CONTEMPORARY WATER ISSUES IN CENTRAL ASIA: CHALLENGES AND SOLUTIONS

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ABSTRACT

Central Asia, situated around the Amu Darya and Syr Darya river basins and bordered by the Caspian and Aral Seas, is grappling with acute water-related challenges that threaten ecological balance and socioeconomic stability. The crisis is exemplified by the desiccation of the Aral Sea due to unsustainable water diversion and escalating pollution in the Caspian Sea, which endangers biodiversity and coastal livelihoods. Climate change has further intensified these pressures through accelerated glacial melting in Kyrgyzstan and Tajikistan, jeopardizing long-term freshwater availability. Growing water scarcity affects agriculture, food security, public health, and regional relations, exposing a paradox of resource abundance amid environmental vulnerability. This paper analyzes the environmental, economic, and social dimensions of Central Asia's contemporary water issues, emphasizing governance deficits, inefficient management, and transboundary tensions. It further evaluates solutions including regional cooperation, modern irrigation technologies, and integrated water resource management to enhance resilience and promote sustainable development.

Keywords: Transboundary Cooperation, Food Security, Irrigation Practices, Public Health, Environmental Governance, and Climate Adaptation.

WATER PROBLEMS IN CENTRAL ASIA: SETTING THE CONTEXT

Across the world, water is emerging as the central strategic resource of the twenty-first century, occupying a position comparable to that held by oil in the previous century. During the twentieth century, access to oil decisively shaped geopolitical alignments, economic development, and the global distribution of power, rightly earning the period the label "the century of oil" (KPMG, 2023), (Kumar, 2015, p. 67) (Yergin, 1991, p. 15). While oil continues to influence international politics, the present century is marked by a rapid transition toward water as the most vital and contested resource for human survival, ecological stability, and national security. Water's indispensability for human development makes it inherently political. Its scarcity - and in many regions, its uneven distribution - has historically triggered tensions and disputes among communities and states (Karesdotter, 2023, p. 2). Today, pressures from expanding populations, unsustainable agricultural practices, hydropower development, and climate change are intensifying global water insecurity, transforming it from a localised environmental concern into a broad geopolitical challenge. As freshwater availability declines and demand continue to grow, competition between upstream and downstream states is expected to deepen (Gleick, 1993, p. 79) (Iceland, 2018, p. 2) - an issue particularly evident in Central Asia, one of the world's most water-stressed regions. The collapse of the Soviet system provided an opportunity for the Central Asian republics to reconstruct and reshape their political systems in ways fundamentally different from the former Soviet authoritarian structure; subsequently, the region's leadership introduced liberal economic measures and elements of democratic governance, thereby adding new political dynamics to the already complex challenge of managing limited water resources (Kumar H. , 2024, p. 5).

Central Asia's water insecurity is shaped by a combination of geographic, climatic, and human-made factors. Although the region is traversed by major river systems - the Amu Darya and the Syr Darya - freshwater availability remains under severe strain. Hydropower is both an opportunity and a geopolitical fault line for Central Asia. Upstream nations such as Kyrgyzstan and Tajikistan depend heavily on hydropower generation, while downstream states - Kazakhstan, Turkmenistan, and Uzbekistan - require large volumes of water for irrigation-intensive agriculture, especially cotton (Kumar, 2026, p. 1016; Russell, 2018, p. 1). This unequal distribution of needs and resources creates a natural setting for competition. Environmental priorities, including biodiversity conservation, the rehabilitation of the Aral Sea, and the protection of local livelihoods, have often been overshadowed by the pursuit of economic goals such as agricultural expansion and energy production. The consequences are evidenced in widespread ecological degradation, heightened water scarcity, and social vulnerabilities that extend across the region.

The roots of the region's contemporary water crisis lie partly in the legacy of Soviet water management. Under Soviet rule, the *Ministries of Land Reclamation and Water Resources* (Minvodkhoz) in Moscow supervised a strictly centralised system of irrigation and water distribution (Weinthal, 2006, p. 5). The breakup of the USSR dismantled this centralized authority, compelling newly independent states to manage water resources independently while still relying on the same river systems.

Since independence, upstream and downstream states have made periodic efforts to cooperate - often through annual, high-level political agreements - but these arrangements remain fragile (Janusz-Pawletta, 2015, p. 196). While Kazakhstan and Kyrgyzstan have experimented with *Water Users' Associations* (WUAs), Turkmenistan and Uzbekistan continue to rely on centralised models reminiscent of Soviet-era approaches (Weinthal, 2006, p. 22). Moreover, the Soviet principle of *"Use It or Lose It,"* which incentivised the exhaustive use of allocated water without stressing conservation, persists due to weak enforcement and limited incentives. Without comprehensive regional cooperation and institutional reform, current consumption levels - combined with outdated infrastructure - continue to contribute to soil salinization, declining river flows, and long-term environmental collapse across the Aral Sea basin (Sokolov, 2013), (Sehring, 2012, pp. 18-19).

The Aral Sea stands as the most visible and devastating illustration of water mismanagement in Central Asia. Once the fourth-largest inland water body in the world, its dramatic shrinkage is emblematic of the region's broader hydrological crisis. Excessive diversion of the Amu Darya and Syr Darya for irrigation, especially for cotton monoculture, has left the sea severely depleted, drastically altering local climate patterns, destroying fisheries, escalating salinity levels, and contributing to widespread health problems (Kumar, 2023, p. 212), (Kumar H. , 2021, pp. 91-92), (White, 2013, p. 23), (CPC, p. 06), (EJF, 2012, p. 6). Thick layers of salt and toxic chemicals now blanket the exposed seabed, fuelling dust storms that ferry pollutants across vast distances, impacting not only agriculture but also regional air quality and public health. These storms exacerbate respiratory diseases, contribute to migration, and perpetuate cycles of poverty - making the Aral crisis one of the most severe examples of man-made environmental disaster (Kumar D. H., 2023, p. 117), (Thompson, 2008).

