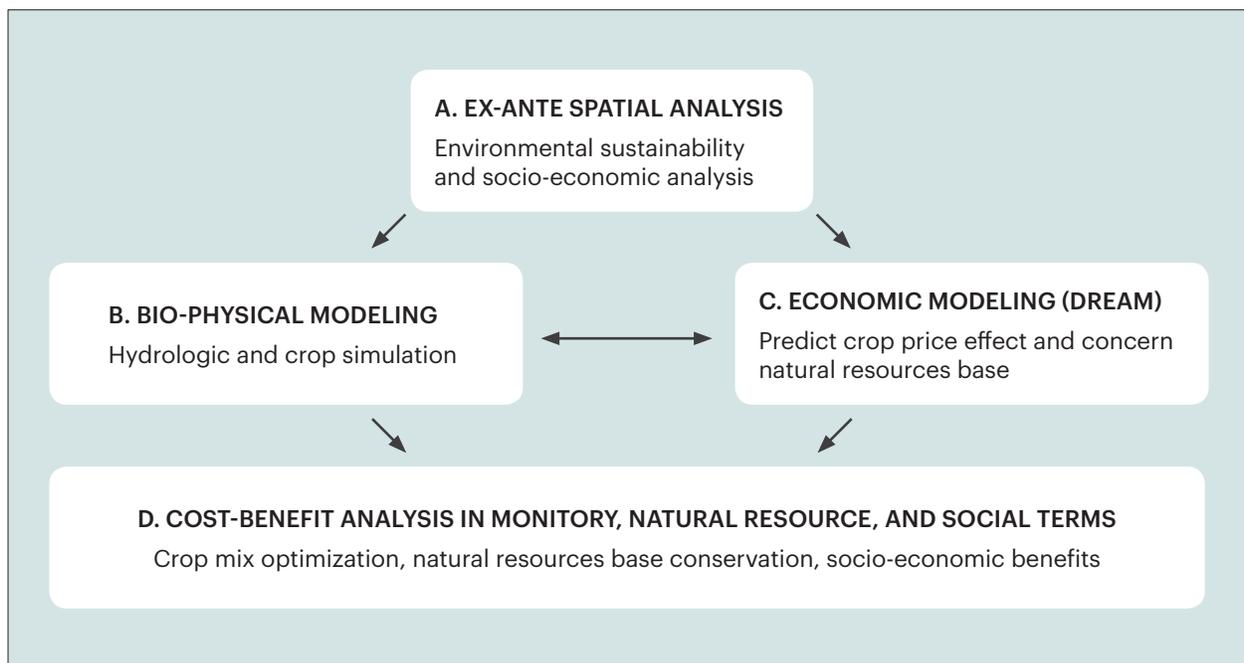


Figure 12. Representative assessment framework for sustainable crop mix.

and land-use. The model outputs for the Indus can help policymakers formulate better policies for land and water management in particular, and environmental management in general. The study will look at how water management practices affect agricultural productivity and vice versa.

III. Economic Modeling (DREAM)

The DREAM (Dynamic Research Evaluation for Management) model, another predictive modeling tool, is designed to measure economic returns to agricultural commodity-oriented research under a range of market conditions. This model will be used to assess price changes in agricultural products as a result of the availability of water resources and relevant crop mix desired. DREAM uses linear equations to represent supply and demand in each region, with market-clearing enforced by quantity and price identities. DREAM is a single-commodity model without explicit representation of cross-commodity substitution effects in production and consumption. Therefore, commodity linkages will be represented implicitly by the elasticities of supply and demand for the commodity being modeled, for which detailed background analysis will be carried out.

IV. Cost-Benefit Analysis in Monetary, Natural Resource, and Social Terms

Water availability will dictate irrigation choices, which in turn will affect cropping patterns and farming practices. Scenarios that describe the irrigated farming practices that exist and will be required in the Indus in the future will be developed. These scenarios will be used to guide the SWAT/DREAM models parameterization in an overall assessment, after calibration and validation of the models to local conditions. Scenarios will be developed using actual and secondary data from field-scale studies as well as expert consultation. With the SWAT and DREAM models, analysis of the environmental and economic consequences (i.e. water balance and cost-benefit) of future irrigation activities can be modelled. The actual optimum crop mix is a product of many situations and decisions. Therefore, to determine the crop mix under an expected irrigation scenario, a crop mix optimization approach will be followed. The crop optimization model consolidates the information from the previous steps, integrating the GIS ex-ante spatial analysis and the SWAT and DREAM predictive modeling. Improved agricultural water management approaches with a focus on equity, efficiency, economy, and sustainability will be the largest outcomes of the project. These results will be expanded to the policy-level using presentation, consultation, and simulation game techniques.

