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Climate Change and Interprovincial Water Conflicts in Pakistan: A Bibliometric Review of the Indus River Basin

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ABSTRACT: This study systematically reviewed the existing literature on climate change and the Indus River water conflict between Punjab and Sindh provinces in Pakistan. We aimed to analyze how scholarly work on climate-induced water conflicts has evolved globally from 1991 to 2020 and to highlight research gaps in the context of intra-state disputes in Pakistan. Using comprehensive searches across multiple academic databases, we identified 115 relevant documents, including journal articles, reports, theses, books, and grey literature. Keywords such as climate change, water conflict, framework, and agent-based modelling guided the selection. We applied VOSviewer and NVIVO to generate bibliometric maps, co-occurrence networks, word frequency charts, hierarchy trees, and visual overlays to examine research trends and thematic clusters. Our results showed a significant increase in publications over the decades, driven by the adoption of computational analytics and complex systems modelling in climate conflict research. However, studies explicitly focusing on the Indus River conflict within Pakistan remain limited. This review underscores the need for more empirical and modelling-based research to inform policy and conflict resolution strategies for sustainable water governance under changing climatic conditions.

KEYWORDS: Indus River, Water Conflict, Climate Change, Bibliometric Analysis, Systematic Review

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Introduction

Our understanding of climate change has passed through evolutionary development. Climate change research has emerged as an interdisciplinary topic of study, which is quantitatively dominated by the USA, followed by the UK, Germany, and Canada. The citation-based indicators exhibit consistently that the UK has produced the largest number of high-impact publications as compared to the rest of the world. The question of human-induced climate change emerged as a fact leading research on future pathways for adaptation and mitigation. The term model and related terms prominently appear independent of time, indicating the relevance of climate modelling (Haunschild et al., 2016). Climate change research has emerged as an interdisciplinary topic of study, which is quantitatively dominated by the USA, followed by the UK, Germany, and Canada. The citation-based indicators exhibit

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consistently that the UK has produced the largest number of high-impact publications as compared to the rest of the world. The question of human-induced climate change emerged as a fact leading research on future pathways for adaptation and mitigation. The term model and related terms prominently appear independent of time, indicating the relevance of climate modelling (Haunschild et al., 2016). Climate change in connection with conflict and peace has grown steadily since 1990, especially after the IPCC assessment report in 2007. The studies on climate conflict and cooperation over water are also the post-AR4 trend followed by the themes of war and violent conflict, political tensions and institutional mechanisms, disasters, and other climatic impacts leading to human displacements. The issues related to climate security have gained more attention. The primary focus of research has been on war and violent conflicts, but the associated issues remained unaddressed (Sharifi et al., 2020).

The US Environmental Protection Agency (USEPA) completed a report on global climate change in 1989. In the same year, a study was published for developing countries. One of them showed the impacts of global warming on water resources in the Indus River Basin. In the Indus basin, 75% of the cropland is irrigated (Wescoat, 1991). Though climate change research in Pakistan is still in its development, there is evidence that projected climate change would have negative effects on agricultural output. It is projected that the rapid glacier melting of the Karakoram glaciers will happen due to higher temperatures, and the flow of the Indus at Besham Qila can increase by 50%. Later, there will be a considerable decrease in inflow, which by the end of the century will decrease to 40%. Many experts have proposed that in the twenty-first century, conflicts over shared water would be a leading source of conflict because of the value of water and its growing scarcity around the world (Qureshi, 2011; Rees & Collins, 2006). Many scholars have stated that recognizing the importance of water and its rising scarcity around the world, conflicts over shared water supplies will be the primary cause of conflict in the twenty-first century (Gleick, 1988; Homer-Dixon, 1996; Homer-Dixon, 1994; Percival & Homer-Dixon, 1996, 1998).

Climate change also is expected to alter the South Asian monsoon patterns. The International Panel on Climate Change (IPCC) in the Third Assessment Report (AR3) reported the rise in the South Asian monsoon by 8–24%, bringing additional water and leading to floods and damage to the infrastructure (Rasul, 2008). Pakistan should start preparing itself for possible future climate change and its impact on Pakistan (Qureshi, 2011). If certain areas experience acute resource shortages, then they will experience direct conflict over such resources more often. In these environments, states will find it more challenging to negotiate bilateral or multilateral treaties to enhance cooperation along river basins (Hensel et al., 2006). Rivers can quickly become the object of disagreement, dispute, and even conflict when the interest of one state is not accounted for by a neighboring riparian state (Kasymov, 2011).

The conflict analysis focuses on human features which are universal and ontological. The solution excludes the analysis of any separated discipline and therefore excludes it from the majority of previous thought and Studies (Burton, 1990). The causes of multiple conflicts are hidden in the desperate socioeconomic conditions of some groups engendered by discriminatory policies regarding accessibility and exploitation of resources. Conflicts over resources are commonplace today, as was the case centuries earlier (Kasymov, 2011). When we try to understand conflict, we are in the realm of political and social reality. The emergence of a tamed system that conforms may be dissuaded or integrated by sacrificing teaches us about the complexity of the dispute and far less about its resolution. Human needs theorists suggest that the pursuit of human needs can, in reality, lead to conflicts or tensions in situations where scarcity of resources occurs, or other incentives

are missing to fulfil the needs, and alternatives for satisfaction are not available immediately. It means, however, that the absence of satisfiers and not the nature of the resources themselves contributes to conflict. If adequate satisfaction is given, the pursuit of human needs may take place without social pressure and conflict prevention (Burton, 1990). The quantitative and qualitative utilization of water in one state affects water use in another downstream state. As the demand for freshwater in countries grows, states become increasingly persistent in advocating their respective state rights and in defending their economic interests.

Long-term historical studies show a coincidence between climate variability and armed conflict. Understanding different views provides a foundation for the prediction of future impacts of climate on violent conflict. However, more comprehensive approaches are needed to disentangle the complex nexus between climate and conflict (Scheffran, 2012). The study indicates that high population growth and environmental scarcities such as croplands, forestry, and freshwater can increase Widespread violence and social conflict in developed countries (Homer-Dixon, 1996). Water scarcity creates different environments for peaceful and militarized conflict management. The areas suffering more acute water resource scarcity will experience militarized conflict over water supplies. High scarcity levels should increase not only the opportunity for river conflicts but they should also the willingness of states to resort to militarized conflict to pursue their water-related interests (Starr, 2005). In the context of the Indus Basin, the water-security nexus has always been a salient theme in the minds of water developers. Conflicts over current large-scale water-development projects in the In Pakistani parts of the Indus Basin are reviewed (Mustafa & Wrathall, 2011).

