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Climate and Development

ISSN: 1756-5529 (Print) 1756-5537 (Online) Journal homepage: www.tandfonline.com/journals/tcld20

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To cite this article: Kathleen Hermans, Nodir Djanibekov, Iskandar Abdullaev, Nilufar Abduvalieva, Aliya Assubayeva, Suzy Blondin, Ihtiyor Bobojonov, Christopher Conrad, Thomas Herzfeld, Johnson Kansiime, Barchynai Kimsanova, Murodbek Laldjebaev, Bakhrom Mirkasimov, Alisher Mirzabaev, Asel Murzakulova, Svetlana Rajabova, Aibek Samakov, Benjamin Schraven, Harald Sterly & Atabek Umirbekov (2025) Future research directions for understanding the interconnections between climate change, water scarcity, and mobility in rural Central Asia, Climate and Development, 17:7, 638-647, DOI: 10.1080/17565529.2024.2436090

To link to this article: https://doi.org/10.1080/17565529.2024.2436090

Published online: 03 Dec 2024.

CLIMATE AND DEVELOPMENT
2025, VOL. 17, NO. 7, 638–647
https://doi.org/10.1080/17565529.2024.2436090

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COMMENT

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Future research directions for understanding the interconnections between climate change, water scarcity, and mobility in rural Central Asia

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ABSTRACT

Central Asia faces substantial water scarcity due to increasing water demand driven by rapid urbanization, population growth, economic development, and inefficiency of irrigated agriculture. These developments are compounded by the effects of climate change, such as rising temperatures, loss of glacier mass and increased frequency of extreme events, including droughts. The region's escalating water scarcity is causing disputes and straining rural livelihoods. Moreover, these challenges drive migration, creating considerable societal impacts. However, these issues remain underexplored in climate change research, making the region a global blind spot in climate adaptation and migration studies. We advocate for innovative research pathways that scrutinize smallholder adaptation strategies, examine the nexus between climate change, water scarcity, and mobility, and investigate tensions and cooperation over water resources. We conclude by emphasizing that substantial investments in inter- and transdisciplinary collaboration, improved data availability and quality, and strengthening of research and institutional capacities are essential to advance interdisciplinary climate impact research in Central Asia. Such efforts are vital for addressing existing knowledge gaps and enhancing evidence-based policymaking to improve the region's position in current and future debates on climate change and sustainable development.

ARTICLE HISTORY
Received 8 May 2024
Accepted 24 November 2024

KEYWORDS
Central Asia; Climate change; Adaptation; Water scarcity; Climate mobilities; Research priorities

1. Climate change impacts and societal challenges in Central Asia

Central Asia – here referring to Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan – is at the forefront of climate change's impacts, with escalating water scarcity posing a severe threat to local populations (Shaw et al., 2022). The region's diverse climate, shaped by a wide altitude range, including high mountains, steppes, and deserts, makes it one of the world's largest arid and semi-arid regions with significant climatic variations among countries. Central Asia has experienced a considerable temperature increase in recent decades, along with more frequent temperature extremes. This rise in temperature, coupled with increased evapotranspiration, has led to the loss of glacier mass and more frequent drought conditions in some regions (Guo et al., 2018; Li et al., 2017). While some rivers fed by melting glaciers may temporarily experience increased runoff, the overall trend is towards diminished river discharge, which significantly impacts the availability of water resources for agriculture (Didovets et al., 2021). Central Asian farmers face substantial water scarcity due to increasing water demand driven by urbanization, population growth, development of economic sectors, and the inherent inefficiency in irrigated agriculture (Figure 1), all compounded by the effects of climate change (Dukhovny & Ziganshina, 2011; Shaw et al., 2022; Tischbein et al., 2013). While climate projections for Central Asia remain limited and uncertain, climate change is expected to decrease water supply and increase supply volatility, especially threatening water availability during summer months in unregulated catchments (Fallah et al., 2024; Jiang et al., 2020; Kayumov & Razzaq, 2024a; Reyer et al., 2017; Shaw et al., 2022). Amidst escalating water scarcity in Central Asia, climate change has the potential to exacerbate transboundary water disputes, threatening food security and potentially causing

