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Climate Change Impacts on the Indus River Basin: Hydrology, Water Quality, and Treaty Implications

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ABSTRACT

The Indus River is highly sensitive to climate variability because most of its flow depends on Himalayan snow and glacier melt as well as monsoon rains. Climate change induces shifts in precipitation patterns, accelerating glacier retreat, and increasing the frequency of floods and droughts in the basin. The objective of this study was to analyze the quality of the Indus water and to assess the effects of climate on it, i.e. how changes in climate affect the hydrological cycle, glacier dynamics and water quality in the Indus basin. Using field data from the Kunar and Kabul rivers (tributaries of the Indus) and a review of climate impacts, significant regional differences in water quality parameters were noted and climate-induced hazards (e.g. floods, droughts, salinity intrusion, ecosystem stress) outlined. The implications of these changes for water security, agriculture and Indo-Pak water governance were studied. It was noted that the Indus Waters Treaty currently lacks provisions for climate-induced variability. Climate change is altering the Indus hydrological regime and water quality, posing challenges to sustainable water management and regional stability.

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1. Introduction

Climate change is a global phenomenon and poses a worldwide challenge, with its' effects manifesting across different geographical regions. Past consensus has confirmed threatening consequences of global climate change on our water resources and environment, globally and regionally. The regions have seen high magnitudes of floods and droughts in previous years, which has raised concerns about the worsening state of our future resources (Sivakumar, 2011; Sun et al., 2025). The exacerbated impacts attributed to climate change have significantly disrupted the hydrological cycle causing disturbances in the natural environment and global water systems (Sohoulande Djebou & Singh, 2016).

The evidence of these disruptions has been observed in the Indus River basin, a critical water resource for Pakistan and India sustaining one of the world's largest agricultural zones (Kazbekov & Qureshi, 2011) During the past years, climate change has made Indus Basin a vulnerable transboundary river system which is now deemed a global problem. As a result, the compound effects of climate change have accelerated Himalayan glacial melt and shifted monsoon rainfall patterns (Hasson et al., 2014; Lutz et al., 2016). Although, Indus Basin is naturally rich in water resources and a large share lies in Pakistan, the growing water crisis in the region has intensified due to rapid industrial expansion, uncontrolled global warming and population growth (Wang, Gillani, Balsalobre-Lorente, et al., 2025). Li et al. (2022) has quoted that being a fundamental human right of getting open access to clean drinking water, water is reckoned to be one of the most important natural resources but due to inadequate attention towards water's quality preservation, as discussed by Baluch and Hashmi (2019), water is constantly polluted due to humans' intrusion and increased soil erosion. Stretching over 3,200 km long, its tributaries drain about 450,000 square miles, with roughly one-third of this area in the Himalayan, Hindu Kush, and Karakoram highlands. In this section, an estimated 50-80% flow of the basin is fed by snow melting and monsoon rainfall, making its hydrological inputs highly climate dependent. A clear picture of hydrological input can be observed at the Jhelum River which is significantly affected by glaciers melting from the Himalayas and summer monsoon rains. This dual dependence makes Indus flows extremely sensitive to climate change (Inam et al., 2022).

Literature over the past decade has underscored that climate change has significantly altered the region's hydrological cycle, which has caused accelerated glaciers and snow melting, leading to increased short-term runoff, yet leading to long term water scarcity Ul Hussan et al. (2020). Under 1960 Indus Water Treaty agreement, Indus, Jhelum and Chenab are western rivers which have been allocated to Pakistan while the eastern rivers Ravi, Beas and Sutlej have been allocated to India. The treaty's detailed arbitration mechanisms have so far prevented water conflicts. However, the Indus Water Treaty does not account for climate change. As Leiserowitz (2005) observe, climate change, now "widely acknowledged as the greatest danger to the sustainability of the world's water resources," is not mentioned in the Treaty. This omission means the treaty lacks guidance on how to handle climate-driven changes in river flows. Increase in population has made the treaty unable to highlight the key factors of hydrological uncertainty, aberrant environmental flows and growing demands in the region.

Over the past few years, dramatic climate-related water events have been recorded in the Indus basin. For instance, severe climate events in 2014 were documented in Pakistan which highlights the seriousness and gravity of Pakistan's' underdeveloped coping mechanisms. This country has been subjected to unprecedented floods and intense monsoon rainfall in recent years. Such as, the 2010 flood which brought major catastrophes to different cities. Although, efforts have been made by constructing dams to lessen the catastrophic climatic events and increase the water storage capacity, yet Pakistan lacks the capacity to store water. The reason is subjected to sedimentation in water dams and consequently increasing downstream floods (Li et al., 2022).

