Environmental Sustainability and Adaptations in Indus Basin

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Abstract

The Indus Basin's advantageous climate and topography rendered it a prime site for the implementation of an irrigation system. This study looks at how the Indus Basin is affected by climate change. Changes in water flow, glacial/snow melt, and catchment areas in the Indus and its tributaries are revealed by trend analysis from hydro-logical stations. A network of canals constituted of trans-boundary rivers was built beside the Indus River System (IRS), soon after the implementation of the Indus Water Treaty, about 70% of its water was allocated for irrigation purposes. An evident increase from 8.5 to 18.2 million hectares (MH) in the cropland area in Pakistan is monitored, whereas in India it increased widely from 2.02 to 8.5 MH that is about three times of the pre-vious figures due to expansion of the Indus irrigation network. Water tables have dropped and water logging has resulted from urbanization and groundwater extraction, while the use of pesticides and fertilizers has lowered the quality of the water.These problems are made worse by climate change, which presents serious obstacles to the region's water security, environmental sustainability, and economic growth.This article provides a comprehensive analysis of the modifications in the Indus Basin irrigation system and the impact of these changes on environmental resources. We can create practical plans to lessen the consequences of climate change and guarantee the Indus Basin has a safe and sustainable water supply in the future by comprehending how it affects the basin.

Keywords: Indus basin, hydro-logical stations, Indus River System (IRS), environmental sustainability.

The Indus Basin has an intriguing geological past and is a crucial water supply that China, India, and Pakistan share. The Great Himalayan Ranges were formed approximately 50 million years ago when the Indian and Siberian plates collided, uplifting the shallow Tethys Sea. (Martin, 2017) The northern Indus Basin is dominated by this magnificent mountain range (Arif, 2021), whereas the eastern and southern regions are made up of level plains in Sindh and Punjab, respectively. The 3,200-kilometer-long Indus River rises in Tibet, China, then flows through India and Pakistan before flowing south. It converges with tributaries like Shyok, Zanskar, Gilgit, Swat, and Kabul, forming the Panjnad by merging with Jhelum, Chenab, Ravi, Beas, and Sutlej (2021). Finally, it discharges into the Arabian Sea (Shamshad, 2018). The upper Indus Basin, covering high-altitude mountainous regions in China's Tibet and India's Ladakh, is physically separate from the lower Indus Basin, comprising the vast Punjab and Sindh plains in Pakistan (Pithawala, 1936).

The region's unique geography and climate support a rich ecosystem, with the northern region experiencing high moisture levels, while the Punjab and Sindh provinces have semi-arid and arid climates, respectively. Historically, the Indus Basin has shown a good rate of water flow annually during different seasons, with a mean volume of water flow at various rivers. This transboundary water resource plays a crucial role in supporting the economies, livelihoods, and ecosystems of China, India, and Pakistan. Effective management and cooperation among the three countries are essential to address challenges like climate change, water scarcity, and environmental degradation. By working together, China, India, and Pakistan can harness the potential of the Indus Basin, promoting regional cooperation, economic growth, and environmental sustainability (Abbas, 2014).

Table 1: Mean volume of flow at rim Stations in million acre-feet (Ali, 2009)

River	Winter (Oct-Mar)	Early Kharif (Apr. Jun.)	Monsoon (July-Sept)	Annual
Indus	12.9	27.9	48.7	89.5
Jhelum	4.5	9.9	8.2	22.6
Chenab	3.7	6.7	13.1	23.5
Ravi	1.2	1.9	3.3	6.4
Beas	2.4	1.9	8.5	12.8
Sutlej	2.0	3.2	8.4	13.6
Total	26.7	51.5	90.2	168.4

The primary Indus River receives the majority, or 52%, of the water in the Indus River system, while its tributaries contribute the remaining 48%. Over 50% of the annual water inflow into the Indus River Basin originates from glaciers, while the other 50% is sourced from a well-defined monsoon system in the upper catchment area (Qaisar, 2018 & DO 35/8588. 1958-1959 (British Archives)). Based on the data obtained over few decades, the Indus River system has experienced a decline in the amount of water flowing through it. (Table 2)