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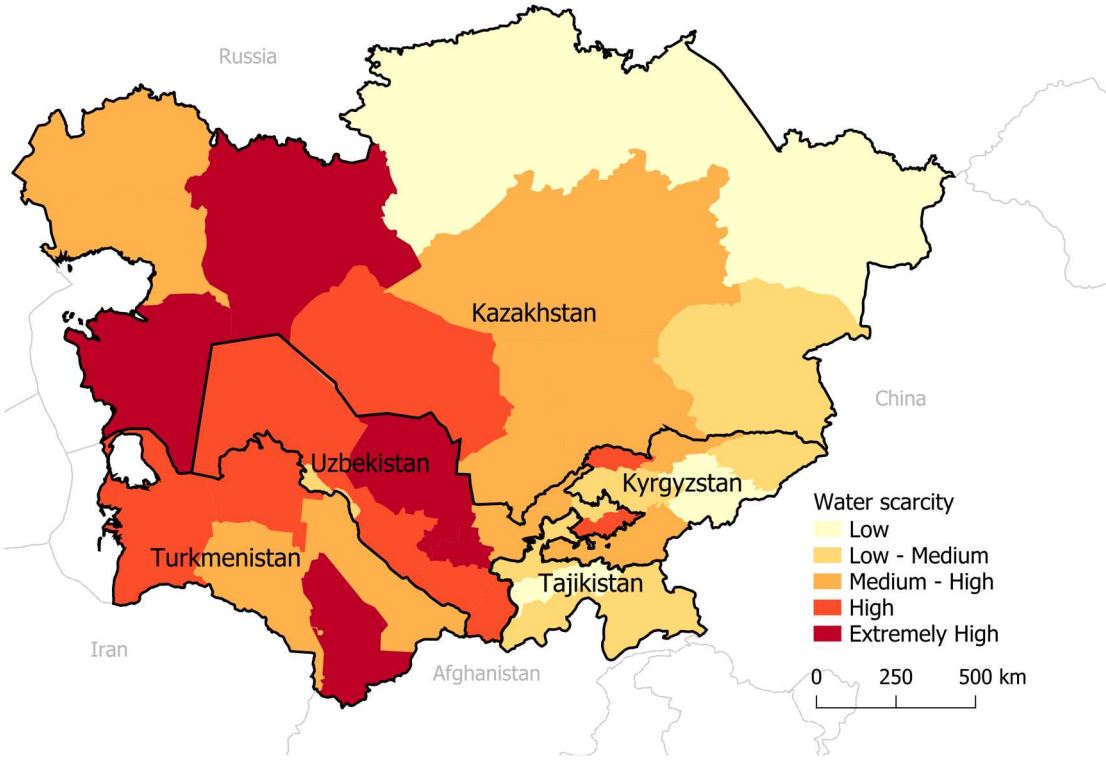

Figure 1. Water scarcity in Central Asia, based on Aqueduct 4.0 Water Stress data, showing the ratio of total water demand to available renewable water resources at the provincial level (adapted from Kuzma et al., 2023).

displacement, particularly in rural Kyrgyzstan, Tajikistan, and Uzbekistan, where economic challenges are already straining rural livelihoods (Lukyanets et al., 2020; Sidle et al., 2023). In addition, constructing the Qosh Tepa Canal in arid northern Afghanistan raises new concerns about the risk of regional water tensions in Central Asia (Duffy, 2023).

Climate change-induced water scarcity compounds inefficient water management practices, further contributing to land degradation, with at least 20% of the total land area in Central Asia already degraded (UNCCD, 2024). Reduced access to water and land degradation have exacerbated ecological degradation, reducing crop yields, contributing to poverty and disrupting rural livelihoods. As a result, internal and cross-border movements have become increasingly common, with people seeking to escape these harsh environmental conditions (Mirzabaev et al., 2016; Qadir et al., 2009). Particularly striking is the plight of the Aral Sea drylands in Uzbekistan and Kazakhstan, which has faced severe water scarcity, soil erosion, salinization, and land abandonment (Bauer, 2021; Löw et al., 2018). Since 2000, more than 500,000 people have left Karakalpakstan, consistently ranking the region among the top five Uzbek regions in terms of departures (UzStat, 2023). According to the World Bank's Groundswell Report, climate change could drive up to 2.4 million internal migrants within Central Asia by 2050 (Clement et al., 2021). However, the complex nature of climate-induced mobility – including short-term displacement, long-distance migration, rural-urban mobility, and circular mobility – combined with the difficulties of predicting these processes, requires a cautious interpretation of such figures (Boas et al., 2019; Schewel et al., 2024). In this dynamic context, it is crucial to recognize that Central Asia's population is highly mobile, with urban areas and neighbouring countries serving as important destinations for those searching for better prospects. Today, migration is a defining factor for Central Asia, with the region's ratio of remittance inflow from international migrants as a share of GDP in Tajikistan, Kyrgyzstan, and Uzbekistan being among the world's highest (World Bank, 2024).