B. Transboundary Groundwater Depletion and Its Consequences on Long-Term Water Availability

Rationale

Groundwater is one of the most important components of water balance. However, its management is always a great challenge for researchers, one which only intensifies when an aquifer is shared among various countries, as is the case in the Transboundary Indus Basin. The hidden nature, lack of measuring mechanism, and sharing of the aquifer between countries are the major causes. Moreover, rapid population growth and increased irrigation development for food security have resulted in exhaustive groundwater abstractions (e.g. Foster and Chilton, 2003; Shah et al., 2007). Spatially and temporally erratic rainfall has resulted in limited recharge, which could eventually lead towards depletion of the aquifer.

Sustainable aquifers can be a primary buffer against drought, as groundwater response to short-term climate variability is slower than that of surface water systems. The mismanagement of this buffering system can lead to serious impacts on the environment and ultimately on food security (Ahmad et al., 2002). Sustainable management of groundwater is considered a more serious challenge than its

development (Shah et al., 2000). The long term, continuous abstractions, in high quantities, can adversely affect the overall water balance when the average value consistently exceeds the recharge over a long period. This could pose severe aquifer sustainability threats, especially when the aquifer is shared across political boundaries. Both in Pakistan and India, groundwater is being used as a supplemental source of irrigation, as surface irrigation is unreliable and not sufficient to meet the growing water demands. The groundwater contribution has reached 50% of total irrigation. According to one estimate, 68 km³ of groundwater is being used annually. This figure can change depending upon the climatic conditions. Large numbers of irrigation wells have been added every year, which has resulted in a 20-30% increase in groundwater abstractions over the last 20 years (Qureshi et al., 2010b). This over-abstraction of groundwater is more prevalent in the provinces of Pakistani and Indian Punjab, and Haryana and Rajasthan states (Shah et al., 2000; Cheema, 2012; Cheema et al., 2013).

Water yields of wells are declining and pumping costs are increasing due to the deepening of the water table. Salinization associated with the use of poor-quality groundwater for irrigation has raised the severity of the problem (Qureshi et al., 2010a). Moreover, sustainable use of groundwater is becoming difficult because of the heavy reliance on the resource for irrigation and municipal use. The situation is even worse from a regional perspective, as negative flux created due to continuous abstraction at one location can disturb the natural groundwater flow paths and cause environmental degradation elsewhere.

Groundwater abstraction estimates are normally carried out using the tubewell utilization factor technique or water table fluctuation methods (Healy and Cook, 2002; Qureshi et al., 2003). These methods become less suitable when applied at a basin scale due to the poor spatial density of the point measurements. Alternatively, abstraction data on groundwater can be derived from hydrological models. The success of these models depends primarily on the availability of comprehensive input data and how well the models are calibrated (Zhang et al., 2008). Long-term time series datasets with high spatial detail are difficult to obtain in spatially heterogeneous basins with a limited gauging network (Sivapalan et al., 2003). A major obstacle in transboundary groundwater management is that the fundamental information on the aquifer is either missing or not accessible. A first pre-requisite for regional-scale cooperation on water issues and comparisons between user states is a standardized description of water flows, not only for streams, but also for aquifers and withdrawals to irrigation systems.

Therefore a comprehensive knowledge base is required that would provide reliable information about the groundwater abstraction/depletion, water table variation, and flow paths. The limited data availability on groundwater and lack of sharing mechanisms between the riparian countries, with their on-going political conflict, make the situation difficult. The use of remote sensing techniques in combination with spatially distributed hydrological models could be a potential alternative used to develop such a database. The information thus obtained could provide vital quantitative evaluation of the groundwater system at a suitable pixel resolution. Such a quantitative knowledge base, taking into account the effects of groundwater pumping on the water table and sub-surface flows, as well as responses of the groundwater system to climate change, would provide insights to water managers and policymakers. Policymakers could take more effective actions if groundwater activities were expressed quantitatively by means of pixels. The benefits of pixel-based information include the availability of information in terms of geographical coordinates, coverage of a discrete land area, quantified abstraction rate, and the identification of land owners.

Such detailed information will not only enable all stakeholders (the policymakers, water specialists, and farmers) to address proper groundwater management and carry out comprehensive conjunctive use/water transfer plans acceptable to both countries, but also help to determine consequences of long-term abstractions on the sustainability of the aquifer.