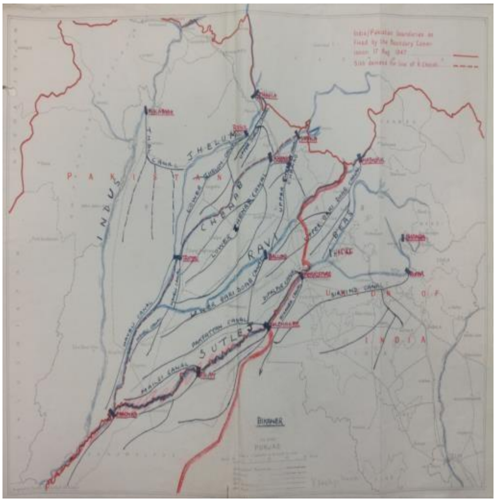

Figure 1. Indus Irrigation System, 1947 [2]

The objective of this article is to assess the sustainability of climate-water governance in the Indus Basin, with a particular focus on the impasse in irrigation practices within the region. The article seeks to underscore the challenges confronting the Indus Basin irrigation system, encompassing the depletion of natural resources, environmental degradation, and the adverse effects of human activities on the river's ecological state. Additionally, the article endeavors to propose recommendations for sustainable water management, such as the adoption of integrated water resource management (IWRM) and the promotion of drought-tolerant crops. Table 2. Indus River System Water Divisions and Characteristics (Basharat, 2012)

River	Water Share (Before IWT)	Water Share (After IWT)	Glacial Contribution	Annual Flow during Monsoon Season	Mean Annual Flow	Catchment Area	Agricultural Area
Indus	116.97 billion m^3	19.48 billion m^3	Snow Melt 25% Glacial Melt 41%,	High	71.2 billion m^3	1,165,000 km^2	1,200,000 km^2
Jhelum	32.08 billion m^3	5.41 billion m^3	Snow Melt (29 to 58%)	High	21.3 billion m^3	41,000 km^2	200,000 km^2
Chenab	53.74 billion m^3	9.02 billion m^3	Total Glacial and Snow Melt 49%	High	24.5 billion m^3	123,000 km^2	300,000 km^2
Sutlej	36.14 billion m^3	6.02 billion m^3	Snow Melt=8-9% Glacial 41-42%	High	20.5 billion m^3	47,000 km^2	200,000 km^2
Ravi	21.67 billion m^3	3.61 billion m^3	Not specified	High	11.8 billion m^3	21,000 km^2	100,000 km^2
Beas	20.35 billion m^3	3.39 billion m^3	Not specified	High	10.5 billion m^3	19,000 km^2	100,000 km^2

Materials and Methods

In this study, authors undertook an exhaustive examination of Pakistan's current water resources, the challenges confronting irrigated agriculture, and prospective strategies to surmount these challenges to ensure the sustainability of irrigated agriculture in the Indus Basin. We have employed a blend of qualitative and quantitative research methodologies, including literature reviews, reports and data analysis to gather information and insights. For this research hydrological data was obtained from surface water hydrology project (SWHP) of WAPDA (water and power development authority of Pakistan) at Jinnah Barrage, Chashma Barrage, Mangla Barrage, Rasul Barrage, Taunsa Barrage from Head works of Indus, Jhelum, Chenab, Ravi, Sutlej, Beas Rivers. Since 1960, WAPDA has installed gauging stations in the area studied. These values were computed to get information such as water share before and after IWT, glacial contribution, annual flow during monsoon season, mean annual flow, catchment area and agricultural area. More over important government reports and literature was thoroughly analyzed for content analysis.

