The Indus Water System: Introduction

Muhammad Shafique[1,2,*], M. Qasim Jan[1,3]

[1] National Centre of Excellence in Geology, University of Peshawar, Peshawar
[2] GIS and Space Application in Geosciences (GSAG), National Centre of GIS and Space Applications (NCGSA), Islamabad
[3]China-Pakistan Joint Research Centre on Earth Sciences, Islamabad, Pakistan
*Email: shafique@uop.ed.pk

The Indus River is among the longest rivers in Asia, having a length of around 3180 km. With a total basin area of around 1.12 million km^2, it originates in the Mount Kailash- near Lake Mansarovar area of the Ngari Prefecture, SW Tibet (Fig. 1&2 Left) and flows northwest through the SW Tibet and Ladakh region before entering Pakistan in district Ghanche of Gilgit Baltistan. From there, it traverses the length of Pakistan, flowing through the provinces of Khyber Pakhtunkhwa, Punjab and Sindh, eventually emptying into the Arabian Sea about 150 km southeast of Karachi. Historically, the river is significant as the cradle of the Indus Valley Civilization (3300–1300 BCE), one of the world's earliest urban cultures, known for cities like Harappa and Mohenjo-daro. The major tributaries of the Indus River originate mainly from the glaciers in the Karakorum, Himalaya and Hindu Kush mountain ranges. Hence, the water level in the river is significantly influenced by seasonal variations in temperature and precipitation, with a minimum in winter (December to February), rising in spring and early summers (March to May) to a maximum in summers and monsoon seasons (June to September) and subsiding again from October. The Indus River System (IRS) receives more than 50 % of the total average river flows from snow and glacial melt, while the remaining is from the rains (WAPDA, 2024).

The IRS water supports agriculture (80%), industry (5%), drinking water (5%), ecosystem (5%), and hydropower energy for some 300 million people across Pakistan, India, Afghanistan and China. The Indus River has a total average annual flow of 146 Million Acre Feet (MAF), of which 106 MAF is diverted to canals for irrigation purposes (PC, 2018). The Indus Basin Irrigation System in Punjab and Sindh in Pakistan comprises six major rivers, three major storage reservoirs, 19 barrages, 12 inter-river link canals, 40 major canal commands and over 120,000 water courses (PC, 2018). In Pakistan, the hydropower capacity of the major dams

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constructed on the Indus River and its tributaries is around 10,847 MW and the capacity of the under-construction projects is 9,776 MW, which signifies the major contribution of the Indus River to the energy demands of the country. The major left bank tributaries of the Indus River in Punjab originate in India, enter Pakistan, and eventually join the Indus River. The Indus Basin and its tributaries across India and Pakistan are governed through the Indus Waters Treaty (1960), giving the rights to Pakistan over the waters of the Chenab, Jhelum, and Indus rivers, while India retains control over the waters of the Ravi, Sutlej, and Beas rivers. For thousands of years, the Indus River has been the lifeline for the society and economy of the region. However, with the onset of climate change impacts, increasing population and urbanization, the IRS is faced with challenges in maintaining its water level, quality and course. Global warming accelerated the melting of glaciers, erratic patterns of precipitation and increased occurrence of extreme weather events, leading to increasing floods, prolonged droughts and growing water stress. The associated devastation along the Indus River and its tributaries is becoming a severe challenge for the sustainable development of the country. Moreover, increasing population, urbanization, anthropogenic activities and industries along the Indus River and its tributaries are adding challenges to the quality and quantity of water in the river.

