Aral Sea Ecological Governance: An Important Pathway for Deepening Scientific and Technological Cooperation with Central Asia (Postprint)

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Abstract

In September 2022, during President Xi Jinping's first overseas visit since the outbreak of the COVID-19 pandemic, the Joint Statement of the People's Republic of China and the Republic of Uzbekistan specifically noted that "China welcomes the adoption by the UN General Assembly of the special resolution initiated by Uzbekistan on declaring the Aral Sea region an ecological innovation and technology zone, which will help save the Aral Sea, restore and improve the surrounding environment, protect natural resources, and enhance the quality of life of the local population," and that "both sides are willing to actively promote synergy between the Global Development Initiative and projects under the UN Trust Fund for Human Security in the Aral Sea Region aimed at improving the ecological, economic, and social environment of the Aral Sea area." Against this backdrop, this article reviews the current status of the Aral Sea and the causes and impacts of its ecological crisis, and analyzes and summarizes the necessity and significance of China's participation in the ecological governance of the Aral Sea. The article argues that China possesses favorable conditions for participating in the ecological governance of the Aral Sea, including policy and institutional frameworks, financial and human resources, and a foundation for project cooperation. It recommends that, under the principles of win-win cooperation, coordinated planning, "acting where appropriate" and "refraining from acting where inappropriate," China should start by exploring scientific issues and improving people's livelihoods, focusing on desertification control, soil and water conservation, modern agricultural technology, and the promotion and utilization of new energy. By leveraging Chinese wisdom, Chinese experience, and Chinese strength to participate in the ecological governance of the Aral Sea and promote its green development, China can effectively facilitate and deepen scientific and technological cooperation with Central Asia, providing scientific

and technological support for the construction of a China-Central Asia community with a shared future and even the high-quality development of the Belt and Road Initiative.

Full Text

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Abstract

In September 2022, President Xi Jinping made his first overseas visit since the COVID-19 pandemic. In the subsequent Joint Statement between the People's Republic of China and the Republic of Uzbekistan, China specifically welcomed the adoption by the UN General Assembly of Uzbekistan's "Special Resolution on Declaring the Aral Sea Region a Zone of Ecological Innovation and Technology," noting that this resolution would help save the Aral Sea, restore and improve the surrounding environment, protect natural resources, and enhance the quality of life for regional peoples. The statement also expressed willingness to actively promote synergy between the Global Development Initiative and projects under the UN Trust Fund for Human Security in the Aral Sea Region aimed at improving the ecological, economic, and social environment. Against this backdrop, this paper examines the current state of the Aral Sea and the causes and impacts of its ecological crisis, analyzing and summarizing the necessity and significance of China's participation in Aral Sea ecological governance. The authors argue that China possesses favorable conditions for participating in Aral Sea governance, including policy and institutional support, financial and human resources, and a foundation of project cooperation. Under the principles of win-win cooperation, overall coordination, and strategic selectivity ("doing something while refraining from others"), China should approach Aral Sea governance by exploring scientific questions and improving livelihoods. Focusing on desertification control, water and soil conservation, modern agricultural technology, and new energy promotion and utilization, China can apply its wisdom, experience, and capabilities to participate in Aral Sea ecological governance, promote green development in the region, effectively deepen scientific and technological cooperation with Central Asia, and provide scientific and technological support for building a China-Central Asia community with a shared future and for the high-quality development of the Belt and Road Initiative.

Keywords: Aral Sea, Central Asia, ecological governance, science and technology, international cooperation

Current Status of the Aral Sea

The Aral Sea is located in the northern part of the Central Asian desert zone, in the Turan Lowland at the border between Uzbekistan and Kazakhstan (43°24 N—46°56 N, 58°12 E—61°59 E). Its water supply primarily comes from the Amu Darya and Syr Darya rivers, which originate from the southwestern slopes of the Pamir Plateau (in Tajikistan) and the western Tien Shan Mountains (in Kyrgyzstan), respectively [1]. The Aral Sea basin formed by these two rivers lies in the heart of the Eurasian continent, covering most of Central Asia and northern Afghanistan, with its eastern border adjacent to China [2].

Research indicates that from the late 17th century to the 1960s, the water level, surface area, and volume of the modern Aral Sea remained relatively stable despite fluctuations, with a minimum water level drop of only about 4 m, an average water level of approximately 53.4 m, an average surface area of about 6.89$×10^{4}$ km^2, and an average volume of about 1,083 km^3. However, starting in 1961, due to a sharp reduction in water supply, the Aral Sea began a process of continuous and rapid shrinkage. Around 1986, the sea separated into the Large and Small Aral Seas (south and north), and by approximately 2007, the Large Aral Sea further divided into eastern and western parts [Figure 1: see original paper] [3]. This rapid shrinkage reduced the sea's volume to 1/15 of its original size over about 60 years from the 1960s, with an average water level drop of 29 m, salinity reaching 150–300 g/L, and coastlines retreating hundreds of kilometers [Figure 2: see original paper] [4]. In just one generation, what was once the world's fourth-largest lake has nearly completely dried up, forming a new desert landscape called "Aralkum" (Aral Sea Desert) covering approximately 5$×10^{4}$ km^2 on the former lakebed, which generates about 1$×10^{8}$ tons of toxic salt dust annually.

