Past, Present and Future of the Indus Water Treaty: Implications for Transboundary Water Governance Challenges and Modernization Prospects

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Past, Present and Future of the Indus Water Treaty: Implications for Transboundary Water Governance Challenges and Modernization Prospects

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Abstract

The Indus Water Treaty has been applauded as a successful water sharing agreement to allocate the water of Indus River system between India and Pakistan. Yet a set of diplomatic, water resources, and climatic challenges have culminated into the current state of suspension and raise questions over the future of the transboundary water governance. This paper presents a critical spatio-temporal analysis of its past, present and future and addresses the prospects for modernization. We analyze the background of the treaty, current challenges it faces, and the outlook for modernization of provisions for the long-term sustenance of the treaty. The spatio-temporal heterogeneity of water availability in the basin, climate change impacts, and natural hazards, increasing population and related economic pressures set in the context of hydro-political tensions have culminated into water stress in the tributary rivers, especially in Chenab, Ravi and Jhelum. Initial disputes over infrastructure development have proliferated with climate change extremes and rising hydro-political tensions with increasing turbulency in the basin. Although the treaty has been used as a tool to respond to existing tensions, its water-sharing provisions have not been the *casus belli* for conflict between the two neighbors. In order to maintain any cooperation in this rapidly changing transboundary basin, especially at a crucial point of suspension, the treaty must be modernized with emphasis on a joint commission process and increasing attention to surface and groundwater quantity and quality, disaster prediction, environmental protection, and above all, identifying and strengthening co-benefits with shared projects to provide future decades of resilience.

Keywords: International Water Resources, Hydrodiplomacy, Water Sharing Treaties, Indus River Basin, Climate Change Impacts, Socio-economic Condition, India-Pakistan

1. Introduction

Water governance in transboundary river basins is complex due to the amalgamation of different challenges such as baseline climatic conditions, water resources availability, and the riparians' socio-economic status, geopolitical relations, and domestic interests (Zeitoun et al., 2013; Varady et al., 2023; Armitage et al., 2015). These challenges are exacerbated by the uncertain changes in water availability and natural hazards driven by climate change, population growth and urbanization; and associated resources requirements in the past few decades; just and effective water allocation and management is increasingly difficult (Varady et al., 2023). At present, more than half of the land on Earth lies in 276 transboundary river basins and 300 aquifers comprising 60% global freshwater flow supporting 40% of the population from 148 countries (MacQuarry and Wolf, 2013; Zeitoun et al., 2013; Wolf, 2002; Giordino et al., 2014). The often-contested use of these international water resources has resulted in numerous conflicts or co-operative agreements/ treaties or both varying spatio-temporally with the shifting human administration boundaries over the historical time period (Wolf et al., 2003). Amongst the successful modern treaties in the world, Indus Water Treaty (IWT) is often regarded as a model of cross-border water agreement for surviving more than 60 years of hostilities between the riparian countries (Parajuli et al., 2003; Wolf, 2002), until its recent unilateral suspension in April 2025. The modern status is debatable as IWT has not undergone major changes since its inception and its praise mainly arises from its survival in the hardship rather than updating with time to increase co-operation.

IWT was established to distribute and manage the water of the six rivers of Indus River System (IRS) between India and Pakistan (Indus Water Treaty, 1960). The treaty, signed in September 1960, is over 60 years old and survived multiple wars, military conflicts, and general hostility between the riparian countries until its suspension in April 2025. Its stability over decades despite the complicated historical and geopolitical conditions during its formation and negotiation made IWT one of the most successful water treaties in the world. It has two unique components. First, it is the only water treaty that physically divides a river system between the riparian countries. Instead of assigning a fraction of flows to each country for use, IWT shares entire access of rivers between India and Pakistan. Second, it is the only water sharing agreement where a third party, the World Bank, played a crucial role in negotiating the rounds of agreements and was also a signatory to the official document. (Miner et al., 2009; Dinar et al., 2013).

Although the collective interest of utilizing the water of the IRS for economic development drove the traditionally non-friendly countries to sign a treaty, a set of regular disputes have been observed to affect its stability in the past few decades which pushed the treaty into a critical phase (Haines, 2017). Multiple disagreements regarding water sharing and hostility between the countries due to rigid geo-politics and their shared history of partition have created antagonism over the treaty.

The recent developments indicate that IWT not only serves as a water management agreement but also has vast geopolitical implications in global security (Qamar e al., 2019). Although IWT has worked well in the past due to its simplistic nature, the geopolitical, climate and social conditions during its formation and at present are remarkably different. The treaty has also not undergone any change/upgradation since its formation due to the difficulties in negotiating and getting the two riparians on common ground. As a result, IWT is not equipped with the attributes that will safeguard the wellbeing of water resources for both riparians while ensuring its long-term sustenance. With the current suspension of the treaty, we are truly at the critical tipping point where each decision severely affects the future of this dynamic river system and the people depending on its water.

In this regard, this study analyzes the past, present and future of the IWT, providing historical background of conditions prevalent during the formation of the treaty, challenges in the transboundary water governance and potential opportunities for treaty modernization. The first section provides background on geographical and socio-economical characteristics and the historical background before and during the formation of the treaty. The second section explores the major challenges reported by both riparians since the formation of the treaty. Lastly, the third section discusses the scope for modernization within the current structure of the treaty.

2. Salient Characteristics of Indus River System

Covering an area of 1.11 million km^2, IRS consists of seven major rivers *viz.,* Sutlej, Beas, Ravi, Chenab, Jhelum, Indus and Kabul. Of the seven rivers, six rivers (except Kabul) originate in India and China and flow downstream to Pakistan and are regulated under the IWT. The three easternmost rivers are called Eastern Rivers and are allocated entirely for India’s use, whereas the water of the three rivers on the western side is allocated for Pakistan’s complete usage; these are referred to as Western rivers (Indus Water Treaty, 1960). A map showing the geographical location of the eastern and western rivers and their basins is shown in **Figure 1**. Salient features of the six treaty rivers are provided in **Table 1**.

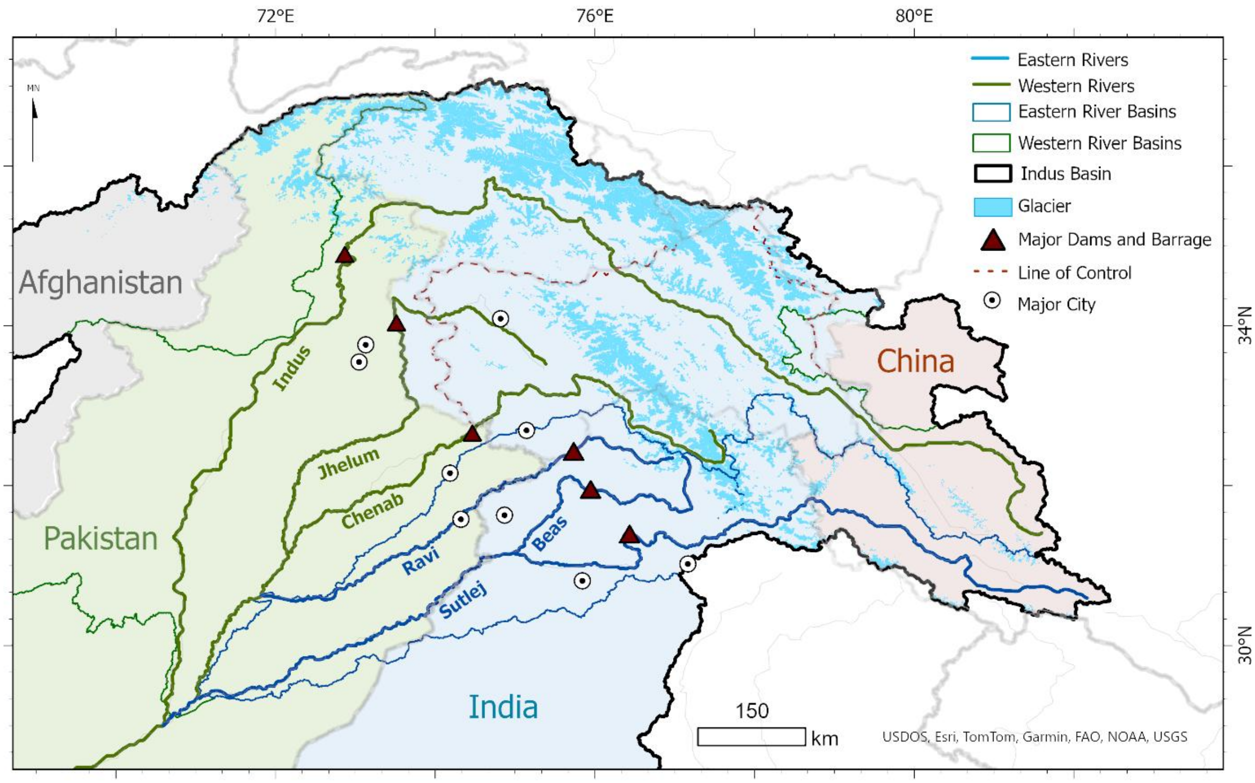

Figure 1. Location map of the rivers of the IWT showing rivers of the treaty and their drainage areas.

