ISSN E: 3006-1466
ISSN P: 3006-1458
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.03 No.01 (2025)

A GEOGRAPHICAL VIEW OF PAKISTAN'S RIVER SYSTEMS AND ITS EFFECTS ON CLIMATE CHANGE

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Abstract

The river system in Pakistan, mainly the Indus River and its affiliated tributaries, is therefore of significant importance in supporting agriculture and the economy and holding off a rich system of biological resources. This paper provides a detailed geographical review of the rivers of Pakistan with a focus on their hydrology and role in ecology. The research adopts secondary research using published sources, hydrological studies, climate analysis, and governmental data to measure river conditions and climate change effects. Secondary data related to climate include the Pakistan Meteorological Department (PMD), reports of NASA, IPCC, selected articles, and institutional publications. The effects of climate change are analyzed throughout the paper through glacier shrinkage, changes in precipitation, and consequences for water availability, crop production, and floods. They also examine feedback mechanisms through which climate change includes enhancing the existing human feedback, like deforestation and the construction of dams. In doing so, this paper synthesizes GIS mapping technology with climate modelling to explore the spatial distribution of climate impacts and interpolates the potential vulnerability of specific areas. As such, the present study reveals the importance of effective and sustainable water management policies, ecosystem recovery, and adaptation to cope with climate change impacts on rivers and the associated population in Pakistan.

Keywords: Pakistan river systems, Climate change, Glacial retreat, Hydrology, GIS analysis, Flood risks, Ecological impacts

Introduction

Pakistan is a unique confluence of topography in which mountainous regions,

ISSN E: 3006-1466
ISSN P: 3006-1458
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.03 No.01 (2025)

scorching deserts, and densely flowing rivers are reinscribed at the fulcrum of the South Asian subcontinent region (Bhatti et al., 2020). These river systems form the root of the climate, hydrology and environmental dynamics of the country (Ali et al., 2021; Waseem et al., 2020), surrounding the glacial melt and monsoon rains of the region in mountains, valleys and plains, making them arteries of life in the country.

Surrounded by this messy hydro-social system, the Indus River runs for over 3,180 kilometres from the Tibetan Plateau through Pakistan to the Arabian Sea. Pakistan relies on the runoff from the Indus and its tributaries, the Chenab, Jhelum, Kabul and Gilgit Rivers, for agriculture, which irrigates hundreds of thousands of acres and feeds millions of people. All water dammed, stored, and channelled from the Indus River system is processed through an intricate system of large dams, reservoirs, and canals, of which the Tarbela Dam acts as a focal point (Shakoor & Ejaz, 2019).

However, the fragile balance of this water-driven ecosystem is largely eroded by the stark realities of climate change. With global temperatures increasing, the glaciers and snow-glazed summits deliver water to the Indus River and its tributaries, which are melting more quickly, causing increased flooding and drought. (Bhatti et al., 2020). This yearly change in water availability significantly impacts agricultural output in the country and raises the probability of hydrometeorological disasters that predominantly affect vulnerable sectors.

Most of the water in the Indus River Basin comes from the melting of glaciers and down from the monsoon season. The latest research shows signs of accelerated glaciers melting in the Himalayas linked to the rising global temperature. This retreat changes the hydraulic behaviour of the river and, therefore, increases the flow in the short term while decreasing organic water availability in the long term as glaciers melt. Such changes put the sustainability of the water resources on which the predominantly agriculture-based economy of Pakistan will greatly rely at risk. Monsoon intensity and variability are also influenced by the phenomena of climate change as well. The area has recorded events of flooding, which have been occasioned by unprecedented rainfall recently.

For instance, in August 2024, Lahore city witnessed maximum rainfall reaching an urban flooding state, human casualties and infrastructure destruction. The readjustment of monsoon patterns is unearthing unpredictable behaviours that destroy crops, shrink yields, and put the rural populace at risk. On the same note, climate change and anthropogenic activities make things even harder for Pakistan's river systems. Socio-ecological impacts such as deforestation and uncontrolled urban and industrial pollution continue to compromise the riverine ecosystems, making them more vulnerable to climate pressures. Some of the disasters include the Indus River, as future studies indicate as one of the most prominent sources of oceanic plastic pollution, demonstrating the plights of the waste management challenges in that country. Of course, realizing these challenges, Pakistan has launched processes aimed at reducing the negative impact of climate change on river systems.

Objects of the ―Living Indus Initiative‖ initiated by the Ministry of Climate Change in partnership with the United Nations are to revive the biological productivity of the Indus River. This ambitious example covers all aspects of river management, including planting trees, including wetlands restoration, and practicing sustainable water conservation measures to help the river cope with climate change impacts. In addition, recent improvements in climatic modelling and remote sensing have made it easier to estimate what climate changes could imply for the region. The climate change projections from the Coupled Model Intercomparison Project-6 (CMIP6) for South Asia have shown a warm and wetter world scenario in the twenty-first century, implying the requirement for water resource adaptation.

Finally, we have seen that the river systems of Pakistan are at a crossroads, in the clutch of several challenges, being the bearers of climate change impacts and intolerance

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CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.03 No.01 (2025)

from human beings. It, therefore, calls for a multi-disciplinary initiative embracing scientific efforts, policy measures and vigorous support from citizens of appropriate communities. This paper has addressed the fact that through adaptive management approaches and regional coordination, Pakistan can help protect its key water assets for future generations.

