

SOCIAL-ECOLOGICAL SYSTEMS PERSPECTIVE ON THE SYNERGY BETWEEN SILK ROAD WATER CULTURAL HERITAGE AND RURAL REVITALIZATION: A CASE STUDY OF THE TURPAN KAREZ, XINJIANG, CHINA

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Abstract. Facing the critical challenges of water scarcity and ecological fragility in the arid zone of Xinjiang, this study reconceptualizes Silk Road water-cultural heritage as complex social-ecological systems adapted to extreme environments. It aims to systematically excavate their embedded Traditional Ecological Wisdom and explore synergistic revitalization mechanisms within the contemporary context of rural revitalization and ecological conservation. Employing a mixed-methods approach integrating field surveys, in-depth interviews (n=90), historical archival analysis, and Geographic Information System (GIS) spatial analysis, the research reveals the following key findings: (1) 1,379 identified heritage sites exhibit a statistically significant clustered distribution along the Tianshan Cultural Corridor, informing a proposed spatial framework of “nodal radiation, belt connection, and network coordination”. (2) Using the Turpan karez as a core case study, it is revealed as an ecological adaptation system providing quantifiable ecosystem services at the micro-scale, including microclimate regulation, soil health maintenance, and agrobiodiversity support. (3) Building on these findings, the study constructs a “Karez+” cultural-tourism integration model incorporating community participation mechanisms and water-rights negotiation platforms, and proposes a trinity paradigm of “ecological conservation, cultural transmission, and community development”. The study concludes that the adaptive revitalization of such heritage constitutes a form of “heritage-based ecological engineering,” offering a culturally-grounded pathway for implementing Nature-based Solutions (NbS) and enhancing socio-ecological resilience in arid regions.

Keywords: *water cultural heritage, traditional ecological wisdom, social-ecological, community participation*

Introduction

Water constitutes the core element for human survival and civilizational continuity in arid and semi-arid regions. In the complex environment of northwestern China, the structural imbalance of water resources has profoundly influenced the formation and development of settlements along the Silk Road. These oasis cities, relying on meltwater, rivers, and artificial systems like the karez, created unique settlement patterns and cultural landscapes. The hydraulic infrastructure and institutions are not merely technological artifacts but are spiritual reflections of human-water relationships and carriers of ecological knowledge (Zhang, 2020). Driven by vibrant commerce and cultural exchange, cities along the Silk Road flourished as key hubs for overland transport and cultural dissemination, with their sustained development crucially supported by advanced hydraulic engineering, mature water management systems, and culturally rich aquatic spaces.

Research on water culture has shown a trend of multidisciplinary integration. Relevant studies have encompassed dimensions such as water institutions, hydraulic heritage, and cultural landscapes (Gu and Tian, 2024). Existing research on water cultural heritage has predominantly focused on regions in East Asia, Central Asia, West Asia, and South Asia. Specific case studies have examined sites and systems such as the Yellow River and the Grand Canal in China (Xu et al., 2024), the karez systems in Turpan (Meng and Zeng, 2025), Persian water heritage (Saatsaz and Rezaei, 2023), and water landscapes in Indian temple gardens (Wahurwagh and Dongre, 2015). With the advancement of the Belt and Road Initiative, research on Silk Road water cultural heritage has grown notably, with scholars conducting extensive exploration in areas such as the dissemination of hydraulic technology, the development of water-cultural landscapes, and the renewal and conservation of water heritage. For example, UNESCO's 'Karez Rehabilitation Project' (2009) demonstrates the modern applicability of traditional hydraulic technology, while the vernacular bathhouse practices in Szeklerland, Romania illustrate the potential for adaptive reuse of water-related cultural heritage (Fekete et al., 2022). This growing body of work aligns with increasing scholarly interest in Traditional Ecological Wisdom (TEW) and the resilience of social-ecological systems. Heritage systems like the karez can be viewed as "living ecological infrastructure," whose conservation and study are critical for contemporary water resource management and climate adaptation strategies in arid and semi-arid regions (Ashraf et al., 2016). The above related studies provide certain insights for this research from the perspectives of research methods and viewpoints.