The desiccation of the Aral Sea represents an unprecedented ecological disaster in human history. The resulting desertification, salinization, and biodiversity loss have severely impacted the ecological environment, socio-economic conditions, and public health of Central Asian countries, with effects spreading to neighboring regions. The Aral Sea ecological crisis has become a major concern for Central Asian nations and the international community, representing an unavoidable challenge for building a "China-Central Asia community with a shared future" and a "Green Silk Road," as well as for implementing the Global Development Initiative. Using Aral Sea ecological governance as a starting point to continuously expand and deepen multi-domain scientific and technological cooperation with Central Asia will facilitate the achievement of these goals.

Causes of the Aral Sea Ecological Crisis

The rapid shrinkage of the Aral Sea results from the combined effects of natural and human factors, with human overexploitation of its tributary water resources being the dominant and direct cause. Beginning in the 1950s, when the Soviet Union decided to develop water and land resources on a large scale in the Aral Sea basin to expand agriculture, the significant drop in water level has closely accompanied the construction and operation of major water conservancy facilities. It was not until 1990 that the Soviet government officially acknowledged the ecological disaster in the Aral Sea region [Figure 3: see original paper].

Scholarly research confirms this correlation: to meet the water demands of newly developed irrigated lands, the total irrigated area in the Aral Sea basin increased from approximately 4$×10^{4}$ km^2 to 7.6$×10^{4}$ km^2 between 1960 and 1990 [7], making it the Soviet Union's largest cotton production and agricultural export base, as well as an important production center for fruits, vegetables, and grapes. Several large-scale water conservancy facilities were constructed and put into operation at unprecedented speeds, including the Karakum Canal on the Amu Darya (diverting over 19 km^3 annually), the Karshi Canal (3.3–5.25 km^3 annually), and the Fergana Canal on the Syr Darya (2.22 km^3 annually), along with the Right Bank Canal (74 m^3/s) and Left Bank Canal (500 m^3/s). By the time of the Soviet Union's dissolution, the total reservoir capacity in the Aral Sea basin had reached 60 km^3. Such massive water diversions meant that the Aral Sea had not received perennial runoff since the 1970s [8]. The actual average annual inflow to the Aral Sea was 56 km^3 in 1960, but this plummeted to 3.5–7.6 km^3 by 1981–1998, with some dry years seeing virtually no inflow from either river [9]. In 2001–2002, artificial lakes and reservoirs were built in Karakalpakstan to intercept runoff flowing to the Aral Sea, after which water from the Amu Darya no longer reached the sea, with only drainage channels and groundwater providing minimal replenishment. By this point, the runoff from the Amu Darya and Syr Darya—the Aral Sea's primary water sources—had been essentially fully exploited.

Impacts of the Aral Sea Ecological Crisis

1. Severe Damage to Regional Ecological Environment

First, reduced runoff and rapid desiccation caused delta degradation and biodiversity loss. Inflow to the Aral Sea delta decreased to 6.7 km^3/year in the 1960s–1970s, dropping further to 0.7 km^3/year by 1981–1986. The lake area in the Syr Darya delta shrank from 1,600 km^2 to about 240 km^2 today, while grassland and wetland areas contracted and cracked soil, sandy soil, and secondary salinized land expanded. Bird diversity decreased by approximately 70 species [10]. As water area shrank and levels dropped, ecosystems in and around the water body were destroyed, causing biodiversity loss. Twelve mammal species, 26 bird species, and 11 plant species are now endangered [11], while once-abundant

bream, carp, and other freshwater fish have drastically declined or disappeared [12].

Second, desertification has accelerated, creating new desert landscapes. As the Aral Sea retreated, large areas of erosion-prone bare land—including saline soil and salt crust—were exposed, intensifying desertification and wind/salt-dust activity in the Aral Sea basin. Saline soil and other bare land types expanded rapidly from 5.24% and 11.83% in 1977 to 28.86% and 38.99% in 2015, respectively. Against this backdrop, desertification accelerated, with the dried portion of the Aral Sea bed continuously expanding. The core area has now completely transformed into a typical desert landscape [13], forming the new "Aralkum" desert covering about 5$×10^{4}$ km^2 [2].