Discussion

3.1. Historical developments in the Indus basin irrigation system

Leaders of the upper Indus basin played a crucial role in the initial phases of canal development, enabling the construction of the complex irrigation system that is currently in operation. The most ancient civilization of the world Indus Valley Civilization was agrarian-based. For the development of their livelihood and boost in economic growth, they were totally dependent upon waters of Indus (Khan, 2008 & Khan , 1991). Various ancient Indian clans and rulers like Cholas, Pandyas, Shakas, Pallavas and Bhoj, were eminent rulers developed the Indus Basin after the decline if Indus Valley Civilization (2008). Significant construction took place in Punjab, Sindh, and the Jammu & Kashmir regions. Further developmental work was later conducted throughout Muslim rule of India followed by British rulers.

3.2. Territorial hydrological developments in British India

In the middle of the 19th century, during Britain's control, construction commenced on the Indus irrigation system that exists today. The development of extensive agriculture in British India was driven by the need for food and the economic benefits associated with agricultural products, especially cotton. A multitude of irrigation canals were restored, several of which were derived from the Indus River system. In order to ensure a consistent water supply for their agricultural regions, Punjab, Sindh, and Khyber Pakhtunkhwa (KPK) constructed several permanent head works. In 1887, the flow of water from the Chenab River was diverted to Sandal Bar through the Lower Chenab Canal (Paustian, 1968). Subsequently, in 1890, construction of the Marala Head works commenced on the Chenab River with the purpose of irrigating the Upper Rachna Doab via the Upper Chenab Canal. The Rasul Headwork's were constructed in 1897 along the Jhelum River to supply water for the Lower Jhelum Canal, which facilitated irrigation of the fertile land in the Chaj Doab region . The Madhopur Headwork's, constructed in 1902 on the Ravi River, provided irrigation water to the Upper Bari Doab region for agricultural purposes. Furthermore, in the year 1905, the Triple Canal Project was officially sanctioned and meticulously planned. For the first time in this undertaking, water could be moved from one river to another. The Upper Jhelum Canal, a gate-regulated stream, was built to irrigate approximately 139,212 hectares (ha) of land each year, spanning from Mangla to Khanki. After its completion in 1917, the Lower Chenab Canal started to discharge into the Chenab River, located beyond the Khanki Barrage, near its upstream end. The Upper Chenab Canal, which commenced 58 km upstream of Khanki at the Marala Barrage and extended to Balloki, facilitated irrigation for approximately 262,236.7 hectares of agricultural land. The water from the canal, which commenced operations in 1912 for the purpose of irrigation, ultimately flows into the Ravi River, situated upstream from Balloki Headworks. The Lower Bari Doab canal, which covered an area of 354,910 hectares in Multan and the Montgomery District (Sahiwal), was supplied by a 0.5 km long weir located on the Ravi River near Balloki. During the British Era, it was one of the most notable irrigation projects undertaken (Vaidyanthan, 1999). In 1921, after World War I, the British administration made the decision to irrigate the arid areas of the Sutlej Valley by repairing and enlarging the existing inundation canals. The project aimed to irrigate a growing area of land and maintain a continuous water supply to the inundation canals after their renovation, achieved by using barrages to control the flow of river water. In 1933, the arid landscape was transformed into cultivable land by the construction of four dams and eleven channels along the Sutlej River. The Ferozepur Barrage was constructed at Ferozepur, with the purpose of irrigating farmed lands in Bikaner State, Ferozepur district, northeastern sections of Bahawalpur State, Lahore and Montgomery (Sahiwal) Districts. The Bikaner Canal, Eastern Canal, and Dipalpur Canal are the three non-perennial canals that are part of the barrage system. Sulemanki Barrage was built with the goal of making irrigation easier in a few regions of the state of Bahawalpur. The Eastern Sidiqia Canal, Fordwah Canal, and Pakpattan Canal are the three permanent canals that the barrage is equipped with. In addition, Tehsil Hasilpur's Islam Barrage made it easier to irrigate about 577,892 hectares of land. Three non-perennial canals—the Mailsi Canal, the Qaimpur Canal, and the Bahawal Canal—were used in the construction of this barrage. Two canals were built after the Sutlej and Chenab rivers joined: the Abbasia Canal, which runs constantly, and the Panjnad Canal, which runs only sometimes. 44,920 hectares of agricultural land were irrigated with the former, and 541,875 hectares were aided by the latter. To irrigate the Bikaner State, Maharaja Ganga Singh built a canal on the river's left bank in 1922 (Maryam, 2021).

