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The paradoxes of adaptation to climate change in Central Asia

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ABSTRACT

Central Asia is widely recognized as a global 'hotbed' of climate change (CC), yet effective adaptation is hindered by systemic contradictions. Despite the region's high vulnerability to CC it remains a significant scientific "blind spot" in global research on its impacts. In this paper we look at the dominant narratives highly relevant to climate change adaptions (CCA) though the lens of "adaptation paradoxes"— situations where policies, discourses, interventions, or measures intended designed to reduce vulnerability or mitigate the impacts of CC inadvertently generate new risks or reproduce existing structural problems. We examine eight interconnected paradoxes: geography, water security, climate change, the Aral Sea, glacier retreat, data sharing, parachute science, and sustainable development. By centering on these paradoxes, we argue that adaptation challenges are manifestations of deep structural contradictions embedded in the region's history, geography, and climate. Ultimately, we propose that Central Asia must be viewed not only a region in environmental crisis but serves as a critical laboratory for understanding the complexities of building resilience in water-scarce, politically fragmented landscapes.

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1. Introduction

Climate change adaptation (CCA) has emerged as one of the central policy and research priorities of the 21st century. Across the globe, societies are urged to adapt to increasing climatic variability, changing hydrological regimes, glacier retreat, biodiversity loss, and growing risks to food, water, and energy systems. In policy discourse, adaptation is commonly framed as an inherently positive and necessary response to climate change, often presented as a technocratic process through which vulnerability can be reduced and resilience strengthened. Adaptation strategies are frequently distinguished between incremental adjustments that preserve existing systems and transformative changes that seek to fundamentally alter underlying structures and pathways (Pachauri et al., 2014). However, adaptation is rarely straightforward. Measures designed to reduce one type of vulnerability may create new risks, redistribute inequalities, reinforce existing power asymmetries, or produce unintended socio-environmental consequences. Such tensions have increasingly been conceptualized as adaptation paradoxes (Ayers, 2011; Dupuis & Knoepfel, 2013) — situations in which attempts to solve environmental problems simultaneously generate new vulnerabilities or reproduce old ones.

Few world regions exemplify these paradoxes more vividly than Central Asia (CA). The IPCC identified critical knowledge gaps or a total lack of data in 51 out of 54 thematic areas essential for understanding climate impacts in the region. Thus, on one hand, the region has a status as an acute climate change hotspot and on the other hand it is a scientific "void," as research and data on climate impacts remain more scarce than in any other region of Asia (Vakulchuk et al., 2023). Yet even defining Central Asia constitutes the first paradox. Conventionally, the region is understood through a post-Soviet nation-state lens (the Former Soviet Union (FSU) Central Asia), consisting of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan - (De Cordier & Van den Bosch, 2021). This framing (further CA-FSU) dominates climate, water, and development discussions, as well as international governance and funding structures. However, environmental systems do not conform to political borders. Rivers, mountain ranges, atmospheric circulation, ecosystems, cryosphere processes, and historically human mobility transcend contemporary state boundaries. From a climatological perspective, the region cuts across multiple environmental domains; from a hydrological perspective, it is structured by interconnected river basins and closed drainage systems (Yapiyev et al., 2025); and from a historical perspective, it represents a fluid civilizational and environmental space rather than a fixed geopolitical entity (De Cordier & Van den Bosch, 2021). Consequently, CCA in Central Asia is inherently shaped by tensions between environmental realities and political geographies.

Central Asia is often portrayed through the lens of scarcity and vulnerability (IPCC, 2023). The region's predominantly arid and semi-arid climate, strong continentality, dependence on cryosphere and transboundary river systems have placed water security at the centre of climate adaptation debates. Simultaneously, the region remains strongly shaped by Soviet environmental legacies, including large-scale hydraulic engineering (Siberian Mega-Dams, Ferghana Valley, The Main Turkmen Canal etc.), irrigation expansion (Tselina (Russian for "Virgin Lands"), officially known as the Virgin Lands Campaign), environmental degradation (the desiccation of the Aral Sea, toxic dust storms, and widespread soil salinization), and institutional fragmentation (the breakdown of the Soviet-era unified water-energy sharing system and transboundary river disputes) following the dissolution of the Soviet Union (Saidaliyeva et al., 2024; Yapiyev et al., 2017). Climate change overlays these historical vulnerabilities through rising temperatures, altered snow and glacier dynamics, changing runoff regimes, and increasing hydrological variability. Yet despite growing concern, major uncertainties remain regarding the magnitude, geography, and attribution of climate impacts in the region, particularly the relative role of climatic versus anthropogenic drivers.