Third, the dried Aral Sea bed has become a new source of salt and dust storms. With intensifying desertification, the formation of the Aralkum Desert over the last two decades of the 20th century created a massive open salt layer on the dried lake bottom, becoming a powerful source for sand/salt dust storm transport and affecting surrounding regions [14]. It is estimated that when the Aral Sea completely dries up, the total amount of salt precipitated will reach 1$×10^{10}$ tons. The resulting salt dust storms could be blown to glaciers in the Tien Shan and Pamir Mountains, accelerating their melting [15]. These glaciers are among the most important sources of water resources in Central Asia, and their accelerated melting would cause incalculable ecological disasters in the already water-scarce and arid regions of Asia and Europe.

2. Massive Shock to Regional Socio-Economic Development

First, the fishing industry has collapsed. Until the 1960s, the Aral Sea region was one of Central Asia's largest and the Soviet Union's most important fishing production bases, with annual catches reaching 4$×10^{4}$ tons—accounting for 1/6 of the Soviet Union's total catch. Fishing production even constituted 80% of the economic output in Moynaq district of the Amu Darya delta, employing over 30,000 people. In 1958, fish catches in this area reached 245,000 centners (24.5$×10^{6}$ kg) [16]. However, as the Aral Sea water body and delta wetlands rapidly shrank, fish resources in the Large Aral Sea completely disappeared, and fishing in the region effectively ceased since the 1980s [17].

Second, crop production has declined. Between 1981 and 2009, cotton and rice production in the region decreased by 30% and 84%, respectively, due to water shortages [16]. This dealt a severe blow to the local economy, which relied primarily on agriculture, animal husbandry, and fisheries, causing large numbers of people to lose their livelihoods.

3. Direct and Indirect Health Impacts on Regional Residents

With the large-scale land development of the 1950s, irrigated agriculture in Central Asia developed rapidly. To increase yields, large quantities of chemical fertilizers and pesticides were applied. These substances, along with other

harmful production and living materials, entered water bodies in the Aral Sea region through surface and groundwater runoff, contaminating soil and groundwater. Toxic substances and salts accumulated in the lake were then dispersed by wind and sand after the lake bed dried up, damaging the health of millions of residents. In Karakalpakstan on the South Aral Sea coast, the incidence of intestinal infections is three times the average for Commonwealth of Independent States countries [16], while rates of stomach cancer, tuberculosis, viral hepatitis, allergies, and typhoid fever rank highest among Soviet republics. The neonatal mortality rate reached 62 per 1,000 people in 1984–1985, ranking first in Uzbekistan [18]. Research shows that among the adult population in the Aral Sea region, respiratory diseases increased from 9,467 per 100,000 people in 1991 to 10,744 per 100,000 in 2016. In Kazakhstan's Aral Sea-affected regions of Kazaly and Aralsk, malignant tumor cases per 100,000 people increased by 61.9% between 2004 and 2013, the highest in the country [19].

The Necessity of Scientific and Technological Cooperation for Aral Sea Governance

Responding to Regional and International Calls and Demonstrating Major Country Responsibility

The ecological and social problems of desertification, salinization, and poverty resulting from the rapid drying of the Aral Sea have increasingly attracted international attention, becoming what scholars call an "ecological hotspot" [18]. In September 1995, leaders of the five Central Asian countries signed the "Aral Sea Declaration" in Nukus, Uzbekistan, reaffirming the negative impacts of water shortage and quality deterioration on land, vegetation, ecology, fisheries, and the lives and health of 35 million basin residents. The declaration called for establishing an international convention for sustainable development of the Aral Sea basin and requested assistance from the UN Development Programme and other agencies [20]. In September 2017, Uzbekistan's President Mirziyoyev addressed the UN General Assembly, urging the international community to address the ecological problems of the drying Aral Sea and to mobilize forces to mitigate its impacts. International organizations and countries, including the UN Development Programme, the European Union, the Global Environment Facility, Germany, and Japan, have actively participated in Aral Sea governance through projects or direct funding [21].

In April 2010 and June 2017, then UN Secretaries-General Ban Ki-moon and Guterres visited the Aral Sea, describing it as "one of the world's worst ecological disasters" [22] and stating that the international community should learn from this tragedy and mobilize governments, enterprises, and civil society to implement the Paris Agreement to ensure such tragedies are not repeated [23]. On May 18, 2021, the UN General Assembly unanimously adopted a special resolution proposed by Uzbekistan declaring the Aral Sea region a zone of eco-

logical innovation and technology [24]. The resolution supports measures aimed at improving the ecological, social, economic, and demographic conditions of the Aral Sea region.

Since the 18th National Congress of the Communist Party of China, under the guidance of President Xi Jinping's diplomatic philosophy of "amity, sincerity, mutual benefit, and inclusiveness" for neighboring countries, China has actively promoted international agendas concerning human destiny, such as climate change response and maintenance of the international free trade system, and is growing into a firm, confident, and responsible major country. Therefore, China should not be absent from the Aral Sea ecological improvement, a concern shared by regional and international society. Active participation in Aral Sea governance will help enhance China's image as a responsible major country and become a trusted partner for neighboring countries.