More than one billion people in South Asia have been afflicted by floods fed by cyclonic events and heavy monsoon rain in the preceding years (Wang, Gillani, Sharif, et al., 2025). On the other hand, fluctuations in the rainfall have also imposed prolonged dry periods threat (Su et al., 2016). Furthermore, warming temperatures are shifting seasonal flows in the Indus River due to constant shrinking of Himalyan Glaciers. In addition to that, rising heat increases evapotranspiration and water stress causing an immense reduction in crop production, especially in arid regions (Ahmad et al., 2021; Shafiq et al., 2021). The Indus Delta is exposed to saltwater intrusion due to rising sea level and decreased freshwater discharge that is harming coastal agriculture, fisheries, and mangrove forests. These resource stresses have exacerbated Indo-Pak tensions as disputes over the sharing of water resources have added to the stress between riparian states". These climate impacts have critical implications for Indus water security and management. As Ranjan (2025) notes, Pakistan is already water-stressed (demand exceeding supply).

As per the historical flow data, the treaty's rigid water allocations may prove ineffective under shifting hydrology. In that case, it is essential to understand the series of climatic events and their impact on shifting hydrological cycles, glaciers dynamics and declining water quality. These measures can help improve the future water planning under the Indus Water Treaty framework. The hydrological shifting is significantly evident in the Indus basin, it is noted that upper area of Indus Basin is exposed to faster warming trends than the plains, which lead to increased downstream floods (Ashraf & Hanif-ur-Rehman, 2019). The importance of analyzing hydrological systems analysis at the watershed level is reinforced by recent studies. Thus, to design enhanced strategies for resilient governance and withstand the climatic events, this hydrological analysis can prove effective in building prone free water governance systems (Ashraf, 2013; Nazir et al., 2025). These ongoing climatic events have been threatening the Indus Basin for several years, but Indus Water Treaty fails to address the hazards posed by climate change (Leiserowitz, 2005; Riaz et al., 2020). These gaps in the treaty are becoming increasingly unsustainable as proved by the unpredictable flow regimes and growing water demands in both India and Pakistan (Sarfraz, 2013). The present article focuses on the climate change aspects of the Indus waters, building on studies such as Ranjan (2025), who analyses river water quality in the Kunar and Kabul tributaries (which flow into the Indus) alongside a discussion of climate impacts. It further highlights the use of sensor-based approach which was developed by Bhatti et al. (2019) for assessing important water quality indicators such as pH, dissolved oxygen, ORP, and temperature in key tributaries such as the Kunar and Kabul Rivers. This empirical foundation has been critical in evaluating how climate change exacerbates water quality stress, especially through thermal stress and acidic runoff.

This paper examines the shifts in the hydrological routine and temperature regimes that alter the water quality parameters such as pH, dissolved oxygen, oxidation-reduction potential, temperature. The paper further comments on the hazards triggered by climatic events such as floods, droughts, salinity, and ecosystem degradation). Furthermore, this study provides valuable discussion on climate impacts' consequences that have destabilized irrigation, ecosystems, and transboundary water governance, while it also highlights the treaty's shortcomings in a changing climate. In general, this literature contains multidimensional pictures of Indus Basin being affected by effects of climate change. It also addresses hydrological, ecological, and geopolitical dimensions that influence the Indus Basin and emphasizes the need for different strategies. However, the treaty remains rigid, and so far, no framework exists to address key water governance issues. These gaps point to critical policy shortcomings and bridging these gaps will demand updated transboundary cooperation that incorporates climate science, real-time monitoring, and flexible management approaches.

In general, this literature contains multidimensional pictures of Indus Basin being affected by effects of climate change. It also addresses hydrological, ecological, and geopolitical dimensions that influence the Indus Basin and emphasizes the need for different strategies. However, the treaty remains rigid, and so far, no framework exists to address key water governance issues. These gaps point to critical policy shortcomings and bridging these gaps will demand updated transboundary cooperation that incorporates climate science, real-time monitoring, and flexible management approaches. Although earlier researchers have focused on many aspects of glacier recession, water variability and the legal aspects of the Indus Waters Treaty, there is an unmet need in bridging the gap between the real-time measurements of water quality and transboundary water governance. More precisely, the implications of climate-related transition in water chemistry and hydrological patterns on the working performance of treaties, as well as their policy components, have not received much attention. The paper helps to fill that gap by integrating empirical water quality data into the major tributaries with an assessment of treaty constraints in the face of climate stress.

This study aims to analyze the impact of climate induced changes on hydrology and water quality in the Indus River Basin. Further, it aims to evaluate the effectiveness and limitations of the Indus Waters Treaty in the context of current and projected climate challenges. Lastly, it focuses on the development of evidence-based policy recommendations for adaptive, climate-resilient transboundary water governance between India and Pakistan.

This study focuses on three main research questions:

1. How are hydrological regimes and water quality in the Indus Basin impacted by climate change and monsoon variability?
2. what are the broader implications of these shifts for agriculture, ecosystems, and regional water security?
3. How might the Indus Waters Treaty be revised or expanded to address hydrological uncertainty caused by climatic conditions and promote cooperative transboundary water management?