The Indus River basin is one of the most depleted basins in the world (Sharma et al., 2010) which provides water to the most extensive contiguous irrigation system in the world, with 90% of its proportion for food production in Pakistan, which contributes 25% of the country's gross domestic product. Pakistan could face severe food shortages linked to water scarcity. By 2025, the shortfall of water will be 32%, which can lead to a food shortage of up to 70 million tons. It is projected that climate change and siltation of main reservoirs will reduce the surface water storage capacity by 30% by 2025 (Qureshi, 2011).

Water resources in the Indus Basin have been intricately linked to the political geography of South Asia since precolonial times (Ayoob, 1968; Wescoat, 1991; Wescoat Jr. et al., 2018). The hydro politics of the Indus Basin has been limited to the international scale or confined to the historical approaches, and very little research has been conducted on the current subnational levels of prevalent and potential water conflict in the Basin (Mustafa & Wrathall, 2011). During specific periods of the year, water even does not reach the sea anymore, making it a closed basin (Expósito & Berbel, 2019). Significant challenges are foreseen for the water sector in the Indus basin. The region is under extreme pressures of population and poverty, unregulated utilization of resources, and low levels of productivity (Sharma et al., 2010).

Objectives of the Study

Given these challenges, this study aims to systematically analyze the scientific literature on climate change and the Indus River water conflict between Punjab and Sindh provinces in Pakistan. The specific objectives are:

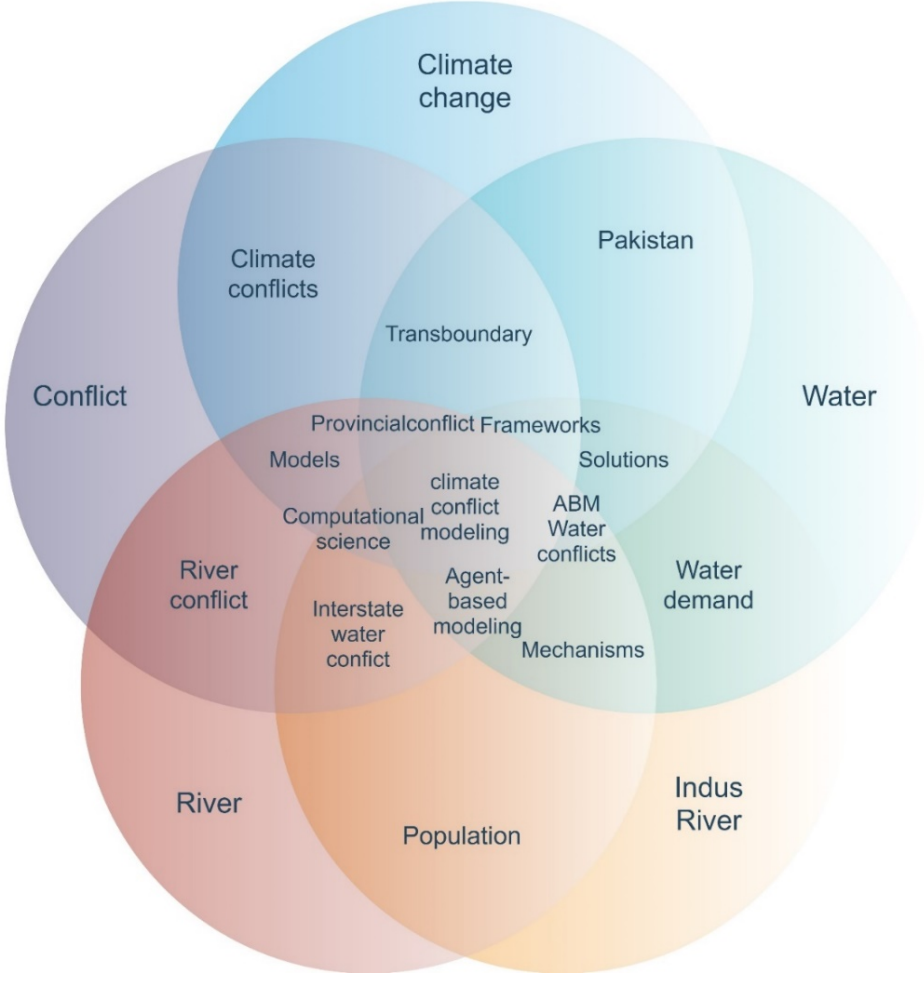
- To summarize the spatio-temporal patterns of the relevant literature.
- To identify conceptual overlaps and interdisciplinary trends in this research field.
- To identify the concept overlapping and interdisciplinary trends of publications in the relevant field.

Material and Methods

We selected the published literature based on the overlaps of some significant and minor keywords. These keywords have causal and correlational linkages among them. The Venn diagram gives a graphical explanation of the selection of samples of literature related to the topic under study.

Figure 1

Keywords Used for Literature Sampling



This bibliographic review of the relevant literature consists of three steps. The first step is the development of the database, which is comprised of five types of literature, i.e. Journal articles, books, reports, thesis or dissertations, news or posters, and grey literature. We did a visual and graphical analysis of the literature by using NVIVO and VOSviewer (1.6.15). We used ArcGIS (10.8.1) for spatiotemporal mapping of the published literature. We produced the discussion based on these analyses applied to the database.