Central Asia's vulnerability is magnified by its dependence on glaciers. Surrounded by high mountains that obstruct moisture, the region receives limited rainfall. Consequently, glaciers in the Tien Shan, Pamir, and Alay ranges provide the majority of river runoff. Yet these glaciers are rapidly retreating due to rising greenhouse gas emissions. Historical data show that between 1956 and 1990, the glacier reserves of Kazakhstan and neighbouring Central Asian states decreased by over one-third, and the shrinkage continues at an annual rate of 0.6-0.8 per cent in area and around 1 per cent in volume (Bolch, 2007, p. 1), (Braun, 2009). If present trends persist, glaciologists predict that Kazakhstan's mountain glaciers may disappear extensively by the end of the century. Given that glacial meltwater currently contributes approximately 25 per cent of the annual river runoff in major basins, the implications for agriculture, hydropower, drinking water, and regional stability are profound (Chen, 2017, p. 673). These climactic transformations require urgent attention, as they directly threaten irrigation systems, hydropower generation, and drinking-water supplies in both upstream and downstream states.

The decline in freshwater availability has significant humanitarian consequences. Many communities in Central Asia - especially in rural, marginalised, or ecologically degraded regions - view access to water as a fundamental right (Kudryavtseva, 2024). This cultural perception can hinder governments from addressing the crisis, particularly when state agencies lack the capacity, political will, or technological resources to reform water usage patterns. Water scarcity exacerbates a range of interlinked security risks such as diminishing agricultural productivity; public health crises due to polluted water sources; unemployment due to collapse of fisheries and farming; rural out-migration; regional political tensions; and potential for interstate disputes. As climate change accelerates, these risks are likely to intensify. For example, rising temperatures have already disrupted crop cycles, increased irrigation demand, and escalated evapotranspiration rates - factors that place enormous pressure on already-stressed water systems. A defining feature of Central Asia's water system is the asymmetry between upstream and downstream states:

- **Upstream (Kyrgyzstan, Tajikistan):** Depend heavily on hydropower; release water mainly in winter when electricity demand peaks.
- **Downstream (Uzbekistan, Turkmenistan, Kazakhstan):** Need water primarily in summer for irrigation; most agricultural economies rely on the timing and volume of upstream releases (Kocak, 2015, p. 1).

This mismatch creates seasonal tensions. The collapse of the Soviet-era water-energy barter system - which once compensated upstream states with energy resources in return for summer water releases - has deepened these disputes. Today, countries often pursue unilateral strategies, undermining regional stability (Gleason, 2001). Central Asia's water challenges are also deeply intertwined with food security. Cotton, wheat, fruits, and vegetables all require extensive irrigation, yet inefficient water use remains pervasive. Much of the region's irrigation infrastructure is outdated, causing substantial water losses through seepage, evaporation, and poor drainage. Moreover, rising temperatures and altered precipitation patterns have led to declining crop yields, shifts in growing seasons, soil salinization, and reduced land productivity. These factors further amplify rural poverty and place additional strain on water systems - particularly in Uzbekistan, Turkmenistan, and Kazakhstan, where agriculture forms a substantial component of GDP and employment.

RESEARCH GAPS

Although a substantial body of literature exists on water-related issues in Central Asia, important gaps remain. Most studies focus on individual countries or specific themes such as the Aral Sea crisis, climate change, or transboundary water governance. Consequently, there is limited scholarship offering a comprehensive regional perspective that integrates environmental, political, institutional, and socioeconomic dimensions of water challenges. Furthermore, existing research rarely evaluates regional cooperative mechanisms and sustainable policy responses within a unified analytical framework. This study addresses these gaps by providing an integrated assessment of contemporary water issues across Central Asia and examining the effectiveness of regional cooperation and governance strategies for sustainable water management.

RESEARCH METHODOLOGY

This study adopts a mixed-methods research design, integrating quantitative and qualitative approaches to examine contemporary water issues and potential solutions in Central Asia. The quantitative component draws upon datasets from government reports and international organizations to assess trends in water availability, climate change impacts, environmental degradation, and regional disparities. Descriptive statistics and trend analysis are employed to identify patterns and emerging challenges across the region. The qualitative component is based on documentary and policy analysis, using primary sources such as government policies, regional agreements, institutional reports, and official documents. Secondary sources include articles, books, policy briefs, and contemporary scholarly literature. Sources were selected purposively on the basis of their relevance, credibility, and recency. The combined approach enables a comprehensive assessment of environmental, political, and socioeconomic dimensions of water governance while evaluating existing institutional mechanisms and pathways for sustainable regional cooperation. The findings are interpreted using the Integrated Water Resources Management (IWRM) framework, enabling a comparative assessment of governance practices, institutional cooperation, and sustainable policy responses across Central Asia.