In conclusion, existing research both domestically and internationally mainly focuses on areas with annual precipitation exceeding 400 millimeters, with insufficient attention paid to water cultural heritage in arid and semi-arid regions. The various civilizations along the Silk Road Cultural Corridor have accumulated rich hydraulic technology and water culture phenomena, and the preserved water conservancy heritage still holds important practical and cultural value today (Kong and Liu, 2022). Therefore, protecting and developing the water cultural heritage on this corridor is one of the important entry points to solve the "rural development challenges" in arid and semi-arid areas. This study breaks through the limitations of purely descriptive descriptions and systematically analyzes the core characteristics and ecological value of water cultural heritage in arid and semi-arid regions from dimensions such as ecological functions, sustainable management wisdom, and cultural inheritance. The specific research objectives are: (1) to systematically identify and classify the types of water cultural heritage in Xinjiang, and to deeply explore the traditional ecological wisdom contained therein; (2) Using quantitative GIS methods to analyze its spatial distribution patterns, revealing the impact of natural resource endowments and the Silk Road cultural corridor on the formation and evolution of heritage; (3) Taking the karez settlement in Turpan as a typical case, this article analyzes its traditional ecological wisdom and ecosystem service functions, providing scientific reference and theoretical basis for the policy formulation and practice of coordinated development of cultural heritage protection and rural revitalization in the future.

Materials and methods

Research area

This study takes Xinjiang as the research area and the ancient Silk Road as the geographical and cultural unit to investigate the water cultural heritage in traditional urban and rural settlements, covering 65 urban and rural areas along the route. By systematically investigating the water cultural relics in traditional urban and rural settlements, and combining the spatial correlation analysis between heritage sites and settlement patterns, this study selects representative water cultural heritage with both diachronic and synchronic research value, aiming to comprehensively investigate water cultural resources and summarize their typological characteristics and value attributes. In terms of demonstration, it focuses on the Turpan Basin in Xinjiang (Fig. 1), which is not only the core hub of the Silk Road, but also a world-famous karez technology model. The selection of Turpan Karez concentration area as the empirical research object is mainly due to its representative role in the dissemination and promotion of hydraulic technology along the ancient Silk Road. The climate in this region is extremely arid, with an annual precipitation of less than 20 millimeters and an evaporation of over 2800 millimeters. Under the special conditions of arid climate and unique topography, the development model that integrates survival guarantee, livelihood development, and ecological sustainability constructed by the local community has been widely recognized by academia as a vivid example of the coordinated evolution of social ecology in arid areas (Memon et al., 2017).

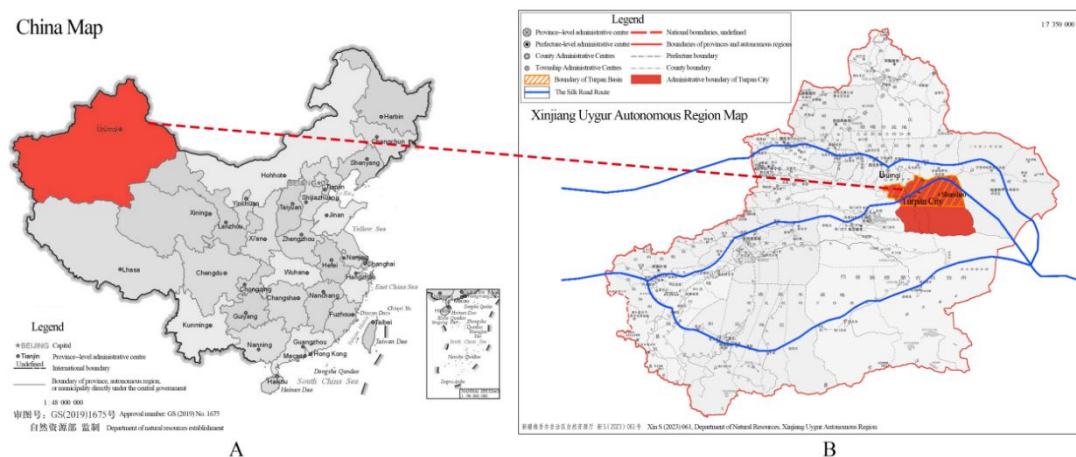


Figure 1. Geographic location of the study area in Xinjiang, China. A: Location of Xinjiang within China; B: Location of Turpan within Xinjiang. Base map adapted from the Standard Map Service of the Ministry of Natural Resources of China (Meng and Zeng, 2025)

