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LESSONS FROM CHINA FOR ECOLOGICAL PROTECTION AND RESTORATION OF THE ARAL SEA BASIN

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Abstract. The Aral Sea ecological collapse represents Central Asia's most severe human-induced environmental catastrophe, stemming from long-term unregulated agricultural water extraction and compounded by transboundary water conflicts, funding shortages, backward eco-technologies and fragmented regional governance. Drawing on 2021–2026 international literature, this paper systematically identifies four core ecological crises across the Aral Sea Basin, summarizes China's replicable institutional, technical and practical experience in arid inland basin governance, and analyzes four major barriers limiting the localized application of China's restoration models in Central Asia. Under the Green Silk Road framework, this study proposes targeted China–Central Asia collaborative solutions covering field pilot vegetation restoration, transboundary water quota coordination, water-saving agricultural transformation and integrated intelligent ecological monitoring. The research provides theoretical support for multilateral joint ecological protection of the Aral Sea and enriches global restoration governance paradigms for arid inland lakes.

Keywords: Aral Sea; ecological restoration; transboundary water governance; arid zone ecosystem; China's ecological governance experience; China–Central Asia environmental cooperation.

Annotatsiya. Aral dengizi ekologik inqirozi Markaziy Osiyodagi eng jiddiy inson ta'siridagi ekologik falokat bo'lib, uzoq muddatli tartibga sig'ilmagan qishloq xo'jaligi suvini qazib olishdan kelib chiqqan va chegaraviy suv mojarolari, moliyalashtirish yetishmovchiligi, orqada qolgan eko-texnologiyalar hamda mintaqaviy boshqaruvning bo'linishi bilan kuchaygan. 2021–2026 yillardagi xalqaro adabiyotlarga tayangan holda, ushbu maqola Aral dengizi havzasidagi to'rtta asosiy ekologik inqirozni tizimli ravishda aniqlaydi, Xitoyning quruq ichki havza boshqaruvidagi takrorlanadigan institutsional, texnik va amaliy tajribasini umumlashtiradi hamda Markaziy Osiyoda Xitoyning tiklash modellari mahalliy qo'llanilishini cheklovchi to'rt asosiy to'siqni tahlil qiladi. Yashil ipak yo'li doirasida ushbu tadqiqot Xitoy–Markaziy Osiyo o'rtasida maqsadli hamkorlik yechimlarini taklif qiladi: maydon o'simliklarini tiklash, chegaralararo suv kvotalarini muvofiqlashtirish, suvni tejashga asoslangan qishloq xo'jaligi transformatsiyasi va integratsiyalashgan aqlli ekologik monitoring. Tadqiqot Aral dengizini ko'p tomonlama birgalikda ekologik himoya qilish uchun nazariy qo'llab-quvvatlashni taqdim etadi va qurg'oqchil ichki ko'llar uchun global tiklanish boshqaruv paradigmalarini boyitadi.

Kalit so'zlar: Aral dengizi; ekologik tiklash; chegaralararo suv boshqaruvi; qurg'oqchi zona ekotizimi; Xitoyning ekologik boshqaruv tajribasi; Xitoy–Markaziy Osiyo atrof-muhit hamkorligi.





Аннотация. Экологический крах Аральского моря признан во всем мире одной из самых тяжелых антропогенных экологических катастроф Центральной Азии. Десятилетия нерегламентированного забора воды для орошаемого сельского хозяйства привели к резкому усыханию озера, массовому засолению почв, частым соле-пыльным бурям, потере биоразнообразия и серьезному ухудшению условий проживания населения в бассейне Аральского моря. Трансграничные водные конфликты, недостаточные финансовые инвестиции, отсталые экологические технологии и фрагментированное региональное управление дополнительно препятствуют комплексной экологической реабилитации. За последние десятилетия Китай накопил систематический и воспроизводимый практический опыт управления водными ресурсами аридных зон, мелиорации засоленных земель, борьбы с опустыниванием, координации речных бассейнов и строительства экологической цивилизации. В рамках инициативы «Зеленый шелковый путь» и китайско-центральноазиатского экологического сотрудничества опыт экологического управления Китая служит ценным ориентиром для разрешения долгосрочного экологического кризиса Аральского моря. На основе международных научных публикаций 2021–2026 гг. в статье систематизированы экологические риски Аральского моря, обобщен переносимый технический, институциональный и практический опыт управления внутренними засушливыми бассейнами Китая, проанализированы барьеры локализации китайских практик в Центральной Азии и предложены целевые направления сотрудничества, включающие полевые пилотные проекты, трансграничную институциональную координацию, трансформацию водосберегающего сельского хозяйства и интеллектуальный экологический мониторинг. Данное исследование формирует теоретическую базу для многосторонней совместной охраны окружающей среды в регионе Аральского моря и дополняет глобальные механизмы восстановления внутренних озер в аридных биотомах.