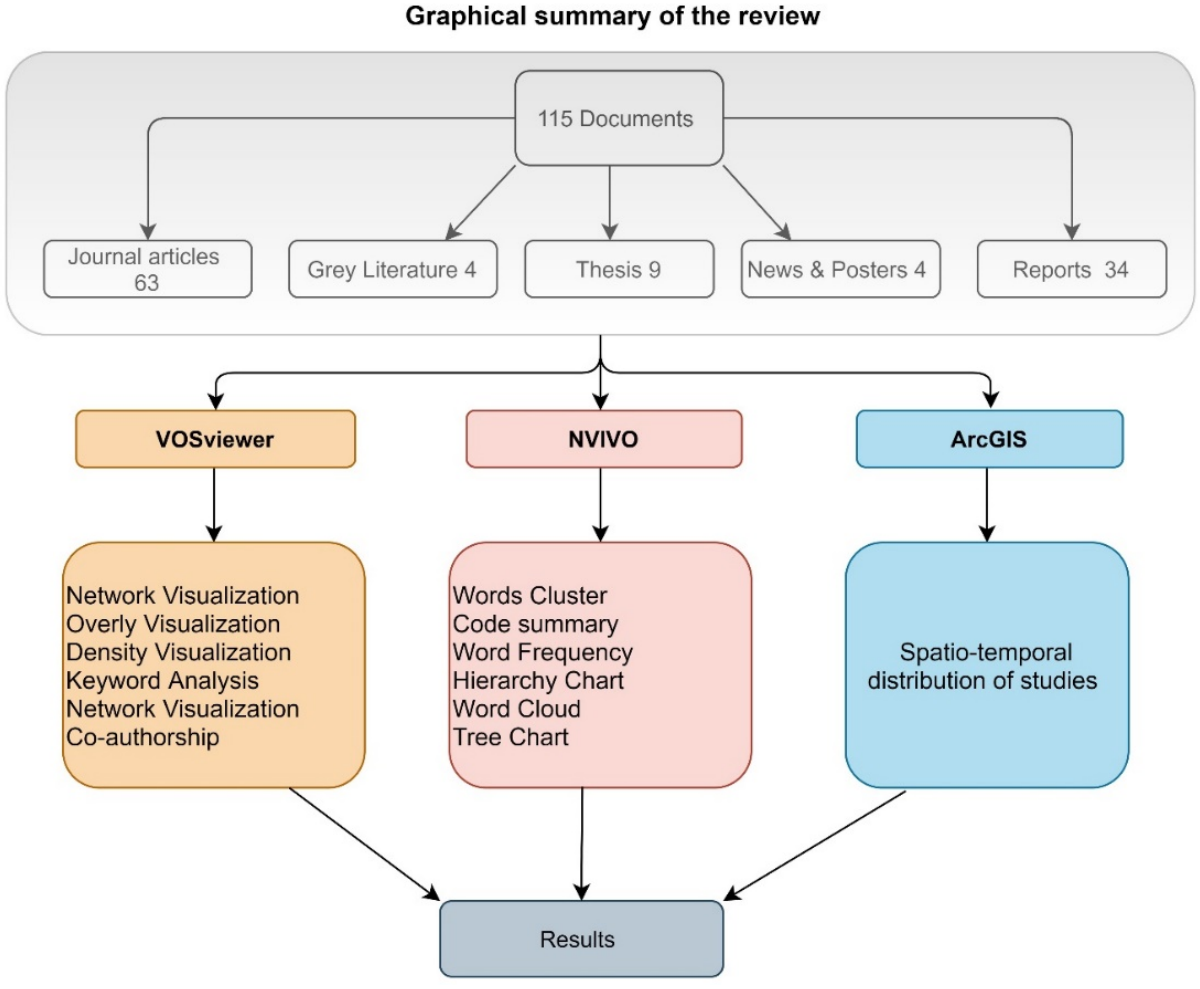
Development of Database

The purpose of the bibliographic analysis is to present a systematic review of the existing literature on the Indus River water allocation conflict between Punjab and Sindh Province in connection with climate change. In this section, we present literature based on the causal or correlational links of conflict, climate change, the

Indus River, Sindh, and Punjab by analyzing 115 documents. We see the chronological development of literature on the topic, which comprehensively discusses water conflict, management, scarcity, complex systems, agent-based modelling, and the framework of the study. Scholars have been working on climate change and related conflicts over the last three decades, but the literature on the conflict between Punjab and Sind is still minimal.

Figure 2

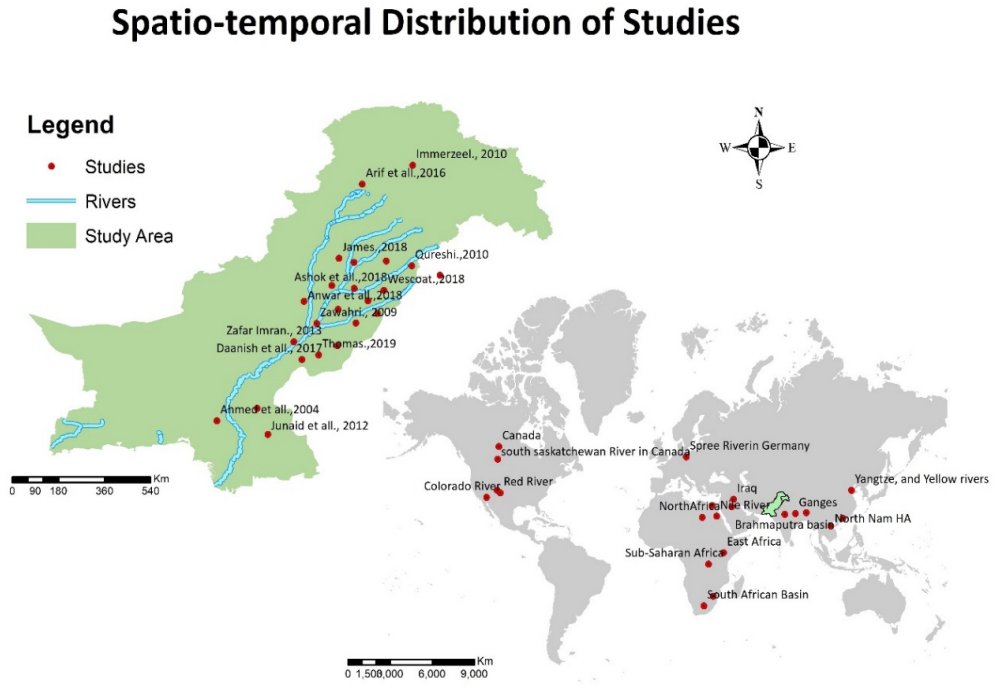
Methodology Flow Chart



We analyzed 115 documents and the metadata of the literature, including 6684 references, 258 authors, and more than 1000 keywords. This data was used for chronological review and growth of spatiotemporal and visual analysis of the study, co-authorship maps, and graphical visual and thematic development. It tells about the structure of available literature in the field of research, the conflict between Sindh and Punjab over the Indus River water, and the related strings of study. The literature was downloaded from reputed journals, Which include water conflict, climate change, agent-based modelling, and water conflict between Punjab and Sindh. We re-arranged the publications in chronological order and processed them in the bibliographic and systematic review tools. We generated word cluster analysis, keywords, word frequency, and graphical analysis by using NVIVO and VOSviewer.