Note: Indus in the paper refers to the main stem of the Indus River whereas Indus River system refers to the 6 rivers (main stem and 5 tributaries) together.

Table 1. Salient features of rivers of Indus Water Treaty

Feature	Indus	Jhelum	Chenab	Ravi	Beas	Sutlej	Source
Catchment area in km^2 *	298139	50859	44856	30607	19505	113441	Present Study
Average annual runoff volume 2000-2015 in km^3/year **	70.3	24.9	28.1	8.5	8.4	16.9	WAPDA Annual Report (2017); Ahmed et al. (2023); Bhakra Beas Management Board
Glacier area in km^2 (Mass in Gt)	19246 (1227)	277 (8.3)	2824 (159)	162 (5.7)	506 (23)	1583 (66)	Kulkarni et al. (2023)

Contribution of snow and glacier melt to annual flow (%) **	70	25	49	16	20	59	Kulkarni et al. (2021)
Hydropower Potential (TWh/year)	615	236	203	51	69	139	Dhaubanjar et al. (2024)
Irrigated Areas in km^2 (% of Basin Area)	44079 (14.8)	25878 (50.8)	24597 (54.8)	26555 (86.7)	8200 (42)	63645 (56.1)	Siddiqui et al. (2016)
Population in millions	37.5	22.2	18.2	28.6	6.7	48.6	Center For International Earth Science Information Network-CIESIN-Columbia University. (2018)
Average Water Stress Index ***	0.9	3.8	4.4	4	2.4	3	Kuzma et al. (2023)

*The catchment area of each river is considered up-to-the confluence point until it meets with another treaty river. For e.g., the catchment area of Beas is considered upstream of its confluence point with Sutlej whereas the catchment area of Sutlej is considered upstream of its confluence with Indus River.

**Average runoff and contribution of snow and glacier melt runoff are given at the barrages shown in Figure 1.

***Water Stress Index is given on the scale of 0 to 5 where 5 indicates extremely high risk whereas 0 indicates low risk.

The rivers of IWT originate in the high-altitude of Himalayan-Karakoram mountain ranges and flow southwestwards towards the Arabian sea. The Sutlej and Indus originate in the Gangdise Shan mountain range in the Southern Tibetan Plateau whereas Ravi, Chenab and Jhelum originate in the western Himalayan range in India. The Beas River originates and flows entirely within Indian territory. Indus and Sutlej are also the largest amongst the western and eastern rivers, respectively. Indian states such as Himachal Pradesh, Punjab, Haryana, and Rajasthan and union territories of Ladakh and Jammu and Kashmir and Pakistan provinces of Punjab, Sindh and Khyber Pakhtunkhwa rely on the water availability in the treaty rivers.

Flood plains of five rivers from Sutlej to Jhelum form the fertile plains of Punjab (meaning panch aab or five rivers with an Indian state and a Pakistan province bearing this name); this region has been a center of agricultural productivity and is essential for food security. Agricultural lands in

IRS supports around 96% and 26% of crop production in Pakistan and India, respectively (Khan et al., 2010; RBI Report, 2011). A population of around 300 million depends on the waters of the Indus River system for domestic, agricultural, hydropower and industrial usage (Immerzeel et al., 2020). Major dams and barrages on eastern rivers distribute the water of Sutlej, Beas and Ravi to the downstream command areas in India, whereas the ones on the western rivers manage and distribute water resources for the agricultural lands in the doabs (area between two rivers) (Jehangir et al., 2002).

3. Data and Methods

3.1 Secondary Data Analysis

The spatio-temporal analysis presented in the paper spatially covers the state of tributary rivers in the IRS and temporally ranges from past (prior to 1960 *i.e.* formation of the treaty), present (1960 to 2024) and future (until the end of the 21st century). Historical background and provisions in the IWT are summarized through a review of literature related to history, laws and policies to provide a fundamental background of issues discussed in the present. The present section provides details of various challenges faced by IWT through identified through academic and literature analysis of secondary data. The secondary data related to river flows and water balance components was summarized from various studies outlined in Table 1. The irrigated areas for 2000 and 2010 are acquired from Irrigated Area Maps for Asia and Africa product at 250 m spatial resolution (Siddiqui et al., 2016) and were used to summarize the change in irrigated areas from 2000-2010 in the treaty rivers. Population was acquired from Gridded Population of the World product v4.0 for the year 2020 at spatial resolution of 1 km. Future projections of socio-economic growth in the Indus basin are acquired from Smolenaars et al. (2021). Lastly, water risk indicators relevant to the IRS such as baseline water stress, riverine flood risk, drought risk and groundwater decline are extracted for the treaty rivers from Water Risk Atlas v4.0 (Kuzma et al. 2023). The challenges are first discussed in detail and later, their interaction is explored through a causal-loop diagram. The Future section discusses the scope for modernization of IWT in detail through a literature review of water sharing treaties and analyzing them in the context of the Indus basin.

3.2 Conceptual Synthesis of *Modernization*

In human history, over 3600 international water sharing agreements have been documented since 850 AD (Wolf, 2002; Giordino et al., 2014). The initial water treaties formed in the era of industrial revolution focused on navigation and boundary demarcation whereas modern water treaties signed after 1820s focus more on the water resources use and management for economic development (Wolf, 2002). Around 700 treaties formed in the modern world after 1820s are often deemed as modern water treaties (Giordino et al., 2014). Some of the successful modern treaties have also been observed to update in a timely manner to increase the basket of benefits (Wolf, 2002). The traditional and modern status of the water sharing treaties is often based upon the time and main objective of their formation. The earlier understanding of *Modern Treaties* focuses on their formation in the *modern* world for the efficient use and distribution of water resources for economic growth. However, this definition has been observed to naturally evolve as the environmental and societal conditions evolved in the 20th century. Water management objectives of the treaties were observed to rapidly shift post-1950 to include characteristics of changing dynamics, especially environmental protection and water quality (Giordino et al., 2014). Along with flexibility, incorporation of local needs, increasing shared benefits and reducing risks have been deemed as important qualities in a Modern Treaty (UN Water, 2008). Thus, the *modernization* discussed in this paper refers to the *process of updating or adapting existing agreements to reflect contemporary challenges, technological advancements, and evolving environmental, social, and geopolitical conditions in a way that makes the agreement flexible and creates sustainable ecosystem conditions and livelihoods for all riparians in the long-term*. The concept focuses on adaptability and flexibility which would inherently be able to tackle the challenges and increase co-benefits and cooperation. In the case of IWT, we hypothesize that its unchanged status from its conception has made the treaty rigid which has resulted in decreasing cooperation over the decades which is null in its present suspended state (Figure 2). The lack of legislation creates large uncertainties regarding the future of the regional water governance for South Asia. If the current state is utilized as an opportunity to modernize the treaty, it could make increase the co-benefits and cooperation in IWT in the future.