Data collection

To ensure the reliability and completeness of the data, this study employs a multi-source data cross-validation approach. The data primarily consists of three categories: historical document data, spatial-attribute data, and field survey data.

Historical Document Sources: This study draws upon multi-source and multi-period documentary materials, including official local gazetteers such as *Annotations on the Chronicle of the Western Regions* (Zhong, 2002) and *Chronicle of Xinjiang* (Wang et al.,

2015); ancient hydraulic monographs such as *Records of Waterways in the Western Regions* (Xu, 1839); historical archives from the Qing Dynasty including *Selected Historical Archives of Xinjiang in the Qing Dynasty* (Bureau, 2012); and advisory reports from the Republican period such as *Report of the Xinjiang Water Conservancy Association* (Yang, 1918). Through critical analysis and cross-verification of these documents, this research systematically investigates the geographical locations, morphological features, and historical continuity of water-related cultural heritage sites along the Xinjiang section of the Silk Road. This process constructs a comprehensive chain of evidence for analyzing the diachronic evolution of these heritage sites.

Spatial and attribute data were derived from *Compilation of Third National Cultural Relics Census of the Xinjiang Uygur Autonomous Region* (Heritage, 2011), which provides the comprehensive geospatial framework, and the specialized monograph *Turpan Karez* (Zong and Chu, 1993), which offers detailed attribute information on this specific heritage system. Together, these sources enable a precise mapping and thorough analysis of the distribution patterns of water-related cultural heritage along the Silk Road.

Data screening and identification criteria: Water culture forms that have historical and functional value, and can deeply reflect the practice of adjusting human water relations or expressing aesthetic needs in the region, will be included in the identification scope. This study combines historical literature review and field investigation analysis to identify three types of water cultural heritage: (1) important water conservancy projects, water conservancy systems, water conservancy figures, and other related heritage clearly recorded in historical texts; (2) Existing water cultural heritage directly related to water and possessing clear physical remains; (3) Intangible water cultural heritage (such as poetry, painting, proverbs, etc.) confirmed through in-depth interviews and continuously passed down among community residents. On this basis, the study extracted heritage site information from text and field survey data and conducted cross validation. Finally, heritage sites were integrated to construct the Silk Road Water Cultural Heritage Database, which covers core fields such as heritage name, type, geographic coordinates, watershed ownership, and protection status.

Field Survey Data: Structured field surveys were conducted from March to August 2023 across 65 settlements in Turpan, Kashgar, and Hotan. Data collection included GPS positioning, photographic documentation, and standardized observational records for sampled sites. Semi-structured interviews were conducted with local residents, community leaders, heritage managers, and tourists. The interview protocol was designed around four core dimensions: heritage perception, current use, conservation attitudes, and developmental expectations. The interviews were audio-recorded and transcribed into textual data for subsequent qualitative analysis.

Data processing and analysis

A mixed-methods analytical framework was implemented. Spatial Analysis (Quantitative): Analyses were performed using ArcGIS 10.8. Kernel Density Estimation (KDE) was used to visualize spatial clustering of heritage sites. Global Moran's I statistic was calculated to assess overall spatial autocorrelation, with significance tested at $p < 0.05$. Heritage distribution was also overlaid with digital elevation models (DEM) and historical route data to examine environmental correlations.