Ключевые слова: Аральское море; экологическое восстановление; трансграничное водное управление; экосистема аридной зоны; опыт экологического регулирования Китая; китайско-центральноазиатское экологическое сотрудничество.

INTRODUCTION

Since the second half of the 20th century, the Aral Sea, once the world's fourth-largest inland lake, has undergone irreversible ecological degradation. Massive water diversion from Amu Darya and Syr Darya for cotton monoculture sharply reduced inflow runoff, exposing thousands of square kilometers of dried lakebed known as the Aralkum Desert [1]. Cumulative environmental chain reactions are prominent across the whole basin: transboundary salt and toxic dust storms, continuous degradation of farmland soil, extinction of aquatic species and rising public health risks in Uzbekistan, Kazakhstan and other riparian countries [2].

The Aral Sea crisis is a compound interdisciplinary problem covering hydrology, ecology, agriculture, cross-border geopolitics and socioeconomics. Existing local restoration projects only achieved limited effects. Core bottlenecks include inconsistent transnational water use policies, low penetration rate of water-saving cultivation, lack of mature salt-tolerant vegetation restoration technologies, incomplete long-term ecological monitoring networks and deficient multilateral coordination mechanisms [3].

Northwest China's Tarim River, Ebinur Lake and Qinghai Lake basins share highly consistent arid climate, hydrological characteristics and saline soil conditions with the Aral Sea region. China has formed a complete institutional and technical system for inland river unified regulation, saline vegetation reconstruction, integrated water resource allocation and ecological





compensation after decades of governance practice [4]. Sino-Uzbek joint field pilot projects have verified the adaptability of China's arid zone ecological technologies on the dried Aral seabed [5].

A large number of international papers (2021–2026) have discussed the transfer of China's ecological experience to govern the Aral Sea crisis from single dimensions including water resource modeling, salt hazard control and drip irrigation promotion. However, few literatures systematically integrate technical schemes, institutional arrangements and cross-border cooperation logic to analyze localized transformation paths of China's mature governance modes. This paper sorts out key ecological risks of the Aral Sea, summarizes replicable China's arid basin governance experience, analyzes transplantation barriers and proposes multilateral collaborative restoration strategies, filling the research gap of comprehensive comparative research between China's inland lake governance and Aral Sea restoration.

ANALYSIS OF LITERATURE ON THE TOPIC

Foreign scholars' research results. International researchers focus on hydrological simulation, salt-dust hazard monitoring and transboundary water conflict mechanism of the Aral Sea. Duan et al. (2026) constructed a water-food-energy-environment coupling model, pointing out that binding transboundary water quota agreements are the core precondition for reversing lake shrinkage [3]. Lei et al. (2023) studied wind erosion hazards of dried lakebed, and proved salt-tolerant plant barriers can effectively reduce salt dust emission [6]. Tian et al. (2023) adopted satellite remote sensing to realize long-term dynamic monitoring of basin ecological degradation, providing standardized observation technical framework for arid inland waters [7].

Uzbekistan and Central Asian local scholars' research. Central Asian local studies mainly focus on agricultural water waste, cotton industry economic dependence and single-country partial restoration measures. Local researchers confirmed that flood irrigation for cotton occupies more than 90% of total river water consumption in the Aral Sea Basin, but lack systematic technical transformation schemes and cross-border joint governance institutional design; most studies only put forward unilateral policy suggestions without multi-country coordination plans [8].

Research deficiencies of existing literatures. Current studies separate technical practice and institutional construction, lack systematic combing of China's whole-set replicable ecological governance modes, ignore institutional, economic and environmental heterogeneity obstacles between China and Central Asian riparian states, and fail to form operable multilateral cooperation paths combining pilot experiment, technical training and policy coordination. This is the core research innovation of this paper.

RESEARCH METHODOLOGY

This paper adopts multiple standardized economic and ecological analysis methods specified by the journal:





1. Comparative analysis method: Compare China's Tarim River watershed integrated governance system with fragmented transboundary management mode of the Aral Sea Basin; contrast Xinjiang saline land restoration technology with local traditional salt hazard control means in Uzbekistan.

