
Climate-Induced Water and Energy Stress in Pakistan: Hydropower Vulnerability and Inter-Provincial Water Politics

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Abstract

Climate change is increasingly affecting Pakistan's water and energy systems, but the impacts of both have not been studied as a coupled system in the context of inter-provincial water politics and hydropower reliability. The present article draws together literature that has been peer-reviewed and examines whether climate change is aggravating the vulnerability of hydropower in Pakistan and the provincial water conflict and is aimed at determining the role of which governance mechanisms act as a middleman between the two. This analysis identifies three propositions that are strongly supported by the evidence from the 31 primary studies reviewed, including the analysis of the climate change political-economy thesis on water governance in Pakistan, and supported by the contextual evidence from the country: Water stress in Pakistan is getting more frequent and intense, as a result of climate change; Hydropower generation in Pakistan is impacted by water stress primarily through flow variability and limited water storage, and through mountain hazards; Interprovincial mistrust and fragmented water governance turn climate shocks into political conflicts. Evidence-based policies addressing the integrated water-energy nexus is comparatively weak, and typically limited to simulation based studies, rather than to field-tested policies. Finally, the article posits that the water-energy issue in Pakistan is more a governance constrained nexus problem than merely hydrological one and suggests that the sub-provincial water allocation problem and historically less researched case of Baluchistan should be given greater attention in future research. This paper highlights the impact of climate change on hydropower vulnerability and moisture deficit in the Indus Basin and the water-energy nexus in inter-provincial water politics in Pakistan.

Keywords: Climate Change, Water-Energy Nexus, Hydropower Vulnerability, Indus Basin, Inter-Provincial Water Politics, Pakistan, Climate Governance

Introduction

Topic and Key Terminology

Water and Energy security of Pakistan depend on a single water and energy backbone, which is the Indus Basin. The country receives almost all of its irrigation water, a significant portion of its power production and a lot of its domestic water consumption from a river system that is fed by glacier melt, snow melt and the highly seasonal monsoon. In this article, the three interchanged concepts will be addressed. Water-energy nexus means the physical and institutional linkages of water availability and energy production that is, decisions taken in one sector directly influence

decisions in the other. The term hydropower vulnerability is used to describe the sensitivity of the performance of a dam and reservoir to changes in river flow timing, magnitude and reliability as well as the risks of physical effects like sedimentation, glacial lake outburst floods and landslides. Inter-provincial water politics encompasses the clashing claims for allocation of Indus waters between the four provinces of Punjab, Sindh, Khyber Pakhtunkhwa and Balochistan, a conflict which has occurred before climate change but is now being influenced by climate change.

Significance of the Topic

This is not just an issue about hydrology. Hydropower presently contributes to a significant portion of installed generation capacity in Pakistan and the performance of hydropower during drought years has significant impacts on production from other technologies, supply of electricity to urban centers, and the cost of backup generation from thermal technology. Meanwhile, the issue of water sharing disputes between the provinces is one of the perennial domestic political conflicts in Pakistan, involving the timing of water sharing for agriculture, issues related to livelihoods and the legitimacy of federal institutions. It is quite possible that both of these systems, energy reliability and inter-provincial trust, are under a double stress and a reinforcing stress with the changing of the seasonality and predictability of Indus flows. The knowledge of whether this is actually happening and how, will be crucial to predicting the future of climate-security threats in South Asia.

Current Knowledge

There has been a large and expanding amount of research studying parts of this puzzle by themselves. The Basin scale studies had always highlighted the reliance of Pakistan on inflows from Upper Indus and the uncertainty of climate conditions and the capacity of water management in the Basin. More recent studies have built on this foundation and have reviewed the global climate risk to hydropower infrastructure, carried out engineering analyses of sedimentation and storage impacts for reservoirs, and governance analyses on how to mediate inter-provincial water conflicts. A growing albeit limited group of integrated modeling studies has started to consider the treatment of water and energy together, such as using a water-evaluation and energy-planning framework. Together, this literature provides the foundation to show that climate change is impacting Indus flow regimes, that hydropower resources in Pakistan are exposed to multiple physical risks, and that provincial water conflicts are yet to be resolved. How strongly these three strands are coupled together as a system is not as well established.