Literature Review

Geographical Overview of Pakistan's River Systems

Pakistan rivers play their role as the country's lifeline for the availability of water resources, which are essential for agriculture and animal and human life. The Indus and its five main branches, including the Jhelum, the Chenab, the Ravi, the Beas, and the Sutlej, form the core of this system. Their source, drainage and huge command areas make them most important, both from an ecological and economic point of view, especially in the context of the Indus Basin. Each of the major rivers is described in brief, describing its geographical characteristics, and specific attention is paid to the importance of these rivers as water sources for ecosystems and people.

Further in the literature, Ibrahim et al. (2024), Hussain et al. (2021), and Bhatti et al. (2020) recommend that Pakistan is one of the ten most affected countries in the world by impacts of climate change on natural assets as well as climate-related disasters. In contrast, water resources are a natural asset that makes countries vulnerable (Bhatti et al., 2020). In Pakistan, unbridled climate extremes are proving devastating as the country has faced horrendous floods in 2010 and 2022, alongside continued numerous deadly droughts with cataclysmic consequences that have resulted in extensive dislocation of the lives of millions, apart from the hugely high economic cost of both (Hussain et al., 2021; Ishaque et al., 2022).

The Indus River

With a total length of 2825 km, the Indus River starts from Lake Manasarovar in Tibet, covering the Ladakh region of India, and enters Pakistan at Gilgit-Baltistan. Stretching about 3,180 km, it flows through the entire length of Pakistan before it reaches the Arabian Sea, at Karachi (Ali & Abbas, 2021). The over 1.1 million square kilometers of resource catchment area supports Sindh and Balochistan's arid ecosystems and contributes to Punjab and Sindh's agricultural outputs (Khan et al., 2020). The Indus River, the largest contributing river in the world, supplies water to the largest irrigation system, the Indus Basin Irrigation System (IBIS), which is pertinent to Pakistan’s agricultural production. It also sustains the aquatic fauna, including the most vulnerable Indus River dolphin (Platanista gangetica minor) inhabiting the river (WWF, 2021).

The Jhelum River

The Jhelum River starts from the Verinag Spring in Jammu and Kashmir and passes through the Vale of Kashmir and enters Pakistan through the state of Azad Jammu and Kashmir. It ends in joining the Chenab River in Punjab. Jhelum River is 725 kilometres long and is very important for hydel power generation for dams such as Mangla Dam generates hydak power and controls the water supplies for irrigation (Haider & Qureshi, 2019). The river's catchment area comprises mountains sensitive to climate change effects such as Glacier melt and landslides, among others. These fluctuations affect the water supply downstream, especially in Punjab, where many farms draw water from the river (Shah et al., 2020).

The Chenab River

Chandra & Bhaga, rising from the hills of Himachal Pradesh, India and passing through Pakistan, becomes the Indus's largest tributary. At 960 km in length and with a large catchment area, irrigation is highly important, especially for foods like wheat and rice grown

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in the Punjab province (Farooqi et al., 2018). Chenab River is one of the most important rivers in India and Pakistan, and it has a critical role in the Indus Waters Treaty. However, a growing rate of glacier melt and the fluctuating monsoon pattern affect it, which can be dangerous for agriculture and hydroelectric power downstream (Abbasi et al., 2022).

The Ravi River

Ravi River begins in the Kangra district of Himachal Pradesh and enters Pakistan, moving westwards. Thus, the Ravi itself, despite being the least of the five rivers, upholds much historical and agriculture value. The catchment area is highly populated, and the river is mostly used for irrigation purposes, especially in Lahore and its adjacent areas (Khan et al., 2019). Despite increased awareness to protect aquatic life and human health interests, the river has been over-exploited and polluted, thus reducing its water quality. These are compounded by industrial waste and untreated sewage, which pollute the Ravi, making it more unsuitable for agriculture and domestic water supply use (Iqbal et al., 2021).

The Sutlej River

Sutlej River starts in Tibet near Mount Kailash and is the longest of five rivers in Punjab, Pakistan and India. The river merging with the Chenab River forms the panjnad River and continues to form the Indus. The Sutlej sustains large areas of agriculture in the southern area of Punjab province and is an irrigation asset under the Indus Basin regime. All the same, the Sutlej has become vulnerable to damming as well as diversions upstream, a situation that has reduced its flows into Pakistan. This has only led to increased water problems in the areas that depend on the resources in the dry season more so (Ahmed et al., 2022). Research conducted by Sarfaraz and associates (2024) suggests that there is a need for early recognition of emotional and behavioural problems among children, but unfortunately, in Pakistan, there is a lack of mental health facilities.

Importance of River Systems for Ecosystems and Human Livelihoods

Those who study the relationship between ecology and society have identified Pakistan's river systems as the nation's lifeline. Environmentally, they preserve Wetlands, Forests and mangroves that host many Biodiversity. For instance, the Indus Delta mangroves have a role of checking coast sedimentation and supporting fish breeding for the fishery resources (WWF, 2021). From a human occupation point of view, all these rivers provide water for human consumption, for crop and livestock production, as well as for industrial purposes. The Indus Basin provides water to more than 18 million hectares of agricultural land and makes Pakistan one of the leading producers of crops like wheat, rice and sugarcane (Khan et al., 2020). In addition, hydropower projects developed on these rivers play a crucial role in meeting energy needs to strengthen the ongoing economic growth and minimize the consumption of fossil fuels (Abbasi et al., 2022). Despite this, most of them are facing the menace of over-extraction, pollution and climate change. Conservation of aquatic resources/ flood control and water use efficiency is crucial for the sustainable development of Paksitan‘s rivers.