Methodology

A three-tiered approach will be adopted to spatially map the groundwater abstraction and depletion in the basin. First, pixel-based spatial maps will be developed by combining information from satellites, hydrological models (SWAT), and GIS (Figure 3). Satellite precipitation (P_{sat}) and actual evapotranspiration (ET_{act}) calibrated using in-situ data in combination with hydrological model information will provide total irrigation values at each pixel. The GIS information on canal flows will be used to infer groundwater abstractions, while GIS-based seepage information will be subtracted to obtain pixel-based groundwater depletion.

Second, spatio-temporal data obtained from the Gravity Recovery and Climate Experiment (GRACE) will be calibrated/validated using water table fluctuation information available from in-situ observation wells. The spatial maps will be used to compare with the maps made in the first step to develop consensus on the spatial groundwater depletion hot spots.

A groundwater simulation model developed by the United States Geological Survey (MODFLOW) will be used to simulate the hydraulic heads, and future predictions will be developed that take into account various groundwater abstraction scenarios.

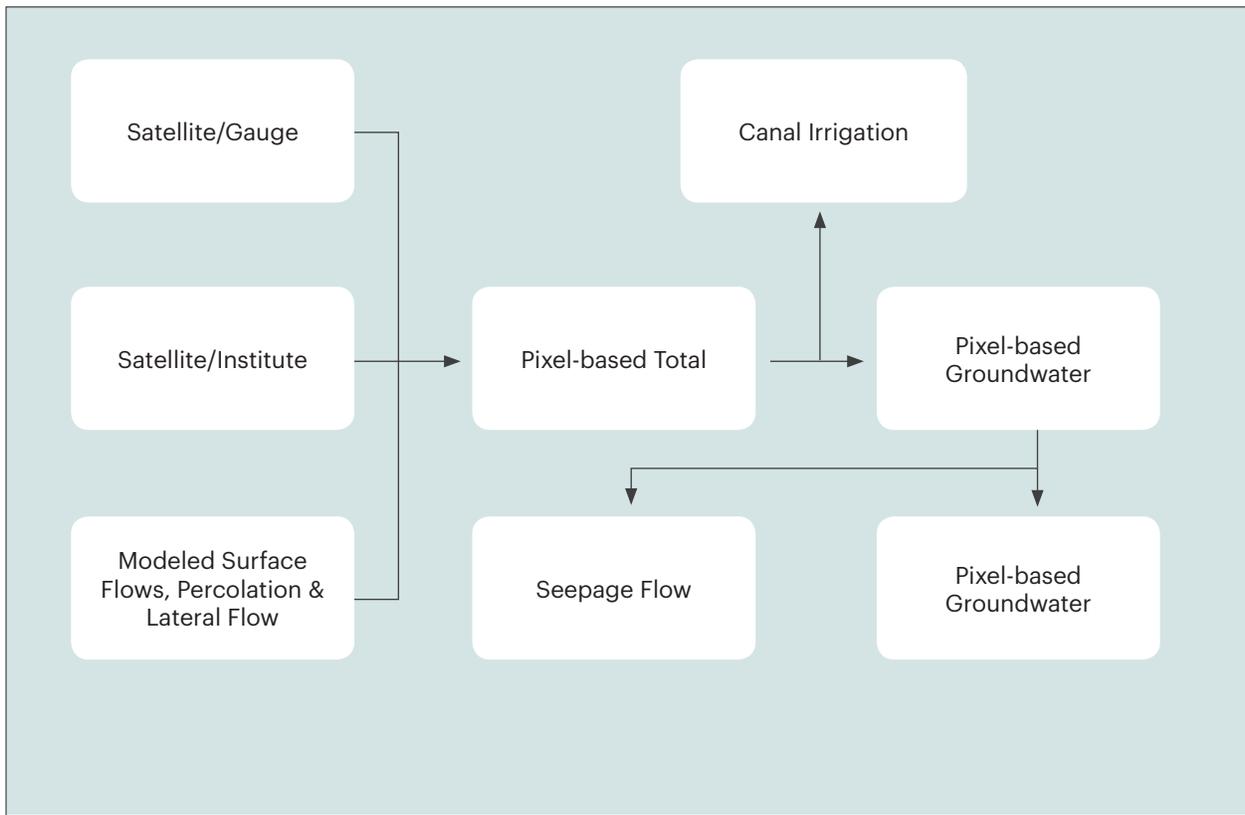


Figure 13. Schematic diagram showing data sources used to infer spatial groundwater abstraction and depletion information.