Serving National Diplomatic Strategy and Expanding China's "Circle of Friends"

Adhering to the purpose of safeguarding world peace and promoting common development to build a community with a shared future for mankind, and deepening diplomatic layouts to forge global partnerships are important components of Xi Jinping's diplomatic thought and focal points of China's diplomatic strategy. Currently, Western-led groups are implementing containment strategies against China globally and blockade policies in science and technology to slow China's development pace. "Science has no borders" has become an empty slogan under the blatant trampling of Western countries. In this context, China should continue to uphold the concept of "science without borders" and building a community with a shared future for mankind, actively carry out targeted scientific and technological cooperation to meet the technological needs of Aral Sea basin countries in solving Aral Sea problems, and strengthen interest connections with regional countries through scientific and technological cooperation to support diplomatic strategy implementation. This will also help China break through blockades, expand its "circle of friends," forge global partnerships, and create a stable and secure development environment for achieving its second centenary goal.

Building a "Silk Road Community with a Shared Future" and Advancing the "Green Silk Road"

Central Asian countries, located in the heart of the Eurasian continent and connected to China by mountains and rivers, are both a geopolitical focus and a key node area of the Silk Road Economic Belt. Except for Turkmenistan, all regional countries are members of the Shanghai Cooperation Organization (SCO). In September 2021, at the 21st meeting of the SCO Council of Heads of State, President Xi Jinping proposed "building a closer SCO community with a shared future" and announced that "China will establish the China-SCO Economic and Trade Institute, launch the second phase of special loans for jointly building the

Belt and Road, focusing on supporting modern connectivity, infrastructure construction, and green, low-carbon, sustainable development projects." Central Asia is an important component of the Silk Road Economic Belt, and deepening scientific and technological cooperation with Central Asia is a necessary path for building a China-Central Asia community with a shared future and further developing the "Silk Road Community with a Shared Future."

Sharing the Chinese Model and Experience to Establish China's Scientific and Technological Reputation

Since the 1990s, Central Asian countries and the international community have made many efforts to improve the Aral Sea ecological environment and mitigate its impacts, achieving some results, such as maintaining relative stability in the Small Aral Sea and partial recovery of fishery resources. However, overall, due to constraints from technical means, economic development levels, and other factors, the Aral Sea problem has not been fundamentally solved, and trends of shrinking sea area, deteriorating ecological environment, and declining regional economy remain uncurbed.

In 2015, China's fifth national desertification and sandification monitoring results showed that China was the first to achieve the UN's Sustainable Development Goal of "zero growth of desertified land by 2030." At the 17th session of the UN Commission on Sustainable Development, it was noted that China's desertification control is world-leading; the secretariat of the UN Convention to Combat Desertification explicitly stated that "the world looks to China for desertification control" [25]. Successful examples such as the Kubuqi Desert control and the Taklimakan Desert Highway protection project have made China's comprehensive management concept of "prevention, control, and utilization" in desertification control a "Chinese solution" to desertification. Additionally, China has achieved remarkable results in watershed comprehensive management, particularly in the Tarim River Basin, which, like Central Asia, is located in an arid zone and is one of China's driest and most ecologically fragile regions. Since the State Council approved the "Tarim River Basin Recent Comprehensive Management Plan Report" in June 2001, over 20 years of implementing water-saving transformation, groundwater development and utilization, river course management, control hub construction, and watershed water resource scheduling management have alleviated severe ecological degradation in the basin, effectively protecting and restoring vegetation in the upper and middle reaches of the Tarim River main stream and initially improving the ecological environment in the lower reaches [26-28].

The Aral Sea basin is located in the Central Asian arid belt, with water shortages and fragile natural environments in its middle and lower reaches. Desertification caused by the drying of the Aral Sea is the main cause of regional ecological and humanitarian disasters. By participating in Aral Sea ecological governance, China can apply its successful experience in combating desertification, salinization, and other land degradation, as well as its watershed comprehen-

sive management concepts of rational utilization, conservation, protection, and management, to local ecological governance. This can also help domestic enterprises expand internationally, allowing the complete chain of China's ecological governance model—from concepts, standards, and technologies to products and management models—to benefit the world, establishing China's scientific and technological reputation through Chinese wisdom, experience, and strength.