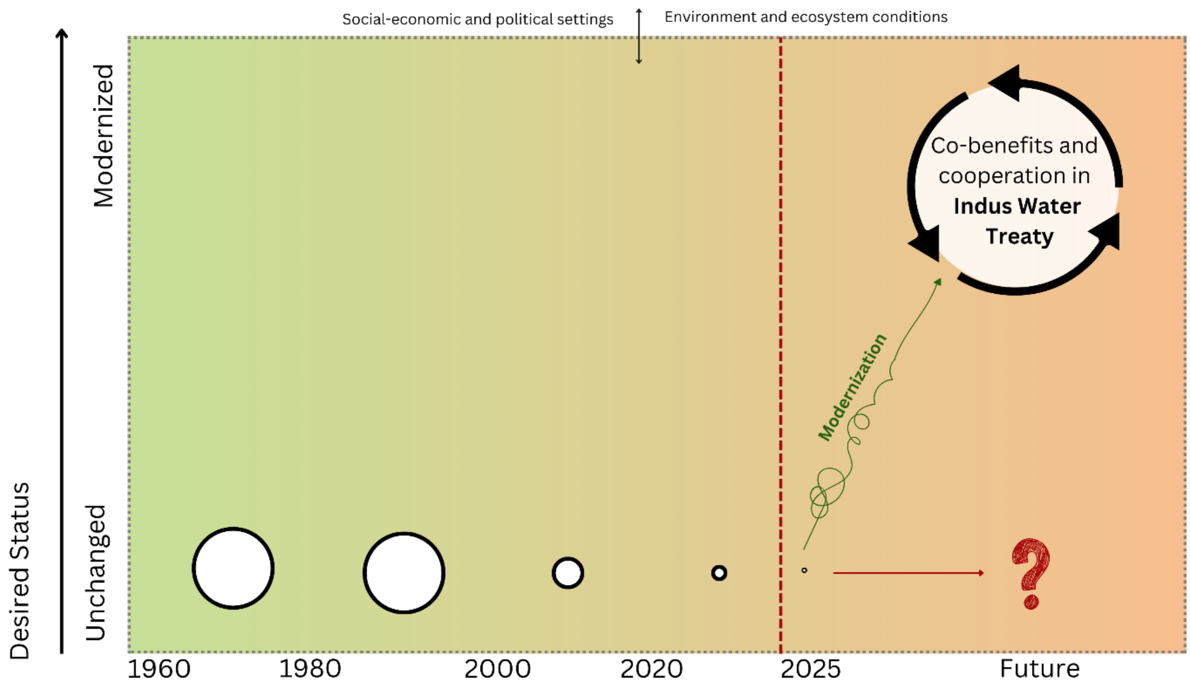

Figure 2. Conceptual diagram of analysis presented in the paper, where we hypothesize that the co-benefits and cooperation in IWT will increase with modernization

4. Past: Historical Background

4.1 Conditions prevalent prior to the formation of the Treaty

IRS has primarily been an agriculture region with a developed irrigation system since the Indus Valley civilization (Irfan et al., 2019). The traditional irrigation method of inundation was upgraded into a modern irrigation system of canals and barrages during British colonial rule which helped agriculture in the Punjab region grow immensely, making it a major economic activity of prime importance (Gilmartin, 1994). By the 1940s, the irrigation system in the IRS consisted of 26 million acres of irrigated agriculture and 34000 miles of canals; it was considered as the most extensive in the world (Dinar et al., 2013). In 1935, water resources were put under provincial jurisdiction which started disputes between Sindh and Punjab provinces where an extensive irrigation network existed (Government of India Act, 1935). Later, the *Indian Independent Act of 1947* established sovereignty to India and Pakistan (Government of India Act, 1947) and the water disputes between the provinces became international issues. The painful partition of the two countries resulted in mass displacement of population, homicide and increased religious and political tension which sowed the seeds of antagonism between the countries that continue today.

These sentiments are crucial to the power struggle and lack of trust leading to disputes over IRS water sharing (Dinar et al., 2013; Qamar et al., 2019). Following, the *Standstill Agreement of 1947* provided continuous flow to Pakistan from the headworks in India. After the agreement expired in April 1948, the Indian provincial government of East Punjab stopped the water into Dibalpur and Upper Bari Daab canals to Pakistan. Pakistan claimed water rights over Indus water under Prior Appropriation, whereas India claimed that Pakistan must also recognize India's water rights (Dinar et al., 2013).

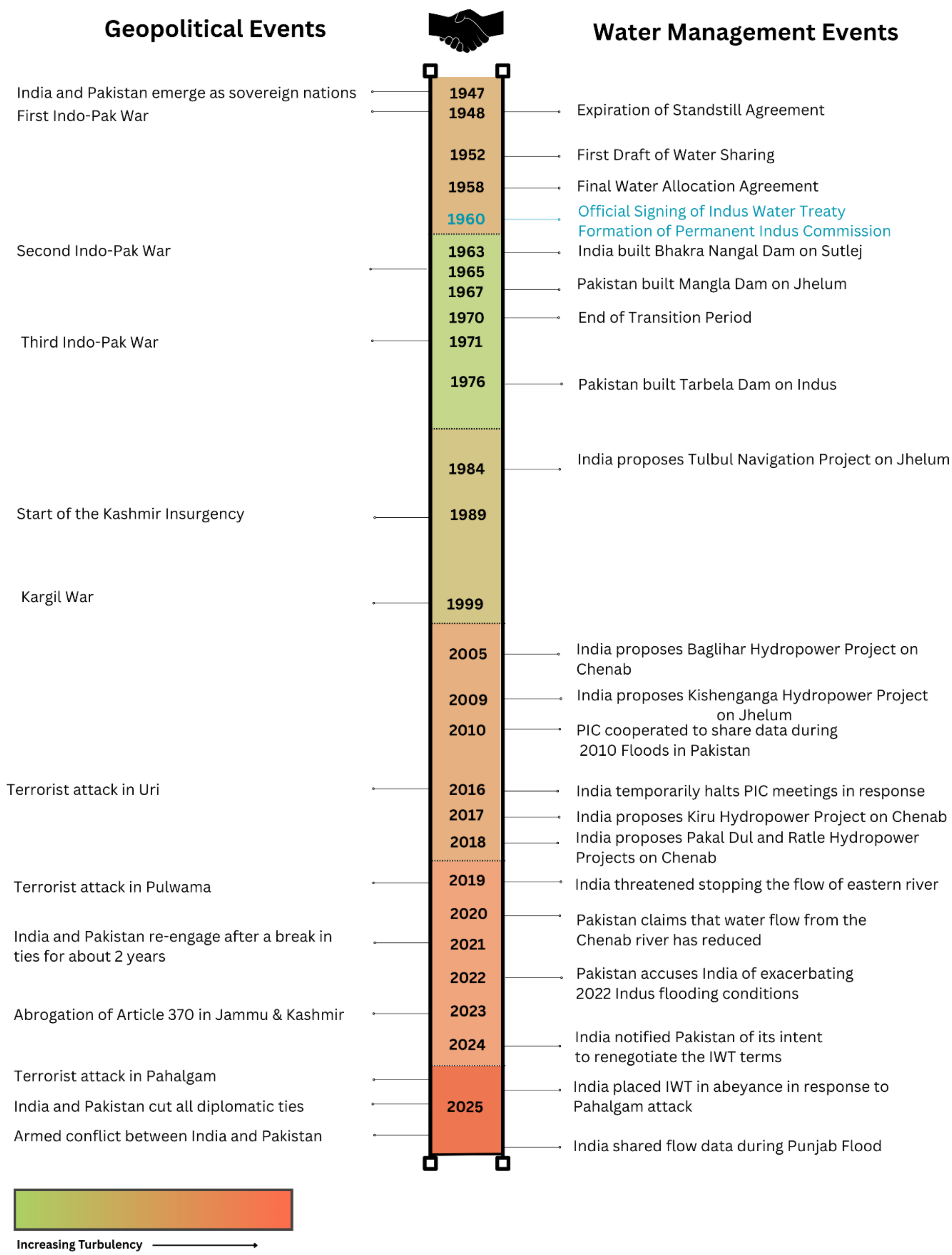
Geopolitical Events
Water Management Events
India and Pakistan emerge as sovereign nations
First Indo-Pak War
1947
1948
Expiration of Standstill Agreement
1952
First Draft of Water Sharing
1958
Final Water Allocation Agreement
1960
Official Signing of Indus Water Treaty
Formation of Permanent Indus Commission
Second Indo-Pak War
1963
India built Bhakra Nangal Dam on Sutlej
1965
1967
Pakistan built Mangla Dam on Jhelum
1970
End of Transition Period
Third Indo-Pak War
1971
1976
Pakistan built Tarbela Dam on Indus
1984
India proposes Tulbul Navigation Project on Jhelum
Start of the Kashmir Insurgency
1989
Kargil War
1999
2005
India proposes Baglihar Hydropower Project on Chenab
2009
India proposes Kishenganga Hydropower Project on Jhelum
2010
PIC cooperated to share data during 2010 Floods in Pakistan
Terrorist attack in Uri
2016
India temporarily halts PIC meetings in response
2017
India proposes Kiru Hydropower Project on Chenab
2018
India proposes Pakal Dul and Ratle Hydropower Projects on Chenab
Terrorist attack in Pulwama
2019
India threatened stopping the flow of eastern river
2020
Pakistan claims that water flow from the Chenab river has reduced
India and Pakistan re-engage after a break in ties for about 2 years
2021
2022
Pakistan accuses India of exacerbating 2022 Indus flooding conditions
Abrogation of Article 370 in Jammu & Kashmir
2023
2024
India notified Pakistan of its intent to renegotiate the IWT terms
Terrorist attack in Pahalgam
India and Pakistan cut all diplomatic ties
Armed conflict between India and Pakistan
2025
India placed IWT in abeyance in response to Pahalgam attack
India shared flow data during Punjab Flood
Increasing Turbulency

