A GeoAI-Informed Analysis of the Chenab River Basin in Jammu & Kashmir: Interdependencies of Hydrology, Infrastructure, and Geopolitics

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Abstract

The Chenab River basin, a critical transboundary water resource in South Asia, presents a Complex system governed by rugged topography, dynamic hydrology, extensive anthropogenic infrastructure, and a contentious geopolitical framework. This paper provides a detailed GeoAI-informed analysis of the Chenab basin as it drains through the Jammu region of Jammu & Kashmir (J&K). By structuring geospatial, hydrological, and policy data into an integrated framework, this study examines the intricate interdependencies between the river's physical characteristics, the vast network of hydroelectric dams, the regulatory constraints of the Indus Water Treaty (IWT), and the overarching impacts of climate change. Our analysis reveals that while the basin's steep geography is conducive to hydropower, the IWT has historically constrained project designs, leading to political friction. The existing run-of-the-river dams significantly alter the river's natural flow and sediment regime, with operational actions like reservoir flushing causing drastic downstream fluctuations. The recent suspension of the IWT by India signals a paradigm shift towards a more unilateral and securitized approach to water management, accelerating infrastructure development. Compounding these issues, climate change acts as a stress multiplier, increasing the risk of catastrophic floods and long-term water insecurity. This paper concludes that the management of the Chenab River is a precarious balance, where GeoAI can serve as a vital tool for modeling complex scenarios and informing more resilient and cooperative water management strategies in a highly volatile environment.

Keywords: Chenab River, GeoAI, Hydrology, Indus Water Treaty, Hydropower, Climate Change, Jammu and Kashmir, Water Resource Management.

1. Introduction

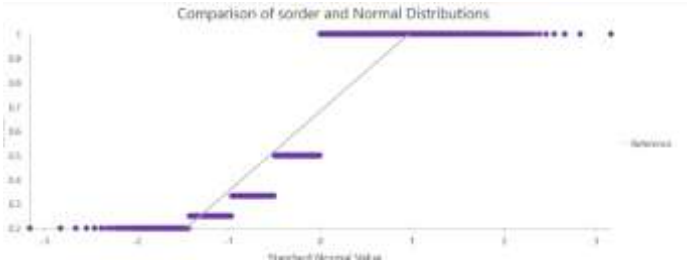
The Chenab River, known as 'Chandrabhaga' in its upper reaches, is a vital artery of the Indus River system, sustaining ecosystems and economies across India and Pakistan (britannica.com). Originating in the high-altitude Himalayas of Himachal Pradesh, it carves a dramatic path through the Jammu region of Jammu & Kashmir before flowing into the plains of Punjab in Pakistan. The basin is characterized by its immense biological and cultural diversity, but also by significant geopolitical and environmental pressures (mershoncenter.osu.edu).

In recent years, the convergence of Geographic Information Systems (GIS) and Artificial Intelligence, termed GeoAI, has provided powerful new methodologies for analyzing complex environmental systems (mdpi.com). By integrating diverse spatial datasets—such as topography, land use, hydrological measurements, and infrastructure
locations—GeoAI can model and reveal intricate relationships that are not apparent from siloed analysis (sciencedirect.com). This approach is particularly suited to the Chenab basin, where water
management is a function of natural processes, engineering interventions, and international policy.

This paper presents a comprehensive analysis of the Chenab River basin in J&K, structured through a GeoAI lens. It synthesizes data on the basin's physical geography, hydrological patterns, anthropogenic infrastructure (specifically hydroelectric dams), and the profound influence of the 1960 Indus Water Treaty (IWT). The objective is to dissect the interdependencies among these elements and assess their collective impact on the region's water resources and management strategies, especially in light of recent geopolitical shifts and accelerating climate change.

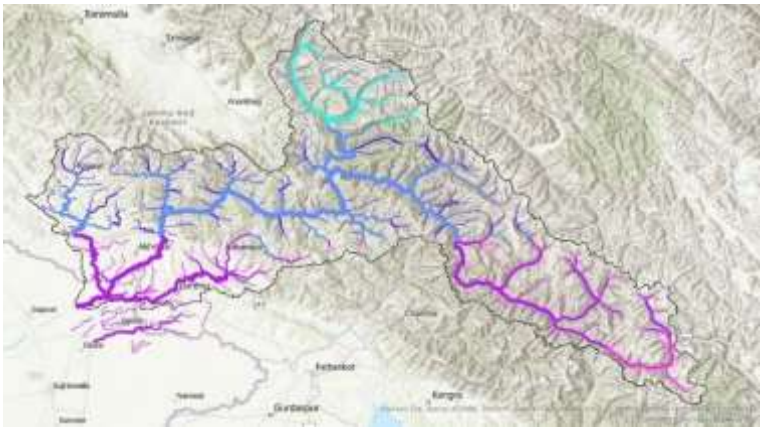
2. Data Collection: Geo-Hydrology, Infrastructure & Policy