Figure 3

Spatial Distribution of the Relevant Literature



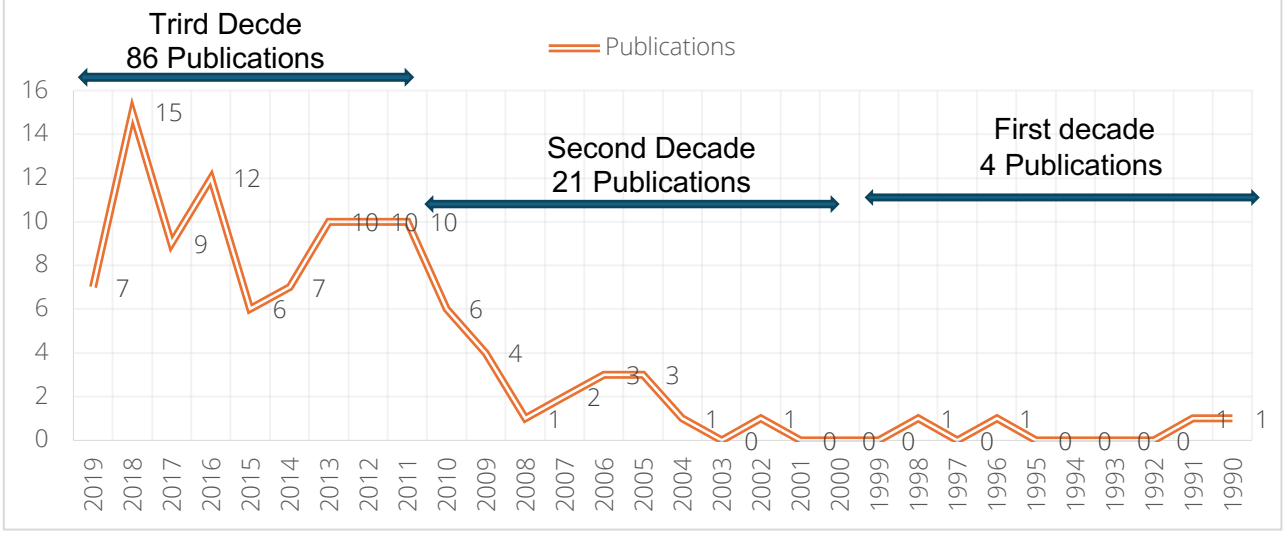
Results

Chronology of Publication since 1991

The water conflict studies debate is grounded in the environment and security literature, which was published by non-scientific communities like international NGOs, state agencies, and think tanks. The scientific assessment of the impact of climate change on national security came from the field of environmental security. Homer-Dixon (1996) and Homer-Dixon (1994) studied the link between environmental degradation and conflict.

Figure 4

Publications on Water Conflict and Security Since 1990



In the first wave of publications on environmental security, a few alternative theories and perspectives on climate conflict nexus emerged (Hardt & Scheffran, 2019). During the Cold War, the publications discussed the linkages between military and environmental security. The database of the current studies sees the following patterns during the last three decades.

First Decade (1991-2000) of Publications

Since 1990, the research on the interrelation between environment and conflict, empirical case studies, mostly focused on national security based on different methods and practical case studies. The graph shows the number of documents is minimal in 1991. In 1990, John Burton published a book named "Conflict: Human Needs Theory", which deals with social conflict. In 1991, a study by James L. Wescoat, Jr was published on managing Indus River Water under Climate Change and argued that global warming is troubling in irrigated basins like the Indus, where some 75% of the cropland is irrigated (Wescoat, 1991). He further elaborated that climate scenario assessment stems from a concern that under certain projections or 'scenarios' of climate change, expected water resource patterns would be disrupted. The scenarios are generally constructed with general circulation models (GCMs), historical records, or sensitivity analyses. Homer Dixon published on the complex ecological political system in 1996 and discussed the effects of demographic and environmental change on political stability (Comtois, 1988; Homer-Dixon, 1996, 1994; Percival & Homer-Dixon, 1996). This research suggests that rapid population growth and environmental scarcities of renewable resources such as cropland, forests, and freshwater can contribute to widespread violence and social conflict, especially in developing countries. The research also highlights important methodological issues that arise when studying complex ecological-political systems (Percival & Homer-Dixon, 1996).

Second Decade (2001-2010) of Publications

In the second decade, the number of publications increased slightly. The links between environment and peace, climate change, and security were published with higher frequency. The concept of climate security or inclusion of environmental security in human security, Environment and energy security, security and migration, Gender, marginalization, environment, and security gained attention. The second decade of publication sees the introduction of complexity theory and a critical focus on the de-politicization of climate change through discourses of resilience, risks, adaptation, and mitigation. The agent-based simulation model was used to understand the water conflict between different users. Le Bars (2002) used ABM with the multiagent approach, which justifies that negotiation between other players can help in resolving water conflicts. In 2006, a study was published by Paul R. Hensel, Sara McLaughlin, and Thomas E. Sowers on Conflict management of riparian disputes. The study explores the linkages between resource scarcity and interstate conflict. Focusing on competing claims over cross-border rivers, they analyzed peaceful and militarized techniques used by states to manage river claims and compared the success of these techniques in resolving the issues under contention (Hensel et al., 2006). In 2009, a Study published elaborates on the design of an agent-based model that integrates three essential types of actors in political science, i.e. the news media, ordinary citizens, and political experts (Liu, 2009).

Third Decade (2011-2020) of Publications

There is a sharp rise in research publications from 2010 to 2019. In the third decade, the highest number of publications shown in graph 86 documents in this decade shown in the graph. 2018 is the peak year of

publication in the graph, and the number of publications is 15. In 2018, a study published by Sandra Ricart et all. Highlighted public attitudes and farmer beliefs toward climate change adaptation. The study presents the scientific understanding of climate change.