Figure 3. Timeline of the major geopolitical and water management events in India and Pakistan that had impacts on functioning of IWT

4.2 Formation of the Treaty and role of the World Bank

Soon after the 1948 standstill agreement, both India and Pakistan approached the World Bank for loans to develop the Sutlej River in their territories. This Sutlej River "Canal Waters Dispute", evolved into the "Indus Water Dispute" (Dinar et al., 2013). After the formal involvement of the World Bank as a neutral third party, multiple rounds of negotiation were held and were rejected by both countries. As a result, the World Bank proposed India and Pakistan draft their own plans of sharing (Biswas, 1992). These initial drafts included allocation of fraction of the flow of each river. The first draft by India suggested 90 million-Acre Feet (MAF) to Pakistan and 29 MAF to India with total of 119 MAF water being allocated. Pakistan countered with 102.5 MAF to Pakistan, 15.5 MAF to India with total 118 MAF being shared (Biswas, 1992; Dinar et al., 2013). Although the drafts agreed upon total water availability, they were widely different in the share of water allocation between the two countries (Biswas, 1992). In the second draft of countries' plans, India demanded 7% of water of western rivers and all the waters of eastern rivers. Pakistan countered with a demand of 70% of water of eastern rivers and all water of western rivers for the country (Biswas, 1992; Dinar et al., 2013). Towards the second draft in 1953, the shift towards distinction of eastern and western rivers was identified. World Bank suggested a new proposal based on the demands in the second draft, which was accepted by both countries in 1958 after more than a decade of negotiations (Miner et al., 2009; Biswas, 1992; Dinar et al., 2013).

4.3 Provisions of the Indus Water Treaty

The final agreement accepted by both India and Pakistan was signed by the prime ministers of both countries and the World Bank on 19 September 1960 in Karachi, Pakistan and is called Indus Water Treaty. Three guiding principles of water sharing were agreed upon and are mentioned in the preamble of IWT, *viz., "1) There is enough water in Indus for both countries. 2) water resources of the Indus should be managed cooperatively. 3) Problems of the basin should be resolved on functional not political level without relation to past negotiations and past claims"*

The treaty drafted regulations of shares of available water, major water management practices and infrastructure and identified the financial and technical apprehensions of both countries and identified a set of international donors who would help in development in the Indus basin with the final allocation of around 32.6 MAF (~19%) flow from eastern rivers to India and 136 MAF (~81%) flow from western rivers to Pakistan (Indus Water Treaty, 1960).

The treaty established a Permanent Indus Commission (PIC) consisting of one commissioner from each country. The responsibility of the commissioners includes submitting an annual report to their respective governments, resolving issues regarding the interpretation and implementation of the treaty and promote cooperations between the countries for development of Indus basin. Furthermore, there are also provisions about mandatory data sharing of daily flows, daily releases from dams and deliveries to the link canals. The treaty also secures future operations and dispute resolving mechanisms using court of arbitration and neutral expert (Indus Water Treaty, 1960; Miner et al., 2009).

5. Present: Contested Co-operation and Challenges

Since the formation of the treaty, its functioning has gone through various geo-political and water management events amongst the plethora of interconnected challenges. After the formal agreement, the two nations focused on the development of water management infrastructure and expansions of agriculture until 1980 through the relatively peaceful transition period of 10 years. Until the early 2000s, the two nations had multiple geopolitical conflicts, but the treaty was observed to work smoothly. The later decade observed a variety of challenges which are elaborated below.

5.1 Hydro-political Disputes

The initial conditions of antagonism between the countries that exacerbated during the early years of independence resulted in multiple military conflicts and four major wars (Figure 3). Although the disputes have softened with years, the two riparians are far from being friends or co-operative. In the Indus basin, water has been historically used in the geopolitical power dynamics (Akhter, 2015; Mallick, 2020). The boundary shared by the countries in the union territory of Kashmir has posed crucial challenge to the functioning of the treaty over the past three decades. As a response to militant attacks on the Indian military in Kashmir, India halted water-related decision-making and alerted Pakistan of its intentions to terminate the treaty (Nandy, 2023). As of April 2025, IWT remains in abeyance, as India unilaterally suspended the treaty as a response to a terrorist attack in Jammu & Kashmir, citing concerns of Pakistan backing cross-border terrorism and affecting national security. The suspension of the treaty by India was received with condemnation by

Pakistan which considered it an ‘Act of War’. Abeyance of the treaty was also followed by further diplomatic crisis and military skirmishes nearing a war situation between the two nuclear armed neighbors. These recent developments indicate that IWT not only serves as a water management agreement but also as a critical communication channel that has profound geopolitical implications in global security (Qamar et al., 2019). Although the treaty has been used as a tool to respond to existing geo-political tension, its provisions themselves have not been the cause of the disputes as opposed to the media portrayals and have the potential to increase the cooperation (Turgul et al., 2024) ; however, the riparians have showcased a ‘to each his own’ attitude during disputes, which has contributed to the aforementioned notion (Earle et al., 2010). The treaty currently lacks plurality acknowledging the dynamics and dependencies of different sectors and actors which are complexly interlinked in cross border resources management in an institutionally complex Indus basin (Bulkeley et al., 2014; Talebian et al., 2025).

Overall, India as an upper riparian, can use all flow of eastern rivers and non-consumptive use of western rivers while they flow in Indian territory but is burdened with greater responsibility of maintaining the flows of IWT rivers. Pakistan, on the other side, is a bigger stakeholder as IRS sustain most of the country’s water requirement and is thus burdened with heavier consequences. Pakistan shared concerns regarding their authority in the treaty whereas India feels larger onus to protect the functioning of the treaty at the expense of their riparian rights (The Tribune, 2022). India uses around 95% of the flows of eastern rivers (Banerji, 2024) whereas Pakistan has compromised its use of Ravi and Sutlej rivers entirely (Zawahri, 2004). On the western rivers side, India utilizes about 17% and 43% of the Chenab and Jhelum River’s water for hydropower generation (Maharajan and Antahal, 2025) and feels frustrations over long delays in developing non-consumptive water management structures on these rivers (Miner et al., 2009) whereas Pakistan has raised concerns over impacts on domestic and agricultural usage downstream of Chenab and Jhelum rivers (Hussain et al., 2021; Mustafa, 2007). Thus, the difference in the role and apprehensions of the two riparians was observed to give rise to lack of trust and concerns of power imbalance increasing tensions (Hanasz, 2014; Hussain et al., 2021; Qamar et al., 2019).