The Sukkur Barrage Project, sanctioned in 1923 and completed in 1932, became the inaugural barrage on the Indus River, featuring seven channels (Vaidyanthan, 1999). The Trimmu Barrage, consisting of three canals, was constructed between 1937 and 1938 on the Chenab River, downstream of the Jhelum River confluence. This barrage was the last one completed prior to the outbreak of World War II. The construction of Jinnah Barrage and Kotri Barrage, two defenses on the Indus River, was underway during the partition of the Indian subcontinent. Additionally, the Bhakra Dam was present on the Sutlej River during that period. The construction of the Kotri Barrage was completed in 1955, while the Jinnah Barrage was completed in 1947 (Stien, 2010).

3.3. Post-partition hydrological developments

The Indus water dispute originated when India acquired the Ferozepur and Madhupur Head works from Pakistan during the partition of India and Pakistan. India's decision to cut off water supplies to the Upper Bari Doab canal made it impossible for any irrigation activities downstream (Siddiqui, 1986). In response to the acute water scarcity, Pakistan promptly constructed the Bombanwali-Ravi-Bedian (BRB) Link Canal to facilitate irrigation in the Upper Bari Doab region. The journey commenced from the Upper Chenab Canal and extended towards the southern direction, covering a total distance of 164 kilometer till reaching Bedian. India constructed two significant canals in order to impede the flow of the Sutlej River into Pakistan downstream. The purpose of constructing the Balloki-Sulemanki Link canal was to facilitate the transportation of water from the Balloki Headworks on the Ravi River to the Sulemanki Headworks on the Sutlej River. This canal serves the function of regulating the water level of the river. The construction of the BRB canal and the Balloki-Sulemanki canal was completed within a span of three years, from 1951 to 1954. Prior to the 1965 conflict, a 101-kilometer canal named the Marala-Ravi Link was constructed to redirect a greater amount of water from the Chenab River to the Ravi River. The building of the Guddu Barrage, which crosses the Indus River and was completed in 1963 in Sindh Province, commenced in 1957. This project aimed to increase the cultivable area in Sindh and Baluchistan by converting the higher inundation canals into perennial canals. The objective was to provide continuous irrigation to 1.13 million hectares of land throughout the year. Later on, the construction of the Kotri Barrage was completed in order to ensure a reliable water supply to the flood canals in southern Sindh. The Guddu and Kotri Barrages transformed a vast barren area into cultivable land. The Taunsa Barrage, a versatile infrastructure built on the

Indus River, was completed in 1958 with the purpose of regulating the distribution of irrigation water (Chaudhry, 2010). The Warsak Dam 2 was constructed in 1960 with the purpose of water storage and energy generation, producing a capacity of 40 MW. Subsequent installation of supplementary generators was carried out to enhance the dam's production capacity (Akhtar, 2017).

A new era of regional mutual co-operation was introduced when Pakistan and India signed the Indus Water Treaty (IWT) in 1960 as a means to address the issues arising from the division of the Indus Basin Rivers. The Indus River receives its water from various rivers that have their source in India. India assumed control of Pakistan's downstream water supplies. In the initial ten years of Pakistan's independence, the country's agricultural output was significantly hampered due to the substantial obstruction or decrease in river water flow. The World Bank and the British Government provided assistance to the twin republics in order to facilitate the establishment of the Indus Water Treaty (IWT). The area of Indus Water Treaty can be visualized from Figure 2.