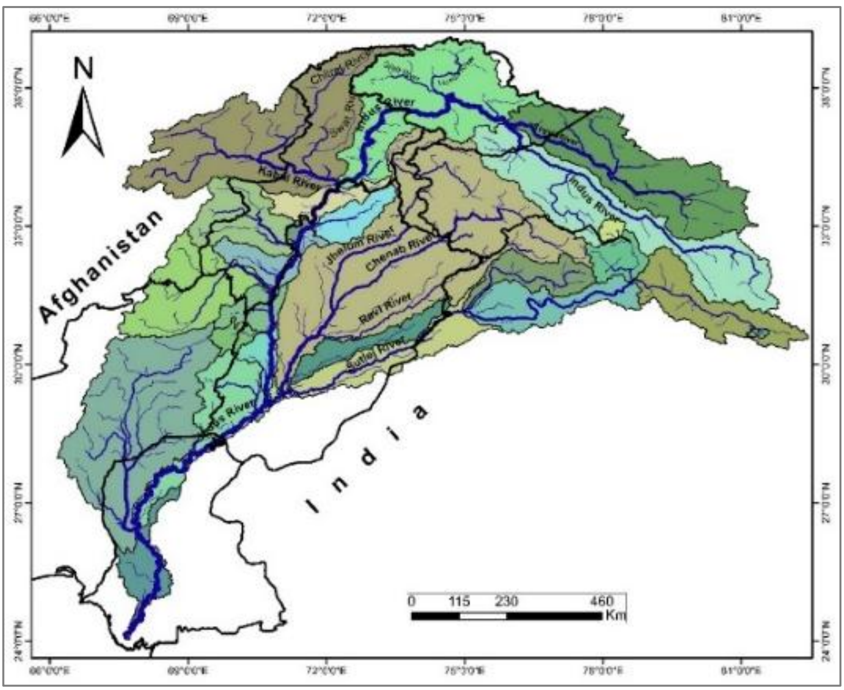

Figure 1. Course of the Indus River and its tributaries (Source: Hydrosheds, (2024).

The Indus River is joined by a large number of tributaries of which the more important in terms of water volume are listed in Table 1 and briefly described in the following. The left bank tributaries include: 1) the Zanskar River, originating from the glaciers in the Zanskar Range of India (Fig. 2 Right). It has two main tributaries, named Stod and Langnak Rivers. After confluence and flowing through the Zanskar valley, the Zanskar River joins the Indus River near the Town of Nimoo where it may be adding as much or more water as the Indus River; 2) Suru River flows largely through the Kargil district of Ladakh, and enters into Kharmang district of Gilgit-Baltistan to join the Indus near Marol. The Dras River is one of the important tributaries of the Suru River; 3) Astore River originates in the Nanga Parbat area and is fed mainly by the streams from the Rupal and Chongra peaks. Flowing through the Astor Valley, it joins the Indus near Jaglot, Gilgit; 4) Soan River originates from the Murree Hills, flows through the Potwar Plateau near Rawalpindi, and merges with the Indus River near the town of Makhad. It contains plenty of rainwater during the monsoons.

Figure 2. Left: Lake Mansarovar, with mount Kailash in the background, is the source region of the Indus River in SW Tibet (Wikipedia). Right: Confluence of the Indus and Zanskar rivers. The Indus, flows left-to-right and Zanskar comes in from the top of the picture and carries more water (Wikipedia).

The five rivers of Punjab merge at different places before joining the Indus at Panjnad, south of Multan. They include, from north to south, 1) Jhelum River, originating in the Kashmir Valley, flows into Pakistan, and joins the Chenab River in the Jhang district of Punjab. The average discharge of the river is 1300 m^3/s, which can reach up to 20000 m^3/s in the monsoon season, and shrinks to 500 m^3/s in dry winter seasons. Two major hydropower projects, the Mangla Dam and Neelum-Jhelum Hydroelectric project, are built on the river; 2) Chenab River, resulting from the confluence of the Chandra and Bhaga rivers, flows through India and Pakistan and is one of the largest tributaries of the Indus River. At the Marala headwork in Sialkot, the average discharge of the river is 977 m^3/s, which can reach 31,148 m^3/s in peak season and shrink to 310 m^3/s in dry season; 3) Ravi River flows through India and Pakistan, and eventually joins the Chenab River in the Jhang district. The average discharge of the river is 267 m^3/s, but swells to 11,015 m^3/s during the peak flow season; 4) Sutlej is the longest river of the eastern tributaries of the Indus River. It originates in SW Tibet near Mount Kailash and flows through India and Pakistan before joining the Chenab River near Bahawalpur, which eventually flows into the Indus River. The river has an average discharge of 500-700 m^3/s, reaching 10,000 m^3/s in peak season and 300 m^3/s in low season; and 5) Bias River merges with the Sutlej River before entering into Pakistan.