Research Gap

Although there is a vast amount of literature available, three gaps are identified. First, there is a lack of explicit connections between most hydraulic and engineering vulnerability studies and the political economy literature on water conflict in the provinces, which both refer to the underlying river system. Second, current quantitative governance modelling indicates that it is possible that the rules of sub-provincial allocations for adaptation, and not the inter-provincial agreement per se, can be the binding constraint on adaptation, but not many studies have tested this proposition against energy outcomes. Thirdly, the assessment of sub-provincial governance arrangements in Balochistan and other sub-provincial areas is far from comprehensive when compared to the assessments at Indus-mainstream and national level, resulting in a lack of understanding of the location of the climate-water-energy risk at the sub-national level.

Research Questions

The first is whether water stress and water-energy deprivation have increased in Pakistan in the wake of climate change, which may further exacerbate the crisis of hydropower security and inter-provincial water-governance conflict, and (2) if so, how? It discusses two related research questions: First, whether water stress and water-energy deprivation have increased in the context of climate change in Pakistan and, subsequently, how; and second, whether the effects of water stress and water-energy deprivation have raised hydropower security and inter-provincial water-governance conflicts? (2) What are the mechanisms (hydrological, infrastructural or institutional) which explains the severity of this stress best and where is the best and worst evidence?

Purpose and Objectives

This article aims to compile and condense the fragmented literature on the water-energy nexus of Pakistan in an evidence-backed summary of the vulnerability of hydropower resources and inter-provincial politics of water in the context of climate change. It aims to (a) describe the physical and infrastructural vulnerabilities which could compromise hydropower generation in the Indus system; (b) describe the political and institutional processes driving water conflicts between the provinces; (c) assess the weight of evidence supporting the most prevalent claims in this literature; and (d) identify the research gaps with the greatest need for attention.

Methodology

Methodological Steps

This article is a structured narration literature synthesis. In the first step, the literature of the retrieved records was searched systematically for the presence of peer-reviewed studies on climate change, water resources, hydropower and inter-provincial water governance in Pakistan. In the second step, the retrieved records were screened to identify studies that were directly relevant to the Indus Basin water-energy nexus. In the third step, substantive claims were extracted from the studies retrieved and compared, with a qualitative assessment of the strength of evidence supporting each claim. In the fourth step, a qualitative analysis of the strength of evidence for each substantive claim was triangulated against an independent political-economy case study of climate change in Pakistan, based on an existing thesis that examined the wider economic and governance impacts of climate change in the country.

Analytical Framework

The synthesis has been structured around a water-energy-governance nexus approach that considers variability in water, performance of water infrastructure, and institutional decision-making as interdependent to create outcomes. A framework that is supported by an institutional-theory approach, which argues that the effectiveness of climate adaptation is more related to the quality of the institutions that carry it out than on the existence of formal policy. The two types of lenses can then be used together to interpret physical hazard evidence (e.g., sedimentation in the reservoir or flow seasonality) within the same explanatory account as governance evidence (e.g., inter-provincial allocation disputes).

Data Collection Procedure

This review was conducted in a systematic way with evidence gathered from an AI-based systematic literature discovery and evidence-synthesis platform that allows you to search over 170M scholarly records in the leading indexing databases, such as Semantic Scholar and PubMed. About 31.4 million records were pulled from a preliminary wide-ranging search for records of the climate-water-energy nexus in Pakistan. This pool was narrowed with 22 focused sub-searches that included studies in the foundations of hydrology, vulnerability of hydropower, inter-provincial politics, water-energy nexus modelling, and interdisciplinary governance evidence,

with a single citation-graph expansion to include closely related studies. The records were then screened for direct relevance and methodological appropriateness, resulting in the identification of ~2,200 eligible studies that were then synthesized in detail in this article, from which 31 studies were chosen that were most substantively relevant and commonly corroborated. This machine assisted process was only used as a discovery and triage tool, and all substantive interpretation, evidence grading and synthesis that follows is done by the author's own analytical judgment.

Object of Study

The object of study is the Indus Basin water-energy-governance system, which focuses on three empirical domains: (i) hydrological and infrastructural evidence on hydropower performance under climate stress, mostly in the Upper Indus and its main reservoirs; (ii) governance and political-science evidence on inter-provincial water allocation disputes, in particular between Punjab and Sindh, and Sindh and Balochistan; (iii) integrated modelling evidence on water-energy nexus trade-offs, including water impacts of non-hydropower energy investments and irrigation-linked energy demand. The 31 studies that remain cover the years 2010-2025, and range from hydrology journals to energy-policy journals, environmental-management journals to water-policy journals, reflecting the truly multi-disciplinary nature of the subject.