RESULT AND DISCUSSION

THE ARAL SEA CRISIS: FROM ABUNDANCE TO DEVASTATION

The Aral Sea was once one of Central Asia's most distinctive ecological systems - an expansive inland water body situated approximately 600 kilometres east of the Caspian Sea, comprising more than a thousand islands separated by lagoons and narrow straits. The name "Aral," meaning "island" in Kazakh, reflected this unique geography. Historically, it consisted of two major components: the *Small Aral* in the northeast and the *Big Aral* in the southwest. Until the early 1960s, the sea covered nearly 68,000 square kilometres, comparable to the size of the Indian state of Odisha, and held more than 1,000 cubic kilometres of water (Kumar R. , 2002, p. 3797). Fed by two important rivers - the *Syr Darya* from the north and the *Amu Darya* from the south - the Aral Sea supported vibrant ecosystems, thriving fisheries, and biologically rich wetlands in its deltas (Islamov, 1998). Numerous species, including the iconic Aral sturgeon, inhabited the sea and were central to the region's livelihood, biodiversity, and food systems. Annual fish production exceeded 40,000 tons, providing employment and sustenance for surrounding communities. However, this once-flourishing ecological system gradually transformed into one of the most striking examples of anthropogenic environmental degradation. Beginning in the Soviet period - particularly from the 1960s onward - massive irrigation expansion, primarily for cotton monoculture, diverted increasing quantities of water from the sea's tributary rivers. Over several decades, this diversion precipitated an unprecedented hydrological collapse that reshaped the region's climate, economy, health profile, and ecological foundations.

Table 1: Major Impacts of the Aral Sea Disaster

Sr. No.	Category	Major Effects
1.	Hydrological	90 per cent shrinkage; inflow drop from 55 to 7 bcm
2.	Ecological	Biodiversity collapse; 2.5x salinity rise
3.	Economic	Fisheries collapse; agricultural losses
4.	Social	Unemployment; migration
5.	Health	Respiratory and digestive diseases; high child mortality
6.	Climate	Hotter summers; colder winters; dust storms
7.	Environmental	Aralkum Desert; salinization; toxic dust

Source: (Karimova, 2018), (Islamov, 1998), (Kumar R. , 2002).

The Aral Sea catastrophe cannot be understood without reference to Soviet-era agricultural and irrigation policies. From the late nineteenth century under Tsarist rule, Central Asian lands, including the Aral basin, began to undergo systematic transformation from nomadic grazing zones into irrigated agricultural areas. Following the Bolshevik Revolution of 1917, this transformation was dramatically intensified. Driven by the strategic goal of achieving self-sufficiency in cotton - often termed *"white gold"* - the Soviet Union sought to convert Central Asia into its primary cotton-producing region. This goal became a defining cornerstone of Soviet agricultural planning. In 1918, Lenin issued directives stressing the importance of increasing cotton yields in Turkestan. Under Stalin, these ambitions accelerated; the *Soviet Ministry of Water* spearheaded gigantic irrigation and water-diversion projects across Kazakhstan, Uzbekistan, and Turkmenistan (Kumar R. , 2002, p.

3797). In pursuit of these agricultural ambitions massive irrigation canals were dug across the desert; water from the *Syr Darya* and *Amu Darya* was redirected deep into agricultural fields; Poor drainage systems were constructed, leading to rising salinity; and Cotton monoculture displaced traditional food crops and local ecological systems. By the late 1940s, Soviet planners had already begun diverting Syr Darya waters to Kizil-Orada (in Kazakhstan) and regions near Tashkent (in Uzbekistan) (Altan, 1995, p. 3). During the 1950s and 1960s, even more aggressive water-withdrawal schemes unfolded as Moscow launched the large-scale *Aral Sea Project*, aimed at converting vast tracts of desert into irrigated cotton fields (Kumar R. , 2002, p. 3798). These interventions produced severe ecological consequences. By the 1970s, the Syr Darya had stopped reaching the Aral Sea entirely (Bedford, 1996), while the Amu Darya reached the sea only in small, diminishing volumes. Soil fertility deteriorated due to widespread salinization and waterlogging, and regional ecosystems began to collapse under mounting environmental stress.

By the early 1960s, the Aral Sea's water inflow averaged 55 billion cubic meters annually - sufficient to maintain its ecological balance. By the 1980s, however, annual inflow had plummeted to only 7 billion cubic meters (Kumar R. , 2002, p. 3799). The resulting environmental degradation was profound: the sea had lost nearly 90 per cent of its original surface area by 2000; salinity levels had increased 2.5-fold, rendering the water uninhabitable for most species (Karimova, 2018, p. 1422); the exposed seabed had transformed into the highly toxic Aralkum Desert, now spanning over 5.5 million hectares; entire fishing ports, such as the once-bustling Aralsk, were left stranded far from the receding shoreline; and desertification intensified as winds carried millions of tons of contaminated salt across agricultural regions as far as the Pamir and Tien Shan mountains, and even to the Arctic. This hydrological collapse reshaped the region's climate. The sea's ability to moderate temperatures diminished, resulting in hotter summers (2-3°C increase), harsher winters, reduced precipitation, and more frequent dust storms (Kumar R. , 2002, p. 3800). As the sea receded, the ecological system surrounding the Aral basin rapidly disintegrated. Major impacts included:

1. **Collapse of fish populations:** The rapid desiccation of the Aral Sea produced a dramatic ecological collapse, with salinity in the remaining water rising to 40 g/L - four times previous levels - creating conditions lethal to most fish species (Ibid, p. 3799). Once-abundant species such as sturgeon, carp, and bream were virtually eradicated. Until the 1960s, the Aral Sea had sustained one of the Soviet Union's most productive fisheries, historically supplying entire railway wagons of fish to famine-affected regions, including the Volga. However, extensive diversion of river water for irrigation progressively destroyed this industry: annual fish harvests fell from 43,430 metric tons in the 1960s to 17,400 tons in the 1970s, and by 1980 fish production had collapsed entirely (Kobori, 1998), (Mainguet, 1998, p. 137). Fishing communities were devastated, and the port town of Aralsk - once a vibrant shipbuilding and trading hub - became stranded amid salt-covered desert. Scientific warnings in the late 1970s that declining water levels would eliminate spawning grounds went largely unheeded (Gorodetskaya, 1978, p. 730), (Borovsky, 1980), and the predicted decline materialised within years. The resulting socio-economic fallout has been severe, marked by unemployment, forced migration, cultural loss, and rising rural poverty.
2. **Decline in biodiversity:** Wetlands, bogs, and lakes in the deltas dried up. Numerous species of birds, mammals, and aquatic life vanished as habitats collapsed. Dust storms destroyed vegetation and further destabilised local ecosystems.
3. **Expansion of the Aralkum Desert:** Salt crusts and pesticide residues accumulated across the exposed seabed. Strong winds carried **50-60 million tons** of dust and salt annually to distant regions (Karimova, 2018, p. 1422). These pollutants damaged agricultural lands, contaminated water sources, and accelerated land degradation.