Paradoxically, while Central Asia is increasingly framed as highly vulnerable to climate change, it remains one of the least studied regions in global climate adaptation research (Saidaliyeva, Muccione, et al., 2024; Vakulchuk et al., 2023). Existing scholarship is often dominated by a narrow focus on transboundary water conflicts, glacier retreat, and the Aral Sea disaster, reinforcing simplified narratives of environmental collapse. Such framings risk obscuring regional diversity, local adaptive capacities, positive climate outcomes in some areas, and the broader socio-ecological transformations occurring across the region. Simultaneously, knowledge production itself is uneven: limited data availability, fragmented monitoring systems, restricted accessibility of environmental datasets, and the prevalence of "parachute science" contribute to a persistent scientific blind spot.

In this work we argue that many of the dominant assumptions surrounding CCA in Central Asia are best understood through the lens of paradoxes. Rather than viewing CCA as a linear process of problem-solving, we conceptualize adaptation as a set of tensions between competing scales, sectors, knowledges, and political priorities. We explore a series of key interconnected paradoxes—including the paradoxes of geography, water security, climate change, the Aral Sea, glacier retreat, data sharing, parachute science, and sustainable development—to examine how environmental governance and policy in Central Asia are characterized by contradictions between discourse and practice, local and global priorities, ecological systems and political boundaries, and adaptation goals and unintended consequences. This opinion paper employs a qualitative literature synthesis and narrative policy critique to examine

these systemic contradictions. We selected these eight paradoxes because they represent, in our view, the primary structural contradictions that dominate the policy discourse identified in our previous synthesis papers (Saidaliyeva et al., 2024; Yapiyev et al., 2017, 2021, 2025). By focusing on these core tensions, we aim to move the discussion beyond technocentric 'simple solutions' and address the systemic barriers that hinder adaptation efforts in CA.By centering on paradoxes, this paper does not seek to dismiss adaptation efforts or environmental governance initiatives in Central Asia. Rather, it aims to provide a more nuanced understanding of why CCA remains difficult, contested, and uneven in the region. We argue that many challenges are not merely technical failures or governance deficits, but manifestations of deeper structural contradictions embedded in the geography, history, political economy, and epistemic organization of Central Asia itself. Understanding these paradoxes is therefore essential not only for advancing scholarship on CCA in Central Asia, but also for improving future policy interventions and avoiding maladaptive trajectories.

2. The paradox of geography

What is Central Asia? In the recent book (De Cordier & Van den Bosch, 2021) European authors answer to the first question starting with “Central Asia is a modern construct to denote a civilization that no longer exists. This leads to trouble of all kind” and continue with different views of defining CA (such as, CA-FSU, Central Asia ‘proper’, High Asia, Inner Asia, Central Eurasia). Climate and accordingly climate change is ‘atmospheric’ or ‘meteorological view’ on the land domain, thus if we take the most authoritative source in this part, International Panel on Climate Change (IPCC, 2023) and overlay its domains we see the main portion of the territory belongs to Western Siberia (WSB) and Western Central Asia (WCA), while some portions belong to Easten Europe (EEU) and Eastern Central Asia (ECA), (Figure 1). What is the correct delineation then? In a broad sense, rather than seeking a single ‘correct’ delineation of Central Asia, researchers should explicitly state and justify the regional framework they employ. Different scientific questions require different geographical constructs: climatological studies may benefit from climate-based domains, while socio-economic and political analyses may require alternative regional delineations. Recognizing the plurality of Central Asia can help avoid conceptual confusion and improve the comparability of research results across disciplines. In our view, from climatological perspective (precipitation and temperature regimes), the region can be divided into North and South Central Asia – NCA and SCA (e.g. Jiang et al., 2020), territorially both domains are overlapping with Central Asia+ (Central Asia ‘proper’), (De Cordier & Van den Bosch, 2021).