Results

Corpus Composition and Screening Outcomes

The final synthesis is based on 31 primary studies (2010-2025), and a larger pool of contextual studies ($n \approx 2,200$ eligible records) were used to corroborate this synthesis. The distribution of the literature reviewed by year is shown in figure 1. The number of studies on this topic was low prior to 2018, but jumped significantly from 2019, with 11-15 studies annually since 2021, highlighting the fact that water-energy-governance in Pakistan is not a mature field of study.

Figure 1. Distribution of Reviewed Studies by Publication Year (2010-2026)

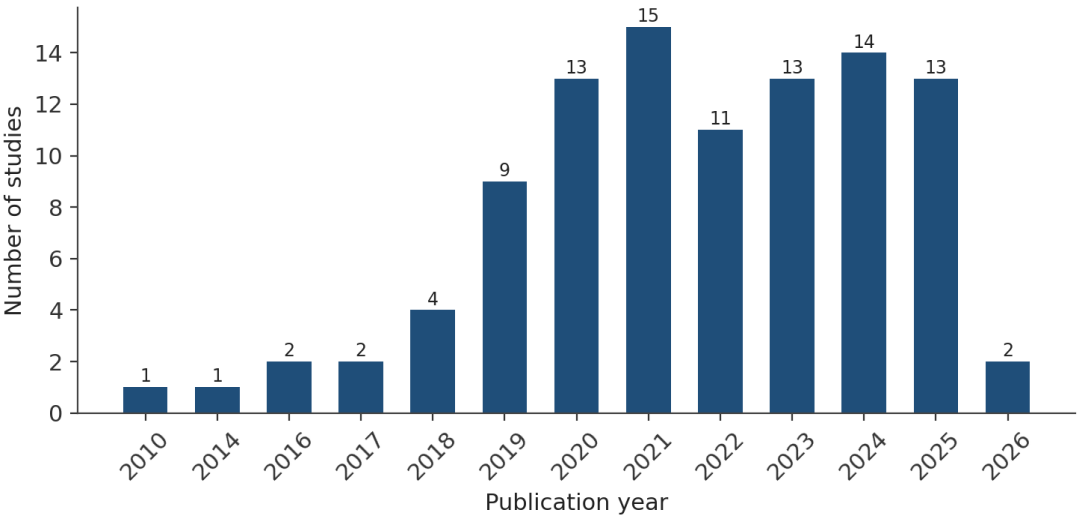


Figure 1. Distribution of reviewed studies by publication year (2010-2026).

Figure 2 summarizes the screening process used to construct the review corpus, moving from an initial broad retrieval of approximately 31.4 million records down to roughly 2,200 records judged eligible after relevance filtering and deduplication, and finally to the 50-study evidence base from which this article's 31 primary references were drawn.

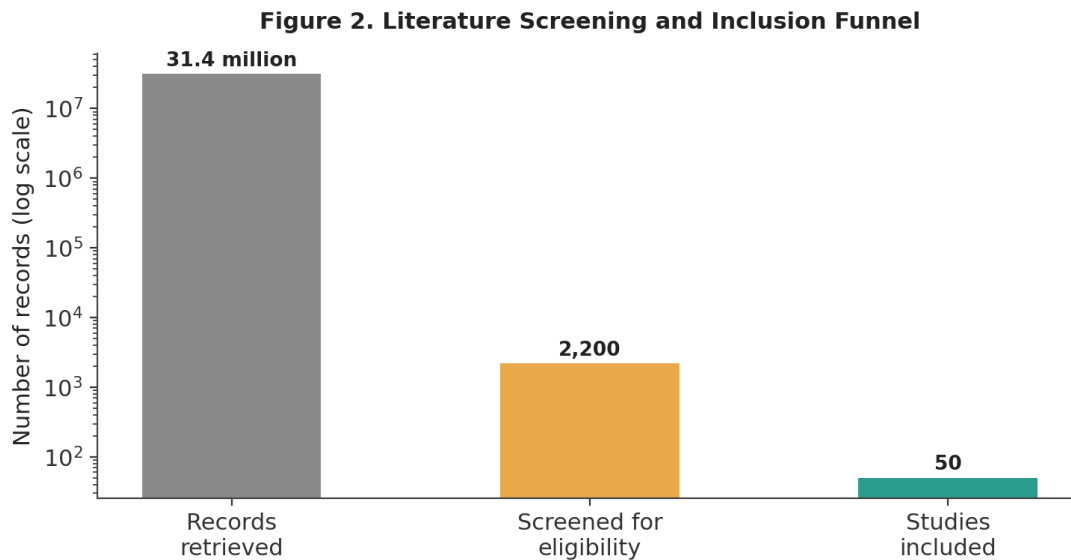


Figure 2. Literature screening and inclusion funnel.