Given the urgent challenges posed by climate change and water scarcity in Central Asia, numerous international and multilateral organizations have been at the forefront of assisting Central Asian governments with climate change adaptation through awareness raising, capacity building, implementing interventions, and financing, including the Asian Development Bank (ADB), the European Bank for Reconstruction and Development (EBRD), the World Bank, the United Nations Development Programme (UNDP), the International Organization for Migration (IOM) and the United Nations Educational, Scientific and Cultural Organization (UNESCO). However, there is a notable lack of climate change science, particularly in addressing the societal consequences, including impacts on rural livelihoods, food security, poverty, conflict, migration and displacement, along with a dearth of attention on adaptation needs, options, and limits (Shaw et al., 2022; Vakulchuk et al., 2022). Despite a growing number of scientific publications on climate change impacts in Central Asia, the attention remains notably low compared to other world regions. Most of these publications are produced by international research groups, with limited representation from local research teams and a significant lack of contributions from the social sciences (Mirzabaev, 2023). Moreover, existing research is often done within isolated academic

disciplines, limiting robust empirical evidence on the linkages between climate change, water scarcity, and mobility. This leaves critical knowledge gaps and hinders the identification of effective policy options.

Here, we highlight the importance of advancing policy-relevant interdisciplinary research on climate change impacts in Central Asia. We identify specific knowledge gaps in the interconnected areas of climate change adaptation, water scarcity, and human mobilities. We propose future research directions to fill these gaps and effectively address the region's challenges. By leveraging insights from environmental and social sciences, we expand the climate change research agenda for Central Asia to include the dimensions of adaptation and mobility explicitly. We specifically focus on smallholders due to the notable gap in research on their adaptation strategies in Central Asia.

2. Research gaps and future research directions

2.1. Smallholder adaptation to climate change

Rural populations in Central Asia range from 42% of the total population in Kazakhstan to 72% in Tajikistan, and these high percentages are closely tied to significant employment in agriculture (World Bank, 2024). Smallholder farmers, who constitute the majority of agricultural producers in the region, are primarily dependent on climate-sensitive livelihoods and disproportionately affected by the adverse impacts of climate change (Lambrecht et al., 2023; Lerman & Sedik, 2018). While other types of farmers, for instance, large-scale commercial farmers, might find it relatively easier to adapt, this is not the case for smallholder farmers. Several agricultural technologies have been tested and adopted to improve resilience in agricultural production, such as drip irrigation and laser-guided land levelling (Christmann et al., 2009). However, these technologies, primarily developed for commercial farmers, necessitate new equipment, a specific skill set, and access to capital, making them hardly applied by smallholder farmers (Lambrecht et al., 2023). Consequently, there is a need for increased investment in research to develop technologies and practices tailored for smallholders, considering aspects like planting structure, crop rotation system, and water management.

Government policies are crucial in shaping the adaptive strategies of Central Asian smallholder farmers, especially in water-scarce regions. Central Asian governments have shown strong political will to address climate change by integrating adaptation strategies into national laws and policies and establishing financial frameworks for adaptation domestically and with international support (Liu et al., 2020). The availability and management of water resources are primarily controlled by local governments through water distribution infrastructure and monitoring stations. However, the accessibility of the respective data is subject to government openness policies, which can affect farmers' ability to respond to climate stressors (Cassara et al., 2020). Furthermore, adopting adaptive strategies, such as water-saving irrigation equipment or cultivating drought-resistant crops, is often incentivized through government programmes that offer rewards or subsidies. This significantly impacts the extent to which smallholders invest in and implement climate-smart technologies.