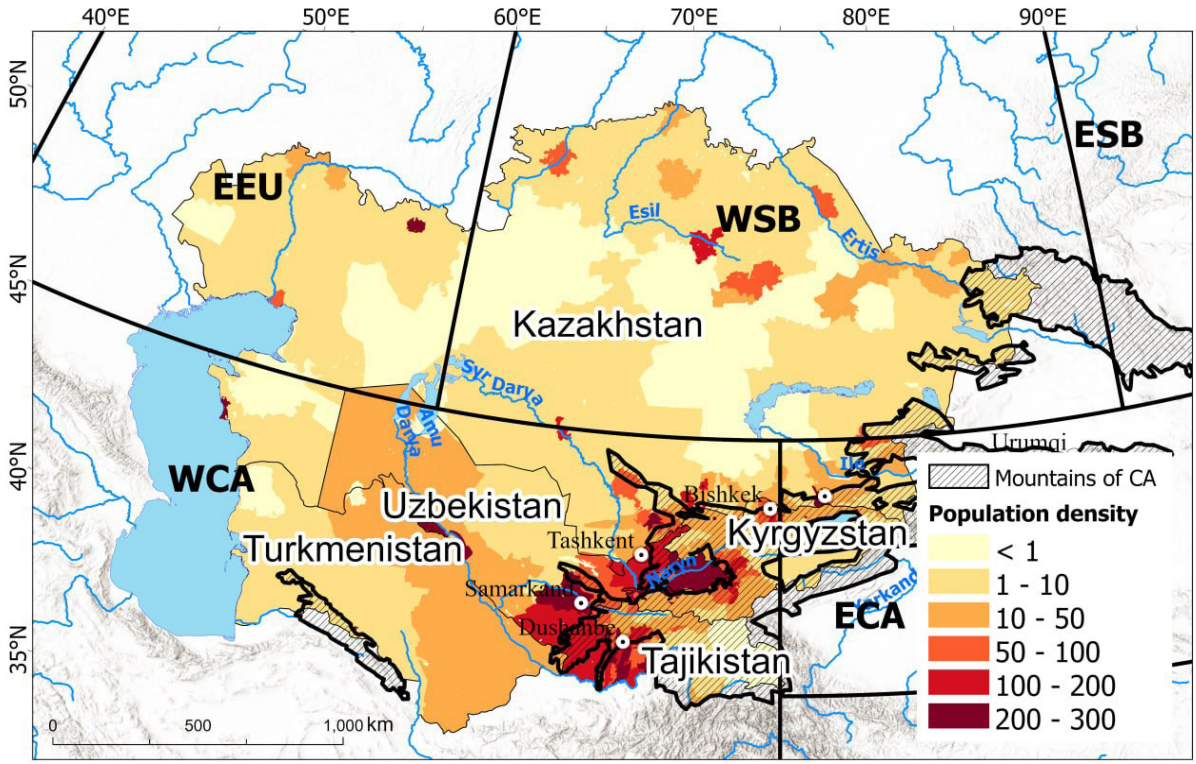

Figure 1. Central Asia (CA – FSU) region with the outlines of the mountains and population density (a number of people per km2) and overlay of domain of International Panel on Climate Change (IPCC, 2023). The map is adapted from Saidaliyeva et al., (2024).