2. Methods

This study adopted a field methodology which had been used by Bhatti, Anwar and Shah 2019. According to their methodology, a floating sensor system was used to collect water quality data from two key tributaries of the Indus River: the Kunar River and Kabul River. This data showed real time records of the water quality parameters. The sensor platform recorded spatially distributed measurements of pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and temperature. Furthermore, GPS positioning was used for location tracking.

Field measurements were conducted in June 2022, at the beginning of the summer monsoon season and peak glacial melt in the Indus Basin. While this period captures critical hydrological dynamics (e.g., increased runoff and temperature fluctuations), the data represents a single season data set and may not fully reflect annual variability. The winter months may not adequately represent dynamic hydrological processes due to reduced glacier melting with limited runoff and exhibit altered water chemistry. As a result, the data collected during that period alone would have yielded limited insights.

In June 2022, two successive tests were performed on each river under similar weather conditions. For the Kunar River (Chitral region), two consecutive daily tests (Tests 1–2) were performed near Chitral Fort, with each test recording parameters at eight fixed points along a designated stretch. Similarly, two tests (Tests 1–2) were conducted on the Kabul River near Warsak Dam under comparable weather conditions. At each sampling point, the device logged parameter values, which were then used to calculate ranges and averages per test. All data were systematically compiled in tables to enable comparative analysis between the two tributaries. This single-season approach provides a focused snapshot of water quality during peak melt season, though future multi-seasonal sampling would help assess annual variability.

Figure 1: Water Floating Device

3. Results

3.1. Water Quality Observations at Kunar River

The pH value of 8-8.5 was observed throughout the first test. There was a sudden decrease in pH observed at point 8. Furthermore, Test 1 showed the DO average of 9.26 mg/L and the highest ORP of 121 mV at point 8. The highest RTD of 18.49 C and a minimum of 17.71 C was also recorded in this test.

Table 1
Ranges of water quality parameters for Test 1 measured in Kunar River

Points	PH value	Dissolved Oxygen	Resistance Temperature Detector	Oxidation Reduction potential
1	8.07	8.5	17.71	92.1
2	8.07	8.96	17.71	90.9
3	8.14	9.44	17.73	94.1
4	8.14	8.96	18.21	96.9
5	8.69	8.96	18.23	98.1
6	8.39	9.44	18.26	95.4
7	8.20	9.44	18.26	99.6
8	4.55	10.38	18.49	121

Test 2 results indicated that the pH values were within acceptable and balanced ranges according to WHO recommendations. Furthermore, Test 2 showed the DO average of 9.954 mg/L and highest ORP of 145.4 mV observed at point 8. The highest RTD of 20.59 C and a minimum of 16.39 C was also observed.

Table 2
PH Values

Ranges of water quality parameters for Test 2 measured in Kunar River Points	PH Value	Dissolved Oxygen	Resistance Temperature Detector	Oxidation Reduction Potential
1	7.75	0	20.11	39.9
2	7.7	8.96	20.33	48.8
3	7.49	8.96	20.36	60.9
4	7.43	8.96	20.56	65.9
5	7.13	10.38	20.59	64.4
6	8.44	9.91	18.91	104.1
7	8.52	10.38	17.07	137.4
8	8.56	10.38	16.39	145.4

3.2. Water Quality Observations at Kabul River

The pH value of 2-4 was observed throughout the first test. This test showed that the water pH was acidic. Moreover, Test 1 showed the DO average of 14.62 mg/L. and showed the highest ORP of 289.9 mV at point 8. The highest RTD of 34.92 C and a minimum of 28.83 C was also noted.

Table 3
Ranges of water quality parameters for Test 1 measured in Kabul River

Points	PH value	Dissolved Oxygen	Resistance Temperature Detector	Oxidation Reduction Potential
1	3,78	14.62	34.28	223.9
2	3.91	14.62	34.92	243.1
3	3.63	14.62	34.35	254.3
4	3.48	14.62	33.54	261.4
5	3.35	14.62	33.03	270
6	3.07	15.1	31.54	278.3
7	2.74	15.1	30.04	285
8	2.72	15.1	28.83	289.9

Test 2's results also showed the same range of pH value. In addition, Test 2 showed the DO average of 15.34 mg/L and displayed the highest ORP of 294.0 mV observed at point 2. The highest RTD of 39.44 C and a minimum of 27.54 C was reported.

Table 4
Ranges of water quality parameters for Test 2 measured in Kabul River

Points	PH value	Dissolved Oxygen	Resistance Temperature Detector	Oxidation Reduction Potential
1	3,61	14.49	27.54	290.44
2	3.55	14.58	31.33	294.0
3	3.60	14.88	28.20	293.30
4	3.95	15.34	39.44	251.22
5	3.75	15.96	38.34	293.0
6	3.04	15.37	31.44	226.0
7	2.09	15.64	31.21	269.2
8	2.96	14.49	34.50	273.0

The observed ranges of key water quality parameters have been summarized in the table. The Kunar River and Kabul River displayed distinct water quality profiles. These recorded results reflected differences in their catchment characteristics and climatic conditions. The Kunar River maintained neutral to alkaline pH levels (8.0–8.5) throughout most tests. While Kabul River showed consistently acidic conditions (pH 2.0–4.0).

