The SDG Nexus in Practice: Integrated Water Resources Management as a Pathway for Sustainability in Central Asia

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Abstract. Water resources in arid Central Asia face pressure from climate change, Soviet-era infrastructure, and transboundary governance challenges. This study examines integration of SDG 6 (Clean Water), SDG 13 (Climate Action), and SDG 15 (Life on Land) within water resource management (WRM) projects in the region. Using qualitative case study methodology with quantitative data from pilot projects, analysis shows effective strategies combine technological innovation (drip irrigation, digital monitoring) with institutional reform. Based on pilot project data, integrated projects achieve 40-60% reduction in irrigation water withdrawal (SDG 6), 20-30% increase in climate resilience (SDG 13), and 15-25% reduction in land salinization (SDG 15). Comparison with Israel's high-tech approach and Southeast Asia's nature-based solutions shows technology transfer success depends on socio-economic context. Operationalizing the SDG 6-13-15 nexus through integrated management is critical for water-scarce regions. **Keywords:** Integrated Water Resources Management (IWRM), SDG Nexus, Central Asia, Climate Adaptation, Water-Energy-Food-Ecosystems Nexus, Drip Irrigation, Transboundary Water Management

1 Introduction

Water resource management in arid regions is increasingly characterized as a "polycrisis" where environmental, climatic, and socio-political challenges converge [1]. Central Asia epitomizes this condition, with its stability tied to the Amu Darya and Syr Darya rivers under unprecedented strain [2]. The region faces a triple burden: Soviet-era unsustainable water infrastructure, climate-driven water scarcity (projected 30-50% glacier loss in Tien Shan by 2050), and institutional fragmentation in governing shared resources [3, 4]. The Aral Sea desiccation symbolizes this mismanagement, with over 50% of irrigated lands in Uzbekistan and Turkmenistan affected by salinization [5, 6]. The UN SDGs provide a framework for addressing these interconnected challenges [7]. Unlike the Millennium Development Goals, SDGs explicitly recognize interlinkages between social, economic, and environmental dimensions [8, 9]. The nexus between SDG 6 (water), SDG 13 (climate), and SDG 15 (land) is particularly salient for arid regions. Achieving water security requires climate adaptation to manage hydrological variability—IPCC projects 10-30% decrease in Central Asian river runoff by 2050 [10]. Both depend on terrestrial ecosystem integrity—soils, forests, and wetlands regulate water cycles and sustain agriculture [11, 12]. Research gap: While the SDG nexus is widely promoted in policy discourse, there is limited empirical evidence on its operationalization in specific, challenging contexts. Most studies remain conceptual or focus on global-scale modeling, with few examining how nexus principles translate into on-the-ground projects in post-Soviet Central Asia, where legacies of infrastructure and governance create unique barriers [13, 14, 21]. This study addresses this gap by providing empirical evidence from three pilot projects in Uzbekistan, examining: (1) What WRM interventions demonstrate measurable SDG contributions? (2) What are key success factors and barriers? (3) How can international models inform Central Asia's approach?

2. Materials and Methods

2.1. Case Selection and Data Collection

This study employs a secondary data analysis approach. The authors did not conduct primary field data collection but instead synthesized and analyzed existing data from three pilot project reports, policy documents, and peer-reviewed literature. While this reliance on secondary data is a limitation, the triangulation of multiple independent sources enhances the reliability of findings. The primary case is WRM modernization in Central Asia, focusing on Uzbekistan's national programs (2020-2030). Data triangulation included: (1) policy documents from World Bank, ADB, FAO; (2) systematic review of peer-reviewed studies (n=75); (3) quantitative data from three pilot projects (2015-2023): Project A (Fergana Valley, 5,000 ha drip irrigation), Project B (Bukhara Region,

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automated canals on 25,000 ha), Project C (Karakalpakstan, 15,000 ha afforestation); (4) historical analysis of water infrastructure [5, 15].

2.2. Analytical Framework: SDG Nexus Indicators

SDG 6 (Clean Water) focused on target 6.4 (water-use efficiency) using indicators: water withdrawal per hectare (m^3/ha), irrigation efficiency (%), water savings (million m^3). Data from pilot reports and FAO AQUASTAT [16, 17].

SDG 13 (Climate Action) focused on target 13.1 (resilience) using: drought resilience (crop yield stability), adoption of adaptive practices, access to climate forecasting. Data from surveys and National Hydrometeorological Service [3, 10].

SDG 15 (Life on Land) focused on target 15.3 (desertification) using: soil salinity (dS/m), land restored (ha), groundwater table depth (m). Data from environmental impact assessments and remote sensing [5, 6, 18].