While integrated water management presents a viable response strategy for the region, the limited profitability of smallholder enterprises complicates its implementation. This implies additional financial resources to sustain and update outdated irrigation systems from Soviet times, costs that low-profit smallholder farmers often cannot cover themselves (Barrett et al., 2017). Climate-driven water shortages are thus expected to increasingly affect the region's rural livelihoods, particularly in areas where smallholders depend on irrigated agriculture for income and food security (Karthe et al., 2015; Lioubimtseva & Henebry, 2009). As much as adopting climate-smart adaptation technologies cushions smallholder farmers and potentially increases profitability (Tadjiev et al., 2023), the economic and institutional barriers discussed herein extensively hinder smallholder's investment in these technologies and their meaningful uptake (Kurbanov et al., 2022; Mirzabaev, 2018). A comprehensive understanding of their unique dynamics, vulnerabilities, and adaptation capacities is imperative to support Central Asia's smallholder farmers in adapting to climate change. Studies highlight the varied effects and adaptation possibilities within the region's diverse smallholder farming systems (Bobojonov & Aw-Hassan, 2014; Karthe et al., 2015). However, empirical evidence concerning socioeconomic, cultural, behavioural and psychological determinants impacting farmers' vulnerability and adaptation to climate change in the region remains notably scarce. This also includes gendered aspects of climate change, water scarcity, and adaptation capacities (Kovaleva et al., 2023; Vakulchuk et al., 2022). This is especially critical given that women – along with disabled individuals, the elderly, and children – are particularly vulnerable to the impacts of climate change and weather shocks (Freudenreich et al., 2022; Standal et al., 2023). The increased engagement of women in agricultural activities due to male migration, such as in the Fergana Valley (Stulina, 2015), accentuates their vulnerability. At the same time, the feminization of farming can empower women by elevating their roles as primary decision-makers and providing earning possibilities (Mukhamedova & Wegerich, 2018). Women, particularly those in female-headed households with access to resources, can experience empowerment, reducing vulnerability to climate change and potentially catalyzing rural transformations (Najjar et al., 2022; Otrachshenko et al., 2024).

Additionally, there is a lack of acknowledgement of the role of traditional knowledge in adaptation strategies and an unclear understanding of climate-related losses (Aleksandrova et al., 2014). This includes how smallholders perceive climate change and how their perceptions relate to their adaptation strategies. Investigating these factors would be essential for designing socially viable interventions for smallholders. Further research is recommended to explore perceptions of climate change, including the local understanding of climate change (Reyes-García et al., 2024) and the role of indigenous and local knowledge and practices in shaping and enhancing climate adaptation strategies.

2.2. Climate change and mobility

Global research on climate change adaptation and mobility is advancing. However, Central Asia lacks empirical evidence on

how climate change and water scarcity affect human mobilities, highlighting an urgent need for comprehensive research (Blondin, 2019; Hermans, 2024). Understanding the diversity of climate mobilities in Central Asia, including leaving, returning, and staying put, is exceptionally challenging due to the varied livelihoods, including mountain farming, pastoralism, and irrigation farming. The varying exposures, vulnerabilities, and adaptive practices across these livelihoods complicate identifying causal links between climate and mobility and necessitate contextualized approaches.

Additionally, the political economy of national and agricultural development necessitates recognizing the government's critical role in rural development, water management and land tenure, potentially impacting domestic intraregional and extraregional mobilities (Spoor, 2018). State decisions in maintaining and operating irrigation schemes in Uzbekistan and Turkmenistan substantially impact livelihoods and potential mobility decisions, while this is less pronounced in other countries. Moreover, in mountainous regions in Kyrgyzstan and Tajikistan, where remittances often form a vital part of rural household incomes (Babagaliyeva et al., 2017; Jeenbaeva & Banerjee, 2022), their influence on smaller-scale agriculture is likely more significant than in areas with large-scale irrigation farming. These complex settings make it inadequate to adopt generic perspectives, necessitating a contextualized understanding of the roles of climate and water scarcity for mobility and the reciprocal influence of mobility on vulnerabilities and adaptation.