5.2 Hydropower Development

As agriculture has played an important role in shaping IWT in the past, hydropower development is a key factor in the present of the IWT. Bhakra Nangal dam (1325 MW) on Sutlej River was developed by India in 1963 and Tarbela dam (4888 MW) on Indus River was opened in 1976 by Pakistan under Indus basin project. These major dams along with few large dams on the tributaries support the irrigation through extensive canals, regulate the water levels and generate ample amounts of electricity for the downstream population and thus have been crucial to the economic development of the respective countries.

Most of the disputes regarding the water sharing were observed to be regarding the development of hydropower projects on western rivers by India (Miner et al., 2009; Akhter, 2010). Salal I, II, Ratle and Baglihar hydropower project on Chenab, Uri and Kishanganga Hydropower project on Jhelum are some of the prime examples. Under IWT, India is allowed to develop run-of-river hydroelectric projects on western rivers but cannot let the flow to Pakistan deplete. Pakistan has opposed the several run-of-river projects proposed by India with the concerns of them violating the treaty. Pakistan was also observed to be concerned about the design, capacity of reservoir, inflows, height and depletion of the flows reaching downstream (Akhter, 2010; Zawahri, 2004). India has countered that the dams do not have pondage and thus cannot interfere with the downstream flows (Iyer, 2007). The disputes were first taken to the PIC and are tried to be resolved internally. However, in all cases, the disputes could not be solved internally and were taken to a *Court of Arbitration* and *Neutral Expert* as directed in the treaty. While disputes regarding many of the hydro-electric projects were resolved over the years, a few projects such as Tulbul Navigation project were suspended (Parajuli et al., 2003).

Overall, high altitudes of Himalayas have large hydropower potential due to steep natural gradients and perennial supply of water. Theoretical hydropower potential in Indus is around 1565 TWh/year out of which 306 TWh/year has been visualized, although most of which is not feasible considering financial, technical and sustainability constrains (Dhaubanjar et al., 2024). Hydropower projects disputes started arising in IWT at the beginning of the early 2000s with the start of Himalayan hydropower boom (Figure 3) (Lord et al., 2020). Amongst the 369 hydropower projects in Indus basin, 47% plants are planned whereas 25% are under construction (Dhaubanjar et al., 2024), thus, indicating that many hydropower plants are in offing in the coming future. Indian states in IRS have been estimated to have a hydropower potential of 33000 MW out of which 11% have been realized (CEA, 2019) whereas Pakistan has potential of 50000 MW out of which 14% has been realized (Scott et al., 2019). Most of the potential are realized for a reservoir and are often not feasible due to topographical constraints (CEA, 2019). Furthermore, the long-standing water and energy demands gaps in the Jammu and Kashmir region (Miner et al., 2009) and increasing energy demands in the Punjab region (Salman and Uprety, 2021) also prompt both countries to look for alternate sources for energy security. Considering the increasing energy demand and gaps in energy supply in both countries (Miner et al., 2009), it is likely that hydropower, especially run-of-river projects may remain an option for energy generation.

5.3 Flooding and Natural Hazards

In the initial years of treaty, the disputes were about new hydropower development whereas we can observe a shift in the nature of disputes as they diversify towards environmental and risk management in the recent decade. Devastating 2022 Pakistan flood sparked the discussion regarding increasing natural hazards and water-related risks in the Indus basin. Indus and its tributaries have been historically prone to flooding hazards triggered due to heavy Indian summer monsoon (ISM) rainfall and snow and glacier melt runoff in the upper basins (Nanditha et al., 2022; Ali, 2013). Historically, the western rivers are associated with the highest number of flooding events in Pakistan but floods in Indus and Jhelum could be controlled due to presence of dams (Tariq and Giesen, 2012). From 1950-2022, Pakistan experienced 35 extreme flooding events with more than 100 fatalities, out of which 2010 and 2022 have been considered the most devastating (Paulikas and Rahman, 2013; Nanditha et al., 2022). During the 2022 flood, Pakistan accused India of causing and exacerbating flooding situation, however, India released official statements reinstating no contribution in increasing the flows and false allegations of water-wars (High Commission of India, 2022). IRS has been identified as an extremely sensitive area for fluvial flooding, where vulnerability is mainly driven by population change which enhances exposure and climate change which increases precipitation (Rogers et al., 2025). Based on the climate change risks experienced by countries between 2000-2019, Pakistan is amongst top 10 countries in the global climate risk atlas whereas India is in top 10 in 2019 highlighting the vulnerability of both riparians to extreme events (Eckstein et al., 2021). Apart from fluvial flooding hazards, increasing vulnerability from glacier lake outburst floods (GLOF) could be an additional concern as glacier retreats have increased potentially hazardous lakes in the Himalayan region (Shugar et al., 2020). GLOFs are result of sudden burst of water from a glacier associated lake which releases tremendous amounts of water downstream. In Indus basin, amongst the 10 susceptible transboundary glacier lakes, 8 have the potential to result in a direct impact transboundary GLOF (Dubey et al., 2024).

5.4 Climate Change Impacts

As most of the water is generated by snow and glacier melt in high altitude, these rivers have seasonality in their hydrological regime *i.e.* low flows in winter and around 75% of the flow in summer (Khanal et al., 2021; Lutz et al., 2016). Eastern river basins receive plenty of precipitation from the ISM system in the form of rainfall at lower altitudes and snowfall at higher altitudes from May to September (Azam et al., 2021). Eastern river basins receive plenty of precipitation from the ISM in the form of rainfall at lower altitudes and snowfall at higher altitudes from May to September (Azam et al., 2021). Western river basins receive more precipitation from western disturbances in the form of snowfall (Dimri et al., 2015). The western basins have a higher dependence on the snow and glacier melt whereas eastern basins are more influenced by snowmelt and rainfall runoff (Khanal et al., 2021; Momblanch 2019; Shirsat et al., 2021). Moreover, the upper parts of the basins in the IRS are also one of the climate-change hotspots, showing a greater degree of warming than the global average (Pepin et al., 2015). As a result, the glaciers in IRS, have been reported to retreat with the average retreat rate of -12.7 ± 13.2 m/a whereas the average area loss rate of -0.3%/a, with a slightly lesser rates of stable conditions of glaciers in the Karakoram range in the Indus (Kulkarni et al., 2021). Glaciers have shown increasing mass loss in the past few decades which ranges from -0.34 meter water equivalent per anum (m.w.e.a^{-1}) in the western river basins to -0.56 m.w.e.a^{-1} in the eastern river basins (Kulkarni et al., 2023). Western river basins also have a higher glacier area and volume compared to eastern river basins (Table 1), creating differences in the glacier buffering to runoff (Pritchard, 2019). Western basins, especially Indus are expected to have a higher glacier buffer with the glacier melt peak water arriving in late 2070s whereas eastern basins have lesser glacier buffer with peak water projected in 2040s-2050s (Huss and Hock, 2018; Kulkarni et al., 2023; Prasad et al., 2019). Changes in precipitation, reduction in snowfall, and less glacier buffer are expected to create differing changes in the hydrological regime and total water availability in the eastern and western river basins. These changes are expected to exacerbate in the future with continued warming and uncertain changes in precipitation with possible decreases in the crucial summer flow peaks (Khanal et al., 2021), thus creating a need to secure the treaty against the changes in interannual and seasonal variability in hydrological regime.

5.5 Socio-economic Growth

Lower basins of the treaty rivers are densely populated regions where rapid growth in the population and economic development causes an increase in water demand. Population of India increased from 400 million to 1 billion whereas population of Pakistan grew from 40 to 150 million from 1950 to 2000 (Dinar et al., 2013). The population increases also led to rapid urbanization and associated increases in water, food and energy demands (Sadashivam and Tabassum, 2016; Mukherji et al., 2018) (Figure 6). Irrigated areas in IRS increased by 13% between 2000 to 2010 with the highest increase observed in Indus (31%) and Chenab (23%). As climate change has been observed to impact the water availability in the Indus River system, the increasing multi-sectoral demands are observed to add stress on the already limited water resources (Rasul, 2014; Yang et al., 2016) which would further impact rigid water governance structures.