This study will systematically integrate historical documents, the latest archaeological findings, and field survey data related to water culture. Building on this foundation, a semi-structured in-depth interview protocol will be designed and conducted with diverse

groups including local government officials, scholars in relevant fields, community residents, and tourists. The interviews will focus on core issues such as the perceived value of water cultural heritage, strategies for its revitalization and utilization, and the management of cultural resources. This research develops an analytical framework based on the dimensions of ecological wisdom, community identity, and tourism expectations. The framework is employed to systematically elucidate the intrinsic connections and mechanisms linking water cultural heritage to regional sustainable development. This will provide a solid theoretical basis and practical reference for heritage conservation and rural revitalization.

Results

Identification, classification, and spatial pattern

This study, conducted within Xinjiang, identified a total of 1,379 water-cultural heritage sites through a systematic survey completed by the end of 2024. These sites can be classified into a system comprising 2 major categories, 8 subcategories, and 35 basic types (*Table 1*). The distribution is as follows: 131 sites fall under “Formation Foundation,” 40 under “Ancient Urban Construction,” 81 under “Human Settlement Environment,” 450 under “Livelihood System,” 315 under “Daily Life, Techniques & Facilities,” 233 under “Spiritual Homeland,” 18 under “Historical Events & Figures,” and 111 under “Folk Literature & Art.” Spatial statistical analysis revealed a significantly non-random and clustered distribution pattern. Kernel Density Estimation (KDE) further identified three core high-density clusters: The Turpan Basin, the Ili River Valley, and the Kashgar Oasis, collectively forming a “core-periphery” differentiation pattern (*Fig. 2A*).

These high-density zone show strong spatial correspondence with the oasis belts along the northern and southern foothills of the Tianshan Mountains, the periphery of the Tarim Basin, and the Ili River Valley. Aligned with the three historical Silk Road trajectories, they manifest distinct spatial morphologies: an “isolated island” type (Turpan), a “beaded string” pattern (Southern Xinjiang), and “independent clusters” (Northern Xinjiang). The study indicates that the agglomeration of water-cultural heritage is essentially a historical product of the coupling among arid-zone water resource constraints, Silk Road civilizational exchanges, and corridor transportation networks (Wang, 2021). Water resources served as a rigid constraint, while the corridor attributes and nodal functions of the Silk Road jointly shaped and reinforced the spatial clustering characteristics of the heritage (*Fig. 2B*).

In conclusion, the distribution of water-cultural heritage highly aligns with the Tianshan Cultural Corridor and the major Silk Road trade routes (Wang and Zhu, 2022), providing empirical support for the spatial development framework of “nodal radiation, belt linkage, and network coordination” proposed in this study. The specific characteristics and values of the eight categories of water-cultural heritage are elaborated in the following sections.

Natural features are the foundation of water culture inheritance

The Tianshan, Kunlun, and Altai Mountains constitute the primary water source region, giving rise to three major river systems—the Tarim, Ili, and Irtysh Rivers—as well as significant lakes such as Kanas Lake and Bosten Lake. Collectively, they form

the natural foundation for the water-related cultural heritage along the Silk Road. Among these, the Kunlun and Tianshan Mountains function as “water towers”, serving as the headwaters of numerous rivers. The Tarim River acts as the lifeline of southern Xinjiang, sustaining the oasis ecosystems within its basin, while Bosten Lake plays a crucial role in regulating the microclimate and groundwater recharge in the Yanqi Basin. These mountains, lakes, and springs are widely distributed across various oases. Settlements along the routes have relied for generations on this hydrological network, developing diverse material and spiritual cultures. Therefore, these natural heritage features are not only the cornerstone for the formation of water culture but also fundamental components of the regional ecological security framework.

Table 1. This classification system is based on a systematic survey covering 1,379 heritage sites, conducted by the end of 2024. (developed by the author)