A foundational step in this analysis was the comprehensive collection of data from diverse sources, including
scientific publications, government databases, and news archives. This data forms the basis for understanding the basin's natural and human- influenced systems.



2.1. Chenab River Geo-Hydrology

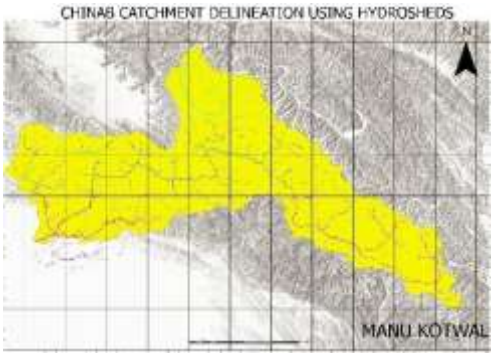
The geo-hydrological profile of the Chenab is defined by its mountainous origin and significant flow.



- **Basin Coverage and Length:** The river is formed by the confluence of the Chandra and Bhaga streams in Himachal Pradesh, India (iasgyan.in). It flows for approximately 974 km (605 miles) to its confluence with the Sutlej River in Pakistan (britannica.com). Within J&K, the Chenab basin covers the districts of Kishtwar, Doda, Ramban, Reasi, and Jammu, with a total catchment area of 29,050 sq. km up to the international border (indiawris.gov.in).

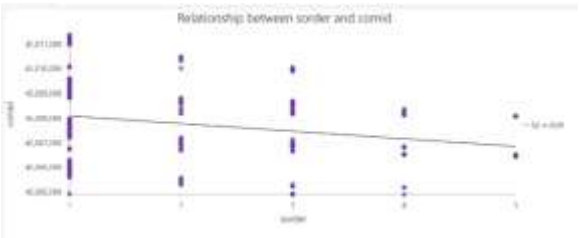
- **Topography and Morphology:** The basin is characterized by a V-shaped valley, particularly in the Kishtwar region, where the river maintains a steep and narrow channel (researchgate.net). A comprehensive study identified the watershed as a seventh-order catchment with an elongated shape (tandfonline.com).
- **Water Discharge and Flood Plains:** The river's flow is highly variable. The historical maximum discharge recorded at Marala Headworks in Pakistan reached an exceptional 31,148 m3/s (Approx. 1,100,000 cusecs) (en.wikipedia.org). More typical high-flow events, such as one anticipated in August 2024, are in the range of 200,000 to 250,000 cusecs (dawn.com). The river's flood plains are the alluvial lowlands that descend from

the uplands into Punjab province (britannica.com).



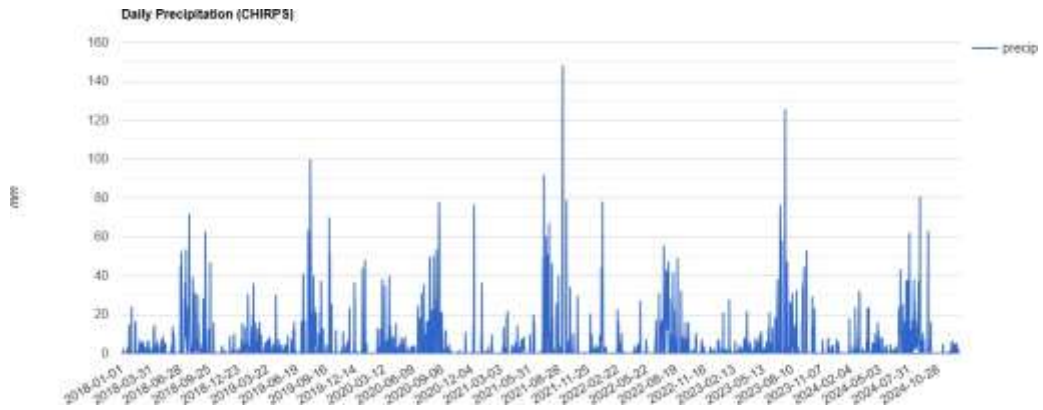
- **Heaviest Floods:** The basin has experienced several catastrophic floods. The 1992 floods, caused by five days of heavy monsoon rains, led to at least 2,496 fatalities across northern Pakistan and India, with significant devastation along the Chenab (en.wikipedia.org).