At present, around 84 million of population resides in the Indian territories of Indus basin whereas Pakistan hosts around 169 million (Smolenaars et al., 2021), with Sutlej being most populated followed by Ravi and Jhelum. It is projected to increase by 103% by the end of the century in the shared socio-economic pathways (SSP) of downhill (D) scenario (abbreviated as SSP-D in Figure 3) in India and by 144% in Pakistan. Most of the population increases are projected to centered around urban centers such as Lahore, Islamabad, Srinagar, Jammu. The associated economic activities of the increasing population are projected to increase gross domestic production (GDP) per capita by about eight-fold, especially in the prosperous scenario (SSP-P) (Wiijngaard et al., 2018; Murakami and Yamagata, 2019) (Figure 4). At present, GDP per capita of India is around 2375 USD with a 7% growth rate whereas Pakistan has GDP of 1545 USD with a growth rate of 6.2% (https://www.worldometers.info/gdp/gdp-by-country/). As a result, large increases in water, energy and food sectors have been projected by the end of the century (Riahi et al., 2017; Smolenaars et al., 2021). The water requirements show steep increases in all scenarios, increasing by 90% in SSP-P and by 220% in SSP-D by the end of the century. This large increase will be complemented by the region's food and energy requirements leading to increases in food and energy requirement by about 200% by the end of the century in SSP-D with an expected increase in irrigation area and higher hydropower development.

Many nexus modeling studies accounting for impacts of socio-economic projections have highlighted the multifold increases in vulnerability of the basin's water resources due to a combined impacts of climatic and socio-economic changes (Immerzeel et al., 2020; Momblanch et al., 2019; Huggins et al., 2022) which require further attention to secure water resources in the future.

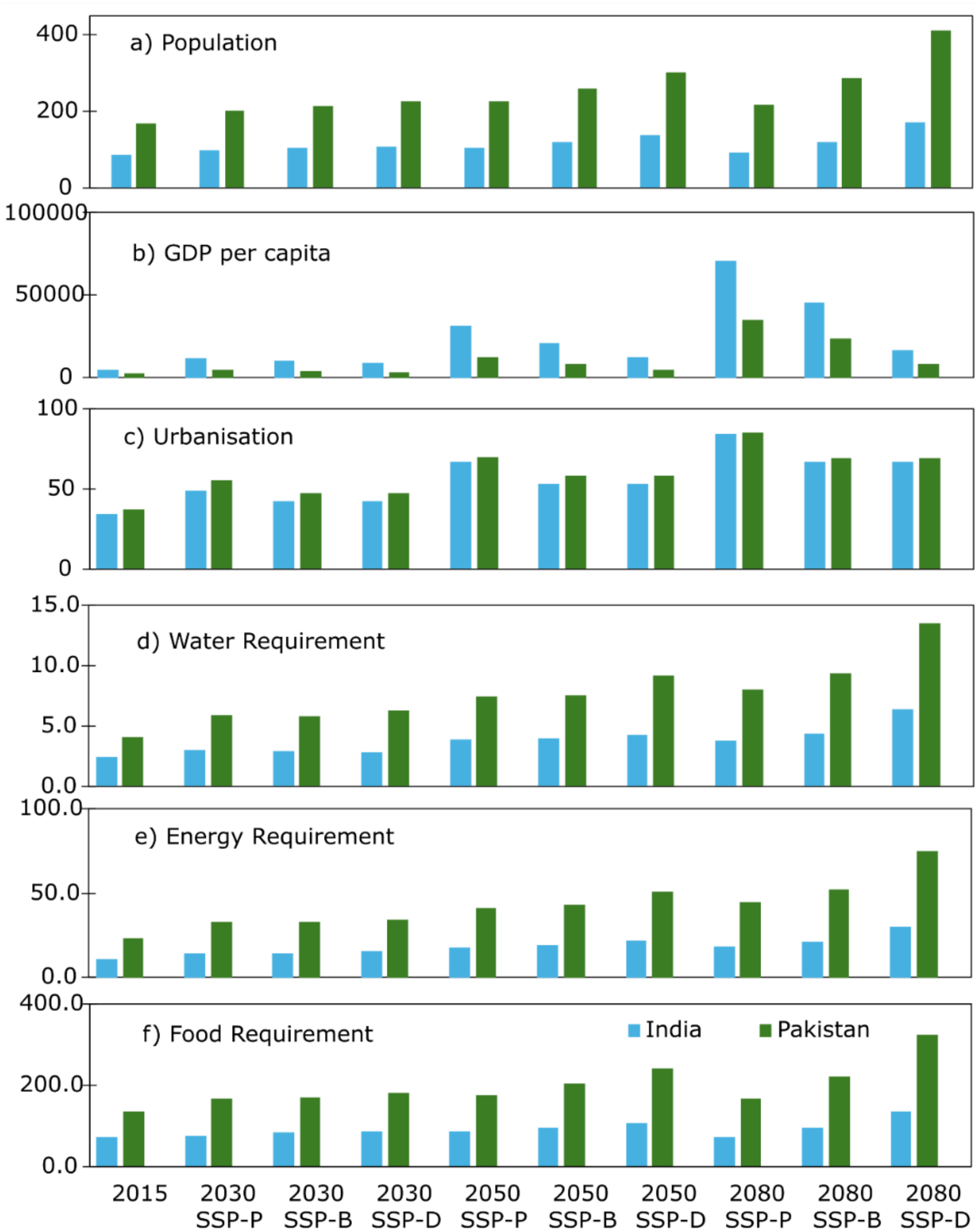

Figure 4. Projections of future socio-economic requirements for the Indus basins of India and Pakistan for present (2015) and future time slices of 2030, 2050 and 2100. India and Pakistan denote to the geographical area of the countries within Indus basin. Population is provided in millions, GDP per capita is in PPP, billions 2005 USD$, Urbanization is given in % of total population living in urban areas, Water Requirement is given in km^3 drinking water /year, energy

requirement is in 10^9 MWh/year and food requirement is in 10^{12} Kcal/year. SSP-P denotes a prosperous scenario, SSP-B is business as usual scenario whereas SSP-D is a downhill scenario (Source: Smolenaars et al., 2021)

5.6 Baseline Water Stress

As a result of the aforementioned challenges, IRS has been classified as a water stressed river basin in many global scale analysis (Immerzeel et al., 2020; Huggins et al., 2022). Immerzeel et al. (2020) has classified IRS as the most critical water tower where water stress is driven by water demands from heavily irrigated areas and increasing population. Moreover, Huggins et al. (2022) also identified IRS as the hotspot of very high water stress resulting in high social vulnerability. Within the treaty rivers, Chenab and Ravi (forming the physical divide of IWT) are observed to have the extremely high baseline water stress indices whereas Indus and Beas have a low and medium risk status, respectively (Figure 5) (Kuzma et al., 2023). Furthermore, the treaty rivers are also at high to extremely high riverine flood risk with Sutlej and Indus being highest risk areas. In the drought risk analysis, Sutlej is at medium risk whereas other rivers are at medium to high risk with Jhelum at extremely high risk. Groundwater table decline is at extremely high to high risk in the plains of all treaty rivers except Indus aligning with the status of Indus aquifer as one of the most stressed aquifers. The analysis of the various water risk indicators emphasizes the high baseline water risk that the IWT rivers are currently under, and which will exacerbate with the governance ineffectiveness.