While the focus on climate-related migration and displacement is increasing, the significance of immobility in response to climate change remains understated. Most individuals, even in high-risk areas, may choose or be compelled to stay in situ, as observed in the Aral Sea region, where extreme poverty acts as a barrier to migration (Aerzte Ohne Grenzen, 2003). The concept of 'involuntary immobility' and the related notion of 'trapped populations' are gaining recognition mainly because they emphasize the vulnerabilities of those concerned (Zickgraf, 2018). Moreover, more attention is needed in climate mobility studies to address the idea of voluntary immobility, including how certain mobility patterns can enable immobility ('leave in order not to leave'; Blondin, 2021). Factors such as place attachment and identity, spirituality, and social bonding may influence people's decisions to stay despite climate risks, emphasizing the need for a comprehensive understanding of immobility in the region.

To explore how different groups navigate the challenges of climate change, it is crucial to recognize that the ability and desire to migrate are shaped by many intersecting social factors, including gender, age, ethnicity, formal education, social networks, and marital status (Thompson-Hall et al., 2016). Yet, none of these aspects have thus far received adequate attention in research on the linkages between climate change, water scarcity, and migration in Central Asia. Therefore, allocating increased attention and resources to research on intersectional aspects, including the dimensions of empowerment, such as decision-making power, resource control, and mobility, is paramount for developing effective interventions that address the diverse experiences and vulnerabilities within the region.

By incorporating mobility into National Adaptation Planning, a framework can be provided to avert, minimize and address displacement systematically and to support migration as adaptation (Mombauer et al., 2023; Scissa & Martin, 2024). This enables prioritizing the needs of affected communities and balancing the consideration of migrants' agency and their vital role in autonomous adaptation, as well as the need to sustain the state's key role in planned adaptation. It is important to explicitly consider the adaptation requirements of the most vulnerable groups, particularly women, the elderly, people with disabilities, and marginalized groups. Mainstreaming mobility into climate adaptation policies requires a deep understanding of the climate change impacts on rural livelihoods and different types of mobilities, including displacement, relocation, labour migration, (in)voluntary immobility, and pastoralism.

Furthermore, research should expand its focus beyond seeing climate change as the sole environmental driver of mobilities, acknowledging the intricate linkages between climate change and land degradation (Hermans & McLeman, 2021). Land degradation in Central Asia, exemplified by severe soil salinization in the irrigated areas of Kazakhstan, Uzbekistan and Turkmenistan, progressively weakens livelihood systems, rendering them more susceptible to climate shocks like droughts. This vulnerability may place affected populations in precarious situations, including displacement and involuntary immobility. Recognizing that land degradation can increase vulnerability to gradual climatic changes, including longer-term shifts in precipitation patterns, is essential in understanding mobility decisions (Hermans et al., 2023).

2.3. Water scarcity, tensions and cooperation in managing shared water resources

Tensions and conflicts over water resources in Central Asia manifest at multiple levels: between countries, among competing sectors of the economy, and within local communities. Each of these levels is characterized by dynamism and interconnectivity. Historically, the expansion of irrigation canals and resettlement efforts during the Soviet era mixed local populations with non-natives, contributing to tensions over the fertile land (Peterson, 2019). Large-scale irrigation infrastructure inherited from Soviet times and water management norms, rules, and agreements linking upstream and downstream riparian states have further fuelled conflicts (Pak et al., 2014). During the independence period, the dispute regarding establishing new hydroelectric stations on the Amu Darya and Syr Darya rivers mirrors the cross-country rivalry between agricultural and energy sectors for regional water resources. In 2022, this culminated in an accord for collaborative development of water and energy infrastructure, demonstrating the dynamic shift from competition to cooperation.