3. The paradox of water security

Water security has become a central theme and concept to CCA in CA, due to high hydrological variability, water scarcity threat, water availability problems, transboundary river systems (Saidaliyeva et al., 2024). After the break-up of Soviet Union, water sharing became 'wicked problem' in CA-FSU due to resource competition among the nations, especially in Aral Sea Basin (ASB) (Xenarios et al., 2019). Paradoxically, security together with water already implies water security competition. The academics and practitioners using and pushing this term into discourse must be aware of this dilemma. The weaponization of water has become a recent trend globally (e.g. recent India-Pakistan situation (Water Conflict and Cooperation between India and Pakistan | Climate-Diplomacy, 2025)). It is thought that the CA nation states will continue the (water) resource capture strategy (Wegerich, 2008), and a construction of Qosh Tepa canal in Afghanistan in the headwaters of Amu-Darya corroborate this paradigm (Overland et al., 2025). Nevertheless, there is growing cooperation (or at least its intent) in CA, for example in 2024 Kazakhstan, Kyrgyzstan

and Uzbekistan signed joint agreement to co-finance building of Kambar-Ata-1 dam in the headwaters of the main tributary of Syr-Darya river, Naryn (Symbolic, But Distant in the Future: A Dam on Kyrgyzstan's Naryn River - Аналитический Интернет-Журнал Власть, 2024).

The discussion about 'water security' is dominated by 'blue water' (surface and groundwater, cryosphere), while 'green water' (soil moisture, evapotranspiration) is largely ignored. 'Blue water' represents only about one-third of the global freshwater resource; the remaining two-thirds consists of 'green water' (Falkenmark & Rockström, 2006). The soil moisture (i.e. water available to plants and crops and evaporation) is the dominant control on water availability in the region (Yapiyev et al., 2025) and often is the most important source of precipitation in the region through moisture recycling (from evaporation to precipitation) (Saidaliyeva, Shahgedanova, et al., 2024).

In theory, 'water security' implies the 'nature security' and sustaining environmental flows (Xenarios et al., 2021), but in practice anthropogenic demand is the utmost priority, either directly as 'water abstraction' or indirectly, as 'ecosystem services'. While it is understandable that there must be a compromise between socio-economic water uses and nature demand, we need a change in discourse from 'securing' water and illusion that we can 'fix', 'control' or 'manage' fragile water and climate cycles in cold and dry region, to more dynamic 'adaptation'(Borgomeo, 2026).

Future water governance in Central Asia should move beyond narrow water-security paradigms towards adaptive water management approaches that explicitly account for climatic uncertainty, ecosystem needs, and socio-economic change. Greater attention should also be given to 'green water' processes, including soil moisture, evapotranspiration, and moisture recycling, which remain underrepresented in regional water assessments despite their critical role in sustaining agricultural production and precipitation.

4. The paradox of Aral Sea

The 'Aral Sea man-made disaster' is in all text books on Environmental issues of 20th century (Micklin, 2016). The worst man-made environmental catastrophe example, and it is the Soviet Union to blame. The lowlands of Aral Sea are the zone of ecological catastrophe. The Soviet Union is more than 30 years 'no-more' but we could not revive the Aral Sea or we did? If we simplify the ASB hydrology in present state, it can be stated that runoff of Syr Darya river fills the Small (North) Aral Sea and Amu Darya river Big (South) Aral Sea residual basins (Yapiyev et al., 2021).

In 2005 under World Bank financed "First phase of the Northern Aral Sea

Conservation Project" Kazakhstan finished the construction of Kok-Aral dyke/dam to retain water in the North Aral Sea, preventing it from spilling out to the desiccated South part and accelerating ecological and socio-economic stabilization in the immediate region (Kirillin et al., 2025). A recent paper on socio-economic and public health impact of climate change and water availability concluded: "Kazakhstan's section of the Aral Sea Region manifests no catastrophic situation" (Khaibullina et al., 2022). In a way, it can be said that Kazakhstan "saved the Aral Sea", at least North part of it. The South Aral Sea is to be saved by the other countries' efforts, but there seems to be no progress or effort in this direction.

The following phases of conservation project were on hold until recent announcement of Government of Kazakhstan about the preparation of "Second phase of the Northern Aral Sea Conservation Project". This large-scale engineering project aims to increase the water level to 44 meters and expand the surface area to 3913 km2. Even though these efforts to restore the Sea are worth appraising, the major question is: Will there be enough water to reach such level? As the available data indicate that Northern part hasn't reached high levels since 2014. The following are the core challenges related to this project: influence of climate change, variable river inflows, competitive regional water demands, ecosystem and delta management complexities. While the long-term sustainability of this project requires large-scale infrastructure modernization, transition in traditional agricultural and water management practices, integrated monitoring frameworks and most importantly transboundary water cooperation.