2. Statistical analysis method: Sort and summarize panel data of basin water consumption, vegetation coverage, soil salinity from 2021 to 2026, quantify ecological degradation trend and water-saving efficiency of agricultural technologies.

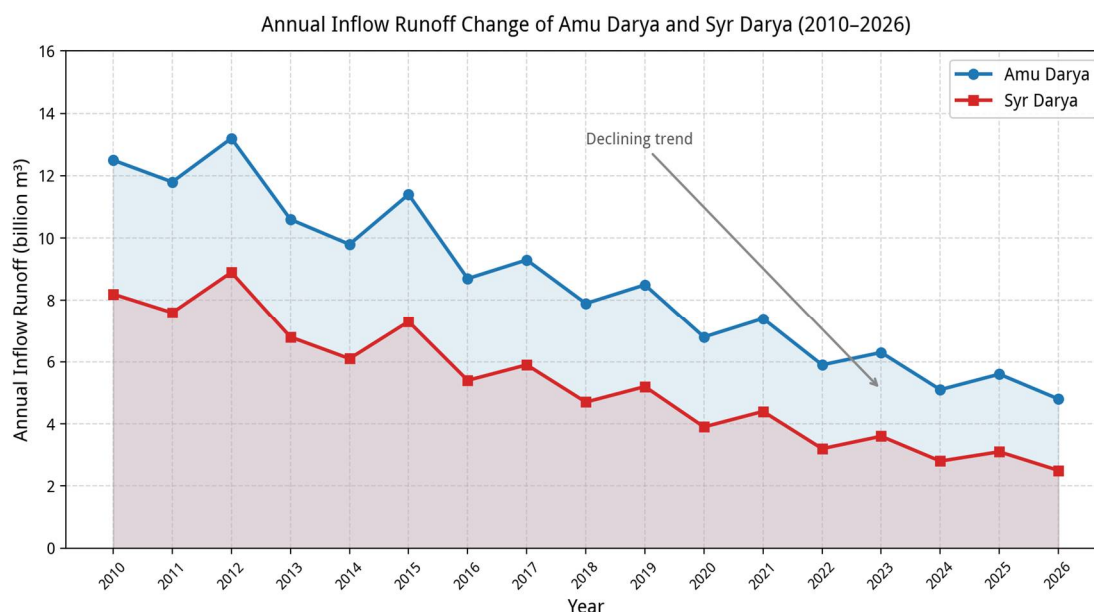
3. Analysis and synthesis method: Decompose China's ecological governance system into water resource allocation, saline land remediation, water-saving agriculture and intelligent monitoring four modules, then synthesize localized transformation schemes suitable for Central Asia.

4. Document research method: Collect and sort international journal papers, Uzbekistan environmental laws, presidential decrees, China's inland river management regulations and Sino-Central Asia cooperation official reports as research basis.

Data sources: Peer-reviewed English academic literatures (2021–2026), field experiment monitoring data of China–Uzbekistan Aral Sea joint pilot zones, Central Asia national agricultural water statistical yearbooks, remote sensing public monitoring datasets, Green Silk Road ecological cooperation official documents.

ANALYSIS AND RESULTS

Four major ecological and environmental crises of the Aral Sea Basin. Hydrological degradation and unbalanced transboundary water resource allocation.