| Major Category | Subcategory | Basic Type | Quantity | Representative Heritage (Examples) | Core Value Connotation |
|---------------------|----------------------------------|---|-------------|--|--|
| Tangible Heritage | Formation Basis | Mountains, Rivers, Lakes, Springs | 131 | Tianshan Mountains, Tarim River, Bosten Lake | Decisive ecological foundation for oases, towns and the Silk Road. |
| | Ancient Urban Construction | Urban Water Supply, Drainage Settlements, | 40 | Jiaohe, Niya , Loulan, Qiuci | Core engineering element shaping city location, layout and defense. |
| | Human Settlement Environment | Historical Streets, Courtyard Houses, Gardens | 81 | Turpan Old Town, Kashgar Old Town, "Ostangboyi" Water Street, Hami Royal Palace Garden | Key factor shaping settlement patterns and community life in arid lands. |
| | Livelihood Systems | Hydraulic Engine, Irrigation Systems | 450 | Turpan Karez-Grape Compound System, Qapqal Buh Agriculture System, Ili Royal Canal Sanghiz | Circulatory link supporting oasis agriculture, crafts and commerce. |
| | Daily Life Techniques Facilities | Bridges, Ferries, Watermills, Artifacts | 315 | Papermaking, Uyghur Tea Culture, Ili River Ancient Ferry, Daur "Water Floating" | Carrier of traditional water-related practices, tools and wisdom. |
| Intangible Heritage | Spiritual Homeland | Beliefs, Festivals, Ritual Spaces | 233 | Dragon King Worship, Kazakh River Deity Veneration, Tajik Water Diversion Festival | Source of cultural identity integrated with beliefs and rituals. |
| | Historical Events, Figures | Management Figures & Events | 18 | Suo Li (Han Dynasty), Lin Zexu (Qing Dynasty) | Spatial locale linked to historical water management and figures. |
| | Folk Literature, Art | Myths, Poems, Proverbs, Paintings | 111 | Kunlun Mountains Flood Myth, Flaming Mountain Evil Dragon Legend | Central theme and inspiration for folk legends and arts. |
| Total | 8 | 29 | 1379 | | |