Climate Change and Its Impacts on River Systems

The global climate is now affecting systems through changes in the rates of glacial melt, precipitation and the increase in the manifestation of severe climate conditions. These changes are processes that can have protracted effects on water supply conditions, especially concerning rivers that play a significant role in agriculture, supplying drinking water, and operating industrial facilities. Since the agriculture sector of Pakistan, which contributes 21% to GDP and 44% of Labor force is dependent on the Indus River system, therefore the climate change-induced variability in water flows are a serious threat to the economic and food security of the country (Shakoor & Ejaz, 2019; Hussain et al., 2021).

Glacial Melt and Its Effects on River Flows

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Climate change-related events have raised a multitude of strategic challenges for Pakistan. Increasing warmth is rapidly melting the glaciers in the north, and unseasonal monsoon rain has triggered unprecedented floods, inflicting unparalleled losses to lives and property (Ishaque et al., 2022). The nation stood 8th amongst the 10 most vulnerable countries to the impacts of climate change over the past 20 years, but the nature of Pakistan's vulnerability was recently demonstrated. The scale of the crisis was evident with comments by the finance minister, who estimated that the recent floods would cost over $30 billion in economic losses and affect 33 million people (Ishaque et al., 2022). Massive glacier retreats have been observed in the Hindu Kush Himalaya region, the source of major South Asian rivers (Pant et al., 2017; Ishaque et al., 2022).

Glaciers in northern areas of Pakistan serve as natural reservoirs of water by providing sustained meltwater to river flows and during periods of droughts (Nanditha et al., 2023; Shakoor & Ejaz, 2019). However, global warming has accelerated glacial melt, temporarily boosting river flows before glaciers ultimately retreat, threatening water supplies in the long term (Shakoor & Ejaz, 2019). Pakistan has major rivers whose flow variation significantly affects the lives of the people (Shakoor & Ejaz, 2019; Hussain et al., 2021; Bhatti et al., 2020; Ishaque et al., 2022), and these rivers are considered the lifeblood of an agriculture-based economy because they are the main source for irrigating the dry lowlands making a significant contribution to agricultural output in this country.

Changing Precipitation Patterns and Monsoon Variability

Global climate change has, in some ways, shifted rainfall and the monsoon that is prevalent in the South Asian region. More extended and unpredicted monsoon periods, their beginning and ending, duration and intensity, pose serious difficulties for agriculture and functioning water systems (Wikipedia, 2024). These variations have been attributed to climate change, particularly the elongation of the Indo-Pacific warm pool, although other causes include increased temperatures during rainfall and reduced temperatures during the dry season (Wikipedia, 2024).

Increased Frequency of Extreme Weather Events

With increased intensity and frequency, the instances of extreme climatic conditions is evident in floods and droughts. For instance, it was estimated that global river flows in 2023 decreased dramatically because of intense drought and heat, posing risks of water scarcity when demand is on the rise (Reuters, 2024). Conversely, in mid-2024, monsoon rains were too extreme and produced deadly and devastating floods in Pakistan and India (Le Monde, 2024). These conflicting features exemplify the instability of river-water systems under altered climate conditions.

Long-Term Implications for Water Availability

The interaction between changes in glacial melt rates, shifts in precipitation, and more frequent extreme weather events presents serious threats to sustained water availability. The glacial-fed river flows that might be produced by glacier melt accelerate and are expected to reduce significantly as glaciers continue to melt (Springer, 2022). This would disrupt the balance between the availability of water and food and agricultural needs for water, potentially endangering food and water security. Also, the high frequency of floods and droughts overloads water management facilities and raises the potential for both water deficit and water quality problems (Wikipedia, 2024; Le Monde, 2024). These issues require conceptually and methodologically combined water resource management approaches that respond to the multifaceted effects of climate change on rivers.

Anthropogenic Factors Exacerbating River Challenges

People have also worsened the situation faced by river systems, on top of which is climate change.

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The following anthropogenic factors are key contributors:

Deforestation and Land Degradation

Wildlife habitats, including landslides, wetlands, groundwater, forests, rivers, and floodplains, have been affected by deforestation, which was largely occasioned by agriculture, urban development, and timber production. Tearing down forests destroys the water-storing capabilities of land and leads to more surface running and deposition in rivers. This decreases soil quality through overgrazing, mining, unsustainable agriculture, and interrupted water laws on the land. Downstream in the Indo-Gangetic Basin and large-scale deforestation in the upland regions of the IB basin have compounded flood events during the monsoon period whilst decreasing the rates of groundwater recharge (Khan et al., 2020).

Industrial and Domestic Waste Pollution

Direct discharges of untreated industrial effluents and domestic sewage are the major sources of water pollution in the Pakistani rivers. These wastes contaminate water sources and ultimately dangerously affect aquatic and related life forms. For instance, the Ravi River, identified as among the country's most polluted rivers, pollutes the rivers with toxic waste discharged from industries around Lahore (Iqbal et al., 2021). In the same way, domestic waste and agricultural runoff, which contains fertilizers and pesticides, also enhances eutrophication, which forms dead zones in rivers.

Water Resource Hassle and Dissolution

It is known that water levels in rivers have been lowered by pumping the supplies for irrigation and industrial demands. Currently, Pakistan relies on the Florence model in crop irrigation, a very wasteful mode since it administers water floods to the crops (Ahmad et al., 2022). Lack of sound water management policies, noncompliance of the laid down water policies, and protracted political struggles over water resources compound the problem. Effects of infrastructure development (Dams & Canals). Other developments like; building of dams, canals for irrigation as well as energy generation are tremendously related to the surface water resource, but they interfere with rivers' natural processes. Big worthy structures of Tarbela and Mangla adversely affect the flow regime, sediment slip and impact bottom habitats. Furthermore, several canal watershed systems in the areas of the Indus Basin have disrupted the Water Infiltration and Soil Structure, resulting in waterlogged and saline affirmations in agricultural production. Many of these projects do not have adequate strategies to handle their impact on the environment and people, thus resulting in conflict and eviction of people. Here, based on information generated from the same locations as the interviews, I fill in the blank with data about these six species.