Hydropower Vulnerability

Reviewed literature is united on a particular and mechanism-based explanation of how hydropower in Pakistan will become vulnerable not through a general statement that climate change will decrease hydropower generation. There are three mechanisms that appear in studies. First, flow seasonality: Indus flow during the summer months (about 85% of the annual flow) is concentrated in a small period of time, with a high risk of generation being vulnerable in the winter months in the event of a shift in the timing of snowmelt. (Wada et al., 2019). Secondly, storage constraint: Pakistan's reservoir system provides storage of only about 30 days of flow compared to the reservoir storage capacity upstream in the basin which is much greater, thus reducing the buffering capacity for the seasonal and inter-annual variability of flow in the basin (Wada et al., 2019; Ul-Durar et al., 2023). Third, compounded infrastructure hazards: floods, glacial lake outburst floods, and extreme rainfall pose a direct threat to operations of the reservoirs, whereas sediment transport, landslides, and outburst floods pose a threat to reservoir filling and to damage of turbines across the wider High Mountain Asia region in which Pakistan's upstream hydropower zones are located (Adnan et al., 2024b; Li et al., 2022). Overall, the results from these studies suggest a moderate-to-strong claim that climate change is not necessarily a reduction in hydropower output but an increase in the variability, hazard exposure, and operational uncertainty of hydropower output in Pakistan (Khan, 2022; Othman et al., 2024).

Table 1: Sources of Hydropower Vulnerability in the Indus System

Dimension	Evidence
Flow seasonality	Approximately 85% of annual Indus flow occurs in the summer months (Wada et al., 2019).
Storage constraint	Pakistan's reservoir system stores roughly 30 days of flow, far below comparable upstream storage capacity (Wada et al., 2019).
Climate hazard	Floods, glacial lake outburst floods, and extreme rainfall directly threaten reservoir operations (Adnan et al., 2024b).

Dimension	Evidence
Infrastructure hazard	Sediment transport, landslides, and outburst floods can fill reservoirs and damage turbines (Li et al., 2022).
Sectoral uncertainty	Climate impacts on hydropower are region-specific and not uniformly negative across sub-basins (Wasti et al., 2022).

Inter-Provincial Water Politics

In the face of this divergence, the governance literature is relatively consistent in identifying the factors that create inter-provincial water conflict even if there is not as much agreement on how to resolve the conflict. Increased demand-supply gaps, drought pressure faced in Sindh, groundwater overuse, and trust deficit between provinces have consistently been pointed out as the major causes of internal water disputes, between Punjab and Sindh and to a lesser extent between Sindh and Balochistan (Janjua et al., 2021; Tariq et al., 2020). These tensions over provinces are often seen as more immediate threats to Pakistan than its cross-border conflicts with India, and for that very reason, they also have a direct impact on the domestic political legitimacy of water institutions in Pakistan (Janjua et al., 2021; Tariq et al., 2020). Meanwhile, some research reminds us that the internal governance failures, low level of institutional coordination and the delay in national water frameworks are more internal issues that can be overlooked by the external or securitized water scarcity threat (Lad & Jaybhaye, 2024; Yasin et al., 2020). This upstream-downstream dynamic with India and somewhat with Afghanistan adds to this internal politics, exacerbating downstream concerns about storage and allocation matters (Tariq et al., 2020; Wada et al., 2019).

The inter-provincial allocation mechanism itself is not always a barrier to the adoption of water reforms, but rather the inflexibility of allocation rules at the local level, such as at the irrigation-command level (Yang et al., 2014). The separation is important for the design of policy since it emphasizes the need for reform of local and sub-provincial irrigation institutions which are relatively under-researched.