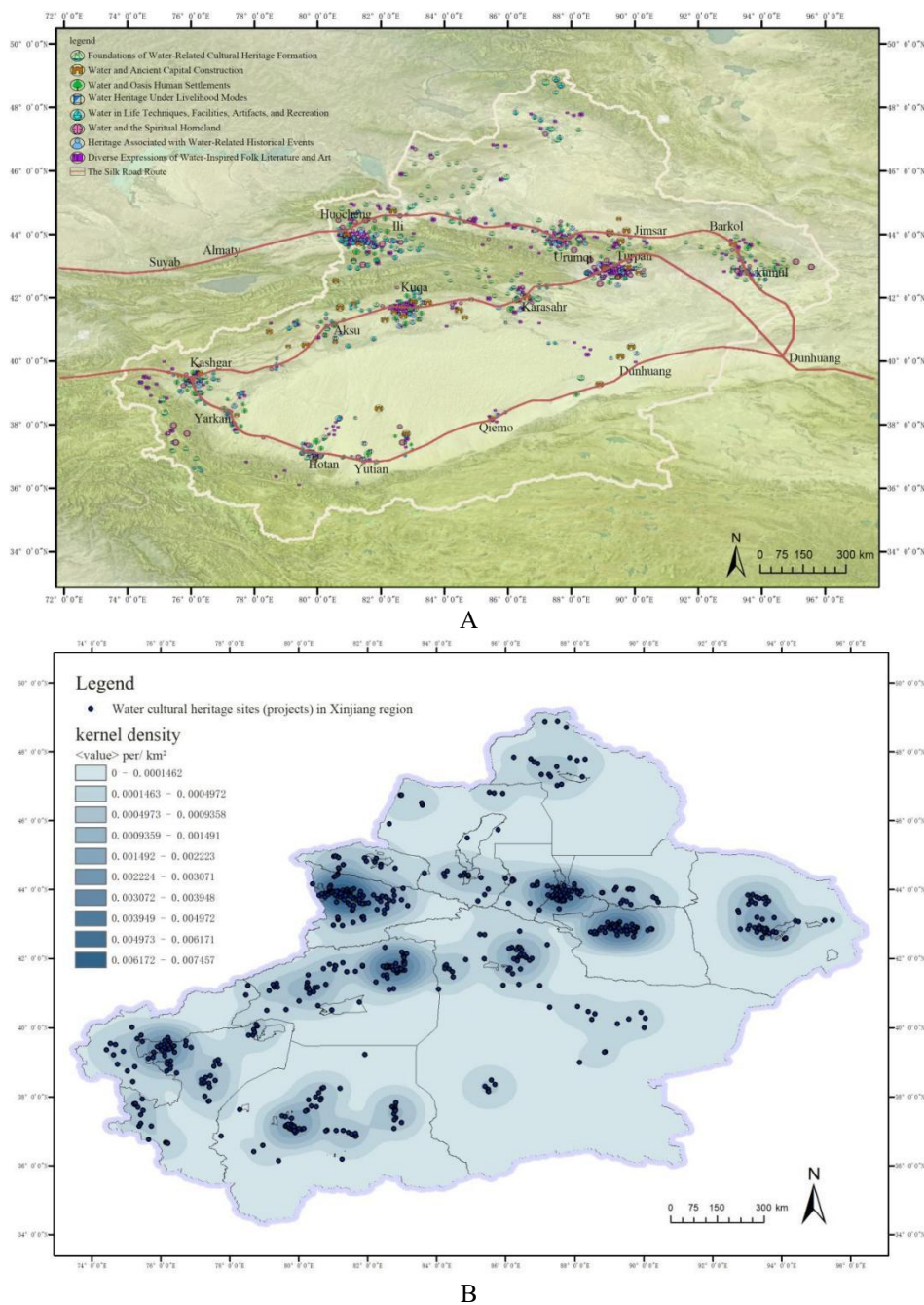


Figure 2. Analysis of the Spatial Pattern Characteristics of Water Cultural Heritage in Xinjiang
 A: Spatial distribution map of water cultural heritage in Xinjiang (adapted based on Google Maps), B: Kernel density analysis of water cultural heritage in Xinjiang (B), (drawn by the author)

The spatial layout of oasis cities was profoundly shaped by both water and ancient capital construction

The surviving remains of urban water supply and drainage infrastructure reflect not only the technological ingenuity and regional adaptations developed to cope with the arid environment historically, but also served as the core infrastructure that ensured urban operation, maintained stability in the Western Regions, and kept the Silk Road

unobstructed (Zhang et al., 2013). These remains bear witness to the planning philosophy of the central dynasties in governing the frontier, while also revealing the convergence of values among multiple ethnic groups in the construction of urban spaces—such as water network organization, street texture, and courtyard greening—thus becoming material carriers of multicultural identity.

A total of 40 ancient city sites closely associated with water systems collectively illustrate the ecological adaptation logic of “emerging due to water and declining due to its absence.” For example: The Jiaohe Ancient City utilized mesa topography and groundwater systems to establish its defense and water supply; the rise and fall of Loulan Ancient City was directly linked to the shift of the Tarim River’s course and the exhaustion of water sources; and the remains of canals and ice cellars at the Niya Ancient City reflect the precise management of scarce water resources by the Jingjue Kingdom. These cases reveal the fundamental constraint that water resource dynamics imposed on the sustainability of settlements. The survival wisdom embodied by these ancient cities in coping with arid-hot climates and stringent water environments also offers significant historical insights for contemporary urban conservation and renewal (Macpherson et al., 2017; Guo and Meng, 2018).

Water and oasis human settlements

Building upon the oasis environment, hydraulic technology and ecological values have collectively facilitated desert development, supported commercial and cultural exchanges in arid regions, and created an exemplary model of integration between oasis and nomadic cultures. The 81 heritage sites of water and human settlements demonstrate the integration of people, water, and space on a micro-scale. The canal network in the Old City of Kashgar (such as the “Wustanbowie” Water Street) shapes the texture of streets and lanes as well as community public spaces (Jiang, 2015); the karez communities in Turpan form a three-dimensional habitat of “underground canals–aboveground houses–courtyard grape trellises,” effectively reducing evaporation and regulating the microclimate; traditional courtyard Laoba (water ponds) serve multiple functions including water storage, cooling, landscaping, and community interaction, embodying low-tech ecological wisdom in arid regions. During interviews conducted in the old town of Turpan in July 2023, local residents widely regarded the karez system not only as a public water infrastructure supporting the human settlement environment, but also as an important carrier of “oasis nostalgia” and the transmission of local ecological wisdom. As an artificial irrigation and drinking water system, part of the Karez water is used for ecological maintenance, achieving multi-level utilization in water allocation. The ancient irrigation canals in Qapqal County, Xinjiang, can be regarded as an exemplary model of harmonious coexistence between human activities and water resources (Pan, 2020; Kong, 2024). To this day, the banks of the canals in this area remain a core space for residents (especially the elderly, women, and children) to fetch water, wash clothes, and exchange information (*Fig. 3A,B*), vividly illustrating the multi-dimensional social significance and cultural continuity of water-centered public spaces.