Preventing the Spread of Aral Sea Ecological Disaster Impacts Beyond the Region and Effectively Reducing Potential Damage

The disasters caused by the drying of the Aral Sea have not only directly or indirectly negatively impacted the region's ecology, socio-economy, and resident health, but the toxic particles generated by salt dust storms have spread to areas hundreds or even thousands of kilometers away. Research shows that salt dust particles smaller than 16 m in salt dust storms can travel 9$\times10^{\{2\}-3.2\times10}\{3\}$ km [29], while cracked soil, cracked-pattern soil, and saline soil in the dried lake bed are the main sources of salt dust [30]. Studies in the 1970s already tracked toxic salt dust to the fertile Fergana Valley over 1,000 km to the southeast, as well as to the Black Sea coast of Georgia and the Arctic coast of the Soviet Union [31]. In recent years, scholars using remote sensing and other technologies to simulate salt dust diffusion from the Aral Sea have found increasing dust activity in the region [32,33], with typical Aral Sea dust even discovered in the Greenland ice sheet, Norway, and Belarus—thousands of kilometers from Central Asia [34], spreading northeast to the Russian Siberian Plain, southward covering the Iranian Plateau, and potentially even affecting the Junggar Basin in western China [35].

Based on this trend, as the water body continues to shrink and dried areas and desertified regions further expand, the possibility that toxic salt dust, aerosols, and other substances originating from the dried Aral Sea bottom could affect western China and other regions under suitable climate, terrain, and geomorphological conditions is real. Therefore, actively participating in comprehensive Aral Sea ecological governance can both help Central Asian countries improve their ecological environment and prevent the ecological negative impacts of the Aral Sea crisis from spreading beyond the region.

Foundation for Aral Sea Ecological Governance Cooperation

Policy and Institutional Support

Since President Xi Jinping first proposed the Belt and Road Initiative in September 2013, China has continuously increased support for the initiative, promoting its high-quality development, including the concept of "Green Belt and Road" construction, and advancing the building of a community with a shared future

for mankind. In May 2010, the first SCO member states' science and technology ministers meeting was held in Beijing, where parties agreed to carry out multilateral scientific and technological cooperation within the SCO framework [36]. This meeting subsequently evolved into a regular ministerial-level meeting held every two years. On April 8, 2022, the sixth SCO science and technology ministers meeting was held in Tashkent, adopting the "Action Plan for Scientific and Technological Cooperation in Priority Areas of SCO Member States (2022–2025)," the "Implementation Mechanism for SCO Multilateral Joint Scientific Research and Innovation Projects," and the "Cooperation Plan for Artificial Intelligence Development Among SCO Member States' Authorized Agencies" [37], providing institutional and action-based support for future scientific and technological cooperation among SCO members.

Additionally, in May 2017, the former Ministry of Environmental Protection issued the "Belt and Road Ecological and Environmental Protection Cooperation Plan" [38]; in September 2017, the Belt and Road desertification control cooperation mechanism was officially launched to promote green Belt and Road construction [39]. The "China+Central Asia Five Countries" Foreign Ministers' Joint Statement in June 2022 made ecological, environmental, water resource, and green development cooperation important components, emphasizing support for international cooperation in multiple fields including saving the Aral Sea [40]. In September 2022, during President Xi Jinping's visit to Uzbekistan for the SCO summit, the China-Uzbekistan joint statement specifically welcomed Uzbekistan's Aral Sea initiative and expressed willingness to actively promote synergy between the Global Development Initiative and projects under the UN Trust Fund for Human Security in the Aral Sea Region [41].

The China-Central Asia Summit held in Xi'an on May 18–19, 2023, marked the establishment of a high-level meeting mechanism between China and the five Central Asian countries. The "Xi'an Declaration of the China-Central Asia Summit" explicitly stated that "all parties are willing to promote technical and talent exchanges and cooperation in desertified land and saline-alkali land management and development, water-saving irrigation, pest control, animal husbandry, and veterinary medicine to enhance the sustainable development resilience of agricultural systems," and that "all parties reaffirm their willingness to work together to ensure food security under climate change conditions, noting the importance of conducting agriculture in a more ecological manner that protects biodiversity and rationally utilizes water and land resources," as well as "strengthening cooperation in renewable energy such as hydropower, solar energy, and wind energy, deepening peaceful use of nuclear energy, implementing green technology and clean energy projects, and practicing innovative, coordinated, green, open, and shared development concepts." These contents are closely related to Aral Sea ecological governance and will serve as important guidelines for China's future scientific and technological cooperation with Central Asia.

Human and Financial Resources Support

After decades of rapid development since reform and opening up, China's GDP has risen to second in the world, with significantly enhanced comprehensive national strength. In 2020, China's GDP exceeded 100 trillion yuan for the first time, reaching 101.3567 trillion yuan (approximately US$14.72 trillion), ranking second globally. In 2016, China's total research and experimental development expenditure reached 1.56767 trillion yuan (approximately US$234 billion), second only to the United States and ranking second in the world. During the same period, China's total number of R&D personnel exceeded 240,000, ranking first in the world. Central Asian countries not only lag far behind China in these indicators but also fall below world averages [42]. According to statistics from China's Ministry of Commerce, as of the end of July 2021, China's total investment in various SCO member countries exceeded US$70 billion, with Chinese enterprises contracting projects worth over US$290 billion [43]. In January 2022, at the video summit commemorating the 30th anniversary of diplomatic relations between China and the five Central Asian countries, President Xi Jinping announced that "China is willing to continue providing vaccines and anti-epidemic materials to Central Asian countries, increasing joint production and technology transfer of vaccines and specific medicines," that "in 2022, China will provide another 50 million doses of vaccine aid to Central Asian countries and establish traditional medicine centers in countries in need," that "in the next five years, China plans to provide 1,200 Chinese government scholarships to the five Central Asian countries," that "in the next three years, China will provide US$500 million in gratuitous aid to Central Asian countries for livelihood project construction," and that "China will provide 5,000 training places to help countries cultivate professionals in health, poverty reduction, connectivity, and information technology, enhancing endogenous development momentum." These facts demonstrate that China now has the capacity to provide external support in terms of funding, technology, and human resources.