Furthermore, new developments on the water-energy-climate nexus in Central Asia necessitate an expanded research agenda. For instance, Kazakhstan's shift towards hydrogen production and potential nuclear power plant construction for meeting energy demands poses challenges in securing sufficient water resources amidst competing needs (Rivotti et al., 2019; Tleubergenova et al., 2023). Additionally, advancements in agricultural water efficiency, such as farming pumps

and drip irrigation, are tied to electricity supply. Applying solar or wind power to address these electricity requirements in agriculture presents opportunities for climate mitigation, which requires significant financial investments as well as robust legal and regulatory frameworks, with substantial differences between individual countries in terms of technologies, policies and investments (Kayumov & Razzaq, 2024b; Laldjebaev et al., 2021). Together, new opportunities and challenges are emerging within the traditional water-energy nexus, compounded by uncertainties and impacts of climate change. This necessitates additional research, including studies on regional cooperation for energy trade among countries. Scholars have documented historical violent conflicts among diverse communities in Central Asia, exemplified by tensions between Tajik- and Uzbek-speaking agriculturalists and Kyrgyz agro-pastoralists in the Fergana Valley since the late 1980s (Arynova & Schmeier, 2021; Bichsel, 2013; Olimova & Olimov, 2022; Reeves, 2011). These conflicts arise along the lines of access to scarce land and water resources, specifically in borderland areas (Pérez-Martín, 2017; Reeves, 2014). While most Central Asian water conflict studies typically focus on transboundary water conflicts among riparian states, limited research exists on domestic water disputes in the region (Sehring, 2020; Peña-Ramos et al., 2021). Future research should specifically investigate the significant socio-economic, cultural, institutional, and political predictors of smallholder disputes over water resources. In addition, it is recommended to deepen the understanding and assessment of new forms of smallholders' informal cooperation around water management, as well as the role of third parties in escaping and resolving local disputes over water resources. Climate change exacerbates water scarcity in the region alongside factors such as population growth, limited institutional capacities, disagreements over water allocation, and the techno-centric approaches of riparian countries aiming to secure national water interests, particularly through hydropower development in upstream nations and agricultural expansion in downstream regions (Assubayeva et al., 2022; Xenarios et al., 2020). While historical water disputes often were traditionally addressed locally, severe droughts in 2000-2001, 2008, and 2021 have elevated water scarcity to national and regional levels, intensifying pressure on transboundary rivers and potentially impacting social stability and regional security (Jiang & Zhou, 2023). Despite the recognition of various factors contributing to water scarcity, there remains a notable gap in understanding the interplay between climate change-induced droughts, socio-political stability, and regional security dynamics, particularly regarding the potential for collaborative strategies to mitigate water-related conflicts and ensure sustainable water management across riparian countries in Central Asia.

3. Addressing the key limiting factors

To guide future research across the presented priorities and develop knowledge infrastructure in Central Asia, significant investment in inter- and transdisciplinary climate impact research is essential. In turn, advancements in climate impact research in Central Asia necessitate addressing the limiting factors throughout the entire research-making chain, as outlined in the following.

Scarce climate observation networks and poor quality of existing standards in Central Asia impede adequate climate monitoring and climate-related studies in the region, thereby limiting the advancement of climate and hydrological modelling for predicting the impacts of climate change on water resources and comprehensively understanding risk occurrences (Xenarios et al., 2019). Navigating socio-economic data adds complexity to the situation. To effectively monitor the effects of climate change on communities and their adaptation strategies, including migration, necessitates access to **high-quality longitudinal household data**, capturing socio-economic changes with a high degree of spatio-temporal detail (Carletto et al., 2023; Enenkel et al., 2020). Despite this imperative, systematic and multi-year household surveys, which offer valuable insights into societal transformations, such as the Life in Kyrgyzstan Study, Kyrgyzstan Integrated Household Survey, and the World Bank's Listening to Central Asia surveys provide limited information on environmental aspects and remain scarce across the region, relying almost solely on international support. Existing databases and knowledge platforms, for instance, for water management (Abdullaev & Rakhmatullaev, 2014) or climate change research (e.g. https://ca-climate.org/eng/cacip.php), need to be explored, validated, and updated. Another major constraint for transdisciplinary climate research and action is the limited openness in **data sharing** (Ziganshina & de Schutter, 2022). Combined with discrepancies in data definitions and measurements across different institutions and countries, this significantly hampers inter- and transdisciplinary climate research and action in Central Asia. To effectively address these challenges, it is recommended to establish a regional coordinating body tasked with tracking and monitoring key indicators related to climate change, mobility, water use, and extreme events. Additionally, to improve data collection, accessibility, applicability, and comparability, significant investments should be made in data infrastructures, including the development of regional repositories using advanced technologies and promoting the use of these tools across disciplines, adhering to open science principles throughout the region.