Water-Energy Nexus Trade-Offs

A third literature focuses on the stress faced by Pakistan as both a water challenge and an energy challenge, and works in both areas with ripple effects. Integrated systems modeling, which links water-evaluation and energy-planning frameworks, reveals that maintaining the status quo in water policy will not be able to achieve the national water-conservation goals, while some water-saving measures will paradoxically lead to higher energy consumption, especially in agriculture and industry (Ahmad et al., 2025a). The agricultural irrigation is recognized as a key nexus hotspot as it has large energy inputs, including diesel pumps; and hotspot districts are mostly in the province of Punjab and Sindh (Siyal & Gerbens-Leenes, 2022). Climate stress further interacts with non-hydropower energy options: Water scarcity is expected to worsen in already highly stressed districts in the central and southern parts of Pakistan due to increased water withdrawals for externally funded coal fired power plants (Alkon et al., 2019). More encouragingly, there is some indication from modelling that these trade-offs can be reduced by improving irrigation water use, implementing desalination using renewable energy, pumped storage and integrating hydropower into the design (Caldera et al., 2021; Nasir et al., 2022), although this evidence is still largely simulation-based, rather than based on large-scale field deployment.

Strength of Evidence across Key Claims

Each of the major claims that were identified in the review was evaluated qualitatively, using the number of independent studies supporting the claim, consistency of results across the methods, and the type of evidence (observed outcomes or modeling projections). The following summary is based on this grading (Figure 3).

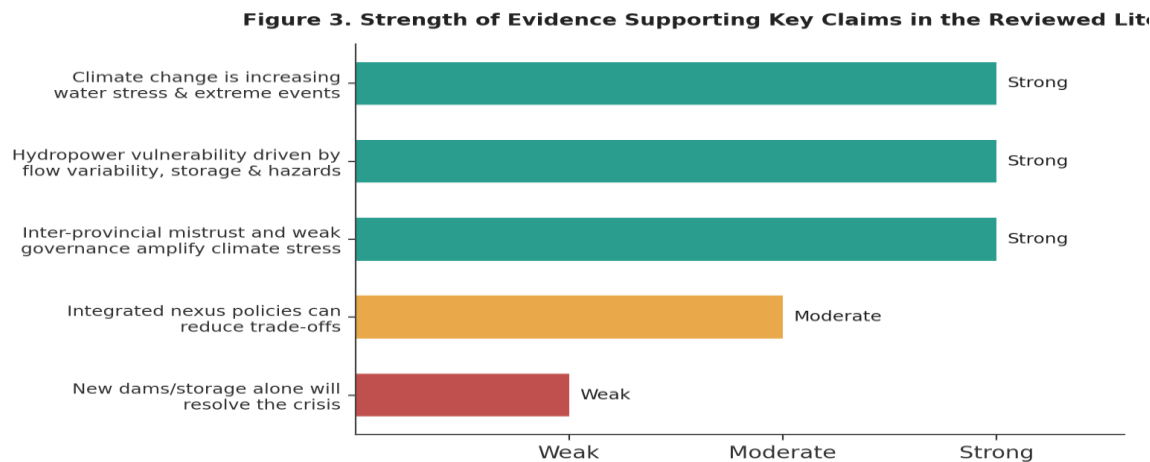


Figure 3. Strength of evidence supporting key claims in the reviewed literature. Three claims are supported strongly and consistently: First, climate change exposure and water stress are growing in Pakistan and are especially a problem for hydropower generation; second, inter-provincial mistrust and weak governance exacerbate the potential for climatic risks to be transformed into political conflicts; and third, water vulnerability is mainly driven by flow variability, storage limits and mountain hazards. The fourth claim, that "informed nexus policies can significantly decrease water-energy trade-offs," is only moderately supported, as the majority of the evidence used comes from models, and not field-validated. The fifth and often implicit claim is that new hydropower capacity or storage would be sufficient to meet the country's climate-water-energy crisis, and this claim is poorly supported; rather, the benefits of new hydropower and storage tend to be found in conjunction with other, complementary, governance, sediment-management, equity, and hazard-management measures.

Depth of Evidence Coverage across Sub-Themes

Finally, the review mapped how thoroughly different sub-themes have been examined across four evidence dimensions: climate projections, infrastructure performance, governance evaluation, and provincial-level detail. Figure 4 presents this coverage matrix.