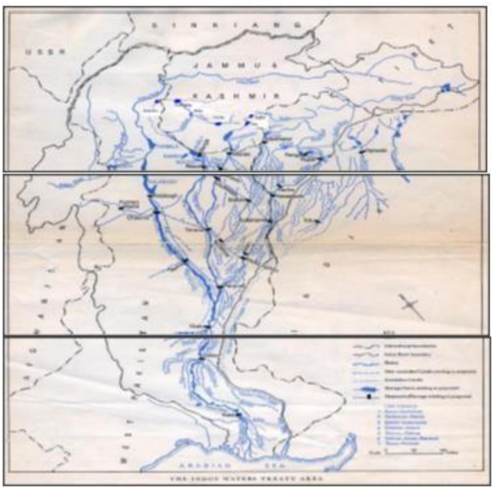

Figure 2. The Indus Water Treaty Area (1999)

Pakistan was granted control over the Indus, Jhelum, and Chenab Rivers in the western region, while India was given the water rights to the Sutlej, Ravi, and Beas Rivers in the eastern region, as stipulated by this treaty. After a decade, both countries were authorized to utilize their allocated water resources autonomously. Pakistani districts dependent on the eastern rivers for agriculture experienced water scarcity due to the construction of dams by India, which altered the water flow as stipulated in the treaty. The "Indus Basin Development Fund" project by the World Bank allocated a total of eight billion US dollars to finance the construction of canals, barrages, and dams in order to address water scarcity in Pakistan's eastern rivers (Biswas, 1992). Furthermore, connection canals were constructed to link the rivers of Punjab in the western and eastern regions, with the purpose of ensuring a consistent supply of water to the crops. Owing to insufficient funds, the project had to be completed in two stages. The construction of Mangla Dam on the Jhelum River in 1967 was a significant component of the initial phase (Khan, 2002).

Several enhancements and alterations were implemented on several of the barrages and canals. Upon the completion of the first phase, the World Bank approved an extra sum of 1.2 billion US dollars, which subsequently initiated the commencement of construction on the second phase in 1968. The construction of Tarbela Dam on the Indus River was completed in 1976. This dam has the capacity to store sufficient water during the dry season to fulfill demand (Siddique, 2012). Mangla and Tarbela dams were responsible for the majority of Pakistan's hydroelectricity generation. The flow of water in rivers such as Rasul, Sidhnai, Chashma, and others was altered by modifying several barrages. The governments of Punjab and Sindh are currently engaged in proactive efforts to save water by implementing canal and watercourse lining measures. The Ghazi-Barotha and Neelum-Jhelum hydro power projects have been successfully completed to generate electricity (Sharma, 2009). The water flow in rivers of Pakistan is diminishing as a result of climate change and the increasing need for water for agriculture purposes. This scarcity of water is anticipated to worse in the near future. Given these concerns, the Pakistani government plans to construct more dams along the Indus River to increase its water storage capacity. Table 3 depicts the present network of canals, encompassing irrigation canals, connecting canals, barrages, and dams.

Table 3: Hydrological Developments in the Indus River System (1999)

River	Hydrological Development Dams	Barrages/Head Works	No. Of off taking canals	Water Passing Through/capacity
Indus	Nimoo Bazgo Dam	Jinnah Barrage (1)	4	1720 cu ft/s
Indus	Tarbela Dam	Chashma Barrage (2) Taunsa Barrage (4)	4 3	18406 cm3/S
Jhelum	Mangla Dam	Mangla Barrage Rasul Barrage	2	7.4 million acre feet
Chenab	Salal Dam	Guddu Barrage (4) Marala Headworks Khanki Headworks - Qadirabad Headworks Trimmu Barrage -	2	10,000-228,000 acre feet
Chenab	Baglihar Dam	No barrage	3	475 million m3
Ravi	Rangheet Dam	Balloki headworks /No barrage	0	24,637m3/s,,219200 00m3/s
Ravi	Sagar Dam	Sagar Reservoir	3+	2,659,139 acreft
Beas	Pandoh Dam	Pandoh Lake	3+	350992 cu ft/s,33,239 acre feet
Beas	Pong Dam	-	3+	437,019 cu ft/s, 6947,812 acre-ft
Sutlej	Bhakra Nangal Dam	Sulemanki Headworks	3+	7.551 million megalitres