4. **Salinization and soil degradation:** Poor irrigation infrastructure and inadequate drainage caused widespread salinization. Agricultural productivity plummeted, and large areas became unsuitable for crop cultivation.

The Aral Sea crisis therefore represents not only ecological collapse but also a multi-generational public health emergency. Health consequences stemming from the Aral disaster are among the most serious outcomes of the crisis.

1. **Toxic dust and respiratory illnesses:** Dust storms, now occurring for up to 60 days per year, carry salts, pesticides, and chemical residues from exposed seabeds. These pollutants contribute to chronic bronchitis, asthma, throat and lung infections, and increased rates of cancer. The WHO's recommended maximum salinity level in drinking water is regularly exceeded; in some areas, salt levels reach 6 g/L, four times above the safe threshold (Kumar R. , 2002, p. 3800).
2. **Water contamination and digestive diseases:** Chemical runoff from agricultural fields has contaminated water sources. Communities consuming this water experience elevated rates of kidney disease, diarrhoeal illness, hepatitis, and gastrointestinal disorders. Mortality rates for respiratory and digestive diseases near the Aral Sea exceed national averages (Buckley, 2003, p. 1).
3. **Impacts on children and maternal health:** Pesticide contamination affects food, water, and even breast milk. High levels of toxic residues in breast milk - stemming from mothers' consumption of cottonseed oil and pesticide-laden animal fat - pose severe risks to infant health (Jensen, 1997, p. 191). Children in the region face high rates of anaemia, respiratory infections, and other environmentally linked illnesses.
4. **Overall human-development decline:** Environmental health deterioration has contributed to rising infant mortality, reduced life expectancy, higher rates of chronic disease, and psychiatric stress linked to environmental trauma (Kiessling, 1998, p. 562).

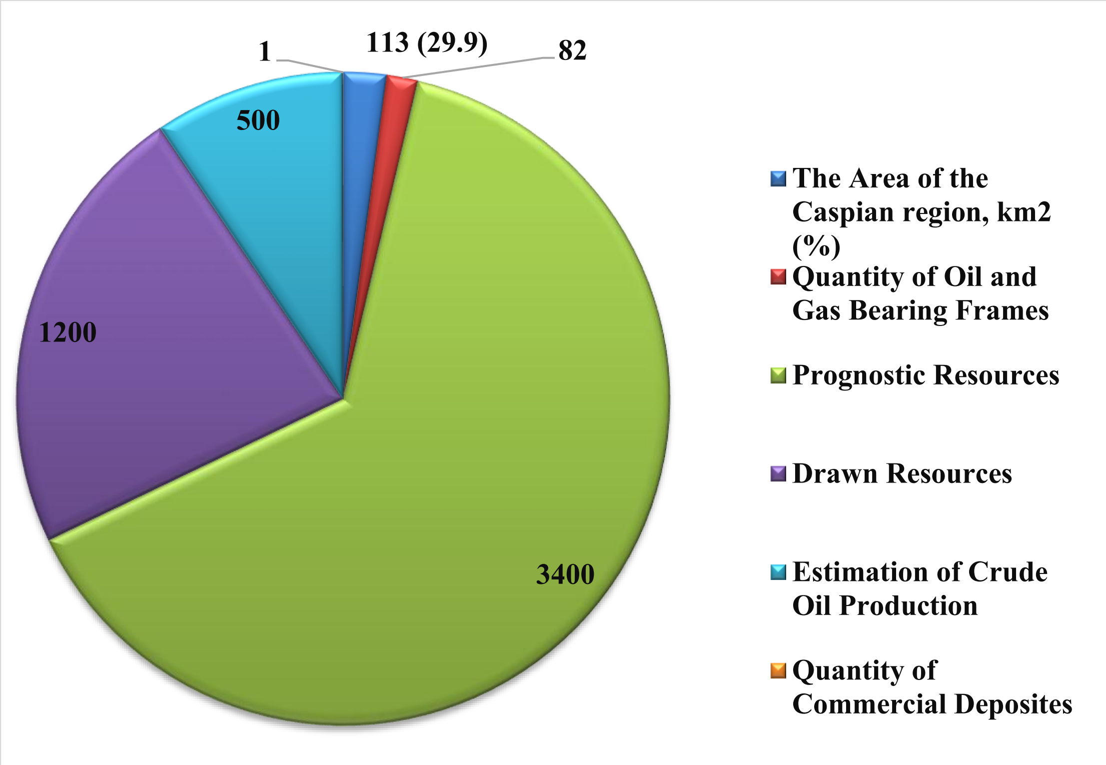
Despite decades of damage, various initiatives have attempted to restore parts of the Aral Sea or mitigate the worst consequences. Before the onset of Glasnost, Soviet authorities often discouraged open discussion of the crisis. In his book titled *"The Environmental Heritage of Soviet Agriculture"*, Bo Libert notes that scientists hoped ambitious canal projects, such as the southward diversion of Siberian rivers, might restore water flows; however, these plans ultimately proved economically and environmentally unviable (Kumar R. , 2002, p. 560). Following the USSR's collapse, the newly independent states signed several agreements to coordinate water releases and energy exchange. In 1992, the *Inter-State Commission for Water Coordination* (ICWC) was established (Bernauer, 2012, p. 233). The World Bank, UNEP, and UNDP developed a three-phase programme involving 19 projects to address water management and support Aral Sea rehabilitation (Kirmani, 1997, p. 12). In 1998, Kazakhstan, Kyrgyzstan, and Uzbekistan signed a tripartite agreement on energy-water exchange, later joined by Tajikistan (Bernauer, 2012, p. 233). These mechanisms attempted to restore seasonal water-energy cooperation.