Anthropocene, as a new geological era in the context of the environment, climate security link, and human security, gained attention from different disciplines. In 2017, Focus on various institutions and on how the link between climate change and security is included/addressed or institutionalized. Discussion on how actors manage the link in what terms and what future activities, risks, and potentials might be

in 2020 Emergence of a next research phase on topics such as complex crises, tipping points, compound risks, how different actors (ranging from global governance and states to civil society) address the climate-security nexus, the merging of research communities, and a focus on the science-policy interface

In 2012, Scheffran et al. summarized the relationship between climate change and violent conflict. They compared the results, methodologies, and data in the peer-reviewed literature for understanding the climate conflict debate. They pointed out the coincidence between climate variability and armed conflict. In their view, causal pathways such as precipitation changes, freshwater scarcity, food insecurity, weather extremes, and environmental migration are instrumental in disentangling climate conflict nexus.

Going beyond the mere use of global data sets, we consider selected intermediate pathways and address regional differences in how climate change and violent conflict affect human security. In this context, the role of human development and institutional processes in multiplying or minimizing potential conflicts is discussed. Finally, we identify shortcomings, challenges, and questions for future research within the integrative framework of human-environment interaction.

The study published in 2012 highlighted that "the Indus basin of Pakistan is vulnerable to climate change, which would directly affect the livelihoods of poor people engaged in irrigated agriculture. The situation could be worse in the middle and lower part of this basin, which occupies 90% of the irrigated area". Poor nations would mostly bear the cost of climate change as most affected regions fall in the developing world. Moreover, communities in these developing countries are primarily engaged in farming, a highly vulnerable sector to climate change, and have limited resources to adapt to climate change (Ahmad et al., 2014). The graph shows the highest number of publications in 2017, 2018, and 2019. In 2017, a study by Basar Baysal and Ulu Karakas discussed different perceptions and approaches to climate change and security. In 2017, a report published by Daanish Mustafa et al. (2011) named Contested Water highlighted the Subnational Scale Water Conflict in Pakistan.

In 2018, another study published by James L. Wescoart Jr. presented the Socio-Hydrology of Channel flows in complex River basins, Rivers, Canals, and Distributaries in Punjab, Pakistan. A socio-hydrologic analysis of channel flows in Punjab province of the Indus River basin in Pakistan. The Indus has undergone profound transformations, from large-scale canal irrigation in the mid-nineteenth century to partition and development of the international river basin in the mid-twentieth century, systems modelling in the late-twentieth century, and new technologies for discharge measurement and data analytics in the early twentieth century (Wescoat, 1991).

Ashok P. Dimn, in 2018, the climate change modelling approach was adopted. In the same year, Faizan Ali published a study on Climate Change Induced Conflicts in Pakistan: From National to Individual level. Climate change leading to migration and conflicts is observed in many parts of the world, and it is becoming a potential

future in Pakistan. Climate change refugees in Pakistan undergo victimization, in situ mitigation, or migration, all three of which have consequences. Direct and indirect security threats posed by climate change can cause significant economic losses to Pakistan. Arguably, there is growing evidence of a relationship between climate change and conflicts in Pakistan (Ali et al., 2018). In 2019, a book was published on the Indus water basin.

Types of Studies

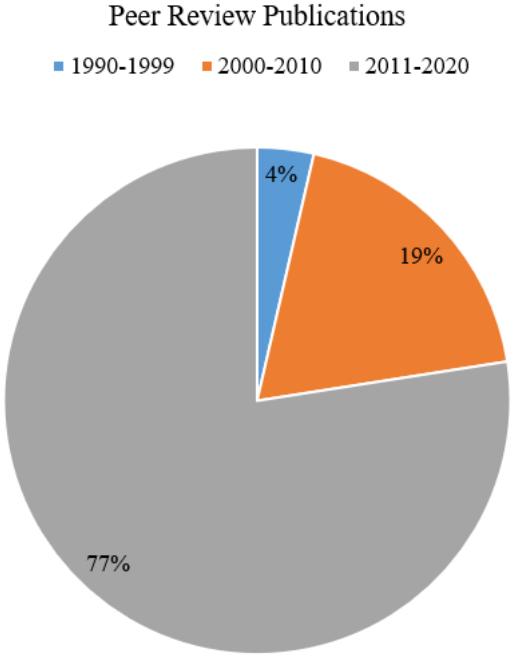
In the beginning, systematic assessment methods and tools are absent in understanding water and resource conflicts among the stakeholders. The scholar community was not interested in applying a comprehensive framework of studies to understanding water conflicts. Most of the literature was generated by journalists, columnists, and International organizations. The Indus Basin water conflict was studied only by hydrologists and engineers in the beginning. It still misses the attention of ethnographers and geographers.

Peer-Review Articles

The graph shows the percentage of peer-reviewed publications in the last three decades. There has been an evident rise in peer-reviewed publications in recent times, with 77% of the total articles published from 2011 to 2020. The second cluster of publications is from 2000 to 2010, in which 19% of articles were published. The smallest portion is between 1990-1999, with only 4% share. The contents of these scientific papers evolved from simple to complex, in which the number of stakeholders in the conflict has increased since 1991. Scholars introduced the application of complex system science with a better computational capability.

Figure 5

Publications in the Last Three Decades



The academic community of different disciplines has come forward to present their perspectives. The environmental conflict has gained attention in engineering, social science, and computer science. However, we could not find any application of the agent-based approach to the Indus water conflict. Islam and Susskind (2018) elaborated on the use of the complex system and negotiation theory in a transboundary watercourse,

but no model was presented. A framework of ABM was developed by Akhbari and Grigg (2013), who applied the ABM approach to California's Sacramento-San Joaquin Delta region. The perspective of socio-hydrology has had some useful publications in recent decades (Wescoat Jr. et al., 2018; Yang et al., 2013). The variable and stakeholder selection for understanding environmental conflicts is different in different studies. In 2019, it was argued that the increasing temperatures, higher precipitation variability, weather extremes, or sea-level rise due to climate change are considered to affect human security through a variety of interconnections in the coming decades (Froese & Schilling, 2019). The water conflict in the Indus within Pakistan could not gain much attention from academic scientists. Most of the work in the basin is done by government organizations and departments. It is estimated that per capita water availability in Pakistan will be reduced to less than 600 m^3, which would mean a shortfall in water by 32%, which will result in a food shortage of 70 million tons by the year 2025. The surface irrigation system of the Indus Basin was originally designed to provide low-intensity irrigation to cover larger areas in the canal commands. However, as cropping intensities increased, the demand for more water also increased, putting additional pressure on surface irrigation systems (Bhutta & Smedema, 2007).