C. Application of Envision Modeling Framework for Integrated Natural Resource Planning in the Indus River System Under Alternative Future Scenarios

Methodology

ENVISION is an integrated policy and landscape modeling platform developed at the Department of Biological and Ecological Engineering at Oregon State University by professor and head of the department Jon Bolte with a team of other interdisciplinary researchers. Complete information on this modeling platform can be accessed at their webpage (<http://envision.bioe.orst.edu/Default.aspx>). This platform is a multi-paradigm modeling framework developed for analysis of natural, human, and other associated coupled systems, which takes spatially explicit inputs into consideration for solutions to predicted and alternative future scenarios. It allows for different policy options to be modeled as land use outcomes, based upon imputed environmental assumptions, for a variety of timescales. Figure 4 shows the conceptual framework of the ENVISION platform.

Rationale

Mathematical tools for water resources planning and management were traditionally designed for sectoral applications, such as with groundwater modeling tools, surface water modeling tools, and canal water scheduling tools. Recently, the complexity of water resources management, impact of inter-sectoral trade-offs, and trend of integrating all sectors under one system, are increasing. As a result, the applicability of sectoral tools is becoming very limited. Stakeholders and users of water are looking for new generation tools that allow integration across domains to assist their decision-making processes for short-term operations and long-term planning, not only to meet current needs, but those of the

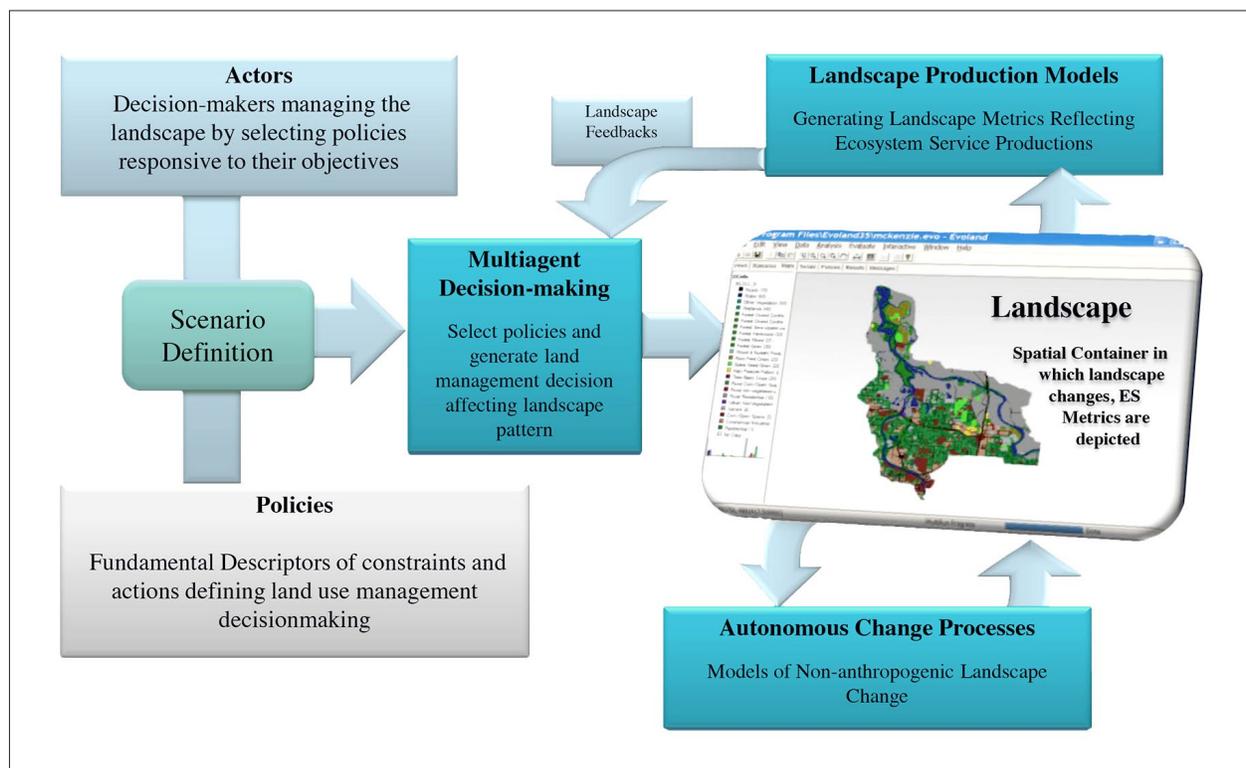


Figure 14: Conceptual framework of integrated ENVISION model. Source: Oregon State University, 2008.