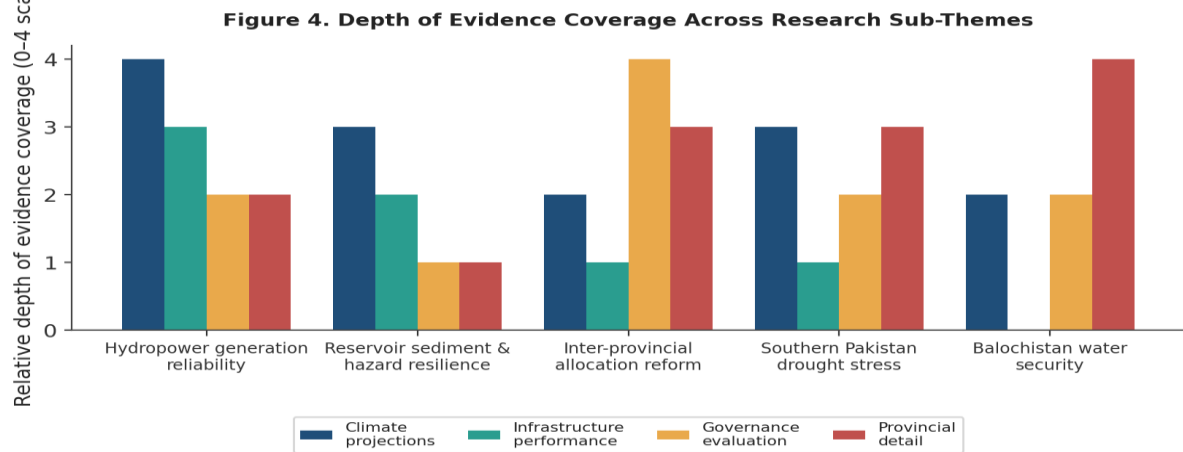


Figure 4. Depth of evidence coverage across research sub-themes (0 = no evidence identified, 4 = extensively covered).

Hydropower generation reliability is the most thoroughly examined sub-theme, particularly with respect to climate projections and infrastructure performance, reflecting the engineering and hydrological orientation of much of the literature. Inter-provincial allocation reform is comparatively well covered from a governance perspective but only lightly examined in infrastructure terms. Balochistan water security stands out as the weakest-covered sub-theme overall, with a near-complete absence of infrastructure-performance evidence despite the province's acute exposure to drought and water stress, confirming the geographic imbalance noted qualitatively throughout the literature.

Discussion

Answering the Research Questions

To go back to the first research question, the evidence reviewed here shows that climate change is driving a clear increase of water and energy stress in Pakistan and this stress is making Pakistan more vulnerable to hydropower and inter-provincial water-governance conflict. This is not a controversial or minor discovery; it is supported by other studies on hydrology, engineering and governance in a variety of ways and from different sources. The second research question – which mechanisms best explain the severity of this stress – has a more differentiated response. The vulnerability of hydropower is not necessarily a result of overall losses in water volume, but is largely the result of shifts in flow timing, low storage margins, and exposure to physical hazards. The strong demand-supply imbalance and mistrust of institutions are the key factors that drive inter-provincial conflict, which seems to be exacerbated most by the observance of inter-provincial rigid allocation rules rather than by the formal inter-provincial framework itself, and shows no particular relation to transboundary anxiety.

Supporting Arguments and Coherence with the Political-Economy Literature

The results are in line with and complementary to the political-economy literature related to climate change in Pakistan. A related thesis-based case study on climate change's political economy effects on Pakistan also reveals that physical exposure is not the only factor that impacts the economic and political consequences of climatic shocks, as governance capacity and institutional coordination, and fiscal constraint, are also crucial factors (Sajjad, 2026). The study outlines how repeated flooding and disaster response costs gradually displace long-term development investments and the absence of a climate governance 'gap' between policy ambition and implementation in Pakistan. The water-energy-specific conclusions drawn in this article are best understood as one such line of instantiation of that pattern: formally rational water and energy policy can be created; however, its effectiveness is routinely eroded by disjointed institutional structures, confusing allocation principles, and constrained fiscal capacity for sediment control, storage expansion, and irrigation modernization.

Discrepancies and Unresolved Tensions

Not every finding in the literature reviewed is in one direction. However, basin-wide hydrological studies (Wada et al., 2019; Khan, 2022) indicate that while the reliability is decreasing in the longer-term, there may be an increase in flow in some Indus sub-basins in the near-term due to glacial melt. Likewise, although quantitative governance modeling underscores the challenge of sub-provincial allocation rigidity as the key adaptation hurdle (Yang et al., 2014), the majority of the qualitative political-science literature continues to focus on inter-provincial and transboundary conflicts as the main obstacle to adaptation (Janjua et al., 2021; Tariq et al., 2020). It is not a contradiction, but rather a scale of the analysis: while policy attention at the treaty level

or provincial level might neglect sub-provincial irrigation institutions where, according to the models, the most binding constraints may lie, it is important to note that.