The principal Right Bank Tributaries of the Indus River include: 1) Shyok River, which originates from the Rimo Glacier and the Siachen Glacier in the eastern Karakoram Range, flows through the Ladakh region, and NE Baltistan and merges with the Indus River east of Skardu; 2) Shigar River, originating from the Baltoro Glacier in the Karakoram range, flows through the scenic Shigar Valley, known for its spectacular landscapes, including rugged mountains and fertile fields. The Shigar River eventually joins the Indus River near the town of Skardu; the 3) Hunza River originates near Khunjerab in northern Pakistan and runs through the breathtaking Hunza Valley with stunning landscapes, high peaks, and glaciers, and joins the Gilgit River near Gilgit, before the two merge into the Indus; 4) Gilgit River originates from the Shandur Lake at the border of Chitral and Ghizar districts. It flows through the scenic and rugged mountainous terrain of the Gilgit Valley, creating deep gorges, and takes along the Hunza River to join the Indus River near Bunji; 5) Kandia River results from the glaciers and snow melt in the Upper Kohistan of Khyber Pakhtunkhwa province (KP), and flows through the rugged and deep gorges of the remote Kandia Valley, eventually merging with the Indus River to the SW of Sazin; 6) Swat and Dir Rivers owe their origin to melting of snow and ice of the Swat- and Dir Kohistan. They join near Chakdara and flow into the Kabul River in the Charsadda district of KP; 7) The Afghanistan-Pakistan transboundary Kabul River originates in the glaciers of the Hindu Kush Mountain ranges. It is joined by the even bigger Kunar (Chitral) River near Jalalabad before re-entering Pakistan to ultimately merge with the Indus River near Attock; 8) Kurram River originates in the Hindu Kush, flows through the Kurram Valley of KP and eventually merges into the Indus near Dera Ismail Khan (DIK); 9) Tochi River, also called the Gambila River, originates in Khost, Afghanistan, and flows through North Waziriztan and Bannu before joining the Kurram River. It is an important water source for agriculture in Tochi Valley; 10) Gomal River also originates in the Hindu Kush Mountains of Afghanistan. It flows primarily through

South Waziristan in Pakistan and joins the Indus River near DIK; 11) The Zhob River originates near Muslim bagh in Balochistan and flows on a northeast course for 410 km before joining the Gomal River near Khajuri Kach. Along the Zhob valley are located ancient sites going back to over 3,000 years BC.

Table 1. Left and right bank tributaries of the Indus River, length, watershed area and major source (length and watershed area of the rivers are from the global drainage dataset and could vary with other sources).

River	Length (km)	Watershed area (km^2)	Major sources of water
Left Bank Tributaries			
Zanskar	95	2,435	Glaciers in the Zanskar range and Ladakh, India
Suru	184	1,878	Panzella Glacier
Astore	91	3,988	Nangra Parbat glaciers
Soan	219	7,728	Rain and springs, foothills of Patriata and Murree
Jhelum	766	49,768	Verinag spring, Snowmelt from Pir Panjal and Himalaya
Chenab	960	45,365	Chandra and Bhaga rivers
Ravi	720	38,289	Glaciers in the Himalayas of Himachal Pradesh, India
Beas	409	17,317	Uhl River and Sainj River
Sutlej	1450	87,793	**Rakhshar Lake in Tibet**
Right Bank tributaries			
Shyok	550	60,293	Rimo and Siachen Glaciers
Shigar	95	7,036	Baltoro and Biafo Glaciers
Gilgit	218	27,360	Shandur Lake, Ghizar/Kohistan-Hindu Kush glaciers, Rainfall, Nullahs
Hunza	214	11,723	Glaciers, snowmelt, high-altitude lakes, and springs
Kandia	90	597	Glaciers and snowmelt of upper Kohistan
Kabul	700	71,674	Snow/glaciers from Hindu Kush and Broghil
Kurram	320	11,188	Snowmelt
Gomal	400	24,855	Springs
Tochi	90	9,578	Spin Ghar range
Zhob	410	15000	Kan Mehtarzai range near the Afghanistan-Pakistan border