The outlined research priorities call for mixed-method approaches that link quantitative with qualitative data and methods. Enhancements in **monitoring and forecasting hydrological processes**, specifically droughts and floods, are needed to improve the responsiveness of water allocation systems. This involves exploring the potential of early warning systems and strategies for data and information sharing. For practical recommendations, however, knowledge of existing demographic and socio-economic framework conditions for the necessary changes in human-environment interaction and potential impacts of decisions is essential. This is also true for applying remote sensing technologies that hold promise for refining water allocation systems, supporting the forecast of droughts, improving land management and monitoring settlement dynamics, thereby underscoring the need for an interdisciplinary approach to navigate the intricacies of climate change and water resource management. Global reanalysis and satellite-based climate products are increasingly

accurate and have emerged as helpful alternatives when in-situ data on climate or land conditions is unavailable due to resource constraints or other geographical or security-related challenges for data collection (Peña-Guerrero et al., 2022; Zandler et al., 2020).

The sustainability of inter- and transdisciplinary climate impact research in Central Asia is undermined by fragile local research and governance capacities. Over the past two decades, investment in research has steadily declined despite governments' intentions to increase research intensity (Suleimenov, 2021). This constrained the development of in-house research capacities and led to low attractiveness of the field and gender and age disparities among research staff. The region lacks robust and long-term strategies to enhance research capacity, involving sustained investments in research skills and facilities, as well as linking the research outputs into evidence-based policy making (Chankseliani et al., 2022). Consequently, there is an urgent need to augment **financial support, especially for social science research on climate change impacts**. This includes establishing and fostering international and interdisciplinary scientific collaborations, such as the initiative 'Green Central Asia', launched by the German Federal Foreign Office in 2020. It facilitates knowledge exchange and amplifies representation for local researchers and civil society voices in climate change, environmental justice, and conflict research, contributing to climate adaptation and security within policymaking spheres. Besides, many international and multilateral organizations have been leading efforts to assist Central Asian governments in adapting to climate change, primarily through capacity building, policy advice and financing. In cooperation with national governments, international funding organizations can take a leading role in boosting financial support for climate change research and establishing sustainable models for long-term investment in climate impact science to strengthen local research capacities.

Promoting **research collaboration within and across the region** will enhance knowledge and data sharing and drive innovations in climate adaptation. Fostering international and interdisciplinary partnerships can be achieved through conferences, panels, workshops, and special issues, targeting Central Asian researchers and involving Central Asian studies societies like the European Society for Central Asian Studies (ESCAS) and the Central Eurasian Studies Society (CESS). There is a significant need to build human and technical capacities in Central Asia, particularly through interdisciplinary research and education in climate change and adaptation. Essential qualifications measures include developing and expanding comprehensive Bachelor's and Master's programmes and establishing research groups for early-career researchers, which can foster interdisciplinary climate impact research in Central Asia with a strong link into practice and policy-making. To address the underrepresentation of Central Asian research in global discussions and to support high-level international research, teaching, and exchange, it is essential to enhance the visibility and accessibility of local research, particularly through English-language publications. This involves leveraging regional capacities by promoting bilingual journals, such as the Central Asian Journal of Water Research. To facilitate the integration of local academics into global research networks, tailor-made mobility programmes for students, doctoral candidates, postdocs, and established academics are essential. This includes promoting and expanding individual support programmes and joint study opportunities and degree programmes, taking into account existing funding schemes, such as the Aga Khan Foundation International Scholarship Program, the European Union's Erasmus Mundus programme, the German Academic Exchange Service, and the US Fulbright Program. Additionally, international or national research labs, joint chairs, dedicated centres, and networks are essential to cultivate inter- and transdisciplinary collaborations in research, education, and capacity building in the fields of research outlined above.

Acknowledgements

All authors gratefully acknowledge funding received from the German Academic Exchange Service (DAAD) under the CAWAMNET project.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Deutscher Akademischer Austauschdienst: [Grant Number: 57663154].

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