The flood in 2014 was also exceptionally severe, causing more human and economic losses than any event since 1992 (geoenvironmental- disasters.springeropen.com).



2.2. Infrastructure and Policy Landscape

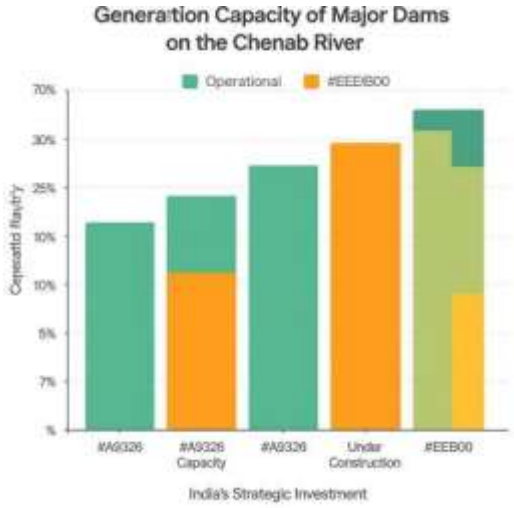
The natural river system is heavily mediated by human-built structures and political agreements.

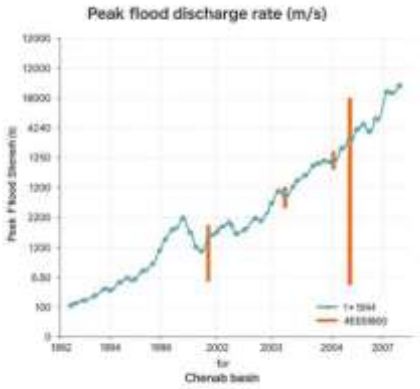


- **Dams on the Chenab Catchment:** The steep gradient of the Chenab in J&K has made it a focal point for hydropower development. Key projects include:

◦ **Salal Dam:** A 690 MW run-of-the-river project commissioned in 1987, it was the first hydropower project built by India in J&K under the IWT regime (en.wikipedia.org).

- **Baglihar Dam:** A 900 MW run-of-the-river gravity dam commissioned in two stages (2008 and 2015-16). Its construction was a point of contention with Pakistan, resolved by a neutral expert (en.wikipedia.org).
- **Dul Hasti Dam:** A 390 MW run-of-the-river project commissioned in 2007, featuring a 70-meter high gravity dam (en.wikipedia.org).
- **Under-Construction Projects:** India is aggressively pursuing several new projects, including the 1000 MW Pakal Dul Dam, the 624 MW Kiru project, the 850 MW Ratle plant, and the 540 MW Kwar project, all primarily in the Kishtwar district (gktoday.in).





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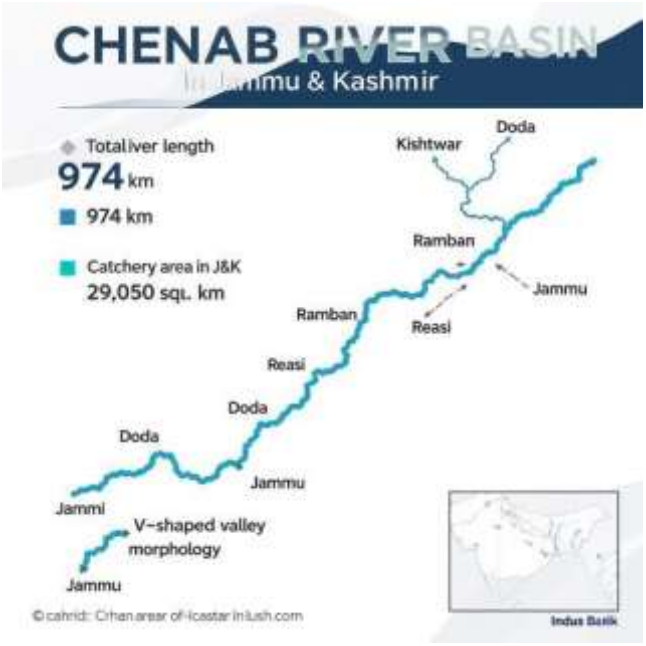
CHENAB RIVER BASIN
Jammu & Kashmir
Total river length
974 km
974 km
Catchery area in J&K
29,050 sq. km
Doda
Kishtwar
Ramban
Jammu
Reasi
Ramban
Reasi
Doda
Doda
Jammu
Jammi
V-shaped valley
morphology
Jammu
Indus Basin