Table 5
Ranges of water quality parameters measured in Kunar and Kabul) Rivers

Parameter	Kunar River	Kabul River
pH (range)	8.0 – 8.5 (approximately)	2.0 – 4.0 (acidic)
DO (mg/L)	9.3 – 10.38	14.6 – 15.3
ORP (mV)	95– 145	227 – 294
Temperature (°C)	17 – 20	28 – 37

Table 6
Summary Statistics (Mean, SD, Min–Max) by Test and River

Parameter	Mean (Kunar River)	Min (Kunar River)	Max (Kunar River)	STD DEV (Kunar River)	Mean (Kabul River)	Min (Kabul River)	Max (Kabul River)	STD DEV (Kabul River)
PH Value	8.20	7.13	8.69	0.43	3.40	2.09	3.95	0.57
Dissolved Oxygen	9.95	8.50	10.38	0.61	15.00	14.49	15.96	0.45
Resistance Temperature Detector	107	90.9	145.4	19.00	270	223.9	294.4	21.30
Oxidation Reduction Potential	18.5	16.38	20.59	1.25	33.5	27.09	39.44	3.60

The results indicate several important trends in the water quality parameters of Kabul and Kunar River. The Kunar River's pH remained near neutral to slightly alkaline (mostly 8.0–8.5) in all tests. In contrast, the Kabul River's water was highly acidic, with pH values generally between 2.0 and 4.0 across tests. Rajmohan et al. (2025) notes that this pH difference may be influenced by monsoon rainfall and catchment geology.

Dissolved Oxygen (DO) - Kunar River DO averaged about 9–10.7 mg/L (Test 1: 9.26 mg/L to Test 2: 10.38 mg/L). Kabul River DO was significantly higher, around 14.6–15.3 mg/L in the tests. The comparison suggests that DO in Kunar was "more balanced" (less variable) than in Kabul, possibly reflecting differences in flow regime or organic content (although no definitive cause is given).

Oxidation-Reduction Potential (ORP): Kunar's ORP readings were relatively low (about 95–145 mV, with the highest values in each test as listed). Kabul's ORP was much higher and more stable (mostly 230–300 mV). These observed readings of ORP can be attributed to fluctuations in varying oxidant/reductant loads (Sediqi & Komori, 2023). Water temperature (Resistance Temperature Detector readings) in Kunar ranged roughly 17–20 °C across tests, with cooler minimum values. Kabul River temperatures were considerably higher, from about 28°C up to nearly 40 °C. RTD values vary in both rivers but do not specify climate causes. Overall, water quality was better in the mountainous Kunar River. Its pH was near neutral, and DO was moderate, whereas the Kabul River had extreme acidity and high ORP.