Socio-Economic Implications

Several issues in the river systems have devastating effects and go along with socioeconomic vices that affect agriculture, communities, and national economies. Impact to the Economy, Agriculture and Food Security Rivers are the most important source of water supplying food crops like wheat, rice, and cotton require irrigation in Pakistan. However, the use of excessive water and climate change affect the availability of water for agriculture.

Climate-Induced Crop Failure

Several factors affect planting and hence the output: In most rivers, there are fluctuations in the flow of the streams throughout the year and there are in most cases longer periods of dry season which greatly reduce the expected yields (Khan et al., 2020). To water scarcity, farmers have to undertake very costly groundwater extraction, contributing to the problem.

Effect of Water Shortage for a Community

Reduced river water availability and quality were associated with tensions in access to water in urban and rural regions. Clean drinking water remains an even worse problem, especially in the southern part of Pakistan. Water should be accessed easily since women and children

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CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
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CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
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especially affect their health and education through long-distance water fetching (Shah et al., 2020). Internally displaced and flood-induced migrations Often, different storms and floods with a massive number of affected populations, as happened in 2022, have left millions of Pakistani people without homes. These floods eradicate properties, human settlement structures and means of in, making people fit into urban centers in search of shelter and income.

This only leads to overcrowding, bad housing conditions and worsening social and economic team in cities. How much does climate change truly cost? Reviewing the economic losses of climate-induced disasters, They affect the country's gross domestic product through the exertion of loads costs of floods and droughts. Losses to crops, infrastructure and properties are estimated to be billions of dollars each year. For instance, in 2010, flood losses were as high as $10 billion, which underlined that for adverse climatic conditions, the economy of the country remains rather sensitive (UNDP, 2022). Also, crops, fresh produce, and livestock are produced poorly. At the same time, there are high incidents of diseases in water-chocked regions; hence, high incidences of waterborne diseases put more pressure on the economies.

Mitigation and Adaptation Strategies

Addressing the challenges experienced in river systems requires a communal attempt at policies/ laws from the government, technological improvement, and contributions from the community.

Overview of Government Initiatives

Pakistani MoCC has initiated the Living Indus initiative to address the issue of an interlinked ecosystem of the river Indus. The major strategies that form part of the solution include afforestation, rewetting of the wetlands, and responsible water use. The program involves the community and adopts and promotes gender mainstreaming for equal benefit (Ministry of Climate Change, 2022).

Role of Technology (GIS, Remote Sensing, Climate Modeling)

In the process of controlling, supervising and planning of the river basins, technological evolution is used. Integrated applications of Geographic Information Systems (GIS) and remote sensing enable real-time monitoring of river flow, sedimentation, and pollution. Climate change modelling applied in rivers enables the forecasting of future shifts in hydrology, which supports the creation of mitigation and adaptation approaches (Ahmed et al., 2022).

Regional Cooperation for Transboundary Water Management

The issue of water management becomes critical for many rivers as they are shared either by several countries or cross borders of different states. In this category, India-Pakistan's Indus Waters Treaty is an example of a sharing treaty. Enhancing such treaties and cooperation among the South Asian countries can improve resource utilization and can also minimize conflicts (Farooqi et al., 2018).

Sustainable Practices for Water and Land Management

Technological development and practical adaptation, including sprinkler irrigation, the use of fertilizer, and differing crops, may decrease water usage and improve production stability. Afforestation/forestation activities and soil conservation support the maintenance of watersheds and the replenishing of the water table. Utilizing treated wastewater for non-portable water usage reduces the demand for freshwater (Khan et al., 2020).

Case Studies on Climate Change and River Systems in Pakistan:

Case studies provide a detailed and contextual understanding of how climate change impacts river systems in Pakistan. They focus on periods, actions and results, and their purpose is to demonstrate how the environmental, social and economic spheres are connected.

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Case Study 1: Analyzing the Effects of the Retreat of Glaciers to the Indus Basin It is further reported that about 70% of the water of the Indus River is from the Himalayan Glaciers that supports dry season flow. But, the global temperatures are increasing and the Hindu Kush – Himalaya has experienced a great glacial melt back. The annual research by the International Centre for Integrated Mountain Development (ICIMOD) shows that glaciers in this area have been rapidly retreating, losing between 10%- 25% of their volume within the past 50 years (ICIMOD, 2019; Wester, 2019).

Impact on River Flows: When glaciers start to melt, river flows tend to rise rapidly because the disappearance is caused by accelerated melting. Still, this effect is only later when the stimuli are temporarily eliminated, and their absence has the opposite impact. As years go by glaciers melt, and irrigation during the summer months is affected badly by affecting the agricultural practices and hydropower generation. This phenomenon is already visible in the areas that rely on the Indus and its Shyok/Hunza tributaries, where changes in summer flows harm irrigation and hydropower generation, such as the Tarbela Dam.

Lessons Learned: This case supports reconsidering sustainable water management policies that account for the ongoing decrease of river flows in the future. This shows the importance of mobilization for developing other water storage technologies and the efficiency of irrigation technologies so that impacts of reduced glacial melt can be managed.