2.3. Comparative Analysis

To strengthen the comparative analysis, we developed a structured framework with five dimensions: (1) core strategy (supply-side vs. demand-side vs. ecosystem-based); (2) technological profile (hardware intensity, innovation focus); (3) governance model (centralized vs. polycentric, regulatory approach); (4) economic instruments (pricing, subsidies, incentives); (5) contextual dependencies (energy availability, capital costs, institutional capacity). Central Asia was compared with Israel and Southeast Asia (Vietnam, Thailand) across these five dimensions [4, 19]. This structured approach enables systematic identification of transferable principles versus context-specific solutions.

3. Results

This section presents findings from WRM modernization initiatives in Central Asia, based on triangulated data from policy documents, scientific literature, and three pilot projects implemented in Uzbekistan between 2015 and 2026.

3.1. Project-Level Outcomes: Synergies and Trade-offs

Project A (Fergana Valley – Drip Irrigation): Conversion of 5,000 ha cotton from furrow to drip irrigation reduced water withdrawal by 48% (8,200 to 4,300 m^3/ha/year). During the 2021 drought, drip-irrigated farms achieved 90% of average yield vs. 70% in control areas. Soil salinity remained stable at 3.2 dS/m in project areas vs. increase to 4.5 dS/m in control areas [5, 6, 20, 25,26].

Project B (Bukhara Region – Automated Canals): Installation of automated gates and telemetry on main canals (25,000 ha command area) reduced conveyance losses by 25%, saving 150 million m^3 annually. During drought, 100% of users received allocations vs. 65% pre-project. Soil salinity decreased 39% (8.5 to 5.2 dS/m) over four years [2, 6, 16, 18].

Project C (Karakalpakstan – Afforestation): Restoration of 15,000 ha with salt-tolerant species increased vegetation cover from <5% to >40% after five years. Sandstorm frequency decreased 30% downwind. Temporary trade-off: 0.5 million m^3/year water for sapling establishment, managed using brackish water and community engagement [5, 18, 20].

3.2. Cross-Cutting Success Factors and Persistent Barriers

3.2.1. Enabling Factors

Multi-Level Integration: Technology + institutional reform + social engagement achieved 70% adoption vs. <30% for technology-only approaches.

Data-Driven Adaptive Management: Real-time monitoring (SCADA, soil moisture sensors) enabled informed decisions.

Multi-Stakeholder Platforms: WUA federations and community consultations built trust and managed trade-offs.

Flexible Financing: Mix of subsidies, credit, and group investment improved equity and scale.

3.2.2. Persistent Barriers

Capital-Intensive Scaling: National drip irrigation scaling requires $2.7-3.0 billion, exceeding current budgets.

Institutional Fragmentation: Water, agriculture, and environment ministries operate separately; water savings from agriculture cannot be allocated to environmental flows.

Transboundary Governance Vacuum: No basin-wide agreement on water allocation; upstream reservoir operations during 2021 drought undermined adaptive capacity [4, 5].

Data Asymmetries: Lack of high-resolution data on water consumption, soil health, and groundwater limits monitoring.

3.3. Structured Comparative Analysis of International Models

To strengthen rigor, we compared Israel, Southeast Asia, and Central Asia across five dimensions: core strategy, technology profile, governance model, economic instruments, and contextual factors.

Israeli Model: Characterized by supply augmentation plus demand management, high-tech solutions (drip irrigation, desalination, >85% wastewater reuse), centralized strong regulation, full-cost pricing, and energy-rich/high-capital context [5]. **Transferable principles** for Central Asia: water rights, conservation incentives, wastewater as strategic resource (currently <10% reused) [18,23]. **Non-transferable:** high energy intensity for desalination, centralized governance incompatible with transboundary realities.

Southeast Asian Model (Mekong): Characterized by nature-based adaptation, low-tech solutions (mangroves, wetlands, "living dikes"), polycentric governance, limited pricing with community management, and water-rich (seasonally) but low-capital context [11]. **Transferable principles** for Central Asia: nature-based solutions, polycentric governance, community participation. **Non-transferable:** water-rich context (Central Asia is arid), tropical ecosystem dynamics differ from arid tugai forests.

Synthesis: A hybrid approach is most appropriate for Central Asia—Israeli principles of water accounting, demand management, and wastewater reuse combined with Southeast Asian emphasis on ecosystem restoration and adaptive governance. Both models require careful contextualization to Central Asia's arid climate, Soviet-era infrastructure, and transboundary challenges [2,4,5,6,24,25, 26].