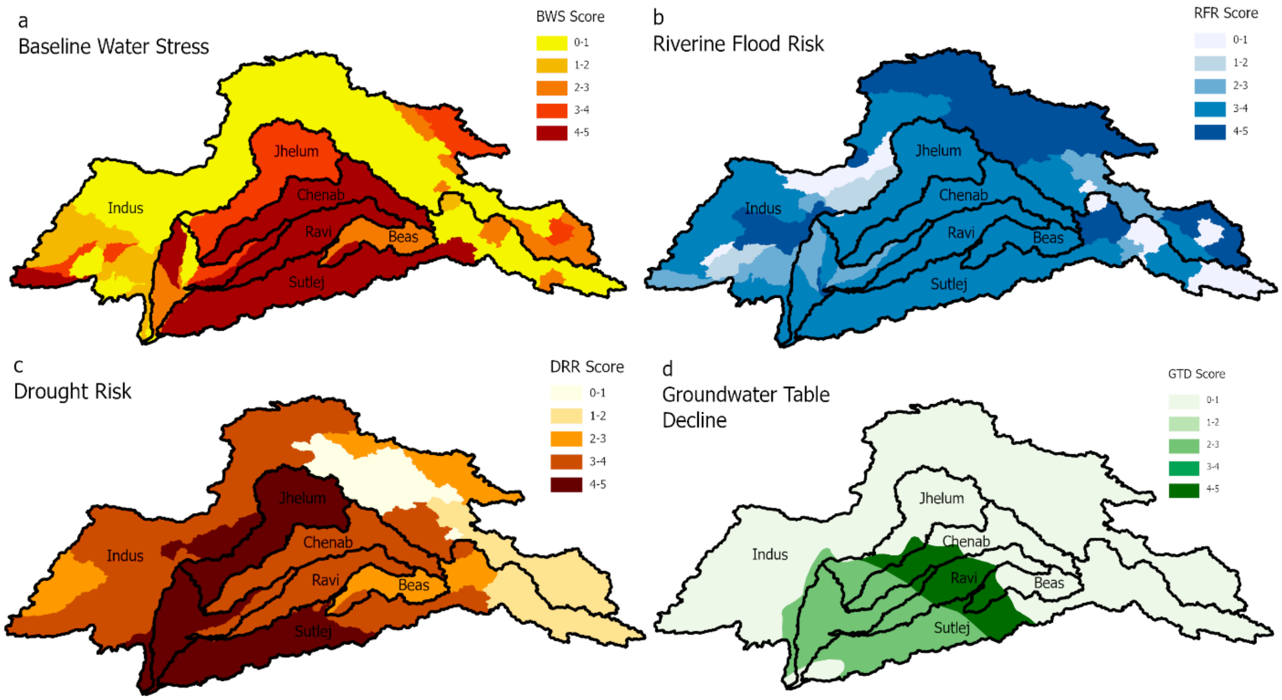

Figure 5. Water risk indicators for IWT rivers based on Aqueduct Water risk Atlas v4.0, all scores are given on a scale of 0 to 5 where 5 indicates extremely high risk and 0 indicates low risk (Source: Kuzma et al. (2023)

5.7 Interconnected Challenges

Over the years, the nature of the challenges IWT has faced has changed from disputes regarding water management development projects to natural hazards risks to changing water availability which highlights the conditions during the formation of the treaty are changing rapidly. Although these challenges remain the major cause of unsettlement in the present, their interaction with the other newly emerging challenges is increasingly affecting already limited cooperation in the basin (Figure 6). We reckon that the interconnections between various bio-physical, socio-economic and governance related challenges may create unprecedented dynamics in the basin which will further evolve in multiple directions in the future.

6. Future: Modernization

6.1 Need for Modernization

In addition to the emerging challenges, the current legislation under IWT is often considered rigid, which may not be enough in the changing dynamics of basin. As the uncertainty in water resources will increase in the coming future, both riparians will inevitably feel the need to secure resources for their countries, which could increase the tensions. Freshwater Agreements Atlas highlights four criteria for the treaty writing and updating which include adaptable management structures, flexible water allocation and quality, equitable distribution of benefits and detailed conflict resolution mechanism (Wolf, 2002). Adaptable management structure emphasizes allowing certain levels of flexibility that can incorporate changing basin dynamics and new information and technologies which are currently lacking in IWT. Furthermore, clear and flexible allocation should include water quality along with water quantity. Equitable distribution of benefits encourages to include benefits beyond water that can cover energy generation and risk management. Detailed conflict resolution mechanisms are a requisite for a successful water treaty which has been crucial in the functioning of IWT. The current shortcomings of the treaty are observed to mainly arise from its lack of flexibility, limited sharing resources and benefits and ‘to each his own' perspective added to already changing environmental and social dynamics in the basin. If the treaty is not modernized to be flexible, the current lack of any legislation would exacerbate the challenges with escalation of conflicts and cascading effects into livelihoods of people.

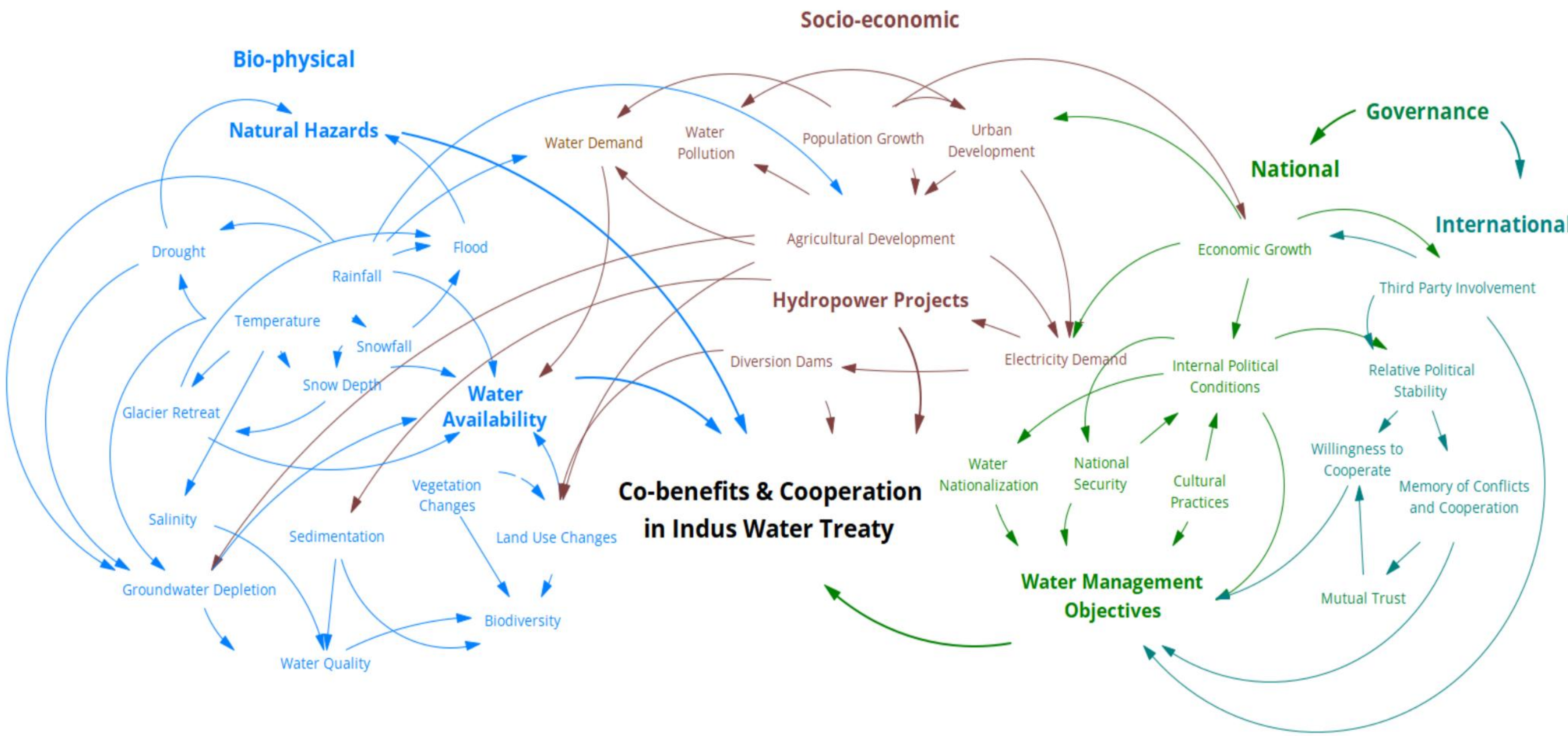

Figure 6. Complex causal loop of interconnected challenges that affect the realization of co-benefits and cooperation in the IWT. Thicker elements highlight the major challenges observed in the present.

Overall, IWT would benefit by adding flexibility to incorporate changing conditions in the basin clause related to climate change related changes in water availability and natural hazards by increasing climate-cooperation, securing water quality and groundwater resources along with surface water, finding co-benefits beyond water to water-related sectors to increase bilateral engagement and strengthening the conflict resolution mechanism (Miner et al., 2009; Banerji, 2024; Wolf, 2002).