Three canals were included in the construction of India's Harike Barrage on the Sutlej River in 1952: the Rajasthan Feeder Canal, the Makhu Canal, and the Ferozepur Feeder Canal. This project was a component of India's larger Indus basin ambitions. By building the Bhakra Main Line Canal and a vast network of distributive canals to feed the dry Rajasthan desert, the Indira Gandhi Irrigation Canal system enhanced the Rajasthan Feeder Canal in 1961 (Raza, 2023). The Ravi-Beas Link Canal, built in 1954, was designed to divert water from the Ravi River to the Beas River. The Bhakra Nangal Project, which involved the building of the Bhakra Dam, was already in progress when partition took place and was not completed until the early 1970s. The purpose of building the Bhakra Main Line Canal from the Bhakra Dam was to make irrigation easier. To regulate the water flow into the Nangal Hydel Channel, the Nangal Dam was constructed. 13 km downstream of Bhakra is where it is located. The project has a total power generation capacity of around 1,325 MW and provides irrigation water to a land area of 4.04 million hectares in Rajasthan, Punjab, Haryana, and Himachal Pradesh. In 1975, the construction of the Pong Dam on the Beas River enabled the storage and subsequent utilization of water through the Shah Nahr system. The Beas-Sutlej Link Canal, which establishes a connection between the Beas and Sutlej rivers, together with the Pandoh Dam, were constructed in the year 1977. Despite the commencement of the Sutlej-Yamuna Link Canal construction in 1982 at Nangal Dam, the Indian Punjab Government has exhibited significant opposition, resulting in the incomplete status of the project.

Located in the Ladakh region of Jammu and Kashmir, on the Indus River, the Nimoo-Bazgo Dam was completed in 2014 and is under Indian sovereignty. India is constructing the Kishanganga Dam near Bandipore to divert the flow of water from the Neelum River into an underground power station, which will generate energy (Mirza, 2008). On both sides of the border, there are numerous other projects that are still in the developmental phase. These projects mostly include harnessing water to produce energy, such as the Diamer-Bhasha and Mohmand Dams in Pakistan, and the Pakal Dul Dam in India. Nevertheless, to fulfill the water requirements for agriculture, these immense concrete structures will store and distribute a substantial amount of water throughout the arid season (Irfan, 2019).

3.4. Climate variability and irrigation imperatives in Indus Basin

Modifications to irrigation systems and changes in climate go hands in hands from ancient times. The expansion of agricultural land and the improvement of productivity have resulted in a population growth in the Indus basin. Consequently, this has stimulated the development of urban centers and industries, which in turn have increased the need for water in residential areas, farms, and power plants. The ample availability of resources and favorable habitats resulted in a rapid increase in population. A significant number of indigenous species in the Indus Basin became extinct due to the growing development of the area. Rehabilitating the Indus River's indigenous floodplains and wetland area, together with reinstating its original path, will provide protection to the urban area against inundation. A significant number of people are vulnerable to floods due to the high population density residing on floodplains adjacent to rivers. During such instances, the occurrence of a flood, similar to the one that took place in Pakistan in 2010, results in more economic devastation. A significant number of dams in the Kashmir region have been constructed in precarious locations, leading one glaciologist to refer to them as "water bombs." The intricate undulating topography in the Himalayas proved unsuitable for the construction of the approximately fifteen dams undertaken by the Indian government. The melting glaciers and increasing temperatures in this mountainous region are resulting in the temporary overflow of the Indus River, posing a threat to human-built infrastructure (Gilmartin, 2020 & Laghari, 2012).

The rising silt load is causing an avalanche in the river. The flood prone area grew as a result of the reservoirs gradual loss of storage capacity from siltation (Janjua, 2021). Decreasing storage capacity increases the likelihood of flooding in nearby communities during periods of high water flow. Table 3 is a thorough summary of the effects and measures taken to reduce the negative impacts of the Indus River.