Case Study 2: 2010 Super Floods The biggest deluge in Pakistan's history occurred in 2010, in which nearly 20 million people were affected by flood. Unprecedented monsoon rains flooded the Indus River, and disaster occurred in the areas of Khyber Pakhtunkhwa, Punjab, Sindh and Balochistan provinces. Flood affected an area of 160000 square kilometers, damaged crops, and affected millions of people (UNDP, 2011).

Causes: The floods were caused by unprecedented monsoon rains and worsened by climate change. In upstream areas, the communities have poor infrastructure and continue to clear forests, which compounded the effects of the disaster in these areas, while disaster risk reduction mechanisms were not in place to reduce the effects of the disaster.

Impact on Communities and Economy: The flood last year, is reported to have affected the farming communities in a big way as it led to damages worth $10 billion. Wheat, rice, and sugarcane were also culled, causing food scarcity and high food inflation. Also, shattered tracks, roads, bridges, as well as irrigation systems hindered economic operations and development, as well as response and relief operations.

Lessons Learned: The flood of 2010 emphasized the gap in flood control measures including building more reservoirs and constructing better river barriers. Thus, it also identified the early warning systems or the community transaction-oriented disaster preparedness program that would seek to minimize the risk of disasters affecting high-risk groups.

Case Study 3: Pollution in the Ravi River Out of the total eighteen rivers in Pakistan, the Ravi, one of the tributaries of the Indus River, has assumed its name as one of the most polluted rivers in the country. It has suffered from severe industrial effluence, untreated sewage, and agricultural drains, thereby becoming highly toxic and unfit for human consumption, crop spraying, and supporting aquatic environments. A survey on the water quality of River Chenab was conducted by WWF-Pakistan in year 2018, because of which it was concluded that heavy metals and biological contaminants have reached a very alarming position in the river water (WWF-Pakistan, 2018).

Impact on Ecosystems and Health: Very high pollution has affected aquatic resources, affecting the number of fish. People dwelling in different communities along this river source draw their drinking water from this source, which causes waterborne diseases like diarrhea,

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cholera and skin infections. It has also been stated that irrigation with polluted water decreases crops yields the way farmers have it.
Government and NGO Interventions: To this end, local governments and NGOs have developed cleanup drives and other sensitization efforts. Measures include building wastewater treatment facilities and improving legal initiatives that preserve the river‘s surrounding the environment.
Lessons Learned: The need for proper waste management and proper implementation of legal measures have been brought out in the case analysis of rivers like Ravi. It does the same in relation to the issues arising from pollution and the promotion of public understanding and participation.

Case Study 4: Community-based Water Management in The Thar Desert in Pakistan is one of the most arid zones in the country, especially in the part of the region that is southeast of the country. Sources of water in this area include small, seasonal rivers, and water from wells and borrows. Year after year more inconsistency in getting rain or lack of enough rain for a long time has made earlier water sources ineffective.
The Intervention: Some of the projects that have been set up with the support of the government and other local NGOs are community-based water management. These include the construction of small check dams and rain-water harvesting structures for water storage in the rainy season. There has also been training offered to communities on water use and proper farming techniques.
Impact on Livelihoods: It has been noted that progress towards these goals has enhanced the access to clean water for drinking and irrigation so that local people are not so vulnerable to drought impacts. Using drought-tolerant crops has improved food production for food security and income value addition in agriculture. Lessons Learned: This case study shows that communities provide efficient solutions for water management in desert areas. This underscores efforts of enhancement of traditional techniques with modern technology in irrigation issues to do with water scarcity challenges.

Case Study 5: Indus Delta Degradation Another case of destruction of a coastal ecosystem is the consequences for the Indus Delta, which lies at the mouth of the Indus River, the consequent reduction in the supply of fresh water and an increase in sea level. With many being an erstwhile mangrove swamp region, the delta is now on the brink of salinization, land erosion, and loss of species diversity. Another source — another Pakistan Council of Research in Water Resources (PCRWR) concluded that only 10% of the pre-withdrawal freshwater flow reaches the delta presently (PCRWR, 2020).
Impact on Ecosystems and Communities: The losses of the delta area have caused the decrease of mangroves, which are important in protecting the coastal area and shelter for breeding fish. The coastal regions' fishing and agricultural employing populations are now becoming less and more vulnerable to cyclones and storm surges. Mitigation Efforts:
Some of the measures towards the restoration of the delta involve planting mangroves and increasing freshwater flow downstream. These projects are to rehabilitate the ecosystem and enhance the robustness of the affected communities.
Lessons Learned: ITC also affirms the practical importance of achieving a more effective measure of the relations between water utilization in the upper stream and the ecological demands downstream. This also applies to the need for environmental rehabilitation into water policies across nations.