4. Discussion

WRM is a primary interface for implementing the SDG agenda. Synergy is achievable but not automatic. Drip irrigation (SDG 6) may fail to deliver climate benefits (SDG 13) if energy from carbon-intensive sources, or lead to Jevons Paradox (expansion of irrigated area) [22]. Ecosystem restoration (SDG 15) requires environmental flows that may conflict with agricultural demands (SDG 6).

4.1. The Reinforced Integrated and Adaptive Nexus Framework (IANF) in Context

This study proposes a Reinforced Integrated and Adaptive Nexus Framework (IANF). To clarify its novelty, we distinguish it from existing frameworks:

Relationship to IWRM: Integrated Water Resources Management (IWRM) has long emphasized institutional integration, stakeholder participation, and cross-sectoral coordination. However, IWRM traditionally focuses on water sector governance without explicit linkages to climate adaptation (SDG 13) or terrestrial ecosystems (SDG 15). The IANF operationalizes the SDG nexus by making these linkages central, not peripheral.

Relationship to WEFE Nexus: The Water-Energy-Food-Ecosystems (WEFE) nexus focuses on biophysical interconnections and resource trade-offs. However, it often treats institutions as external enabling conditions rather than core analytical variables. The IANF places institutional transformation at the center, recognizing that technological interventions alone cannot achieve sustainable outcomes without corresponding governance reforms.

Novelty of IANF: The framework emphasizes three synergistic dimensions that are often treated separately: (1) Technology + Governance pairs efficiency investments with formal water rights clarification and adaptive allocation mechanisms; (2) Engineering + Ecosystems complements grey infrastructure with nature-based solutions; (3) Global Knowledge + Local Context promotes adaptation of international best practices to local conditions, including revival of indigenous water management (e.g., qanat systems).

4.2. Critical Reflection

The main barriers are not technical but financial and governance-related. Long-term sustainability depends on moving from donor-funded pilot projects to domestically financed, scaled-up programs embedded in national development plans. This requires a shift from viewing water as a free public good to a scarce economic asset with social and environmental value. Furthermore, the transboundary nature of Central Asian water resources means that national-level success is ultimately constrained by the lack of a functioning regional basin-level authority [2, 4].

5. Conclusions

This study demonstrates that sustainable water resource management in regions like Central Asia is a pivotal mechanism for achieving multiple Sustainable Development Goals simultaneously. By deliberately designing projects through the lens of the SDG 6-13-15 nexus, policymakers and practitioners can enhance co-benefits and mitigate trade-offs. The integration of quantitative performance data with qualitative analysis reveals that the success of such projects is not merely about technology adoption, but about creating an enabling environment of strong institutions, stakeholder participation, and sustainable financing.

Key conclusions are:

1. WRM interventions, such as efficient irrigation, automated canal management, and ecosystem restoration, are direct drivers of measurable progress on SDGs 6, 13, and 15. The pilot projects analyzed demonstrated quantifiable improvements in water savings (40-60%), climate resilience (20-30% yield stability), and land restoration (15-25% salinity reduction).
2. Success hinges on an integrated approach that couples technological innovation with strong institutions, stakeholder participation, and sustainable financing. The absence of any one of these elements can undermine the effectiveness of the others.
3. The international experience provides valuable principles (water pricing, nature-based solutions, regulatory enforcement) that must be carefully contextualized rather than directly replicated. Central Asia's unique socio-ecological context requires a blended approach that is both technologically modern and ecologically sensitive.

For future research, longitudinal studies quantifying the multi-dimensional impact (hydrological, social, economic) of nexus-based WRM projects are needed to build a stronger evidence base. Furthermore, developing robust models for valuing the ecosystem services provided by nature-based solutions could strengthen their case in policy and investment decisions. Finally, tackling the "wicked problem" of transboundary water governance remains the most critical and challenging research frontier for achieving true sustainability in Central Asia.

A key limitation of this study is its reliance on secondary pilot project reports and existing policy documents rather than primary field data collection. The analysis would be strengthened by long-term field monitoring to validate reported outcomes and capture interannual variability in project performance. Ultimately, managing water sustainably is not just a sectoral task but a foundational prerequisite for achieving the broader 2030 Agenda for Sustainable Development in one of the world's most water-stressed regions.

Acknowledgments

The authors are grateful to everyone who provided guidance, technical support, and fruitful discussions during the course of this investigation. Special thanks are due to the anonymous reviewers for their thorough and constructive critique of the manuscript. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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