The Indus River System is the lifeblood of Pakistan's agriculture, hydropower, industry, local transportation and drinking water, and indeed its economy. It feeds the country's extensive irrigation network, one of the largest in the world, irrigating about 14 million hectares of farmland mainly contributing to the food security of the country. Agriculture is a key sector in Pakistan's economy, contributing around 24% to the country's GDP and employing about 50% of the labor force (PBS, 2024). The tributaries of the Indus system provide water for the canals, barrages, and reservoirs that distribute water across the agricultural plains, enabling millions of farmers to cultivate various crops throughout the year and support livestock farming and agriculture-related industries. Moreover, the Indus River plays a critical role in supporting activities in various industrial sectors in Pakistan. Thus, sustainable water management practices associated with irrigation water are essential to ensure food availability and minimize the risks of food shortages. It is worth mentioning that the Indus River played a crucial role in the development of the Bronze Age (3300-1300 BCE) Harappan civilization.

The Indus River is a crucial source of hydropower in Pakistan, with many hydropower projects developed along its course and its tributaries. These projects contribute significantly to the country's energy needs and are vital for sustainable development. The major Hydropower Projects on the Indus River System include the Tarbela Dam (expanded to 5,800 MW) on the Indus River, Mangla Dam (1150 MW) and the Neelum-Jhelum Hydropower Project (969 MW) on the Jhelum River, and Warsak Dam (240 MW) on Kabul River. Malakand Power Project on river Swat leverages the natural flow of water with an installed capacity of 81 MW. The hydropower projects under development include two major Dams, i.e. the Diamer-Basha (4500 MW and storage capacity of 6.4 MAF) and Dasu (4320 MW and storage capacity of 1.2 MAF) on the Indus River, and Mohmand Dam (800 MW) on the Swat-Dir Rivers, with the potential to significantly contribute to the hydropower, water storage, flood control, agriculture system and economic development of the country (WAPDA, 2024). Moreover, other major hydroelectric projects are in the planning phase. The Indus River System, while serving as a lifeline for Pakistan, also plays a crucial role in supporting agriculture and hydropower generation in Afghanistan (as briefly discussed by Kakakhel and Jan in a later paper) and India (over 20,000 MW).

The sustainability of the Indus River System faces numerous challenges, particularly water scarcity driven by global warming and climate change, a rapidly growing population, and various forms of pollution. Industrial and urban waste discharge, along with agricultural runoff into the river, is deteriorating water quality, damaging ecosystems, and threatening its use for drinking, agriculture, and industry. Pollution is also affecting marine life, and the reduction in water runoff to the Arabian Sea poses further risks to sea life, mangrove forests, and the irrigable delta, which is vulnerable to salty seawater intrusion. The increasing population, unplanned urbanization, and rising agricultural demands are driving over-extraction of groundwater, which, combined with poor management, may reduce water availability for irrigation. Industrial activities along the river are also harming the surrounding environment and biodiversity. Climate change, glacial retreat, and fluctuations in river flow further threaten the reliability of water supplies in the Indus River basin. Additionally, institutional challenges and transboundary conflicts complicate the effective management and sustainable use of the Indus River System.

This book is a collection of papers most of which were presented in a series of webinars on the Indus River System during 2023. These papers address many of the issues mentioned in this introductory statement. We give here briefs on the contents of the papers included as full-length articles following this introduction.