Books and Grey literature

We found some perfect books on the designed study. The scientific communities have ignored these books, but these documents are a comprehensive piece of work on the Indus water conflicts. The Sindh-Punjab water disputes 1859-2003 by Palijo (2003) are very instrumental in understanding how the socio-political rift among the provinces evolved. Daanish Mustafa wrote in every format. He produced the most prolific publication on the Indus water conflict and climate change. Sidiq Khan (2019) created a detailed edited book on the security and sustainability of the Indus Basin. The use of a complex system approach in the water conflict was comprehensively covered in Water Diplomacy: A Negotiated Approach to Managing Complex Water Networks by (Islam & Susskind, 2012). The use of agent-based modelling on environmental conflicts was published by (BenDor & Scheffran, 2018), which is an excellent compilation of scientific literature on ABM usage in different conflict spaces.

Reports

A comprehensive literature on the Indus is available in the form of reports and policy papers by the USAID, World Bank, UNDP, USIP and the Government of Pakistan ((UN), 2008; Herbert, 2017; Mustafa et al., 2017). The World Bank in 2019 showed that Water security in Pakistan is undermined by poor water resource management and poor water service delivery, including irrigation and drainage services and domestic water supply and sanitation services. Water resources planning has historically focused on supply augmentation and has not addressed sustainable resource use or been linked adequately to broader economic planning.

Thesis and Dissertations

Natalie A. Nax, in 2016, evaluated the Indus Basin Treaty in the context of climate change in her thesis, which aims to challenge the Indus Waters Treaty. She argued that due to changing environmental conditions, what made the Treaty successful in the past will no longer be relevant in the future (Nax, 2016). This argument is supported by relevant literature reviews of journals and reports done by policy analysts, academics, and water management experts. Additionally, she addresses the need to mitigate climate change by explaining the consequences climate change will have on the ecosystem and infrastructure of India and Pakistan.

Troost (2015) proposed Agent-based modelling of Climate Change Adaptation in Agriculture about Central Swabian Jura and discusses different approaches to model validation, calibration and uncertainty analysis and their suitability for the use with mathematical programming-based ABMs in order to deal with the uncertainty involved in using ad hoc parameterizations. Giuliani (2014) presented agent-based water resource management in complex decision-making Contexts with multiple institutionally independent but physically interconnected actors complexity characterizing most of the decision-making problems in environmental contexts.

Analysis by VOSViewer

We processed the selected publications in the VOSviewer, which is a freely available open-source application developed by the Center of Science and Technology Studies (CWTS), Leiden University, the Netherlands. It produces a visualization of the bibliometric landscape of our selected topic. It makes excellent visualization based on the number of citations by any author or publication or bibliographic coupling of the literature.

Network and Overly Visualization

The over-visualization is identical to the network visualization, except articles or documents are coloured differently. Their label and circles present network Visualization articles. The size of the circle and label of the article are determined by the weight of the publication. The higher the weight of the item, the larger the label and the circle of the publication. The colour of an item is determined by the cluster to which the item belongs. Lines between items represent the links (viewer Manual, 2020). Figure 6 shows networks of articles with a minimum number of 1 article by an author. The author of the publication is taken as the unit of analysis. Islam, Shafiqul has the maximum number of co-authored documents, which have a link strength of 4 in the database. The third number of co-authors in the database are Anwar and Arif. The number of documents is two, but the link strength is the highest, which is 13. The documents by Arif, Anwar, and Muhammad are fourth by link strength, which is 8 in the database.

Figure 6

Overlay/Network Visualization

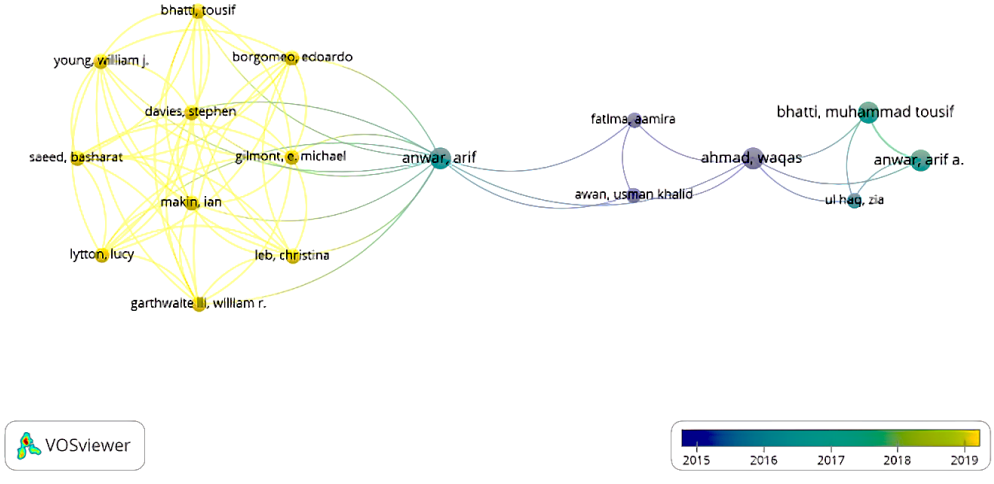


Figure 6 shows the score in the database. The colour bar shows only scored documents from the database. The highly scored records were found from 2015 to 2019 in the database. Anwar Arif has the lowest score,

while Fatima, Ahmad, waqas, and Usman have shown slightly higher. Jürgen Scheffran, Michael Link, Saeed, Lucy, and Davis have the highest scores in the over-analysis Visualization of co-authorship. The yellow colour shows the complex structure in the above figure, which shows the most elevated score documents in over visualization.

The Most Influential Authors

The total strength of the co-authorship links with other authors is shown. The authors with the greatest link strength are selected. The figure shows co-authorship found from 2014 to 2017 in the given database. According to this research group, the studies on the climate-conflict nexus have been using quantitative techniques for the analyses of climate and conflict. The use of models of climate-conflict linkages is scarce. The studies in this field are based on an elected set of climatic variables (temperature, precipitation, and extreme weather events), which are studied as a causal connection to specific aspects of violent conflict. They argued the use of a complex model of the direct and indirect causal relationships between climate change and conflict is needed. Climate change has various dimensions, like environment, economics, society, and politics. The climatic variables directly influence the social systems and indirectly via complex pathways by affecting environmental resources and human security, which leads to ambiguous results (Scheffran, 2012).