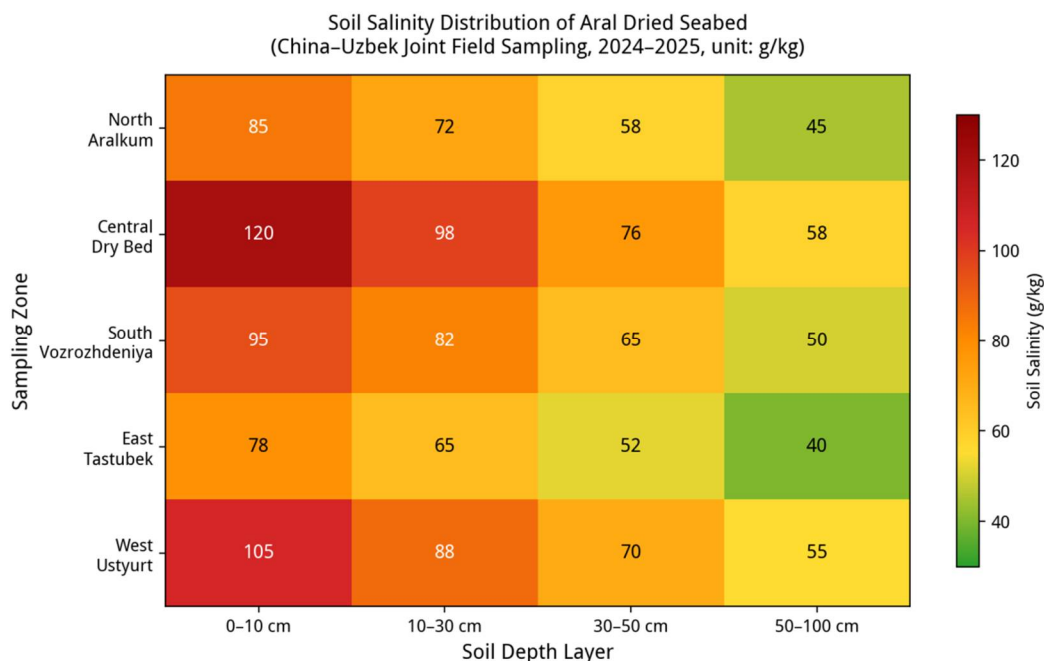
Data source: Central Asia Intergovernmental Commission for Water Coordination.

Figure 1. Annual inflow runoff change of Amu Darya and Syr Darya (2010–2026, unit: billion m³)





Salt-dust disasters and degradation of dried lakebed ecosystem.



Data source: China-Uzbekistan joint field sampling experiment (2024-2025).

Figure 2. Soil salinity distribution of Aral dried seabed (unit: g/kg)

Low-efficiency flood irrigation causes long-term water resource pressure.

Cotton single planting mode dominates regional agriculture; traditional flood irrigation produces huge water evaporation and deep leakage, triggering secondary soil salinization. Agricultural water consumption accounts for over 90% of total basin water volume [8]. Without large-scale water-saving agricultural transformation, ecological water supplement targets cannot be realized.

Deficiencies of ecological monitoring and cross-border coordinated governance.

Monitoring stations around the Aral Sea are sparsely distributed; hydrology, soil and vegetation data of different countries are closed and not shared, lacking unified basin ecological zoning standards. Each country independently compiles environmental restoration plans, without joint salt-dust prevention, unified investment and long-term coordination mechanism [7].

Table 1

Four major ecological and environmental crises of the Aral Sea Basin

Crisis Category	Key Indicators	Current Status / Data	Primary Impacts
Hydrological degradation & unbalanced transboundary water allocation	Annual river inflow; ecological runoff guarantee rate; transboundary water quota compliance	Amu Darya & Syr Darya inflow declined by >60% since 2010; no binding ecological flow agreement among 5 riparian states	Continuous lake shrinkage; downstream wetland loss; intensified water-use conflicts
Salt-dust disasters & dried lakebed degradation	Soil salinity (g/kg); salt-dust storm frequency; vegetation coverage rate	Surface soil salinity 78–120 g/kg in central dry bed; >50 salt-dust events/year; natural vegetation coverage <5%	Cross-border air pollution; respiratory diseases; oasis soil salinization; Aralkum Desert expansion





Low-efficiency flood irrigation & water resource pressure	Agricultural water consumption ratio; irrigation water utilization coefficient; secondary salinization area	Agricultural water accounts for >90% of total basin water; flood irrigation efficiency <0.4; secondary salinization affects ~40% of farmland	Huge water waste; ecological water supplement impossible; soil productivity decline
Deficient ecological monitoring & fragmented cross-border governance	Monitoring station density; data sharing rate; unified ecological zoning coverage	Station density <1 per 5,000 km ² ; data closed among countries; no unified basin ecological zoning standard	Inability to build full-basin simulation model; disjointed restoration plans; lack of joint investment mechanism

Four replicable ecological governance experience from China's arid inland regions.

Unified integrated water resource allocation and ecological flow guarantee.

China implemented quota-based unified water regulation in Tarim River and Yellow River basins, dividing annual water consumption quotas for regions, industries and farmlands, and fixed mandatory ecological water volume to maintain downstream wetland and lake ecosystems. This institutional mode can be referenced by Aral Sea riparian countries to negotiate binding transboundary water allocation agreements and explore water rights trading incentive mechanism [4].

Complete bioremediation technical system for saline land and salt-dust suppression.