Limitations of the Study

There are several limitations to this review. First, because this is a literature synthesis and not an original empirical study, the findings have only as much reliability as the primary studies they're based on, many of which use rather different timeframes, climate model speculation, and definitions of water stress, undoubtedly restricting easy comparisons. Second, the evidence base is geographically unequal with a significant lack of evidence from Balochistan and other sub-provincial governance settings compared to the Indus mainstream, limiting the extent to which conclusions can be generalized to the whole country. Third, many of the models of the water-energy nexus reviewed here rely on simulation models, and have not yet been validated against the implementation at a large-scale, and, therefore, the policy-relevant conclusions drawn from these models should be interpreted as promising rather than proven. Finally, although this machine-assisted approach to literature discovery was efficient at scale, it was directed and interpreted by the author and is not a complete replacement for a comprehensive manual systematic review, some relevant items in regional language or in the grey-literature may not have been discovered.

Significance of Findings

Nevertheless, the results of the study have important implications for research and policy. The defensible hierarchy of future research priorities implied by evidence-strength grades in Figure 3 is consistent with the need to avoid re-litigating strongly supported claims related to water stress, hydropower vulnerability, and integrated nexus policy; and the need to further test claims related to infrastructure-only solutions, which are supported by moderate and weak evidence. The general conclusion is that in addition to the inter-provincial framework, sub-provincial allocation rigidity may be the key adaptation constraint that needs to be addressed, as such a reform may not be enough to get to the desired outcomes.

Novelty of This Article

The novelty of this article is that three literatures - hydrological and infrastructural hydropower research, political-science water-governance research, and water-energy nexus modeling - are explicitly connected in a synthesis that relies on evidence, and that the evidence is triangulated with an independent political-economy case study of climate change in Pakistan. This article does not take the approach of many existing articles of separating the vulnerability of hydropower from the provincial water politics off the droughts, but rather shows that they form one coupled climate-governance system; the article presents also a transparent evidence-strength grading (in Figure 3) and sub-theme coverage mapping (in Figure 4) that makes the gaps in current knowledge explicit rather than implicit.

Directions for Further Research

The above identified gaps clearly indicate three directions for further research. Future studies should examine the impacts of sub-provincial allocation rules other than the one used in this study on hydropower reliability, irrigation equity, and groundwater depletion across the domains of climate scenarios, providing the results in terms of these three distinct goals. Existing knowledge on the impacts of alternative sub-provincial allocation rules on hydropower reliability, irrigation equity and groundwater depletion under realistic future climate scenarios is limited and is rarely connected explicitly to energy outcomes, so future studies should provide results for these three goals. Second, sediment management studies are required to be conducted and evaluated for their impact on the climate resilience of the major Indus hydropower assets and studies are usually

focused on individual hazards rather than evaluation of adaptation packages. Most urgently, future research should focus on the evidence gap in Balochistan and other western and southern provinces of Pakistan which are under water-stressed conditions, where groundwater and drought-related issues are not well linked with the broader water-energy-governance body of knowledge, despite the qualitative evidence of exposure provided in the various parts of this review.

Conclusion

This review aimed to explore if the climate change is exacerbating water and energy stress in Pakistan, thereby making its hydropower resources more vulnerable and exacerbating inter-provincial water politics, and to find the most appropriate mechanism to explain such stress. Synthesized evidence leads to a clear answer to the first question and a more complex answer to the second. Water stress is clearly rising due to climate change, and that stress is being felt both in terms of the more unpredictable operations of hydropower in general, and as a source of tension between provinces. But the crisis is not just climatic, it's a governance constrained nexus crisis where the capacity for storage, exposure to sediment and hazards, and - most importantly - water-allocation institutions that are inflexible and disjointed, shape the impact of climatic shocks. In order to alleviate Pakistan's water-energy stress, then, climate resilient infrastructure investment needs to be complemented with institutional changes (rather than the changes in infrastructure) at sub provincial level and not achieved through high level diplomatic agreements in isolation.

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