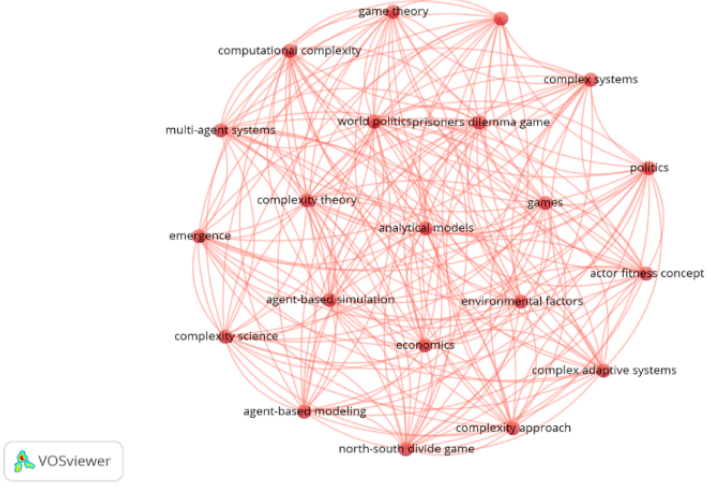
Scheffran argues the definitions of conflict vary with respect to the number of actors, casualties, and the degree of violence. In climate change, most of the studies refer to armed conflict, in which actors use power to achieve their aims. Scholars largely agree that climate change is unlikely to cause armed conflicts between states for the next couple of decades. But what about violent intrastate conflict? It is hypothesized that the predicted impacts of climate change could intensify competition for scarce resources and drive deprived individuals into the hands of violent entrepreneurs, fueling anti-state intentions and undermining the governing capacity of already weak states, which may lead to migration or conflicts (Ide, 2017).

Keywords analysis

The figure shows for each of the 45 keywords, the total strength of the co-occurrence links with other keywords is calculated. The keywords with the greatest total link strength are selected. The keyword density view is based on the framework database of the study.

Figure 7

Keyword Analysis



This part of the study deals with the modelling of conflict in which agent-based modelling is used. Agent-based modelling, Complex systems, environmental factors, and politics are with twenty link strengths. Other keywords have lower link strength. The link strength ranges from 1 to 20 in the database, in which 1 is the lowest link strength while 20 is the highest link strength in this database.

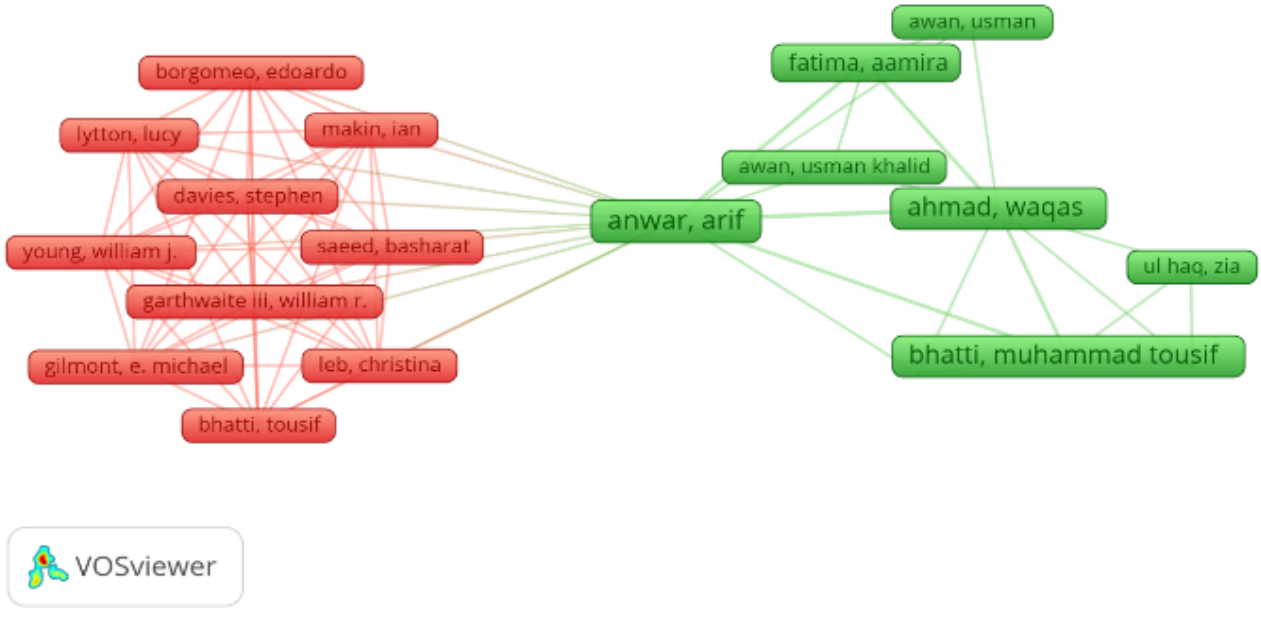
The above view shows the keywords, which are represented by labels and circles. The weight of the keywords determines the size of the keyword's labels and circles. The higher the weight of the keyword, the larger the label and circle of the keyword. There are 45 keywords found in the database. The agent-based approach is increasingly applied for understanding and modelling complex human-environment interaction.

Keywords Co-occurrence

Co-occurrence of the keywords is shown in the figure below. Four keywords co-occurred in the literature review database in VOSviewer. For each of the four keywords, the total strength of co-occurrence links with other keywords will be calculated. The keywords with the greatest total link strength will be selected. The keywords are Management, Pakistan, Water resource development, and Water-supply. The total link strength is three of each keyword.

Figure 8

Keyword Co-occurrence by Different Authors



Co-Authorship between databases

The figure shows Co-Authorship between two databases of the study. One database is related to the water conflict of Indus River water distribution between Punjab and Sindh provinces, and the second database is based on the study of modelling Conflict through Agent Base Modelling. In the above view, 288 authors' co-authorship shows the link between publications. The minimum number of documents for an author is one. In this view, Anwar and Arif have the maximum number of link strength, which is 20. Ahmed, Burian, Rafique, and Rais are second at link strength, which is 14. Scheffran Jürgen is the third-highest link strength in both databases. The link strength ranges from 0 to 20.

Analysis by NVIVO

NVivo is a software developed by QSR International for qualitative data analysis. It provides a workspace for researchers to store, manage, query, and analyze unstructured data, including text, images, audio, and video data types. NVivo allows users to complete multiple qualitative analysis functions like sorting, filtering, discovering and building relationships among data, assigning and defining themes and categories for data, visualizing data analysis results, and creating reports (Phillips & Lu, 2018; Woolf & Silver, 2017).