Research Methodology

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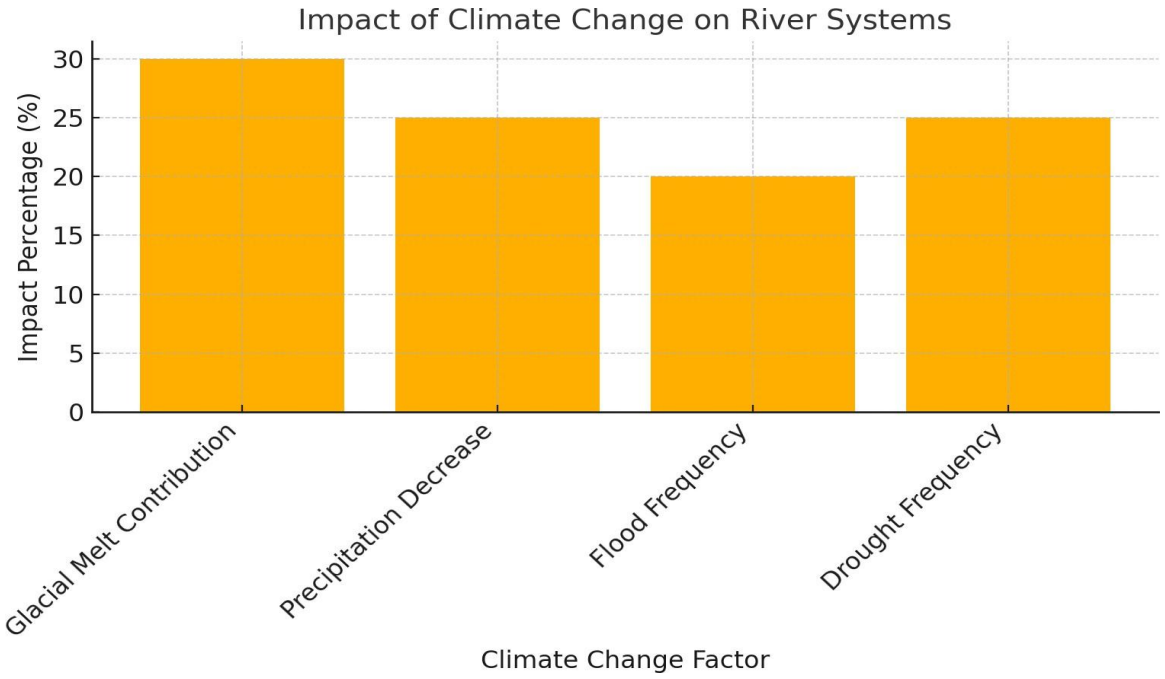
This study employs a structured methodology to analyze the impacts of climate change on Pakistan's river systems. Data collection relied on secondary sources, including published reports, peer-reviewed journals, and documents from government and international organizations such as ICIMOD, IPCC, and WWF. The focus was on glacial retreat, precipitation variability, flood and drought frequencies, and socio-economic impacts. Quantitative analysis was conducted using statistical tools to examine trends in glacial melt, extreme weather events, and water availability. Historical data was compared with recent records to identify climate-induced changes. The qualitative analysis involved reviewing policy documents and initiatives to understand existing mitigation and adaptation strategies.
Geospatial techniques, including GIS and remote sensing, were utilized to map hydrological changes, river basin dynamics, and the geographical spread of climate impacts. Climate models were applied to project future changes in precipitation patterns and river flow dynamics, providing a basis for long-term planning. Specific case studies, such as the 2010 floods and pollution in the Ravi River, were selected to illustrate localized impacts and responses. Data visualizations, including graphs and tables, were created to communicate findings effectively. The results were synthesized to develop actionable policy recommendations for sustainable water resource management and enhancing climate resilience in river systems. This mixed-methods approach ensures a comprehensive understanding of the challenges and opportunities associated with climate change impacts on river systems in Pakistan.

Results



Results and Interpretations

Impact of Climate Change on River Systems

A bar chart illustrates the distribution of climate change impacts on river systems, and a table presents trends in glacial melt and extreme weather events over the years.

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Impact Distribution

- **Glacial Melt Contribution (30%)**: Represents a significant influence on water flow dynamics due to the accelerating retreat of glaciers.
- **Precipitation Decrease and Variability (25%)**: Highlights the challenges posed by altered monsoon patterns, which directly affect water availability.
- **Flood and Drought Frequencies (20-25%)**: Indicates the rising occurrences of extreme weather events, reflecting the vulnerability of river systems.

Table 1: Trends in Glacial Melt and Weather Events

Year	Average Glacial Melt (cubic km)	Flood Incidents	Drought Incidents
2020	18.5	12	8
2021	19.2	15	9
2022	20.1	18	12
2023	21.0	22	14

Table 1: Trends in Glacial Melt and Weather Events

- **Glacial Melt**: Increased from 18.5 cubic km in 2020 to 21.0 cubic km in 2023, showing a steady escalation correlating with hydrological disruptions.
- **Flood Incidents**: Rose from 12 in 2020 to 22 in 2023, demonstrating a sharp rise in flood frequencies due to heavy precipitation and river overflow.
- **Drought Incidents**: Increased from 8 in 2020 to 14 in 2023, reflecting heightened variability and extended dry periods.

Policy Implications

- **Glacial Retreat**: Requires mitigation measures and international cooperation to address long-term water sustainability.
- **Flood and Drought Preparedness**: Calls for enhanced early warning systems and resilient infrastructure to minimize socio-economic impacts.
- **Sustainable Water Management**: Emphasizes strategies to account for declining glacial reserves and variable precipitation patterns.

Table 2: Water Resource Usage by Sector

Sector	Water Usage (%)	Projected Increase by 2030 (%)
Agriculture	90	15
Domestic	5	50
Industrial	3	30
Environmental	2	10