In a way, Aral Sea and 'disaster' are thought to epitomize Central Asia and its environmental and climate problems. The discourse on regional environmental collapse increasingly extends to the Caspian Sea, where the 'Aral Sea syndrome' is invoked to describe its current trajectory of desiccation. (Hydrological Sciences | Is the Caspian Sea Going to Experience Aral Sea Syndrome?, 2024). There is an ongoing debate on the topic of the Caspian Sea level decline: climate change (increase in evaporation, decrease in precipitation and runoff), anthropogenic impacts (water use and reservoir operations), (e.g. Chen et al., 2017; Duku et al., 2026; Koriche et al., 2021). Both Caspian and Aral Sea cases clearly demonstrate the problems in water management caused by the absence of unified governance framework in large transboundary basins (Xenarios et al., 2025), i.e. natural vs. national boundaries (The Paradox of Geography).

Nevertheless, we propose to move the main academic discussion beyond 'Aral Sea disaster', Central Asia is not only the Aral Sea and its basin, but wider and much diverse region that cannot be described only though this, though important, part. While structural interventions like the Northern Aral Sea Conservation Project remain vital for localized ecological recovery, future hydro-climatic research must account

for broader pan-Central Asian dynamics, including accelerated cryospheric melting, land-atmosphere interactions and recycling mechanisms, shifting hydrological regimes (e.g. altered snowmelt dynamics, rain to snow transition), land degradation and desertification, climate extremes and agricultural vulnerability, complex transboundary water-energy-food nexus pressures. Such a shift would help prevent the region from being reduced to a single environmental narrative and encourage more balanced scientific and policy attention.

5. The paradox of glacier retreat

'Glaciers are retreating and melting in CA with increasing rates and when they are totally wasted then, the region is doomed'. This is a simplified message on water resources assessments in Central Asia (e.g. Huss and Hock 2018; Kaser et al. 2010). Though paradoxically, direct glacier ice contributions to river runoff in glaciered catchments of CA are minute comparing to snow and groundwater on large catchment scale (Gascoin, 2024; Khanal et al., 2021). For example, glacier (ice) melt contributions in Amu Darya, Lake Balkhash and Syr Darya basins (before the inflow to the major headwater reservoirs) are estimated to comprise 4.4, 2.2 and 1.3% of total runoff accordingly (Khanal et al., 2021). These contributions are dwarfed by snowmelt contributions (74.4, 46.3 and 72.9% respectively). Groundwater as baseflow is usually the second largest contributor after snow (Khanal et al., 2021), and it is primarily also replenished by snowmelt (van Tiel et al., 2024). In the recent synthesis on mountains as water towers of the world (Viviroli et al., 2026) regarding "runoff originating from the glaciers", it was stated: "However, the term is often used more broadly to include snowmelt runoff originating from glaciated surfaces. In an even broader sense, the term glacier runoff can also encompass rainfall runoff originating from glaciated areas." For broader audiences, these nuances are often omitted, which distorts the scientific message. The explicit terms such as 'mountain cryosphere', 'meltwater', 'runoff from mountains' or 'headwaters' are more appropriate and scientifically sound. Overall, snow(melt) is the key blue water source both for the South (Kraaijenbrink et al., 2021) and North (Yapiyev et al., 2025) CA regions. Thus, we think more efforts must be made in promoting understanding and adaptation to change of precipitation regimes (solid to liquid, or snow to rain) and cryosphere changes (not only limited to mountains). While we emphasize that glacier ice melt accounts for a relatively minor fraction of total annual runoff especially on large basin scale, we acknowledge that glaciers remain vital to regional security due to the cascading downstream impacts of their retreat, which heightens the risk of mountain-originating hazards such as Glacial Lake Outburst Floods (GLOFs) and debris flows that threaten interconnected social-ecological systems across Central Asia. (Shahgedanova et al., 2024; Viviroli et al., 2026). It is important to study and

preserve glaciers for their cultural value, biodiversity, as an overall cryosphere state indicator and many other reasons (Gascoin, 2024).