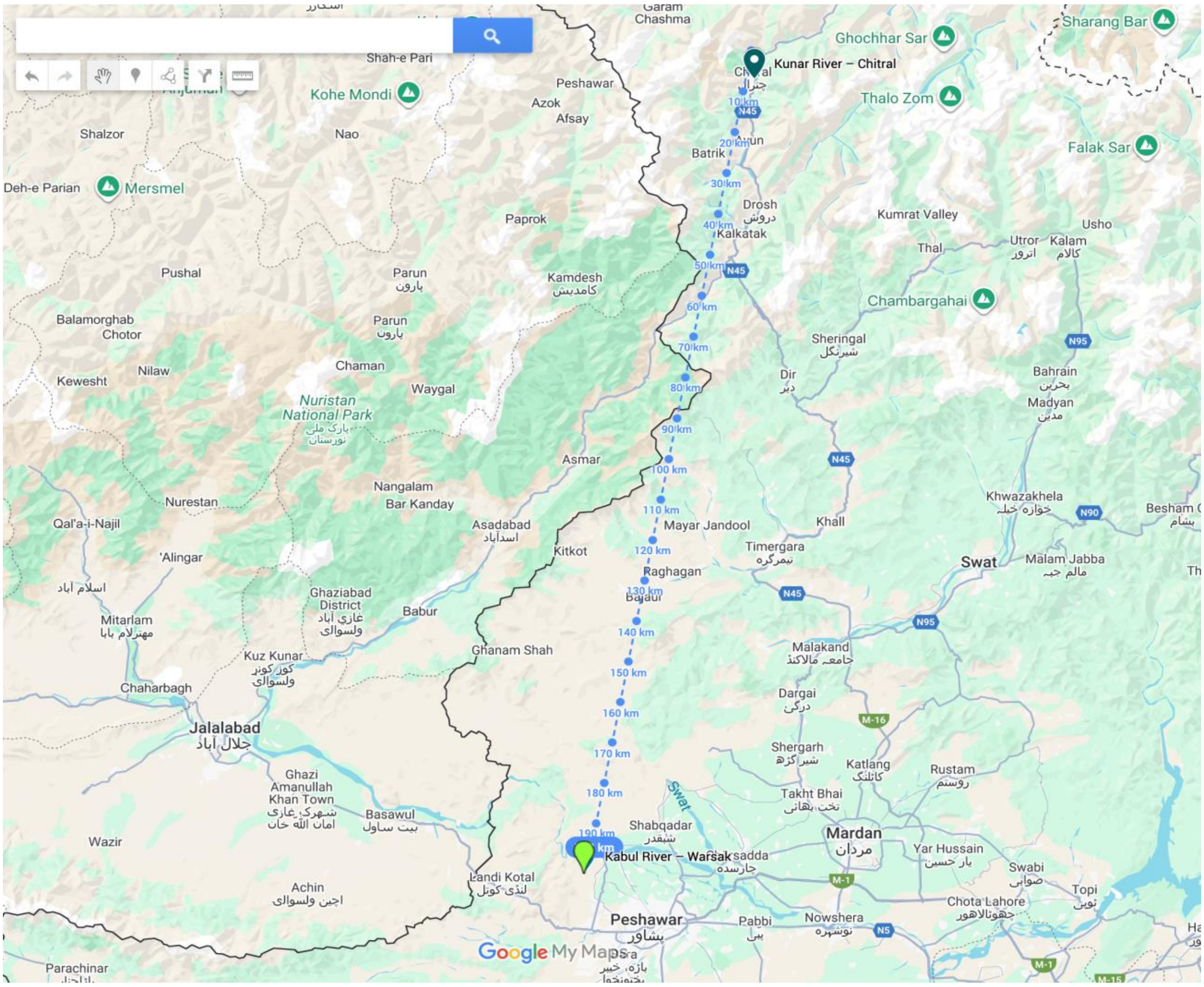

Figure 2: Map of sampling sites in the Indus River Basin. Field data were collected from the Kunar River near Chitral Fort in the north and the Kabul River near Warsak Dam, west of Peshawar. These tributaries represent distinct hydro-climatic zones feeding into the Indus River

Due to differences in climate and geology, the water quality results of the two rivers showed different responses. The results and observations of Kunar River showed cool and buffered nature of the river because most of the water is fed by glaciers. On the other hand, Kabul River recorded results that showed hot temperatures and acidifying inputs.

3.3. Climate and Hydrology Observations

This study does not provide new quantitative climate data, but the report discusses climate trends and hydrological vulnerabilities. We summarize the relevant findings here:

As noted, most of the Indus flow originates from glacier melting. It is expected that Himalayan glaciers will shrink in the coming years due to an increase in temperature (Bolch et al., 2019). Hence, any warming-driven glacier shrinkage will eventually reduce baseflows particularly in rivers present in western Kashmir (e.g. Jhelum, Chenab, Indus headwaters) which are fed by both spring snowmelt and the summer monsoon. Climate change is intensifying monsoon rainfall and severe downpours have become more common that have caused massive floods. Conversely, more variable rainfall leads to droughts in dry seasons. The Pakistan Federal Flood Commission data of 1950 to 2013 has cited about the financial losses and affected area due to 21 major floods that brought major catastrophes. Furthermore, it has been noted that Indus Delta has been affected by saline water due to an increase in riverine flooding and constant rise in the sea level. As a result of this intrusion, the coastal agriculture and mangroves have been severely polluted and damaged.