Table 4: Climate change problems and their mitigation measures in Indus Basin (2022)

Problem	Description	Mitigation Measures
Water Logging and Salinity	Increased water table due to excessive irrigation and salinity affects areas like lower and middle Indus Basin, leading to soil salinity	Improved irrigation methods, drainage systems, and crop selection, use salt-tolerant crops, and apply soil amendments techniques e.g. use of gypsum, improve soil cover, use of agroforestry and agro ecology
Habitat Fragmentation	Dams, barrages, and canals disrupt natural habitats	Construction of fish ladders, mangrove restoration projects, and habitat connectivity
Increased Flooding	Climate change and human activities leading to increased flooding	Construction of levees along the coastline, mangroves plantation, and increasing water flow
Riverine Pollution	Industrial and agricultural waste contaminating rivers	Establishment of wastewater treatment plants, reduction of mangrove burning as fuel, and public education
Groundwater Extraction	Over-extraction of groundwater resources	Implementation of sustainable groundwater management strategies, rainwater harvesting, artificial recharge, awareness campaigns to educate farmers and the general public about the importance of sustainable groundwater management and the impacts of pesticides and fertilizers on groundwater quality. Use of organic farming methods, precision agriculture techniques to reduce chemical inputs, and proper disposal of agricultural chemicals to minimize groundwater contamination.
Declining Delta	Decreased flow of water and sediments to the delta	Increasing water flow, reduction of mangrove burning as fuel, and mangrove restoration projects

Since 1851, the issue of salinity has been noted in a number of the Indus basin regions. At first, it was found that the areas of Jammu and Kashmir suffered from a salinity problem. In Punjab, there were also reports of problems with salt. To monitor the overall groundwater level, a vast network of observation wells was installed around the basin. The artificial irrigation system in the region caused an abrupt rise in the height of the water table in open water table wells in Punjab. Though little is known about them, the diversion of the river channel and the building of unlined irrigation canals between 1850 and 1950 are primarily responsible for the basin's high water table, excessive salinity, and water logging. Because of increasing drainage, geographical considerations, and the lack of salt in the upper strata, water logging is more common in Punjab than salinity. As a result, people tend to think that Punjab's situation is superior to Sindh's. Salinity was only a problem in Punjab in areas with poor drainage and mountainous terrain. Between 1940 and 1950, the water table in the middle Indus basin, specifically in the lower Punjab and upper Sindh regions, reached its peak. Subsequently, from 1960 to 1980, it experienced excessive waterlogging. The salinity of this region is moderate, falling between the salinity levels of the upper and lower parts of the basin. From 1970 to 1980, the combination of salt and waterlogging caused a decrease in crop yield on 20 to 30 percent of irrigated area (Winston, 2013).

People had no choice but to rely on groundwater aquifers, which were quickly depleted due to altered weather patterns and overuse of surface water, hence restricting the availability of water. The irrigation system in the Indus basin is inefficient and cannot adapt to the different needs of crops for water throughout the year. As a result, switching from surface to ground water irrigation is required. The existing irrigation infrastructure became unable to meet the heightened water requirements resulting from the transition of the farming community from traditional irrigated agriculture to more water-intensive practices, driven by the escalating food demands due to population development and economic competitiveness. Because of its simplicity and affordable installation expenses, miniature tube wells are employed to recover more than 80% of underground water. The salinity in a substantial portion of the agricultural region in the Indus basin is caused by the poor quality of groundwater and its frequent use in irrigation (Qureshi, 2021).

As a result of the construction of dams and barrages for irrigation purposes, the Indus River has been divided into 17 divisions thus endangering the wild life the rare dolphins have been eliminated from some of these areas. Only six of the seventeen segments of the river had these species, perhaps because river water is used for agriculture and there is less water flow during the dry season. Habitat fragmentation, together with habitat deterioration, contributed to the decline of the dolphin population (Braulik, 2014). This aspect of Indus fragmentation affected both the geographical and temporal distribution patterns of the dolphins. The dolphins' historic home in the Indus River has significantly decreased to only 20% of its original length as a result of habitat fragmentation. The decline in the dolphin population can be attributed to potential factors such as chemical contamination and unintentional fatalities resulting from fishing equipment (2010). Dolphins frequently die when they are trapped in canals and are unable to return to the river. During the winter season, there is a significant amount of fishing activity taking place in the small river channel located downstream of Sukkur Barrage. This fishing activity has a negative impact on the dolphins in the area (Reeves, 1998).