Chenab River at Marala Headworks
Historica River for Marala Headworks
Aug 2024
Historical maximur:
31,18,148 m/s
2300,00-270,000
1510
160
150
150
160
40
20
30
20
0
25,8,00-270,109
1962
19-12
20-11
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Test flow
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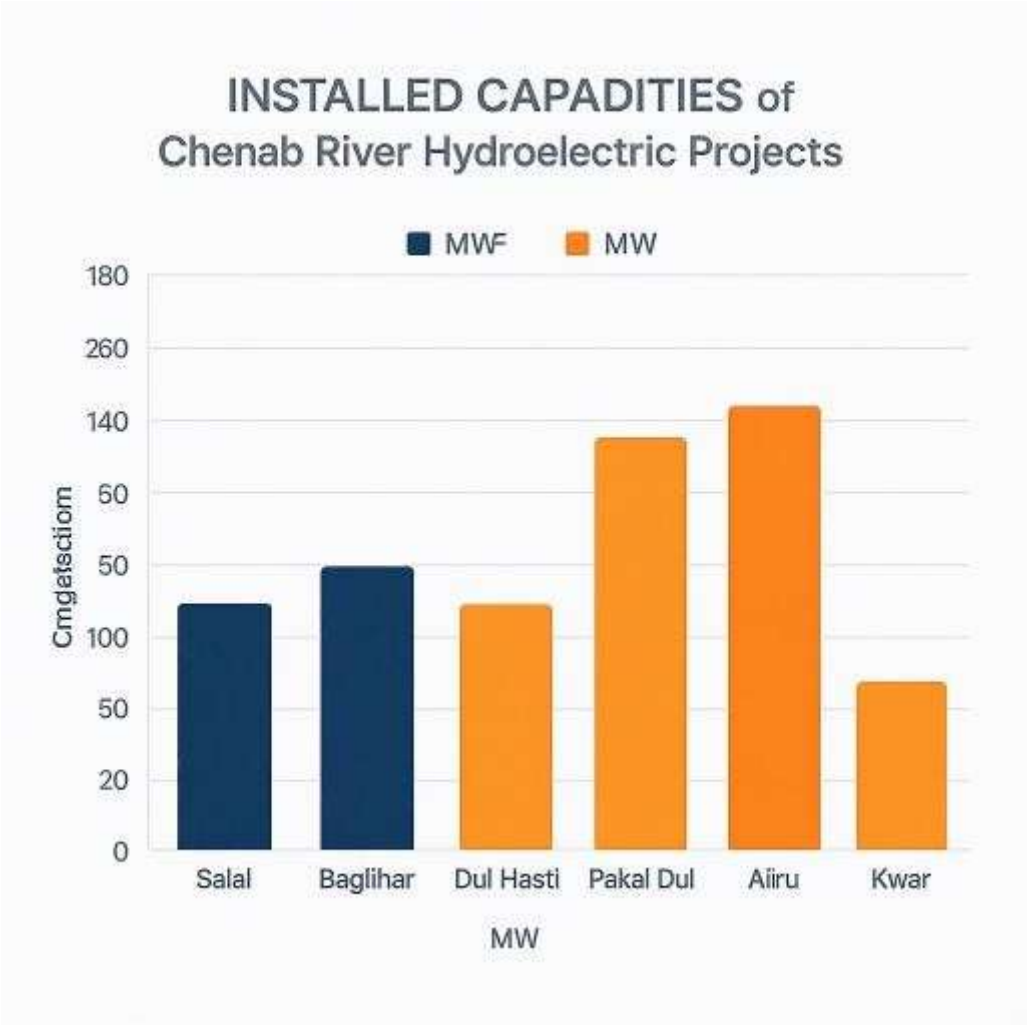
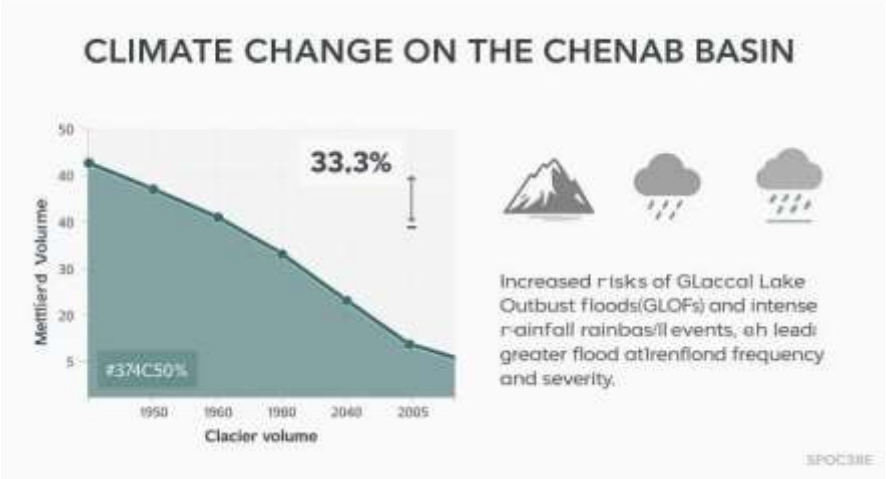
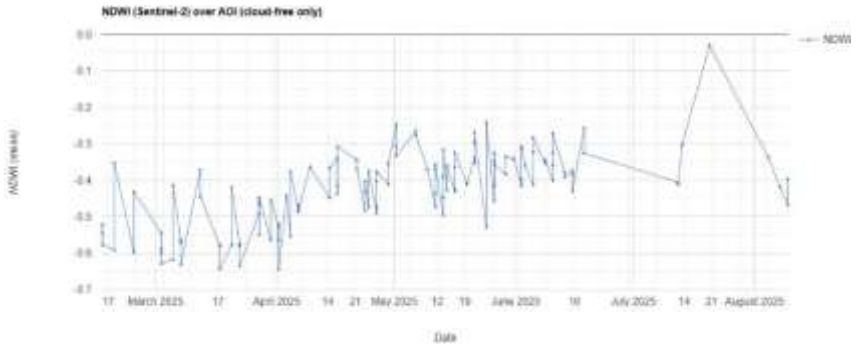