ISSN E: 3006-1466
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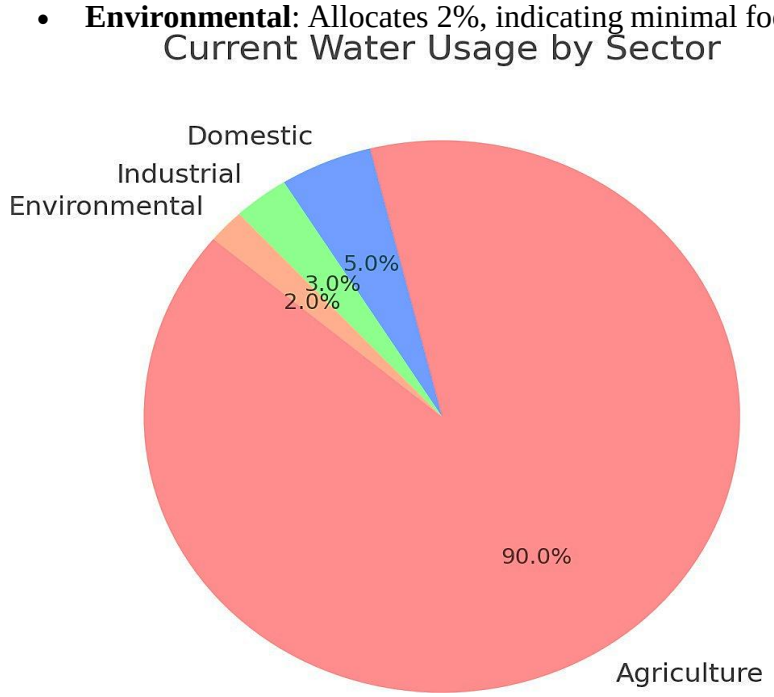
Table 2: Water Resource Usage by Sector

- **Agriculture**: Accounts for 90% of water usage, underscoring the critical reliance on river systems for irrigation.
- **Domestic**: Uses 5%, a figure expected to increase significantly with urban population growth.
- **Industrial**: Represents 3%, reflecting limited industrial water demands compared to agriculture.
- **Environmental**: Allocates 2%, indicating minimal focus on ecological water needs.



Graph 1: Projected Increase in Water Usage by Sector (2030):
The pie chart shows the dominance of agriculture in water usage, emphasizing the sector's dependence on efficient irrigation practices. Domestic, industrial, and environmental sectors account for much smaller proportions.

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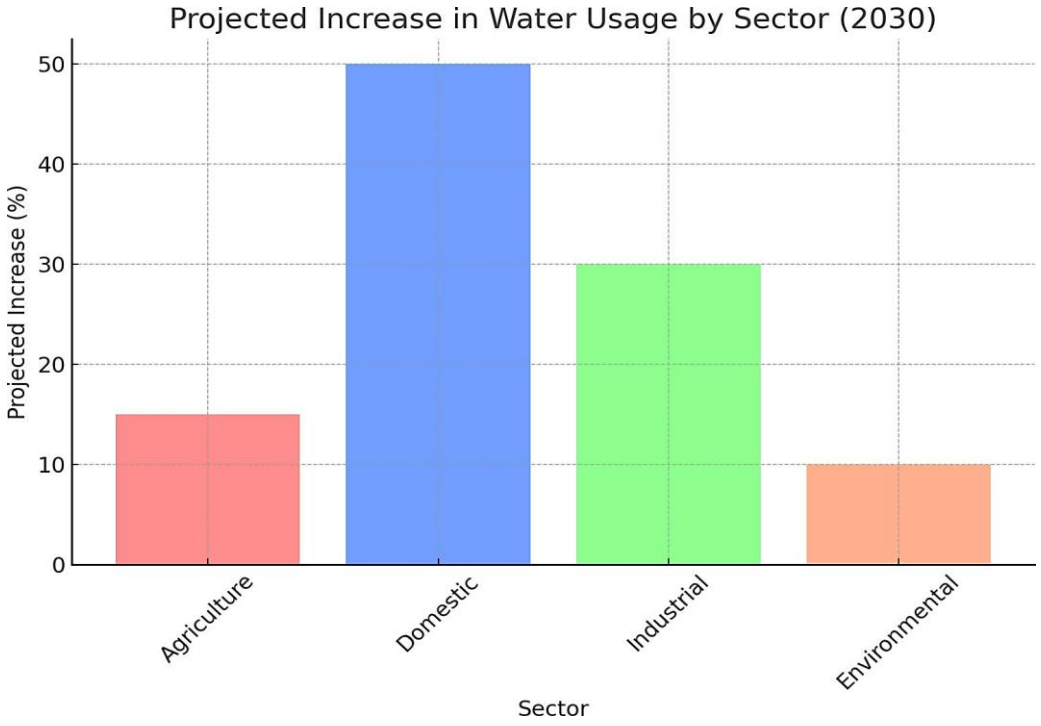

Graph 2: Projected Increase in Water Usage by Sector (2030)

The Graph 2 bar chart illustrates the expected growth in water demand.

- **Domestic Water Usage**: Predicted to rise by 50%, driven by urbanization and population growth.
- **Industrial Water Usage**: Projected to grow by 30%, reflecting industrial expansion.
- **Agriculture**: Will see a 15% increase, highlighting the need for sustainable water management in farming.
- **Environmental Needs**: A modest growth of 10%, showing an increasing but limited focus on ecological preservation.

Discussion

The talks are focused on the importance of the climatic change effects on Pakistan's river regime with a specific accent on the links between the glacier shrinkage, changed precipitation and tendencies toward the increased frequency of extreme meteorological conditions. Although the glacier melt increases the river flows in the short term, at the same time, it decreases available water for all other uses as glaciers continue to decline in size, with negative impacts, especially for the downstream irrigation and hydropower sectors. Fluctuating monsoon patterns add to the inherent water misallocation problems and amplify communities' exposure to flood and drought risks. Human activities, including deforestation, pollution, and irrational water use, add more stress to river systems.

Such instances as the pollution of rivers such as Ravi and the over-exploitation of water resources, especially for agriculture, make it pertinent to look for better ways of controlling and managing it. Examples, including the floods in early 2010, show these challenges' socio-economic impacts, including displacement, malnutrition, and the cost of damaged property. This study supports the blended water management approach with the consideration of both ecological habitats and human requirements.