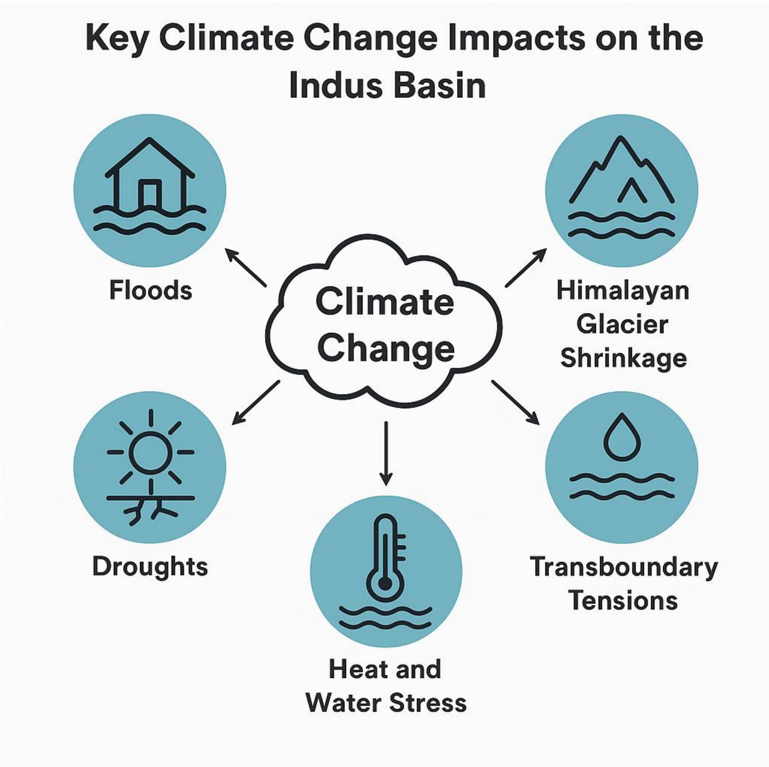

Figure 3: Key climate change impacts on the Indus basin Climate change causes both intense floods and severe droughts; it drives Himalayan glacier shrinkage; increases regional heat and water stress; amplifies saltwater intrusion; and heightens transboundary tensions over water.

4. Discussion

4.1. Hydrological Cycle and Glacial Melt

The dependence on snow and glacier melt means that rising temperatures will increase runoff (from faster melting) and later decrease it (as glaciers recede). The report notes that glaciers "provide water to the Indus basin" but are shrinking due to warming. In the long term, retreating glaciers could reduce dry season flows by up to 20–30% which will lead to reduced water supply in the dry season. Meanwhile, precipitation regimes are shifting, which have triggered major floods due to increased monsoon rains (Cui et al., 2025). These floods inundate large areas and damage infrastructure while warmer dry seasons as recorded in 2014 exacerbate drought conditions. This variable pattern of heavy rain falls followed by dry spells show a clear sign of climate change. The flood report data (21 major floods since 1950) demonstrate substantial rise in Pakistan's flood risk. Importantly, the Indus Water Treaty's water allocations assume stable historical hydrology. However, with retreating glaciers and shifting monsoon patterns, actual river flows may decline below the treaty's historical benchmarks, leading to potential shortfalls. The present study warns that "climate change is not included in the Indus Water Treaty" and that it "provides no prediction for the adverse circumstances" brought about by a changing climate. As a result, the basin's hydrology is entering a new regime that the 1960 treaty never envisioned.

4.2. Hydropower and Energy Security under Climate Stress

The hydrological alterations due to climate of the Indus River Basin not only impact on the agricultural productivity and water supply, but also bring about profound effects of energy systems, especially hydropower. The possible reduction of flows in rivers especially during dry seasons because of glacier retreat and rain-variability, have the potential to reduce the generation capacity of the major hydropower plants. Frequent floods and augmented soil erosion indeed are additional factors that reduce the capacity of dams to store water and impact the performance of turbines, which causes higher maintenance costs and reduces operating efficiency. There is also the issue of reduced water quality, which is caused by subsequent factors such as heightened salinity, acidity, and concentration of pollutants, which requires more energy-intensive procedures in water treatment especially in areas such as Karachi and Lahore cities. The energetic needs of a municipal water system will probably increase as water becomes harder to treat and deliver safely, which forms a sort of feedback cycle between water scarcity and energy stress. Increasing the effects of each represents the case that there should be integrated water-energy planning within climate adaptation strategies.

4.3. Water Quality and Climate Linkages

While the focus of the study was on water quality, some climate related observations can also be made. The temperature record of Kabul and Kunar Rivers show that water temperature depends on air temperature and the season. Because Kabul River (around 39 °C) showed much higher water temperatures as compared to the Kunar River (around 30 °C), which may be due to warmer weather and slower water flow in the Kabul area. The Kabul River surprisingly showed higher dissolved oxygen record of about 14–15 mg/L as compared to Kunar River that recorded a range of ~9–10 mg/L. This could be due to other factors like photosynthesis or water movement, but it also shows that the Kabul River can still support aquatic life even with low pH levels. However, the very acidic pH (between 2 and 4) in the Kabul River is harmful and can dissolve metals and hurt fish. The study also suggests that this acidity might be caused by the type of rocks in the area and heavy rains during the monsoon season, which wash acidic materials into the river (Ayoubi et al., 2024).

Dissolved oxygen (DO) and oxidation-reduction potential (ORP) serve as important indicators of water quality stress. This can be explained in the context of climate factors that increase or decrease the range of these two indicators. DO level increases due to rising temperatures and decreases due to excessive growth of algae. The increased algal growth is observed during droughts, which is also climate-induced factor. ORP on the other hand is also affected by the change in DO values such as increase in the DO value, the ORP increases and decreases when DO value falls. Therefore, it is noted that maintaining adequate DO and ORP values is critical for ecosystem health in a changing climate. In addition, increasing saltwater intrusion and untreated industrial waste, agricultural pesticide runoff, and animal waste degrades water quality. These factors are linked to climate-driven lower flows that accumulate contaminants in the water. For instance, the capacity of freshwater declines during droughts which makes irrigation canals and rivers more stagnant and saline. Furthermore, waste and fertilizers can also be swept by immense floods and deteriorate the water ecosystem.