Project Cooperation Foundation

In recent years, with support from the Ministry of Science and Technology, the Chinese Academy of Sciences, local science and technology departments, and international scientific organizations, Chinese research institutions and universities have carried out scientific research activities in the Aral Sea region, including ecological environment monitoring, demonstration of salt-tolerant plants, and efficient agricultural water-saving technologies, achieving some results. Chinese Academy of Sciences institutions have also established the "Alliance for Monitoring and Management of Central Asian Ecosystems Under Climate Change Impacts" with national research institutions in Central Asian countries, signed the "Urumqi Declaration—China-Uzbekistan Innovation Cooperation: Ecological Restoration of the Aral Sea Region," jointly issued the "Green Aral Sea International Science Initiative," established the "ANSO Green Aral Sea Science Initiative Project Implementation Office" under the Alliance of International

Science Organizations, regularly publish the "SCO Science and Technology Information Dynamic Monitoring Express" covering Central Asian countries, and support the cultivation of young scientific and technological talents in Central Asia through multiple channels. These initiatives aim to build an international scientific and technological cooperation platform, cultivate Central Asian scientific and technological talents, and disseminate scientific and technological developments in Central Asia. Most importantly, these cooperative projects have established stable cooperative relationships with research institutions under Kazakhstan's Ministry of Agriculture, institutions under the Uzbekistan Academy of Sciences, the Uzbekistan Presidential Center for Innovative Development of the Aral Sea Region, and universities in both Kazakhstan and Uzbekistan, laying a solid foundation for further deepening cooperation in this field.

Cooperation Principles for Aral Sea Ecological Governance

1. Adhere to Win-Win Cooperation

Participation in Aral Sea governance scientific and technological cooperation should follow the principle of mutual benefit and win-win outcomes. That is, the output of experience, technology, and capital should both meet regional needs and align with China's geopolitical, science and technology diplomacy, and technology export needs. Cooperation areas should satisfy both parties' demands, and results should achieve mutual benefits. Cooperation that pursues unilateral interests is unsustainable and will negatively affect cooperation in other fields.

2. Strategic Selectivity: "Doing Something While Refraining from Others"

In cooperation, attention should be paid to strategic selectivity. One major cause of the Aral Sea ecological disaster is the irrational use of water resources, and transboundary water issues are among the most sensitive focal points for Central Asian countries. Since independence, Central Asian countries have adopted a series of measures to solve transboundary water resource utilization problems in the Aral Sea basin, including integrated watershed management and bilateral and multilateral water allocation agreements. However, due to complex national interests and geopolitical factors, almost all signed memorandums and agreements have not been effectively implemented [44], and water resource allocation of international rivers including the Amu Darya and Syr Darya remains a key destabilizing factor concerning major regional interests. Therefore, China should refrain from involvement in unresolved potential conflict areas such as transboundary river hydropower development, water allocation, and nuclear power plant construction to avoid causing international disputes that would affect cooperation effectiveness.

3. Emphasize Overall Coordination

Although some Chinese research institutions have conducted work on Aral Sea ecological environment governance and achieved certain results, compared with Europe and the United States, China's activities in this field suffer from late start, insufficient investment, small scale, lack of overall coordination, and insufficient sustainability. Therefore, future participation in Aral Sea ecological governance should advocate and emphasize the principle of overall coordination, mainly in two aspects: First, cooperative projects should have top-level design during the planning stage, coordinating research demonstration and promotion, multi-field (multi-disciplinary) collaboration, and the connection between research institutions and enterprises; second, project scales should be coordinated, requiring both large-scale scientific plans with long-term investment and slow results, as well as "small but beautiful" projects that directly address livelihoods, are down-to-earth, and solve urgent problems. These two approaches complement each other and can proceed in parallel.