M. Ashraf and Mahar et al. give detailed accounts of the water resources and related issues of the IRS. M. Ashraf reviews the Pakistan water issues and the way forward. The country has one of the largest irrigation systems and the 4th-largest groundwater aquifer in the world. However, both surface and groundwater are subject to several constraints, such as inadequate storage, neglect of rain-fed areas, inefficient irrigation systems, and groundwater depletion. These issues can be overcome by increasing the resource base (construction of small, medium and large dams, rainwater harvesting, recharging the groundwater aquifer), improving conveyance and irrigation efficiency, changing the existing cropping pattern, and public awareness. Mahar et al. discuss the water resources, challenges and opportunities of the IRS. Pakistan's water resources are under stress due to challenges of poor governance, low storage capacity, increasing water demands, groundwater depletion, climate change, water pollution, urbanization, population growth, and Indus Delta deterioration. They also propose a way forward to address these challenges.

The next six papers deal with climate change threats in the HKH region. Lone et al. highlight the importance of the Indus River Basin (IRB), its regional climate, cryosphere, and the challenges posed to its water resources by climate change. They offer detailed insights into climate projections, indicating an increase in liquid precipitation, particularly in high-altitude areas, alongside a decline in solid precipitation by the end of the 21st century. The study explores the implications of these changes for the cryosphere, surface and groundwater resources, and socio-economic vulnerabilities, emphasizing the need for adaptive strategies and climate resilience. Winiger in his contribution on the HKH landscape under transition, highlights the challenges in the HKH region and stresses the need for long-term environmental, social, economic and cultural determining aspects, to provide sound recommendations for practical measures. Based on multidisciplinary local and regional case studies, the central issues related to the IRB are outlined. The paper strongly emphasizes the need to strengthen collaboration among the universities in the region and outlines the research priorities. Romshoo et al. evaluate the impact of climate change on cryosphere and river discharge under future scenarios from different global climate models. They analyzed the glacier changes in the Upper Indus basin and reported a high rate of melting and consequent potential impacts on the water supply to the downstream communities. They underline the gaps for water management in the changing climate scenario, and stress the need for collaboration between India and Pakistan. A. Ashraf highlights the climate-induced vulnerability of the glacial resources and associated challenges to agricultural water management in the Upper Indus Basin of the HKH in Pakistan. He applied the glacier indexing approach and analyzed the glacier's vulnerability to climate change based on their area, elevation and region. The paper also analyses the sustainability of glaciers for the irrigation network. Shah and Jan discuss the impact of global warming on the temporal and spatial aspects of the HKH glaciers and the sustainability of the water resources He also discusses the high degree of vulnerability of these glaciers to climate change and the challenges and measures for the sustainable water supply. Aftab describes the surface and groundwater scenarios of Balochistan and highlights the past, present and future water resources and challenges. The chapter discusses the province's water resources in the past (1970s) and how the changing dynamics including population increase, industries, modern techniques of water extractions and climate change have impacted the water resources of the province and associated hazards and water scarcity. The chapter proposes an Integrated Water Management Strategy for the sustainable utilization of water resources.

The next five papers deal with the application of space technology and water management. Ali and Jadoon in their manuscript on groundwater monitoring and management in the Indus basin, use multi-sensor data to evaluate the spatial and temporal changes in groundwater using GRACE satellite data. They also analyze variations in groundwater storage and highlight the land subsidence due to groundwater extraction. Iqbal and Salik, in their article on Remote Sensing and Energy Balance perspectives on the water cycle in the lower Indus basin, highlight the significance of evapotranspiration (ET) in the terrestrial water cycle, linking energy, water, and biogeochemical processes. Open-source remote sensing data and a one-source energy balance model are applied to map the ET across large areas in the D.I.Khan District in Khyber Pakhtunkhwa province, to support the water management challenges in the context of climate change.

Azam presents a comprehensive insight into the impact of water on the behavior of agricultural soil and the significance of water storage and release under saturated and unsaturated conditions. The paper also highlights the importance of these relationships in arid climatic zones, such as the Indus River. Kamran et al. discuss the institutional changes introduced over the past 150 years in the Indus Basin Irrigation System. The chapter highlighted the Participatory Irrigation Management reforms introduced in the late 1990s for improving water management and recovery charges. The success of self-governance in irrigation management requires appropriate policy interventions and implementation. Abbasi et al. provide information on the Australia-Pakistan Water Security Initiative project implemented in two marginalized urban communities in Islamabad and Rawalpindi. The project focuses on integrated and holistic management of urban water to increase liveability and sustainability. Under the project, nature-based and engineered infrastructure interventions have been adopted to improve access to safe water and sanitation services, conservation and recharge, and ensure community resilience to climate change.