Effective solutions embrace the production of water through irrigation, afforestation, and incorporation of other methods of irrigation, such as geographical information systems (GIS) and climate modeling. Other means for increasing more resilience are regional cooperation on

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ISSN P: 3006-1458
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the issues of transboundary waters and community activities. The outcomes of the present study suggest that there is an imperative need for policy solutions to pre-empt the climate effects and ensure sustainable futures of the rivers of Pakistan.

Policy Recommendations

Managing climate change impacts and anthropogenic loads in the form of nutrients on Pakistani rivers call for sustained policy actions and management solutions. Based on the study's findings, the following recommendations are proposed:

1. or Integrated Water Management (IWRM) The water resources of Pakistan require the implementation of IWRM to mitigate the conflict of demand for water between different sectors, such as agricultural, industrial, domestic and environmental uses. This framework should ensure that water is fairly distributed, there is little wastage, while improving efficiency from such techniques as drip and sprinkler irrigation. Further, policies should aimed at recharging the aquifers beneath by protecting the wetlands.
2. Improving the Flood and Drought Partnership Systems Measures are needed in disaster risk reduction measures for vulnerability reduction involving floods and droughts. GIS coupled with remote sensing technology applied to real-time monitoring of river flows can enhance the production of improved flow forecasts and, thus, minimize risks. Building new reservoirs or uplifting the existing ones, like Mangla and Tarbela dams, can help leave a longer water storage capacity and better flood control regulation.
3. Subtheme I: Glacial Monitoring and Climate Adaptation As Himalayan glaciers are quickly depleting, monitoring stations will be instrumental in determining the long-term impacts on stream flows. Measures like climate-smart crops and patterns in planting should be included in the agricultural policies that have given rise to the changed water availability regimes. Hashtags
4. International coordination is also inevitable for partnerships to support and address cross-boundary issues directly linked to glacier contamination.
5. Management and Improvement of the Physical Environment To lower the degree of river pollution, it is possible to regulate the standards of environmental policies on industrial and domestic waste management. The operational and development of adequate and higher complexity WWTPs, especially those along water bodies such as rivers Ravi and Chenab, should be considered a high priority. Projects that involve the restoration of the loss of ecological processes can include the reforestation of mangroves in the Indus Delta area, thus boosting the system's stability and the diversity of species.
6. International River Basins of South Asia: Cooperation or Conflict? Since most of its rivers are international, cooperation with other countries is important for developing those water resources. Negotiating and updating the Indus Waters Treaty with India and including in the Treaty provisions for climate change adaptation and climatic variability can significantly reduce future conflict and ensure more equitable use of the waters.
7. Community and Public Relations also stated that local communities must be educated on water conservation and pollution. Open awareness education and community involvement programs, such as rainwater management and tree planting programs, foster ownership. Local governments and NGOs must also mobilize the community and accept changes in water conditions by practicing sustainable approaches.
8. Exploiting Technology and Innovation Technological developments, like climate modelling by means of artificial intelligence or smart agriculture, would allow for improving resource allocation and the accuracy of climate change prediction. Future SAP stress could be minimized through the development of sustainable renewable energy sources such as solar-powered water pumps.

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ISSN P: 3006-1458
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9. Policy Integration and Institutional Strengthening means there should be policy collusion between the federal and the provincial governments regarding water policy implementation. Pakistan is home to institutions such as PCRWR, which, if funded and staffed appropriately, will be better placed in conducting surveillance of such rules and limitations.

Conclusion

Indus and other rivers of Pakistan are crucial for the overall development of the country's agriculture and economy as well as the sustainable environment. Nevertheless, the significant effects of climate change and other uncontrolled human activities pose a real threat to these species. Changes in climate characterized by decreased glaciation, shifting monsoons, and amplified rates of extreme conditions have continued to alter water availability and demand, including scarcity, pollution of water sources, and degradation of the environment. Accordingly, this work imparts the importance of considering integrated water management for these issues.

Even though agriculture takes a large share of freshwater resources, prophet awareness of the consequences of efficient water use in irrigation techniques Calls for policy direction on sustainable use of water in urban and industrial sectors. The examples used in this paper, like the 2010 floods and pollution of the Ravi River, are evidenced by social and economic impacts, which include displacement, food insecurity and ill health. In Pakistan, mitigation and adaptation approaches are inevitable to improve the robustness of river systems.

Practical imperatives encompass such measures as further enhancing the management of floods and droughts, popularization of afforestation, and development of improved facilities for wastewater treatment. Also, using other technological tools like GIS in climate modelling, forecast impacts can be conducted in anticipation of future effects. This paper establishes that the cooperation of states in a region about transboundary water resources, particularly the Indus Waters treaty, remains relevant since it fosters and encourages the proper sharing of water resources rather than promoting conflict. Organizing awareness and involving the community are some of the crucial methods of sustainable development. However, through educating the local communities to engage in such activities as rainwater harvesting and tree planting, they will be able to cultivate a culture of conservation among themselves.

Moreover, compliance with the directions of water activity regarding climate change adaptation goals and improving institutional support is necessary to implement plans and measures. Therefore, it can be maintained that the continued existence of the river systems of Pakistan depends on the country's capacity to manage climate change and anthropogenic impacts through innovative policy frameworks that are progressive and that embrace multiple stakeholder engagement. Using science, technology, and participatory approaches, Pakistan can preserve its water resources and develop lessons that can guide the country as it meets emerging environmental problems in the future. The time is now for the stability of those vital water sources and rivers, depending on the near future of the country's water security and ecological sustainability.

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