Cooperation Programs for Aral Sea Ecological Environment Governance

Scientific Research Areas

1. Mechanism of Salt Dust Output from the Aral Sea Desert and Accurate Prediction of Diffusion Directions. The area of salt dust release in the Aral Sea basin and surrounding regions expands annually, with total annual salt dust release reaching hundreds of millions of tons, becoming the most direct factor in the spread of the Aral Sea ecological disaster. Current research is mostly based on remote sensing and modeling methods. Future work still requires multi-country and multi-institution collaboration to establish monitoring networks and enrich measured data. Based on this foundation, more accurate revelations of toxic salt dust propagation pathways, distances, impact ranges, and development processes can help predict hazard scopes in advance, enabling early warning and prevention for potentially affected areas.

2. Research on Desertification Control Measures and Salt Dust Source Management in Dried Lake Basins. Researching and developing practical biological, mechanical, and chemical dust and sand fixation materials and their utilization technologies is an urgent scientific and technical problem. Key directions include breeding, planting, and utilizing plant species adapted to salinized land in the Aral Sea region, and studying the survival and growth mechanisms of residual plants on the Aral Sea beaches and dried lake bottom. Research results in this field can be effectively applied to desertification control on the dried lake bottom and the restoration and reuse of degraded land in the Aral Sea coastal areas affected by desertification and salinization.

3. Monitoring, Research, and Assessment of the Impacts of Aral Sea

Desiccation Under Climate Change on Regional and Global Climate, Ecological Environment, Economy, Society, and Human Health. Currently, there is consensus that the formation of a new salt dust source in the dried Aral Sea basin has caused severe negative impacts on the climate environment, ecosystems, socio-economy, and human health of surrounding regions. However, scientific principles, degrees, pathology, and countermeasures regarding whether dust clouds at higher altitudes and longer distances affect global climate, and whether they act on ecosystems and human health at deeper levels, still require further research.

Livelihood and Development Areas

In 2017, the Uzbekistan government issued the "National Program for the Development of the Aral Sea Region for 2017–2021" [45], and in early 2022 released the "Development Strategy of New Uzbekistan for 2022–2026" [46]. The main components of these programs include afforestation and sand fixation, improving people's living standards, developing infrastructure, ecological tourism and efficient agriculture, and improving clean drinking water supply and water resource management levels—closely related to people's livelihoods and economic and social development. In response to regional countries' needs in improving Aral Sea livelihoods and economic and social development, the following areas of scientific and technological cooperation are recommended:

1. Establishment and Utilization of Windbreak and Sand Fixation Vegetation. China's "prevention, control, and utilization" model in desertification control is a proven successful path that can be applied to desertification control on the dried Aral Sea lake bed. By selecting native and Chinese salt- and drought-tolerant forage, medicinal, and edible plant varieties for the prevention and control of degraded land on the dried lake bed, ecological protection measures such as sand fixation and vegetation restoration can be combined with the development of plants' economic value utilization to achieve harmonious parallel development of protection and utilization.

2. Water Quality Monitoring and Improvement. Due to excessive fertilizer and pesticide use causing groundwater pollution, and the accumulation of large amounts of toxic substances in the dried lake bed, strong winds blow toxic dust from the lake bottom into rivers, contaminating river water. Combined with funding and technology limitations, drinking water pollution in the Aral Sea region has become a long-term difficult problem to solve. Unclean drinking water can cause various diseases in human digestive organs and blood, posing serious threats to people's health. Therefore, improving drinking water quality for regional residents is an urgent livelihood issue.

3. Utilization of Modern Agricultural Technology. One fundamental cause of Aral Sea desiccation is the excessive and extensive utilization of water resources from its tributary rivers. Basin countries are also actively promoting water-saving irrigation technologies. For example, Uzbekistan plans to increase

the coverage of water-saving irrigation technology from 0.308×10^{4} km^{2} to 1.1×10^{4} km^{2} by 2023, while Kazakhstan intends to increase this value from 0.2×10^{4} km^{2} to 0.42×10^{4} km^{2} by 2025 [47]. Northwest China is extremely similar to Central Asia in terms of natural environment and also faces relative water shortages. After decades of scientific and technological 攻关, China has made significant progress in modern agricultural technologies including drought-resistant crop breeding, integrated water resource management, water-saving irrigation (including under-film drip irrigation), and smart management. These achievements and experiences can be applied to agricultural and pastoral development in the Aral Sea region to promote rational and efficient water resource utilization.

4. Promotion of "New Energy + Industry" Technologies. Central Asian countries have committed under the Paris Agreement to reducing carbon dioxide emissions by 2030, with Kazakhstan reducing emissions by 15%, Kyrgyzstan by 14%, and Uzbekistan by 35%. The region also has enormous renewable energy potential, with solar power potential reaching 3×10^{6} MW in Uzbekistan and 3.7×10^{6} MW in Kazakhstan [47]. However, due to late start, limited technology reserves, and funding shortages in developing new energy in Aral Sea basin countries, external support is urgently needed. China is the world's largest producer of solar, wind, and other new energy sources, with mature technology and experience across the entire industrial chain from design, manufacturing, and construction to operation and utilization. Particularly, China has achieved good results in combining new energy with urban and rural infrastructure development and small industrial development. Introducing Chinese new energy technology and experience to the Aral Sea region and Central Asia as a whole has great potential. Besides meeting large-scale industrial and social needs, it can also promote livelihood improvements in remote and underdeveloped areas, including lighting and drinking water purification, as well as small industrial development such as greenhouse construction—beneficial measures for achieving win-win outcomes.