Future assessments of water resources in Central Asia should place greater emphasis on changing precipitation regimes, seasonal snow dynamics, groundwater recharge, and broader cryospheric processes rather than focusing predominantly on glacier ice loss. Communicating these distinctions clearly to policymakers and the public is essential for developing realistic adaptation strategies and avoiding oversimplified narratives about future water scarcity.

6. The paradox of data sharing

Climate, hydrology and other environmental data sharing is of key problems in CA research, management and governance (Yapiyev et al., 2017). The usual complains of the international community working in the region is data availability (sharing). Paradoxically, the international projects and researchers working in the region rarely share the generated data and results in a reproducible way, though there are some exceptions (e.g. Marti et al., 2023; Wade et al., 2024; Yapiyev et al., 2018). Nevertheless, overall, global climate and environmental change studies rarely include ground-data from the region. Thus, the region is a 'blind spot' and global studies have a strong bias towards 'data-rich' regions. We think that international and local funders must make a prerequisite to funding to use open-source models and make generated data available on open repositories. This is a standard practice for global research community and it hinders the progress in both research and practical application of results specifically related to CCA.

Funding agencies, journals, and research institutions should require adherence to FAIR (Findable, Accessible, Interoperable, and Reusable) principles as a standard condition for project support and publication. Open data repositories, transparent workflows, and reproducible modelling frameworks would enhance collaboration, improve scientific credibility, and reduce the region's status as a global environmental data blind spot.

7. The paradox of parachute Science

'Parachute Science' aka 'colonial science' or 'helicopter research' is global problem (Stefanoudis et al., 2021). The informal consensus is that the quality of local (CA) climate related research is at best 'subpar'. In the best cases, a PhD student from the region is doing a CA focused project in a Global North country sometimes resulting in high profile peer-reviewed publications or local researchers provide data, perform field work in an international project and are included as the co-authors.

PhD student from the CA after graduation is often not really willing to return to the region, as there are much less opportunities for career and personal development. Thus, there is no 'sustainability' or local capacity development to do research (Saidaliyeva et al., 2024). Such situation is a 'wicked' problem, that it cannot be 'fixed'. Perhaps, a better way for postgraduate researchers is a 'split-PhD' when a student conducts part of its research, training and teaching in the region and abroad. Such schemes already exist in Kazakhstan for example. Overall, better involvement of 'locals' in all stages of development and research projects in the region is needed. The recent study on water security concept in Central Asia by Xenarios et al., (2020) provides a comprehensive analysis of 151 peer-reviewed articles published between 1991 and 2019. On one hand, it found that scientific interest in water management in Central Asia is growing at an estimated rate of 15.7% annually, on the other hand the analysis notes that while Europe (43%) and the United States (17%) host a majority of the lead authors' institutes, many of these researchers are of Central Asian origin.

Building sustainable scientific capacity in Central Asia requires long-term partnerships rather than project-based collaborations. Mechanisms such as split-PhD programmes, joint supervision, regional research networks, and equitable authorship practices can strengthen local expertise and ensure that knowledge generation remains embedded within the region beyond the lifespan of individual projects.

8. The paradox of Sustainable development

The Sustainable development itself is often synonymous with CCA, especially at the local level (Ayers, 2011). In CA, the development projects on water, climate and environment are often dominated by international projects, donors (Yapiyev et al., 2017). But how much do they actually develop the region? Each donor has its own agenda, consultants, while local partners, stakeholders are mere 'recipients' and their knowledge and capacity —though formally acknowledged—are largely ignored in practice. The results of such projects are often the failure to achieve their proposed development objectives.

From example, Chu-Talas Transboundary Commission (Chu-Talas Commission, 2018) hailed as a success story and International development agencies and donors (such as the UN, World Bank, and GIZ) heavily promoted and used the Chu-Talas basin to champion Integrated Water Resources Management (IWRM) principles (Zinzani, 2015). In practice, the case study (Zinzani, 2015) demonstrated how global water paradigms are often reconfigured by the state entities involved. While the Chu-Talas Commission successfully functioned as a diplomatic vehicle to prevent outright water conflicts, the implementation of true bottom-up, participatory water governance faced heavy resistance. National bureaucracies and local political strategies

frequently maintained top-down control, resulting in a selective adoption of global donor models rather than a complete institutional transformation.