INSTALLED CAPADITIES of
Chenab River Hydroelectric Projects
MWF
MW
180
260
140
50
50
100
50
20
0
Salal
Baglihar
Dul Hasti
Pakal Dul
Aiiru
Kwar
MW


CLIMATE CHANGE ON THE CHENAB BASIN
33.3%
Increased risks of GLaccal Lake Outbust floods(GLOFs) and intense rainfall rainbas/ll events, eh lead greater flood atlrenflond frequency and severity.
1950
1960
1980
2040
2005
Clacier volume



- **The Indus Water Treaty (IWT):** This 1960 treaty, brokered by the World Bank, is the cornerstone of water management in the basin (britannica.com).

  - **River Allocation:** The IWT allocated the waters of the three "Western Rivers" (Indus, Jhelum, and Chenab) to Pakistan, while India gained rights to the three "Eastern Rivers" (Ravi, Beas, and Sutlej) (reuters.com).
  - **Indian Rights on Chenab:** India is permitted non-consumptive use of the Chenab's waters, which includes run-of-the-river hydropower generation. However, the treaty places specific restrictions on dam design and storage capacity to ensure downstream flows are not impeded (aljazeera.com).
  - **Suspension of the Treaty:** Citing national security concerns, the Government of India suspended the IWT in April 2025, a move that has no legal provision within the treaty itself and has drastically altered the region's water politics (en.wikipedia.org).

3. GeoAI Synthesis and Analysis of Interdependencies

Organizing the collected data into a geospatial framework allows for a deeper analysis of the interrelationships between the basin's physical, infrastructural, and political layers.

3.1. Synthesis of Geospatial Data

For a GeoAI analysis, the data can be structured into thematic layers:

Layer Category	Key Attributes	Data Points and Relevance
Topography & Morphology	Catchment Area, Elevation, Slope, Valley Shape	29,050 sq. km catchment in J&K. Steep V-shaped valleys are ideal for high-head hydropower projects. Elongated basin shape influences runoff characteristics.
Hydrological Characteristics	Discharge (Max/Mean), Flood Regime	Maximum recorded discharge of ~31,148 m3/s. High seasonal variability requires large spillway capacities for dams and robust flood management.
Anthropogenic Infrastructure	Dams (Location, Capacity, Type)	A cascade of dams (Salal, Baglihar, Dul Hasti, etc.) along the river's course in J&K, designed primarily as run-of-the-river to comply with the IWT.
Policy & Regulatory Framework	IWT Designation, Usage Rights	The Chenab is a "Western River" under the IWT, fundamentally constraining the design and operation of all Indian infrastructure on it.