While natural processes might diminish water resources, human activity has significantly enhanced agricultural and industrial production through the establishment of irrigation systems and residential settlements. Anthropogenic activities in farming and industry introduce fumigants, pesticides, chemicals, heavy metals, and illnesses into the water supply. This can have harmful effects on human health and water quality. Urban areas exhibit substantial water requirements and serve as a primary contributor to water pollution as a result of the discharge of solid waste and municipal sewage. The water's quality and quantity were both adversely affected, making it unsuitable for ingestion by humans and animals. Unquestionably one of the most incredible irrigation systems in the world is the Indus system. The Indus basin provides food, work, and leisure activities for people in Pakistan and India, but its natural resources have been depleted due to intense competition for large-scale water use. The agricultural sector is responsible for the majority of river effluent, with other notable sources being industries, residential areas, and urbanized regions (Habib, 2021).

Mangroves played a crucial role as an ecological resource in the lower Indus basin, and the Indus delta supports a diverse range of plant and animal species. The loss of the mangrove species can be attributed to various factors, including river pollution, reduced water flow, and the exploitation of mangroves for sustenance and energy purposes. The decline in mangrove populations has resulted in the elimination of spawning and rearing grounds, leading to a decrease in the populations of many fish and macro invertebrate species. India's upstream storage has significantly reduced the flow of the

Sutlej River. The process of desiccating the riverbed, transforming it into a sandy desert, has completely eradicated the area's formerly stunning aquatic environment and all of its visual attractiveness . The drying up of the river led to a dramatic decline in biodiversity and agriculture, which in turn affected the regional environment. Following the abandonment of arid regions, individuals escaped the devastation of their constructed infrastructure. The depletion of the river caused an exodus of people from the region, ultimately resulting in the formation of the Sutlej Valley. The civilization in this valley is on the brink of extinction due to a few more years of mismanagement (Punjab Canal Dispute, Supplementary note and Summary; UK, 1948-1950 & Kidwai, 2019). A significant portion of its culture has already been eroded.

Conclusion and recommendations

The Indus irrigation system, a vital water resource shared by China, India, and Pakistan, is one of the most impressive globally. However, fierce competition for large-scale water use has exhausted the basin's natural resources, despite providing food, jobs, and leisure activities to people in all three countries. Large-scale artificial structures have altered the natural course and outflow of rivers, leading to ecological catastrophes.

The vegetation pattern in the region changed as groundwater levels increased during the initial phases of developing the irrigation system, which coincided with the expansion of agricultural operations made feasible by the ample supply of irrigation water. This region is highly inhabited due to the presence of a significant number of individuals who sustain themselves through extensive agricultural practices. However, the over utilization of chemicals in both urban and rural environments has been linked to various diseases and abnormalities in the local human population. After more than a century of irrigation system development, environmentalists have concluded that rivers must be handled sustainably. To maintain ecological conditions, governments must ensure a minimum ecological flow downstream.

The decline in fish and other creature communities has been steady due to decreasing water levels and habitat fragmentation. Unregulated water consumption and human activity within the watershed area in all three countries have exacerbated the issue. Intensive farming has made river water unavailable for irrigation, leading to groundwater extraction and a decrease in the groundwater table. Urbanization and industrialization have increased subsurface water usage for manufacturing and human consumption, depleting groundwater aquifers significantly. China, India, and Pakistan must enter into a new pact to implement strict measures to restrict harmful human activities. Developing drought-resistant crops and implementing integrated water resource management (IWRM) is essential to minimize water utilization and ensure effective use of surface and groundwater resources.

Stringent regulations should be implemented to curb excessive pesticide and fertilizer application, and water storage infrastructure should be improved to mitigate economic effects on the agricultural community during low water seasons. The Indus Water Treaty requires major improvements to address environmental issues brought about by climate change and growing tensions between the three countries. Negotiations are necessary to ensure a sufficient amount of water in the river system, meeting the biological needs of the basin. Sustainable management of the Indus River system is crucial to prevent long-lasting, irreversible consequences.

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