The next three papers take up the 2022 devastating floods in the Lower Indus Basin (LIB) and challenges to the Indus Delta. Yousafzai discusses the 2022 widespread and intense flooding in the LIB and relates it to the hydrology alteration due to climate change, unplanned urbanization and population growth. Pakistan, according to him, is faced with a myriad of geologic hazards and natural disasters, and the threat of potential future floods due to climate change, and suggestions are proposed for mitigation. Memon discusses the water storage and diversions in the Upper Indus Basim, causing serious challenges in the Lower Indus Basin, especially the water shortage in the Indus Delta. This is, accordingly, resulting in huge economic and ecological losses. A list of recommendations for conserving, preserving and developing water resources in the Lower Indus Basin has been given. Siyal and Siyal give details of the delta of the Indus River, including a description of its landscape, resources, dynamics, and vulnerabilities. It ranks as the world's 5th largest delta of wetlands, with 7th largest mangrove ecosystem globally. The vulnerability of the delta stems from various factors, including diminished river flows, reduced sediment deposition, coastal erosion, intrusion of surface and subsurface seawater, diminishing active delta area, soil salinity and sodicity, degraded groundwater quality, land subsidence, climate change, and rising sea levels. The shoreline has shifted inward 860±92 m between 1972 and 2018.

The following three contributions concern transboundary waters. Yousafzai describes global water disputes and agreements, and their potential impacts on the socio-economic conditions of the countries. The article explores transboundary water resources in different regions of the world where some countries benefited disproportionately while others were disadvantaged, resulting in disputes that require urgent resolution. Kakakhel and Jan discuss in detail the issues between Afghanistan and Pakistan over the waters of the trans-boundary Kabul River (KR). The chapter outlines the river's water sources, challenges associated with them, and the history of dialogues and meetings between the two neighboring countries. Historically both eastern Afghanistan and the Peshawar basin have heavily relied on the waters of the KR. The authors stress the need for mutual understanding and reaching a win-win situation through an inclusive agreement for long-term monitoring, management and sharing of the water resources of the KR and its tributaries. Sheikh in his article discusses the 1960 Indus Water Treaty between India and Pakistan on the governance of the cross-border Indus Water System. Climate change-induced hydrological and hydro-climatological variabilities are upsetting the historical trends, and together with population growth, are posing challenges to the treaty. Sheikh provides suggestions for the peaceful sharing of the Indus water.

The following paper by Jan and Shafique gives a brief overview on various aspects of the geography of the uppermost Indus River Basin in the Ngari prefecture of southwest Tibet. They also describe the two stems of the Indus river and cultural and religious significance of the Mount Kailash and Lake Manasarovar, the area from where four of the most powerful rivrs of south Asia originate. In the last paper, Hussain gives an interesting and absorbing description of the expeditions he led from the source to the delta of the Indus River, barring the section in Ladakh. The travelogue comprises a wide variety of observations which would interest all readers. Hussain and his team may be the first to report the spring from which the northernmost and principal branch (Sênggê Zangbo, meaning Lion River) of the Indus originates.

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References

Hydrosheds, 2024. HydroBasins. from https://www.hydrosheds.org/products/hydrobasins

PBS, 2024. Pakistan Bureau of Statistics, Agriculture statistics, https://www.pbs.gov.pk/content/agriculture-statistics

PC, 2018. 11th Five Year Plan (2013-18), Planning Commission, Ministry of Planning, Development and Reform, Government of Pakistan.

WAPDA, 2024. Hyderl Generation Capacity of Pakistan, Water and Power Development Authority (WAPDA), Ministry of Water Resources, Government of Pakistan.