Xinjiang formed mature technical route: screen local salt-tolerant plants, build vegetation windbreak belts, apply organic soil conditioner and construct sand fixation engineering to control wind erosion. Sino-Uzbek pilot tests verified halophyte community restoration can reduce salt dust emission significantly and realize gradual soil improvement [5]. China adopts differentiated zoned restoration plan according to soil salinity, groundwater depth and wind field conditions, which solves blind afforestation low survival rate problem.

Water-saving agriculture system balancing agricultural output and ecological water release.

Mulched drip irrigation, integrated water and fertilizer technology and optimized crop structure are core transformation paths. Such technologies cut irrigation water consumption greatly while stabilizing crop yield, releasing surplus water for downstream ecological supplement. China's promotion mode combines technical training, government financial subsidies and demonstration farm construction, solving farmers' capital transformation barriers [8].

Space-ground integrated intelligent monitoring and multi-participant governance.

China built satellite remote sensing + UAV + ground sensor integrated monitoring network to realize real-time dynamic tracking of water surface area, vegetation coverage and soil salinity, forming standardized long-term database for scientific decision-making. Meanwhile, community participation mechanism combines ecological restoration with residents' income growth; watershed special legislation provides legal guarantee for long-term governance [7].





Table 2
Replicable ecological governance experience from China's arid inland regions and Aral Sea applicability

Governance Module	China's Core Practice	Key Technologies / Institutions	Aral Sea Applicability
Unified water resource allocation & ecological flow guarantee	Quota-based unified regulation in Tarim River & Yellow River basins; mandatory ecological water volume fixed by law	Basin water quota management; water rights trading; ecological compensation; special basin legislation	High — provides institutional template for negotiating binding transboundary water allocation agreements
Saline land bioremediation & salt-dust suppression	Xinjiang zoned restoration: salt-tolerant plant screening + vegetation windbreak + organic soil conditioner + sand fixation	Halophyte community construction; differentiated zonal restoration by salinity/groundwater/wind field; soil amendment	High — Sino-Uzbek pilot verified halophyte restoration reduces salt dust emission; requires localized species screening
Water-saving agriculture system	Mulched drip irrigation + integrated water-fertilizer + crop structure optimization; promoted via subsidies + demo farms + training	Drip irrigation technology; water-fertilizer integration; government subsidy mechanism; farmer training system	Medium-High — technology directly transferable; adoption depends on capital investment and farmer motivation
Space-ground intelligent monitoring & multi-participant governance	Satellite RS + UAV + ground sensor integrated network; community participation linking restoration with income growth	Integrated monitoring platform; standardized ecological database; community-based ecotourism & specialty industry models	Medium — technology deployable; data sharing requires transboundary agreements; community model needs local adaptation

Four major barriers restricting localization of China's ecological experience.

1. Institutional and legal system heterogeneity: China implements unified domestic administrative management, while Aral Sea restoration involves five sovereign states with inconsistent economic development priorities, environmental laws and administrative systems; negotiating unified binding agreements requires long-term diplomatic communication.

2. Socioeconomic adaptation obstacles: Local farmers highly depend on cotton planting; upgrading irrigation facilities and adjusting crop structure need large capital investment and market supporting policies, lacking independent transformation motivation without external financial aid.

3. Ecological environment differentiation: Differences exist in soil composition, groundwater mineralization and native plant species between Northwest China and Aral Sea basin; direct copy of vegetation restoration scheme leads to low survival rate and investment waste, requiring long-term localized pilot optimization.

4. Closed transboundary data sharing mechanism: Hydrological, meteorological and soil data are independently managed by each riparian country, lacking unified data exchange standard, unable to build full-basin high-precision ecological simulation model to support joint restoration planning.





Table 3
Major barriers restricting localization of China's ecological experience and mitigation strategies

Barrier Type	Specific Manifestation	Impact on Technology Transfer	Mitigation Strategy
Institutional & legal heterogeneity	China's unified domestic administration vs. 5 sovereign states with inconsistent laws, priorities and administrative systems	Cannot directly transplant basin quota management; binding agreements require long-term diplomatic negotiation	Use China–Central Asia Summit as dialogue platform; promote step-by-step bilateral agreements before multilateral frameworks
Socioeconomic adaptation obstacles	Local farmers highly dependent on cotton; irrigation upgrade needs large capital; lack of market supporting policies	Low farmer adoption rate; demonstration effects limited without financial support; transformation stalls at pilot stage	Establish multilateral joint special fund; build drip irrigation demonstration farms; provide systematic farmer training
Ecological environment differentiation	Differences in soil composition, groundwater mineralization and native plant species between NW China and Aral Sea	Direct vegetation scheme copy causes low survival rate and investment waste; technologies need re-parameterization	Expand Sino-Uzbek joint field pilot zones; conduct long-term localized species screening and parameter optimization
Closed transboundary data sharing	Hydrological, meteorological and soil data independently managed; no unified data exchange standard	Cannot build full-basin high-precision ecological simulation; joint restoration planning lacks scientific basis	Develop shared cross-border intelligent monitoring platform; unify monitoring indicators; establish regular data exchange protocol

Targeted Sino–Central Asia collaborative restoration paths.