One of the most successful interventions in the Aral Sea basin has been the construction of the Kokaral (Kok-Aral) Dam, completed in August 2005 (World Bank Group, 2005). Designed to retain water flowing from the Syr Darya into the North (Small) Aral Sea, the dam significantly raised water levels, reduced salinity, enabled a partial revival of fisheries, and brought water closer to some previously abandoned communities. In the years immediately following its completion, fishermen reported daily catches of up to around 100 kilograms, reviving local livelihoods and economic optimism. During his 2010 visit to the region, UN Secretary-General Ban Ki-moon described the Aral Sea crisis as *"one of the worst environmental disasters in the world"* and called for stronger international action (RFE/RL, 2010). International and UN-supported initiatives, including the programme *"Sustaining Livelihoods Affected by the Aral Sea Disaster"* (2012-2015), have contributed to improvements in health, livelihoods, and community resilience, although the overall challenges facing the Aral Sea region remain profound (UNTFHS, 2017).

ECOLOGICAL RICHNESS AND RISING THREATS TO THE CASPIAN SEA

The Caspian Sea constitutes a unique and resource-rich ecosystem encompassing mineral, biological, agroclimatic, balneological, and recreational components. It hosts approximately 1809 species and subspecies of animals, including around 1069 species of freely living invertebrates, 325 species of parasites, and 715 species of vertebrates (Casp Info, 2019). Among these, the Caspian sturgeon is of exceptional global significance. Considered one of the oldest fish species on earth, existing for nearly 200 to 300 million years, its resistance to infections and medicinal relevance highlight its biological and genetic value. The Caspian Sea remains the only basin sustaining a productive sturgeon population, contributing nearly 90 percent of world production (Ibid, 2019). Furthermore, it holds substantial reserves of valuable freshwater fish species such as bream, carp, kutum, mullet, perch, sazan, salmon, strat, and zander.

Figure 1: Kazakhstan's hydrocarbon resources in the Caspian Sea, in mln. tons



Source: This Pie Chart has been drawn based on the views mentioned in the reports (Casp Info, 2019), (ITACAProject, 2019, p. 28).

However, this critical ecosystem faces escalating environmental threats. Rising pollution levels originate from river inflows, industrial and municipal wastewater, and extensive offshore and onshore oil extraction. Increasing sea level, coastal flooding, and oil exploitation have collectively intensified environmental degradation, contributing to air, water, and land pollution, ecological imbalance, and biodiversity loss in the region. Natural pollution sources also exist, notably clay or mud volcanoes, nearly 50 percent of which are located in the Absheron Peninsula, frequently erupting across the South Caspian and shaping coastal formations (Ibid, 2019). Since 1978, the Caspian Sea's water level has risen continuously (AllRefer, 2016). This phenomenon has already submerged over a million hectares of land in Kazakhstan's Atyrau province and threatens numerous settlements and vital oilfields if the trend persists, underscoring the urgent need for environmental and policy interventions.

CLIMATE CHANGE, GLACIER MELT, AND EMERGING WATER VULNERABILITIES IN CENTRAL ASIA

Central Asia's water crisis must also be viewed through the lens of accelerating climate change. The region's dependence on glacial meltwater, its location within arid and semi-arid climatic zones, and its legacy of unsustainable agricultural practices have magnified its exposure to global warming. Over the last several decades, scientific studies have documented a rapid decline in glacial area and volume, rising temperatures, recurring droughts, and hydrological variability - all of which interact with pre-existing institutional weaknesses and socioeconomic vulnerabilities. These changes create a fragile water-energy-food nexus, where climatic shifts amplify water scarcity, undermine agricultural production, and intensify political tensions. For Central Asia's growing population, projected to reach 100 million by 2050 (ERI, 2020), these pressures represent not only environmental threats but fundamental questions of human security. Central Asia receives little rainfall, as surrounding mountain ranges block moist air masses. Consequently, glaciers in the Tien Shan, Pamir and Alay act as critical freshwater 'water towers' that sustain seasonal river flows; melt from snow, glaciers and permafrost together supplies a very large share (often cited as ~60-80%) of runoff in mountain headwaters, though the glacier-only share varies by basin and is substantially lower in many sub-basins. If present warming trends continue, glaciologists predict that the mountain glaciers of Kazakhstan could vanish completely by the end of the century. This decline is not merely an environmental concern; it is a structural shift with far-reaching implications:

- Short-term increases in river discharge may occur as glaciers initially melt faster.
- Long-term decreases in annual runoff will follow as glaciers shrink beyond critical thresholds.
- Seasonal water availability will fluctuate more sharply, with earlier spring peaks and reduced summer flows.

Since glacial meltwater currently contributes roughly 25 per cent of annual river runoff, even minor reductions can severely affect irrigation, hydropower, and drinking-water systems (Chen, 2017, p. 673). This vulnerability is compounded by rapid population growth and increasing irrigation demand. Over the past two decades, research has intensified around glacier degradation in arid regions globally, including Central Asia. Recent reports by the *World Glacier Monitoring Service* and the *World Meteorological Organization* highlight accelerating ice loss, showing that since 1976 glaciers worldwide have lost nearly 9,200 gigatonnes of ice - an amount equivalent to a 25-meter-thick layer covering all of Germany - which has contributed about 18 mm to global sea-level rise (Dussaillant, 2025, p. 1977). The pace of decline has intensified in recent years, with the period from 2022 to 2024 recording the largest three-year glacier mass loss ever observed, while five of the last six years have witnessed the fastest rates of glacial retreat on record (NDTV World, 2025), (WMO, 2025).