Water heritage under livelihood modes

Water cultural heritage related to livelihood systems directly reflects human intervention and regulation of aquatic ecosystems. Oasis agricultural water management has developed adaptive landscape engineering through the differential utilization of mountain springs, river water, and karez systems, including practices such as channeling

springs into canals, constructing reservoirs to retain floodwater, and digging wells to irrigate fields. This has given rise to water-related cultural heritage associated with livelihoods dependent on both natural rivers and human-made hydraulic systems, exemplified by oasis crop cultivation and water-powered ancillary industries. For instance, waterwheels, watermills, and irrigation wheel technology. Driven by the development of water conservancy, three representative types of heritage have emerged: first, distinctive agricultural systems (e.g., the karez-grape cultivation complex and Hami's tribute melon cultural system) (Fig. 4A,B); second, water-powered production facilities (including karez wells, waterwheels, and watermills); and third, commercialized craftsmanship (such as winemaking and sanp paper production). Relevant studies indicate that these heritage types collectively reflect the ecological wisdom of human-water interaction (Pan, 2020; Kong, 2024). Together, they reflect the diversity, scalability, and sustainable livelihood wisdom inherent in water resource management across arid regions. From a global perspective, traditional water conservancy facilities are currently facing severe crises in terms of quantity, scale, and public awareness due to various factors. The irrigation-based agriculture in the dry zone has rapidly changed since the 1950s, being characterized by a general decline in the importance of tank systems to the village community and society (Abeywardana et al., 2018).



Figure 3. Ancient canals continue to fulfill ecological functions. A: Waterscape space along the street in Sanqiao Village, Turpan(); B: Current condition of the ancient canal in Liuxing Street, Yining City (photographed by the author in 2023)

Water in daily life: techniques, facilities, artifacts, and leisure

Heritage in this category centers on ecological practices. These practices focus on water conservation and environmental adaptation. Take mulberry bark paper production. It uses locally harvested mulberry bark. The bark is processed with water-powered mills. This forms an artisanal cycle with minimal water use. Along the Ili River stand ferry crossings and bridges. They are transportation infrastructure. They adapt to seasonal water level changes. This design avoids rigid disruption to the river's ecosystem. Altay fur skis are traditional winter travel tools. They make use of snow and ice resources. They embody adaptation to cold wetland environments.

Water cellars, storage tanks and reservoirs are widely scattered along the Silk Road. There are also various water-drawing and water-using vessels. They are crafted from different materials and in distinct shapes. These objects are more than material manifestations of practical wisdom. They also witness technological dissemination. They bear testimony to cross-cultural aesthetic exchanges facilitated by trade (Huang, 2017).

Not only did these heritage sites cater to the daily requisites of oasis dwellers, but local commercial pursuits also offset agricultural deficits—what’s more, they furnished indispensable material backing for merchants and travelers traversing the Silk Road.



Figure 4. Current Condition of Key Agricultural Heritage Sustained by Oasis Water Conservancy Systems. A: Turpan Karez Agricultural System, Xinjiang; B: Hami Melon Cultivation and Tribute Melon Cultural System, Hami City, Xinjiang (Photographed by the author in 2023)

Water and the spiritual homeland

Reverence for water has profoundly influenced social order, manifesting in a rich array of customs and rituals (Fig. 5A,B). The belief in the water god along the ancient Silk Road can be divided into the worship of the original water body, the regeneration of the water worship function of the ox horn, and the establishment of the image of the dragon god (Meng and Wang, 2022). The worship of water deities and related festivals (such as Karez rituals, the Spring Water Festival, and the Water Diversion Festival) are not merely practices for praying for favorable weather, but also serve as crucial cultural vehicles for carrying the collective memory of oasis communities and maintaining local water-related social order (Zhang, 2010).