Words Cluster View and Code Summary

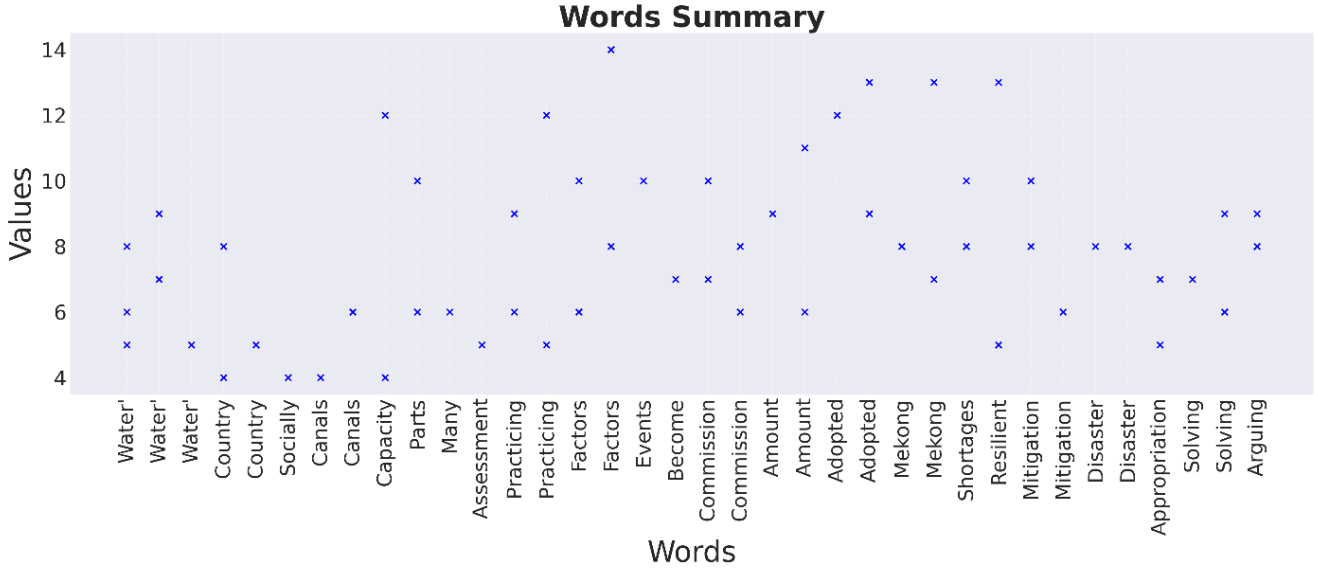
The figure is a visual representation of keyword clustering generated by NVIVO using our selected database. The word cluster is a handy measure which can tell us the significance of any word based on its frequency and weight in the database. The graph shows the major themes in the database. There are five major themes found in the literature, i.e. conflict, management, resource, system, and water.

Word Frequency

The figure shows the word frequency of keywords analyzed using NVIVO. There are eleven keywords in total, with five identified as major keywords in the database: water, conflict, management, resource, and system. Other keywords include river, climate, canal, agent-based model, and irrigation. The results indicate that water is the most frequently used word, appearing 4,206 times in 101 out of 115 documents. The second most frequent keyword is system, with a frequency of 963 in 106 documents. Management appears 943 times in 95 publications, resource has a frequency of 873 in 100 publications, and conflict occurs 858 times across 73 files.

Figure 9

Words Summary



Hierarchy Chart

In the keyword analysis, authors extensively used water, which means water, and related terms such as water scarcity, availability of water, and water storage have a more extensive cluster in the hierarchy query of NVIVO. Conflict is the second larger cluster in the hierarchy, which makes related terms like violent conflict, social

conflict, future water conflict, and conflict management and risk. The smaller cluster in the hierarchy consists of climate and associated terms like climate change. The figure shows that water, conflict, and climate have the largest number of studies, but the study related to the climate change impact on Indus River water is limited.

Figure 6

Hierarchy Chart

Word Cloud

The word cloud shows the most commonly used terms in the selected database. The size of the words indicates the highest weightage of the term in research, while smaller size words show smaller weightage. The cloud expresses climate change, Pakistan water, and River management with red colour; these are the highest weighted words in the research. The second category of keywords shown in black colour the terms are international development, Politics, resource, basin, security, irrigation, system, Conflict, Indus, and Model. These are the second important category of words used in research. Then, the lighter color words show less weighted words in the study.

Figure 7

Word Cloud

Conclusion

This systematic bibliometric analysis sheds light on the evolving landscape of research at the intersection of climate change and interprovincial water conflicts in Pakistan, with a focus on the Indus River Basin. The chronological mapping reveals three distinct phases of scholarly attention: an initial conceptual groundwork during the 1990s driven by foundational theories of environmental security and human needs; a moderate expansion from 2001 to 2010 with increased integration of complexity theory and agent-based modelling; and a significant surge in publications from 2011 onwards, reflecting growing academic and policy interest in the climate–conflict nexus.

Despite this upward trend, the findings highlight persistent gaps. Notably, much of the early literature originated outside the peer-reviewed scientific community and was dominated by hydrological and engineering perspectives, while social scientists, geographers, and ethnographers remain underrepresented in addressing the subnational dynamics of the Indus water dispute. Although systematic tools like agent-based models have been increasingly adopted for global water conflict studies, their application to the Indus River conflict remains minimal. Similarly, the keyword and co-authorship network analyses underscore fragmented collaboration and limited interdisciplinary integration.

This study demonstrates that climate change impacts, rapid population growth, and institutional challenges compound the vulnerability of the Indus Basin's water resources, posing substantial risks to food security, social stability, and interprovincial relations. As Pakistan faces a projected water shortfall of up to 32% by 2025, there is an urgent need for robust, interdisciplinary research frameworks that bridge physical, social, and computational sciences.

In closing, this bibliometric review contributes a comprehensive overview of the scholarly discourse, identifies research gaps, and provides a baseline for future studies. Policymakers and researchers should prioritize developing context-specific models, fostering interdisciplinary collaborations, and applying advanced computational approaches such as agent-based modelling to better understand and manage the complex, multi-scalar nature of climate-induced water conflicts within Pakistan's Indus River Basin.

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