For Central Asia, such shifts pose direct threats. Glaciers feeding the Syr Darya and Amu Darya have extensively shrunk by over the past 50 years, and projections estimate 5 and 15 per cent decline in, respectively, Syr Darya and Amu Darya basin water resources by 2050 (Murzagaliyeva, 2023). Given that these basins support millions of people, such reductions will likely intensify competition over water, aggravate rural poverty, and threaten food systems. Climate change interacts with Central Asia's existing water-management weaknesses in ways that threaten regional stability. Major dynamics include:

1. **Rising Demand and Falling Supply:** Central Asia already withdraws more water per capita than almost any other region, yet its economic productivity per unit of water remains among the lowest globally. Population growth, urban expansion, and agricultural expansion further amplify demand. By 2030, irrigation needs could grow by 30 per cent, and by 2050, total water shortages may reach 30 per cent of demand (Skakova, 2024).

2. **Increasing Frequency of Climate Hazards:** Extreme weather events-floods, mudslides, avalanches, and prolonged droughts-have intensified. Between 2000 and 2024, floods caused more than $1 trillion in losses across the CAREC region and droughts, while less frequent, inflicted over $370 billion in damages (ADB, 2024, p. 1). In Tajikistan alone, land degradation in 2019 cost 8-13.5 per cent of national GDP (World Bank Group, 2020, p. viii). The 2020 Sardoba Dam failure in Uzbekistan, triggered by “abnormally strong winds and heavy rains,” displaced tens of thousands and caused nearly US$10 million in crop losses (Geneva Water Hub, 2020).
3. **Vulnerability of Farmers:** As Lilia Burunciuc, the World Bank’s regional director for Central Asia, noted, farmers are already experiencing the brunt of climate change through crop losses, flooding, and drought - threats that endanger both livelihoods and lives.

Kazakhstan faces acute water challenges across multiple fronts. While it possesses considerable surface water resources, these are unevenly distributed, and many are transboundary. More critically, Kazakhstan grapples with declining water quality. The Aral Sea’s collapse and contamination of the Caspian Sea amplify the country’s water stress. The Caspian is heavily polluted due to industrial discharge, oil extraction, and natural mud volcano activity (Oral, 2003, p. 5). The Aral Sea, once vital to Kazakhstan’s environment and economy, has shrunk to less than half its original size, threatening public health and ecological balance. Kazakhstan has made several legal and policy commitments:

- The Constitution (1995) guarantees citizens the right to a healthy environment (Kazakh Constitution A-31, 1995).
- The *Kazakhstan 2030 Strategy* (1996) prioritises development in harmony with the environment.
- In 1998, the President approved a comprehensive environmental protection strategy shaped by the *Ministry of Environmental Protection* and supported by UNDP.
- Major laws include the *Water Code 1993* and the *Law on Social Protection of Citizens Harmed by the Environmental Disaster near the Aral Sea* (1992).

Despite these measures, water quality remains a major concern, particularly in rural areas where access to clean drinking water is inconsistent. Kazakhstan’s temperature has risen significantly, partly due to reduced water moderating effects from the shrinking Aral Sea (Kaser G, 2010). Increased heat, water stress, and altered crop cycles threaten agricultural productivity. Climate change further disrupts the water cycle, increasing evaporation and reducing water retention in soils. Hazards include water-borne diseases following floods, droughts linked to higher temperatures, and degraded water supplies (Usher, 2014). Children, pregnant women, and women responsible for water collection are especially vulnerable (O’Brien, 2008, p. 26).

Tajikistan is the most water-abundant country in Central Asia - but also one of the most vulnerable to climate change because its economy and hydropower systems depend heavily on glacial runoff. The country contains high percentage of Central Asia’s glaciers and plays a critical role in sustaining regional freshwater resources, particularly during the dry season. Major transboundary rivers, most notably the Amu Darya, rely substantially on meltwater originating in Tajikistan’s high mountain glaciers, while reduced glacial mass also affects downstream flows within the Syr Darya basin. Their rapid retreat threatens water availability for agriculture, hydropower generation, rural drinking-water systems, and urban supply (e.g., Dushanbe’s potable water relies on glacier-fed rivers such as the Dushanbinka). Over 70 per cent of Tajikistan’s population lives in rural and mountainous areas, where agriculture is the primary livelihood (Alieva, 2022). Two-thirds of agricultural production depends on irrigation, yet Soviet-era infrastructure is dilapidated, causing salinization, waterlogging, and inefficient water use, especially in cotton cultivation. Climate shocks - including hailstorms, floods, and pest outbreaks - intensify food insecurity. A severe drought in 2000-2001, which halved Amu Darya water availability, led to widespread malnutrition. With projected 5-30 per cent declines in crop yields by 2050, food security remains a central challenge.

Hydropower represents more than 90 per cent of national energy generation, making Tajikistan the world's third-largest hydropower producer relative to national output (Keyser, 2025, p. 1). Seasonal electricity shortages occur when winter demand peaks but water reserves fall, leading to deaths from cold exposure. As water scarcity intensifies, affected communities increasingly resort to unsustainable coping strategies, including deforestation, overgrazing, extraction of river sediments, and cultivation of ecologically fragile slopes. These practices accelerate land degradation and significantly heighten exposure to natural hazards such as landslides and mudflows, thereby reinforcing a self-perpetuating cycle of environmental stress, energy insecurity, and socio-economic vulnerability.