In sum, while the measured water quality parameters do not directly measure climate, they reveal the baseline vulnerability of the Indus tributaries. The Kunar River (at higher altitude) remains near-neutral pH and cooler; the Kabul River (warmer and more acidic) appears more stressed. If climate change causes more extreme events (intense rains followed by dry heatwaves), water quality could become more erratic – for example, pH swings during floods or reduced DO in stagnant drought conditions. Although, some of the results hint that even without climate change, some tributaries are already acidic or unstable and can further worsen the water quality if left unnoticed (Baocheng et al., 2024).

4.4. Climate-Induced Hazards and Ecosystem Degradation

Climate change is triggering hazards that degrade ecosystems and human wellbeing in the Indus basin. Sadly, over 11,500 people died in major floods between 1950–2013 and have brought devastating losses to humanity. In addition, the ecosystem is damaged and disrupted by floodwater that erodes topsoil and damage watershed forests. Furthermore, extreme droughts in Pakistan have surfaced with rising temperatures which has caused water tables to fall and reduce river flows. The crop production has shattered with increase in dry spells and caused major setbacks to the farmers community. The amount of recharge in the fresh water has dropped with significant increase in droughts and has increased groundwater salinity. Climate change has also caused rapid melting of glaciers which has brought instability in the lakes. These lakes further burst and cause downstream floods that harm the ecosystem and precious lives in the region. The change in the climatic pattern brings heavy rainfall which ultimately makes the mountainous areas prone to landsliding. Recently, landslides have washed away numerous lives in the mountainous terrain of Pakistan which has posed major setbacks to the humanity. These landslides further block rivers and cause flash floods and when untreated events like these unfold, it degrades terrestrial ecosystems and endanger communities.

Rising heat in arid plains stresses both crops and humans. This paper suggests that "increased heat and water stress" from higher temperatures leads to lower agricultural productivity. Heatwaves can kill fish in shallow canals and make rivers warmer, impacting cold-water species. Ecosystem degradation intensifies from natural occurring events when there is no proper planning involved. Coastal vegetation is polluted and damaged when multiple flood events surge and destroy the local ecosystem, habitats and soil quality. The changing water chemistry and concentration of contaminants in the aquatic ecosystems face combined stress from altered flow regimes and changing water chemistry (Baocheng et al., 2024). Moreover, many wetlands and rivers shrink when droughts strike, which further reduces the limit of fresh water on the ground level. Thus, the salinity level on the ground kills vegetation and degrades the quality of the crops. All these observations of surface quality deterioration are linked with climatic hazards.

4.5. Implications for Water Security, Agriculture, and Governance

The climate-driven changes above have far-reaching implications for Pakistan's water security, The variability in Indus flows means that average water availability becomes less reliable. Irrigation planning under the Indus Water Treaty is based on historical flow patterns and does not account for evolving hydrological impacts of climate change. It is also noted that water demand is exceeding the supply which is making Pakistan a water scarce country. Climate change exacerbates this scarcity by increasing flood waste, infrastructure damage and reducing usable supply. Pakistan's agricultural land is also heavily impacted by these severe climatic patterns and country's farming relies on predictable canal irrigation. In addition to that, severe floods destroy standing crops and sowing schedules, while droughts leave fields parched. Apart from droughts and floods, heat stress has also reduced agricultural productivity in many regions (Ashraf et al., 2023) All these factors combined increases saline intrusion which degrades the quality of the fertile lands near the coastal area, while salt deposits from irrigation degrades inland soils. Thus, food security in the basin is directly threatened by these stresses induced by climatic hazards.

This study also points out that the Treaty makes "no prediction for the adverse circumstances" of climate variability. Pakistan has long feared that India could exploit treaty loopholes to induce floods or conserve water upstream. In an age of climate extremes, such fears grow more plausible. Indeed, this study remarks that "tensions over the sharing of water resources have added to the stress between riparian states". For example, if Indian hydropower projects are managed to capture more monsoon flow, downstream Pakistan could face water shortages especially in drought years. Conversely, extreme floods originating in India could be seen as deliberate despite treaty stipulations. Either way, climate uncertainty strains the diplomatic framework. In short, the Indus Water Treaty framework is stress-tested by climate change. Wells et al. (2023) emphasize that technical updates are needed: analysts "acknowledge the need to update certain technical specifications and expand the scope of the Indus Water Treaty to address climate change". Without such updates, treaty inflexibility may jeopardize cooperative management.

4.6. Policy Relevance and SDG Alignment

The results of the present study can have both direct policy implications on the national level concerning the reforms of national policies and on the international level regarding international treaties, particularly the Indus Waters Treaty. Hydrological regimes are found to be in transformations, and the quality of water is being compromised by the climate change which the Indus Water Treaty is yet to overcome as seen in the data. This being the case, the reform of treaties and flexibility in the dynamic water-sharing arrangements should be considered. Detailed revisions and amendments in the water sharing agreements, creation of joint Indo-Pak climate data and forecasting center should be established. In-depth amendments will trigger early warnings when climate extremes occur. Real-time hydrological data will also be shared between the affected countries.