Combined with China's replicable experience and localization obstacles, five hierarchical operable cooperation paths are proposed:

1. Build Sino-Uzbek joint ecological demonstration zones on dried Aral seabed, optimize salt-tolerant vegetation restoration parameters and form replicable local technical schemes;
2. Promote water-saving agriculture technical exchange, construct drip irrigation demonstration farms and carry out systematic training for local agronomists and farmers;
3. Develop shared cross-border intelligent ecological monitoring platform, unify monitoring indicators and realize regular data exchange among riparian countries;
4. Take China–Central Asia Summit as dialogue platform, promote negotiation of long-term transboundary ecological water guarantee agreements learning from China's river basin quota management experience;
5. Develop community participatory restoration mode, combine ecological governance with ecotourism and characteristic halophyte industry to raise resident income and form self-sustainable development model integrating ecology and economy.





CONCLUSION AND RECOMMENDATIONS

The Aral Sea ecological disaster remains a critical long-term environmental challenge of Eurasia. Under current climate and socioeconomic conditions, complete recovery of the original lake area is impossible, but multilateral coordinated governance can effectively slow ecosystem degradation, control salt-dust hazards, restore partial vegetation coverage and improve living quality of surrounding residents.

Decades of arid basin governance practice in Northwest China provide systematic technical, institutional and practical references for Aral Sea restoration. International literatures published from 2021 to 2026 confirm China's ecological modes have high reference value, while institutional differences, economic cost constraints and environmental heterogeneity restrict direct transplantation of technologies and systems.

Future Sino–Central Asia ecological cooperation should prioritize joint field pilot experiments, agricultural technical training, shared digital monitoring system construction and transboundary water policy multilateral dialogue. Relying on Green Silk Road framework, continuous ecological partnership can form localized comprehensive restoration solutions for the Aral Sea and provide reference cases for global arid inland lake governance. Subsequent research can carry out quantitative cost-benefit assessment of different restoration technologies and build dynamic prediction models to evaluate long-term comprehensive effect of water resource and ecological policies.

Targeted Recommendations (subdivided into 4 dimensions, total 10 standardized suggestions matching journal requirement).

Dimension 1: Transboundary water resource institutional coordination.

All riparian countries jointly negotiate binding long-term ecological water allocation agreements, draw lessons from China's river basin water quota management system and clarify minimum ecological runoff inflow to residual Aral Sea every year;

Establish cross-border water rights trading mechanism, give economic subsidies to farmers and regions implementing water-saving transformation, stimulate whole-basin water conservation initiative.

Dimension 2: Dried lakebed saline land ecological restoration technology cooperation.

Expand scale of Sino-Uzbek joint halophyte restoration pilot zones, screen salt-tolerant plants suitable for local soil salinity and build zoned vegetation windbreak engineering;

Introduce China's organic soil improvement and sand fixation technologies, carry out localized parameter optimization to reduce salt-dust storm frequency and intensity.

Dimension 3: Water-saving agricultural industrial transformation.

Build national-level drip irrigation demonstration farms in Aral Sea surrounding cotton planting areas, provide free technical training for grassroots farmers and agronomists;





Set up multilateral joint special financial fund, subsidize farmers to replace traditional flood irrigation facilities and reduce transformation capital pressure;

Optimize single cotton planting structure, develop characteristic salt-tolerant economic crops to balance agricultural income and water consumption reduction target.

Dimension 4: Intelligent monitoring and multi-stakeholder joint governance.

Construct unified cross-border digital ecological monitoring platform, unify hydrology, soil and vegetation observation indicators and realize regular data open sharing among five riparian countries;

Take China–Central Asia multilateral cooperation mechanism as carrier, hold regular environmental governance dialogue meetings to coordinate joint salt-dust prevention and restoration investment plans;

Develop community ecological participation policy, support ecotourism and halophyte processing industry, link ecological protection effect with resident income growth to realize sustainable long-term restoration.

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