Uzbekistan faces one of the most acute water crises in Central Asia, as persistent inefficiencies and rising demand continue to outpace available freshwater resources despite ongoing irrigation reforms. National water use already exceeds renewable supply, and climate and demand projections indicate that water deficits could reach approximately 7 billion cubic meters by 2030 and up to 15 billion cubic meters by 2050 (World Bank Group, 2023, p. 15). These pressures are driven by declining flows in the Syr Darya and Amu Darya basins - projected to decrease by around 15 per cent and 5 per cent, respectively, by mid-century - alongside expanding domestic, agricultural, and industrial demand. Inadequate access to safe drinking water in many communities heightens vulnerability to bacterial and microbial diseases, while rising temperatures further facilitate the spread of communicable illnesses. With approximately 95 per cent of crop production dependent on irrigation, Uzbekistan's agricultural economy is highly sensitive to water scarcity: irrigated agriculture contributes more than 25 per cent of GDP, accounts for nearly 90 per cent of national water withdrawals, and operates at an average efficiency of only about 40 per cent (Ibid, p. 15). Although roughly 4.3 million hectares are equipped for irrigation, only about 2.6 million hectares were actually irrigated in 2019 due to water shortages and deteriorating infrastructure (Ibid, p. 39). Scenario-based assessments suggest that, without significant improvements, agricultural yields could decline by around 10 per cent by 2050, whereas comprehensive adaptation measures - such as modernised irrigation systems and improved water governance - could raise yields by up to 62 per cent (Ibid, p. 38-39). Uzbekistan's 55 reservoirs, with a combined storage capacity of roughly 20 billion cubic meters, offer important regulatory potential, but many require substantial investment to address safety concerns, sedimentation, and hydropower efficiency; nevertheless, weak regional cooperation continues to constrain coordinated water management, multi-seasonal storage, flood mitigation, and irrigation planning (Ibid, p. 40).

Climate change poses a significant threat to food production throughout Central Asia, with climate-impact assessments by organizations such as the *World Bank* indicating that rising temperatures, increasing precipitation variability, heightened pest and disease pressure, and irrigation water scarcity could substantially reduce agricultural yields by mid-century under many scenarios; given the region's heavy reliance on agriculture for employment and exports, such declines are likely to exert upward pressure on food prices, exacerbate rural unemployment, and contribute to increased migration and social stress. In response to growing concerns about water and cryosphere change, 21 March 2025 marked the inaugural *World Glaciers Day* - celebrated alongside *World Water Day* in New York and Paris to underscore the urgent global challenge of glacier loss and water security - and institutions across Central Asia are increasingly fostering dialogue on transboundary water management (WMO, 2025). Regional initiatives, including international conferences and cooperation among national water agencies, European water diplomacy experts and UN bodies, reflect a willingness to strengthen institutional engagement on shared water and food security challenges.

TRANSBOUNDARY WATER POLITICS, GOVERNANCE FAILURES, AND REGIONAL COOPERATION IN CENTRAL ASIA

Central Asia's two major river systems - the Amu Darya and Syr Darya - cut across national borders, linking upstream and downstream states in a complex hydrological relationship. These rivers originate in the high mountain systems of Kyrgyzstan and Tajikistan and flow into the irrigated plains of Uzbekistan, Turkmenistan, and southern Kazakhstan. Because river flows are seasonal and climate-sensitive, cooperation among riparian states is central to the region's stability. Yet, water governance in Central Asia has long been fraught with conflict, inefficiency, and institutional fragmentation. The Soviet-era system - characterised by strong central planning, hydraulic engineering, and fixed allocation quotas - collapsed abruptly after 1991, leaving behind uncoordinated national systems unable to replicate previous levels of integration. As a result, the region today faces recurring tensions over water releases, energy supply, irrigation rights, and environmental degradation. Climate change has intensified these strains. Declining glacier volumes, more frequent droughts, and unpredictable hydrological cycles have heightened competition, pushing water security to the centre of national development strategies. The water-energy-food nexus has thus emerged as a vital determinant of Central Asia's political and economic future.

During the Soviet period, Central Asia functioned as an integrated water-energy system. Upstream republics (Kyrgyzstan and Tajikistan) released water during summer irrigation seasons, while downstream republics (Uzbekistan, Turkmenistan, and Kazakhstan) compensated this release by supplying fossil fuels - coal, oil, and gas - during the winter (Kocak, 2015, p. 1). This *water-energy barter system* ensured predictable river flows and supported vast irrigated agricultural operations. Moscow's *Ministry of Land Reclamation and Water Resources* (Minvodkhoz) oversaw the entire system (Weinthal, 2006, p. 5). Allocation followed rigid Soviet principles, sometimes referred to as *"Use It or Lose It,"* which rewarded maximum water use and left little room for conservation. After the dissolution of the Soviet Union in 1991, the central authority coordinating water use disappeared; newly independent states prioritized national interests over regional coordination; energy-bartering systems collapsed as countries shifted to market pricing; infrastructure that had once served the collective system suffered from inadequate maintenance; and legal frameworks became fragmented and inconsistent.

As upstream states began to generate hydropower in winter - releasing water during cold seasons rather than during summer irrigation - downstream countries experienced severe water shortages during peak agricultural months. This mismatch continues to generate regional instability. At the micro and meso levels, institutional reforms have been uneven. Kazakhstan and Kyrgyzstan have established *'Water Users' Associations'* (WUAs) intended to improve local irrigation governance (Weinthal, 2006, p. 22). However, these associations remain underfunded, poorly coordinated, and restricted in enforcement capacity. In contrast, Turkmenistan and Uzbekistan retain centralised and state-dominated water-management systems. Without meaningful decentralisation, these systems struggle to incentivise efficient water use, leading to ongoing mismanagement, over-irrigation, and salinisation. At the macro level, regional coordination has been attempted through periodic government agreements, interstate commissions, and donor-supported initiatives. Yet many agreements lack enforceability, consistent monitoring, or long-term financing, producing fragile mechanisms vulnerable to political change.