5. Development of Characteristic Drugs and Treatment Technologies for Endemic Diseases. Research the impacts and hazards of negative factors from the Aral Sea ecological disaster, such as salt dust and polluted water bodies, on human and livestock production, and develop corresponding therapeutic drugs and methods. Relying on established international pharmaceutical industry demonstration bases and talent cultivation platforms such as the Central Asian Drug Research and Development Center, focusing on regional characteristic natural drug research, develop characteristic drugs for endemic disease treatment based on native medicinal plants, and jointly carry out prevention and treatment of endemic diseases caused by salt dust with medical institutions from both sides to jointly build a Healthy Silk Road.

Cooperation Models

1. Joint Research and Development. This cooperation model focuses on collaborative research and experimental work in a common field. Participants invest talent, equipment, and capital for joint R&D activities, mainly implemented through projects. The leading entities can be national, research institutions, enterprises, or international organizations. Specific forms include project cooperation, establishment of technology parks, joint laboratories, business incubators, and teaching centers.

2. Technology Demonstration and Promotion. The key to this cooperation model is that the technology provider's technical fields and solutions must align with the partner country's strategic guidelines, technology development plans, and farmers' needs. This requires thorough research on local ecological environments, agricultural production conditions, socio-economic development levels, and national industrial policies and strategic plans before cooperation, strengthening communication and coordination with partners, and proposing targeted technology demonstration types and implementation plans to maximize cooperation effectiveness.

3. Technical Training. Technical training programs for developing countries are gradually gaining attention in China, with cooperation models including science and technology management training and specialized technical training. Currently, technical training projects led by government functional departments such as the Ministry of Agriculture and Rural Affairs, the Ministry of Science and Technology, and the Ministry of Commerce have been implemented for many years under the guidance of the agricultural "going global" strategy. In cooperation with Central Asia, the Shanghai Cooperation Organization Agricultural Technology Exchange and Training Demonstration Base led by Northwest A&F University has conducted beneficial trials. Such cooperation should be fully considered in project design, with hierarchical levels of training objects and content emphasizing specificity.

4. International Student Cultivation. Establish medium- and long-term special funding plans for Central Asia cooperation by governments, scientific and educational institutions, and enterprises to help young talents from both sides engage in professional studies at each other's scientific and educational institutions, cultivating interdisciplinary talents who understand each other's languages, policies, and cultures while mastering professional skills. Additionally, senior visiting scholars and short-term academic exchanges can also be included in this category.

Conclusion

The Aral Sea ecological disaster and its governance are not only priority areas for regional national policies but have also become hot and difficult issues of

international concern. Similarly, the achievements of governance will not only benefit countries around the Aral Sea but also the broader regions outside the area that may be affected. Therefore, to promote China's active participation in the Aral Sea ecological governance process, it is necessary to base efforts on existing mechanisms such as the Shanghai Cooperation Organization and "China+Five Central Asian Countries," use the above-mentioned scientific research and livelihood improvements as entry points, improve multi-level dialogue and coordination systems, promptly propose large-scale science cooperation plan initiatives with distinct Chinese propositions, build smooth financing channels to attract multi-party participation, and actively respond to and implement China's initiatives on promoting global development and synergy with projects under the UN Trust Fund for Human Security in the Aral Sea Region.

Environmental improvement and socio-economic development in Central Asia are conducive to regional ecological security and stability, and the construction of a community with a shared future for mankind also requires a prosperous Central Asia. Using the Aral Sea ecological governance, a regionally and internationally shared concern with fewer geopolitical factors, as an opportunity to promote green development in the Aral Sea region can effectively promote and deepen China's scientific and technological cooperation with Central Asia in broader fields such as agriculture, new energy, information and communication, and transportation. This will provide scientific and technological support for building a China-Central Asia community with a shared future and the high-quality development of the Belt and Road Initiative, contributing China's wisdom, experience, and strength to building a community with a shared future for mankind.

The countermeasures proposed in this paper only involve the Aral Sea region, mainly referring to the Aral Sea coastal areas directly affected by the ecological disaster, including Karakalpakstan in Uzbekistan and Kyzylorda Region in Kazakhstan. Governance of the entire Aral Sea basin requires transboundary water resource allocation and utilization solutions among basin countries, strengthened coordination with basin countries and the international community, and the launch of more comprehensive cooperation and assistance programs including science and technology under the Belt and Road, SCO, and "China+Five Central Asian Countries" frameworks.

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