Signed at the similar time as IWT in 1961, US-Canada Columbia River Treaty is considered as a modern water treaty for its characteristics of finding mutual benefits of hydropower generation and energy sharing, modifications since its inceptions to improve flood risk mitigation and plans to include inclusion of the Indigenous Nations' interests (Stern, 2018; Geranios, 2024; Giordano and Wolf, 2003). Similarly, US-Mexico treaty of 1944 on Colorado and Rio Grande rivers is praised for its flexibility that allows for consensual actions and expansions to include the water quality and broad vision for future of the river basin while overcoming power imbalance (Umoff, 2008). The Nile Basin initiative of 1999 born amongst more conflicts and less cooperative conditions in 10 African countries contains modern programs such as shared vision program, regional trade program with a detailed updated strategies and visions for the river basin (Cascão et al., 2020; Swain, 2011). In all these cases, regular meetings, information exchanges and planning formed a constructive framework of transboundary governance overcoming the inherent challenges. These characteristics of modern water treaties worldwide emphasize the need for modernization of IWT.

6.2 Modernization Sectors

The modernization sectors are identified based on the challenges observed in the present and characteristics of priority adaptation projects present in other contemporary modern water treaties based on the UNEP, (2010) and Earle et al. (2010) and are modified based on regional requirements of IRS (Table 2). Rationales of Improvement of Existing Legislation to enhance flexibility, Climate Change Mitigation/Adaptation for incorporating changing basin dynamics, Environment Protection for increasing long-term environmental sustainability of the IRS, Disaster Risk and Management for reducing water-related risks, Community Engagement for enhancing plurality and adaptability of the governance structure and Dispute Resolution Mechanism for continued cooperation and long term security of the treaty have been prioritized based on the aforementioned challenges.

Table 2. Modernization sectors for IWT

Sr	Sector	Is it included in the IWT?	Rationale
1	Sustainable Agriculture	Partial	Improvement of Existing Legislation; Climate Change Mitigation/Adaptation
2	Water Resources Management	Yes	Improvement of Existing Legislation; Climate Change Mitigation/Adaptation
3	Energy Generation and Sharing	Yes	Improvement of Existing Legislation; Climate Change Mitigation/Adaptation
4	Physical Infrastructure	Yes	Improvement of Existing Legislation; Disaster and Risk Management
5	Groundwater Allocation	No	Environmental Protection
6	Water Quality	No	Environmental Protection
7	Forestry	No	Environmental Protection
8	Ecosystem and Biodiversity Protection	No	Environmental Protection; Climate Change Mitigation/Adaptation
9	Drought Management	No	Disaster and Risk Management; Climate Change Mitigation/Adaptation
10	Flood Management	No	Disaster and Risk Management; Climate Change Mitigation/Adaptation
11	Tourism and Recreation	No	Community Engagement
12	Community Awareness	No	Community Engagement
13	Protection of Indigenous Knowledge	No	Community Engagement
14	Future Co-operation	Partial	Dispute Resolution Mechanism; Improvement of Existing Legislation
15	Scientific Knowledge Sharing	Partial	Dispute Resolution Mechanism; Improvement of Existing Legislation; Disaster and Risk Management; Climate Change Mitigation/Adaptation
16	International Involvement	Yes	Dispute Resolution Mechanism; Improvement of Existing Legislation

6.3. Analysis of Modernization Sectors

As irrigated agriculture has been a major driver of the IWT formulation and implemntation, protection of agricultural practices and inclusion of sustainable agriculture and efficient water use is of high priority for both riparians. Water resources management can secure water resources for both riparians in the cases of interannual and seasonal changes in total water availability, especially in the crucial cultivation season. Water treaties often only consider division of surface water, completely ignoring groundwater (Umoff, 2008). In IRS, around 35-40% of the total flow is attributed to the baseflow/groundwater (Khanal et al., 2021). Indus aquifer, a transboundary aquifer between India and Pakistan, is also one of the most stressed aquifers in the world due to tremendous pumping for agriculture, high levels of pollution and salinity issues, especially in Punjab and Haryana (Umar et al., 2022; Cheema et al., 2014). Modernization would need legislation regarding improving the health of the Indus aquifer. Indus River is also one of the plastic polluted rivers; water quality in the lower basins is decreasing due to phosphate and pesticide dumping from agricultural flows and the urban areas (Khan et al., 2018). Modernization would require water quality legislation on a high priority basis. Water resources management and energy generation have been included in the treaty but only in terms of allocation of rivers and allowance to build hydropower. The treaty would benefit from a detailed energy generation clause and bi-lateral compensation mechanism on energy development or sharing. Pakistan has more physical infrastructure on the river and in the surrounding area, thus, making protection of physical infrastructure a high priority for Pakistan. Further, ecosystem and biodiversity protection are a high priority for both countries as changes in climatic conditions would entail changes in ecosystem functioning. The most beneficial addition to the treaty would be disaster and risk management for both countries. Recent flooding disasters have increased the need of legislation regarding risk management and early warning systems to the highest priority. Transboundary basins often must work co-operatively in order to tackle disasters such as flood and droughts. In India-Nepal Mahakali treaty, Pancheshwar Multipurpose Project, a bi-national project to be installed at border for improved irrigation in both countries and to prevent flooding in the downstream Indian state of Bihar where flooding is a common enemy each year (Hanasz, 2015; Miner et al., 2009). An early warning system would benefit the mountain communities of both countries. Drought conditions would require each country to secure water resources for their country, which would put stress on the treaty, thus making it a high priority inclusion. Further, the upper Indus system has multiple popular tourist areas and holy sites of religious importance for both India and Pakistan which would need to be protected. Community awareness would help in giving priority to management of the IRB. Further, scientific knowledge sharing would benefit the region to prepare for a climate change-induced emergency. Although it is included in the treaty in terms of daily flows data sharing, its modernization would be crucial. The treaty has incorporated future co-operation for long-term sustenance of the treaty in Article 7, its upgradation for modern times would benefit both parties. Moreover, international involvement has been useful for the sustenance of the treaty. The World Bank as a negotiator and neutral third party has helped in resolving disputes and thus has a crucial role in the survival of the treaty (Zawahri, 2009). The role of PIC as an internal facilitator could be enhanced with the help of the third party and utilized more to strengthen the correspondence with frequent meetings of provincial representative stakeholders. Shared development projects through the assistance of the third party would benefit both countries by increasing co-benefits and enhanced cooperation (Cascão et al., 2020).

This paper has sought to identify the challenges and modernization within the current scope of the treaty and considers renegotiation beyond our scope of analysis. We highlight the modern aspects of water sharing, drawing examples of other international water treaties that would benefit IWT and ensure its long-term sustenance. IWT and by extension the livelihoods in the IRS would benefit from a modernization that is carefully and bilaterally drafted to protect the water resources to benefit both India and Pakistan.

7. Conclusion

IWT was successfully used for over 60 years to share and distribute the water resources of Indus and its tributaries between India and Pakistan. Spatio-temporal analysis of the conditions during the formation of the treaty and the present highlight the changing basin dynamics and emerging challenges. Geo-political tensions, climate change impacts, natural hazards, socio-economic requirements and baseline water stress have been identified as major challenges which have contributed to the diminishing cooperation in IWT since its inception and the current state of suspension. If the current suspended state is not utilized for timely modernization, these challenges would exacerbate in the future and have cascading impacts on the people and ecosystems. IWT also lacked the attributes observed in the other modern water treaties in the world which could safeguard its sustenance. Modernization sectors addressing these challenges would enhance the stability of the treaty by reducing risks and increasing security of water resources for both riparians.

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CRediT Author Statement

TSS: Conceptualization, Methodology, Investigation, Visualization, Formal Analysis, Writing-Original draft preparation, Writing-Reviewing and Editing. **LBF**: Resources, Validation, Writing-Reviewing and Editing, Supervision. **CAS**: Validation, Writing-Reviewing and Editing, Supervision, Project Administration, Funding Acquisition.

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