3.2. Analysis of Interdependencies and Impacts

- **Impact of Dam Infrastructure on River Dynamics:** The concentration of dams has transformed the Chenab from a naturally flowing river to a highly regulated system. Run-of-the-river projects, while not designed for large-scale storage, fundamentally alter the hydrological regime. They trap a significant portion of the river's sediment load, which can lead to riverbed degradation downstream and impact aquatic ecosystems (mdpi.com). Operational necessities like "reservoir flushing" to remove accumulated silt cause sudden, man-made floods downstream, followed by periods of drastically reduced flow as reservoirs refill. Following the IWT suspension, such operations at the Baglihar and Salal dams caused the flow into Pakistan to drop by up to 90%, demonstrating how infrastructure can be used to control water flows for strategic purposes (reuters.com).

- **The Overarching Influence of the Indus Water Treaty:** The IWT has long served as both a conflict-prevention mechanism and a source of developmental constraint. For decades, it forced Indian engineering designs to prioritize flow continuity over storage, a point of enduring grievance in J&K, which claims the treaty has stymied its agricultural and economic growth (indianeXpress.com). India's unilateral suspension of the treaty in 2025 has effectively removed these constraints, at least from New Delhi's perspective. This has been followed by an immediate push to fast-track multiple hydropower projects, indicating a strategic pivot to maximize water utilization on the Western Rivers (reuters.com). This move challenges the six-decade- old water-sharing paradigm and significantly heightens the risk of hydro-political conflict (ejiltalk.org).
- **Climate Change as a System-Wide Stress Multiplier:** The entire Chenab system is under severe threat from climate change. The basin's glaciers, which are critical for regulating river flow, are receding at an alarming rate. This not only threatens long- term water security but also creates immediate hazards. The formation of unstable glacial lakes increases the risk of Glacial Lake Outburst Floods (GLOFs), which could generate floodwaters powerful enough to overwhelm or destroy downstream dams and communities (sandrp.in). Furthermore, climate change is expected to increase the frequency and intensity of extreme rainfall events, exacerbating flood risks in a basin already prone to devastation, as seen in 2014(mdpi.com). The lack of a cooperative, basin-wide framework for managing these climate-induced risks is a critical vulnerability.

4. Discussion and Conclusion

The GeoAI-informed analysis of the Chenab River basin reveals a deeply interconnected and fragile system teetering on a knife's edge. The relationship between the river's geography, its hydrological behavior, the infrastructure built to harness it, and the treaty designed to govern it is now undergoing a fundamental transformation. For decades, the IWT, despite its flaws, enforced a degree of predictability. India built dams, but within treaty-defined limits; Pakistan voiced objections, but through established diplomatic and legal channels.

The suspension of the IWT has shattered this framework. Water management on the Chenab is rapidly shifting from a technically constrained, quasi-cooperative model to a politically charged, unilateral one. India's actions to fast-track dam construction and manipulate flows post-suspension underscore a new reality where water is an explicit instrument of national policy.

This new paradigm is unfolding under the shadow of catastrophic climate risk. Pushing for rapid construction of more large dams in a geologically fragile and climatically volatile region, without robust, cooperative risk assessment, is a dangerous gamble (sandrp.in). A GLOF or an extreme flood event could trigger a disaster that cascades across borders, with devastating humanitarian and ecological consequences.

In conclusion, this paper highlights the precarious state of the Chenab basin. The complex interplay of its natural and man-made systems is being pushed to its limits by geopolitical tensions and climate change.

Moving forward, GeoAI technologies will be indispensable for modeling the multifaceted risks the basin faces. Predictive models could simulate the impact of different dam operation scenarios, forecast flood inundation under various climate projections, and identify areas of high vulnerability. However, technology alone is insufficient. Without a renewed commitment to transparent data sharing and cooperative, basin-wide management, the Chenab River risks becoming a flashpoint for conflict rather than a shared source of life and prosperity.

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