There are different United Nations Sustainable Development Goals (SDGs) that support the insights mentioned aligning with key global commitments

- **SDG 6: Clean Water and Sanitation** –
  It draws attention to water pollution, salinity intrusion, and access inequities exacerbated by climate change.
- **SDG 13: Climate Action** –
  It calls for adaptive governance, treaty reform, and infrastructure resilience against flood and drought events.
- **SDG 2: Zero Hunger** –
  It highlights the link between irrigation water stress, declining agricultural yields, and regional food insecurity.

Indus Water Treaty being adapted and forced to incorporate climate resilience mechanisms is therefore not just a bilateral issue, but one of regional sustainability and global development alignment**.**

Figure 3: Visual Summary of Key Climate Change Impacts on The Indus River Basin, Including Altered Hydrology, Water Quality Changes, Extreme Weather Events, Ecosystem Stress, and Treaty Limitations.

4.7. Limitations and Future Research

The current paper deserves attention since it gives us an idea of the hydrological and water quality consequences of climate change in the Indus River Basin; nevertheless, there are a few points to be identified as limitations. The first limitation of this study is that field analysis was performed only in June 2022. This may not represent the whole seasonal variability of water quality parameter and is known to fluctuate throughout the year due to variations in precipitation and temperature. Another limitation that surfaced in the study included the investigation of only physical parameters such as pH, dissolved oxygen, temperature, ORP and considered no research on chemicals such as heavy metals, agricultural runoffs and microplastics.

Other than that, this study did not incorporate interviews with key stakeholders or conduct institutional analysis. The study solely relied on existing literature and secondary data sources. These extra efforts might have helped bring more insight into governance controversies and the questions of treaty compliance. Future studies need to address the multi-seasonal evaluation of water quality and incorporate the advanced chemical analysis and include more qualitative data provided by water managers, local community and policy makers to provide the better strength and usability of results. International comparative research with the Indian tributaries of the Indus system would also contribute to knowledge of similarities of joint vulnerability and promote the conduct of more collaborative treaty reform negotiations.

5. Conclusion

Water resources in the Indus Basin are encountering unprecedented threats by the impacts of climate change. Pakistan's Indus system has already suffered severe floods, droughts, and ecological damage attributable to climate trends (Atif et al., 2021). Unfortunately, it is expected that these impacts will reduce the availability of critical water sources over time. Water security is threatened by the unexpected trends in climate change and agricultural production is also decimated. The crop yields and livelihoods of tens of millions of farmers depend on stable Indus flows, yet those flows now swing unpredictably.

The Indus Waters Treaty must be modernized in the Indus River Basin, making provisions to cope with climate change through a process of modernization to achieve long-term water security and stability in the region. These must involve flexible flow share and allowance schemes, changing discharge thresholds reflected with respect to drought and floods conditions as well as shared common climate impact surveillance system. Trust can be enhanced, and building preparedness can be increased by establishing cross-boundary approaches to data sharing and early warning about extreme events in the hydrological regime. Moreover, it will be necessary to incentivize upstream-downstream coordination especially in times of climate-induced stress events, as a means of preventing resource-based tensions. Such measures would not only make the treaty more resilient to climate variability but also would have a governance structure that is in line with the best international practices of managing the adaptive aspects of water.

Crucially, the Indus Waters Treaty – long hailed as a successful resource-sharing agreement – does not yet incorporate climate adaptation mechanisms. The Treaty provides "no prediction for adverse circumstances" of climate change (Adnan et al., 2024). Without treaty reform or complementary agreements, the changing hydrology could become a source of conflict rather than cooperation. In conclusion, addressing climate change in the Indus basin requires integrated action. Environmental realities are not outside human activity but are their foundation. Policymakers should update their agreements related to water sharing, incorporate climate projections, and invest in adaptation. Some of the policies that should be adopted by the government are improved forecasting, flexible reservoir management and ecosystem protection. If it is understood in clear terms that global distribution of water is increasingly disrupted by the impacts of climate change, further causing droughts in some regions and flooding in others. The Indus Basin countries will come up with different management approaches to safeguard their water future. The Indus's waters and livelihoods will only remain secure and sustainable if climate change is fully addressed in planning and policy.

Authors Contribution

Muhammad Khizar: Writing original draft, revision of draft, reviewing and editing, data collection and analysis, finalizing draft, supervision of project, methodology
Shah Nawaz: Reviewing and editing draft, data analysis assistance, supervision of project, funding support, methodology
Hassan Bashir: Data analysis, project administration, methodology-reviewing
Muhammad Aqeel: Supervision and data analysis, methodology-reviewing

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