Central Asia's water politics are shaped by a pronounced upstream-downstream divide that reflects contrasting economic structures and resource dependencies. The downstream states fear that unpredictable winter releases reduce summer water availability and express concern over large upstream dam projects, including the Rogun Dam (on Vakhsh River - if fully completed, will be one of the world's tallest dams) and Kambar-Ata-1 (Naryn River) (Salewicz, 2025, p. 1) (Eurasianet, 2025), (Kocak, 2015, p. 1). These competing priorities have produced recurring political disputes, particularly involving Uzbekistan, traditionally the region's most water-dependent agricultural state, and its upstream neighbors. Climate change and observed glacier retreat in Central Asia are expected to reduce water availability in some basins in the coming decades, potentially contributing to increased seasonal and long-term water stress.

Table 2: Emerging Institutional Mechanisms for Cooperation

Institution/ Mechanism	Year	Participants	Purpose	Major Challenges
Inter-State Commission for Water Coordination (ICWC)	1992	Central Asian States	Allocation and management of transboundary waters of the Syr Darya and Amu Darya based on Soviet-era principles.	Weak enforcement mechanisms, limited data-sharing, inconsistent compliance by member states, and lack of binding authority.
International Fund for the Aral Sea (IFAS)	1993	Central Asian States with International Donors	Coordination of regional environmental protection efforts and mobilization of financial and technical assistance for Aral Sea rehabilitation.	Chronic funding shortages, political disagreements among member states, and limited implementation capacity.
Water-Energy Exchange Agreements	1998-1999	Central Asian States with International Organizations	Rehabilitation of the Aral Sea basin and modernization of regional water governance through phased, multi-project interventions.	Fragmented project outcomes, dependence on external funding, and limited long-term institutional sustainability.
National-Level Water and Environmental Reforms	1990s-Present	Individual Central Asian States	Domestic reforms in water management, irrigation efficiency, and environmental protection (e.g., Kazakhstan's environmental legislation; Uzbekistan's irrigation modernization).	Lack of regional coordination, weak integration with transboundary frameworks, and limited cross-border policy alignment.
Confidence-Building Measures	10 April, 2025	Tashkent	Fostering trust; Encouraging dialogue; Developing shared strategies; and anticipating future disputes.	Persistent mistrust and historical grievances; Weak institutional frameworks; and Limited transparency and data-sharing.

Source: (Bernauer, 2012, p. 233); (Kirmani, 1997, p. 12).

OBSTACLES AND PATHWAYS TO EFFECTIVE COOPERATION

Effective and sustained water cooperation in Central Asia continues to be constrained by a range of systemic and structural challenges. Deep-seated mistrust among riparian states - rooted in historical grievances and strategic competition - undermines collective action, while fragmented legal frameworks and overlapping institutional mandates weaken governance coherence. These difficulties are compounded by inadequate transboundary data-sharing and monitoring mechanisms, which limit transparency and informed decision-making. Furthermore, pronounced upstream-downstream asymmetries in water and energy requirements generate conflicting national priorities, often reinforced by economic nationalism and unilateral infrastructure projects. Political sensitivities surrounding dam construction, water pricing, and sovereignty further complicate negotiations, while aging and inefficient water infrastructure contributes to significant transmission losses. These institutional and political obstacles are intensified by climate variability, accelerating desertification, and the steady decline of glacial reserves, collectively heightening water insecurity across the region.

Addressing these challenges requires a coordinated regional shift toward integrated and adaptive water governance frameworks. Central to this transition is the adoption of *Integrated Water Resources Management* (IWRM), supported by transparent and institutionalized transboundary data-sharing systems, updated legal regimes, and credible dispute-resolution mechanisms. Revitalizing water-energy exchange arrangements could help reconcile upstream and downstream interests, while targeted investments in modern irrigation technologies - such as drip and precision systems - would enhance efficiency and reduce losses. Complementary measures include expanding water storage capacity, improving reservoir operations, strengthening local institutions such as *Water User Associations* (WUAs), and promoting climate-resilient cropping patterns. The integration of digital monitoring tools for irrigation and drainage, alongside afforestation and land rehabilitation initiatives, would further mitigate environmental degradation. Collectively, these measures can enhance resilience to droughts, floods, and climate shocks, while laying the foundation for durable regional cooperation and long-term stability.

CONCLUSION

Water has emerged as the defining strategic resource shaping Central Asia’s present challenges and future trajectory. Accelerating climate change, growing demographic pressures, and competing sectoral demands have transformed water from a technical resource-management concern into a central issue of economic stability, environmental sustainability, and national security. In this context, sustainable water governance is no longer optional but an urgent regional imperative. Addressing contemporary water challenges requires a multidimensional approach that integrates technological innovation, governance reform, strengthened regional cooperation, environmental restoration, and sustained investment in climate-resilient agricultural systems. Recognising water as a cornerstone of national and human security is essential for aligning domestic priorities with broader regional objectives.

The legacy of the Aral Sea crisis stands as a powerful reminder of the costs of fragmented management and short-term policymaking, while also demonstrating that partial ecological recovery is possible when political commitment, scientific expertise, and financial resources converge. Moving forward, Central Asia’s ability to secure its water future will depend on a decisive shift from competitive, unilateral approaches toward cooperative and integrated regional management. By reframing water as a shared asset rather than a source of contention, the region can lay the foundation for long-term resilience, shared prosperity, and enduring regional stability.

DISCLOSURE OF INTEREST

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