future as well. ENVISION is one such promising tool, ideal for application to transboundary basins. Its powerful “multi-agent modeling” sub-system especially allows for better representation of stakeholder decision-making and policies on landscape management. This modeling framework has been used for variety of places and purposes, including the Big Wood Basin Alternative Futures, Tillamook Coastal Futures, Willamette Water 2100, Central Oregon - Forests, People and Fire, Coupled Natural and Human Systems in the Southern Willamette Valley, Envision Skagit County 2060, Andrews Long Term Ecological Research Site, Bainbridge Island, and Puget Sound, Washington, projects. Various subsystems within the modeling framework, like GIS-based inputs, facilitate a variety of spatially explicit landscape models, and its open, extensible architecture can be adapted to a variety of geographic locations and application requirements. In addition, it functions on an open source model which is freely available and provides many ‘plug-ins’, making it perfect to use with a variety of customized tools under various situations.

Expected Creative Outcomes

ENVISION has capabilities that could provide various path-breaking outputs. Prominently, it will assist in decision-making for complex situations with deep uncertainty and multiple policy alternatives. It will also help water managers understanding of different stakeholders’ choices, while stakeholders can learn the impacts and importance of mutually inclusive decision-making, ideally shaping local attitudes. By doing so, the ENVISION framework can help integrate policies for the greatest impact and weigh alternative policy decisions. The representation of existing socioeconomic dynamics will be not only be better quantified, but the role of these dynamics in land use and land cover change, and vice versa, can also be explored.

Overall Methodology

- A. Formation of respective scientific, policy, and governmental administrative committees
- B. Identification of common emerging threats and respective science-policy actions
- C. Bringing consensus between science-policy actions, methodologies, and data, by mutual consultation between India and Pakistan
- D. Training and capacity building of major identified actors
- E. Based on identified threats, developing an action plan for future initiatives

Institutes Involved and Their Roles

- A. Stimson Center: Coordinator and lead
- B. University of Agriculture, Faisalabad (UAF) - Pakistan: Lead role in coordinating scientific and policy activities in Pakistan
- C. The Energy and Research Institute (TERI) - India: Lead role in coordinating scientific and policy activities in India
- D. United States Department of Agriculture (USDA), United States Geological Survey (USGS), International Food Policy Research Institute (IFPRI), and Oregon State University (OSU): Consultants for the unified methodology, suggestions, and results evaluation

E. Pakistan Meteorological Department (PMD), Water and Power Development Authority (WAPDA), Pakistan Indus Water Commission (PIWC), International Water Management Institute (IWMI), and the Planning Commission of Pakistan, from Pakistan (field-scale data generation and research project responsibilities, as well as stakeholder and administrative actor consultation for policymaking in Pakistan)

F. Indian Meteorological Department (IMD), Bhakra Beas Management Board (BBMB), Indian Indus Water Commission (IIWC), and IWMI, from India (field-scale data generation and research project responsibilities, as well as stakeholder and administrative actor consultation for policymaking in India)

Expected Outcomes

A resilient framework for integrated water resources management in the Transboundary Indus Basin will help all stakeholders to use water resources efficiently as well as effectively. Water allocation issues such as (i) tempered groundwater exploitation, (ii) definition of volumetric water rights, including compulsory return flows, (iii) efficient irrigation systems, with conjunctive use of surface and groundwater, and (iv) vulnerability to climate change, can possibly be addressed through these means. Finally, policymakers will be in better position to use this scientific knowledge for decision making, and scientists will be in a better position to direct their research findings towards policy impacts.

About

About the Authors

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Muhammad Cheema is a non-resident fellow in the Environmental Security Program at Stimson and an Assistant Professor in the Irrigation and Drainage Department at the University of Agriculture, Faisalabad-Pakistan. He is a remote sensing expert and has experience using multi-sensor satellite data to manage water resources in data-scarce river basins. He has a special focus on developing methodologies to efficiently utilize satellite measurements for hydrology and to model conjunctive water-use in the transboundary Indus River Basin.

Dr. Cheema has published peer-reviewed journal articles on emerging water resource issues in the transboundary Indus Basin. He has also delivered lectures on the use of remote sensing for water management at various universities in Pakistan and abroad. He is currently running a number of internationally funded projects on water and agriculture, and is involved in the establishment of a Chair on Precision Agriculture at the Center of Advanced Studies in Agriculture and Food Security. Before joining the Agricultural University in 2007, Cheema served as an Agricultural Engineer in the Pakistan Agricultural Research Council, Islamabad.

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