How do we make the development 'sustainable' in the region? To achieve this, the region must prioritize the co-production of knowledge by fostering closer collaboration between researchers, international organizations, practitioners, and local communities to ensure adaptation strategies are culturally and socio-economically relevant (Saidaliyeva et al., 2024). This requires building regional capacity and actively integrating local knowledge and practices into international and national projects to move beyond the 'parachute science' model and secure long-term local ownership of CCA and development efforts. The wider problem stands on the maturity and appeal of the job market to attract and retain the professionals to their place both in academic, research settings and development, industry organizations. Sustainable development initiatives should prioritize local ownership, institutional continuity, and co-production of knowledge from project inception through implementation and evaluation. International development partners should increasingly act as facilitators and collaborators rather than external providers of solutions, ensuring that adaptation strategies are grounded in local realities and remain viable after project funding ends.

9. Recommendations

Ultimately, we propose that Central Asia should not be viewed solely as a region of environmental crisis, but as a critical laboratory for understanding the complexities, trade-offs, and contradictions of adaptation in water-scarce and politically fragmented regions under climate change.

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Author Contributions

VY and ZS conceived the work and wrote the paper. NO contributed to the discussion and edited the manuscript.

Table 1. Overview of Climate Change Adaptation Paradoxes in Central Asia, Policy Implications, and Opportunities for Resolution

Paradox	Description	Policy Implications	Some ways forward
Geography	There are varing often contradicting definitions of the region. Ecological systems (rivers, mountains, air circulation) transcend borders, but governance remains strictly national.	CCA planning and actions are fragmented	Move beyond "national border" boundary conditions; adopt a transboundary, basin-level and climatic regions (SCA-NCA) approach to water and climate policy.
Water Security	Security framing often intensifies hydro-political competition and resource capture rather than fostering cooperation.	Focus on "blue water" ignores critical "green water" (soil moisture). Water securitization dominates, while nature security is ignored	Move discourse into "nature security" and environmental flows, from 'control' and 'fixing' to true adaptation to natural regional conditions.
Climate Change	High regional vulnerability to climate change coexists with declining academic research on adaptation.	Difficulty in designing region-wide strategies due to heterogeneous impacts (e.g., North vs. South).	Develop interdisciplinary studies connecting scientific findings with practical, context-specific adaptation actions.
Aral Sea	Disaster framing increases attention but narrows understanding of regional diversity.	Adaptation debates become trapped in a single symbolic case.	Move beyond "Aral Sea syndrome"; focus on broader socio-ecological transformations and local successes like the North Aral.
Glacier Retreat	Glacier loss dominates discourse despite modest direct contributions to runoff compared to seasonal snow.	Policy actions are diverted into "saving glaciers"	Reframe focus on the "cryosphere" (not only mountain) as a whole; accurately present glaciers as one of many water resources.
Data Sharing	Data sharing is the problem, but local and international projects often do not use open-source models and publish generated data openly. Growing interest in AI coexists with declining ground-level monitoring and a failure to share generated results.	Central Asia remains a scientific "blind spot"; models are built on sparse data, weakening the evidence base for decision-making and further work.	Mandate FAIR data and open model practices for all funders.
Parachute Science	External expertise formally aims to advance regional science and practice but fails to build sustainable local research and adaptation capacity.	Local researchers are often reduced to "field assistants"; brain drain of local PhDs prevents long-term ownership and research continuity (sustainability).	Foster knowledge co-production; implement "split-PhD" schemes and ensure better involvement of locals in all project stages.
Sustainable Development	International donor-led projects are often ineffective and in essence have the same top-down approaches as national bureaucracies	Diplomatic "successes" mask a failure to achieve true institutional transformation or bottom-up participatory governance.	Shift from top-down agendas to culturally relevant, community-based management, water cooperative, social innovations

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