Specifically, take the “Clear Spring Festival” in Xiamaya Township, Yiwu County, Hami City, as an example. Located in the arid northern foothills of the eastern Tianshan Mountains, water is regarded by the locals as both a symbol of prosperity and a sacred treasure. Field research (April 2023) revealed a clear division of labor during the festival:

men are responsible for dredging water channels, women prepare communal meals and perform music, while children assist with transporting supplies. This activity vividly reflects the well-organized collaborative system formed by the community in response to poor water endowment.



Figure 5. Water-centered festivals. A: Scene of the Clear Spring Festival in Yiwu County, Hami; B: Scene of the Sowing Festival in Taxkorgan Tajik Autonomous County (Photographed by the author in 2023) (photographed by the author in 2023)

Similarly, on the Pamir Plateau, the Tajik ethnic group celebrates their traditional “Xiaogongbahar Festival” on the spring equinox (March 21st) each year. During the ceremony, water officials lead male villagers in breaking ice to channel water and repairing irrigation ditches; women prepare food, children play and fetch water in courtyards, and the elderly gather beside the channels to share meals and pray together (field research, March 2024). This scene clearly illustrates the intrinsic link between water and livelihoods. These rituals not only strengthen collective consciousness in water resource management but also construct a water-centered, sustainable socio-cultural space.

Historically, such practices were common in interactions between the state and the people, as recorded: “In times of drought, not only did common people gather in groups to pray for rain at the Dragon King Temple, but local authorities also held grand ceremonies to implore the dragon for rainfall” (Zhang, 2010). Furthermore, widely circulated water-related proverbs and taboos further reflect people's understanding, cherishment and ecological reverence for water (Liu, 2009), providing a profound cultural foundation for understanding local hydro-social relationships and promoting sustainable water governance.

Heritage associated with water-related historical events

The history of water conservancy development in Xinjiang carries the collective memory of multiple ethnic groups jointly pioneering the frontier. Throughout history, the attention and practices of successive central dynasties regarding water management in Xinjiang ensured the development of agricultural production and improved residents' livelihoods, which in turn gave rise to many notable figures and events in the history of water governance.

Historical archives are not merely tools for deciphering the evolution of water-related issues. They constitute a vital component of the institutional framework for societal water management (Hein, 2020). The evolution of water conservancy in Xinjiang embodies the collective memory of multiple ethnic groups jointly pioneering and developing the borderlands. Water possesses an innate capacity to bind all things together. It seamlessly integrates the manifold values of social environment, economy and culture (Boccaletti, 2020). The emphasis and concrete actions placed on Xinjiang's water management by central dynasties throughout history not only guaranteed agricultural development and improved residents' livelihoods. Such efforts also gave rise to numerous notable historical events and distinguished figures in water governance.

In 74 BCE during the Western Han Dynasty, Suo Li diverted water from the Zhubin River for farm irrigation. As early as the Northern and Southern Dynasties, the progressive principle of "determining land use and crop yields based on water availability" took root in the Turpan region. Hydraulic watermills found their mention in *History of the Song Dynasty*. Following the pacification of the Dzungar rebels in the Qing Dynasty, farmland water conservancy projects gradually spread across the entirety of Xinjiang. Yang Jigu of the Tang Dynasty oversaw the construction of water channels in Xizhou. Every water governance initiative subtly consolidated the ruling foundation of the central regime while propelling social progress and development.

Records of Waterways in the Western Regions compiled by Xu Song in the Qing Dynasty (Zhu, 2010) consistently linked water governance practices closely with border administration, laying a solid groundwork for hydrogeographical research in the region. During his tenure in Xinjiang, Lin Zexu presided over the construction of the Huangqu Canal and Longkou Water Diversion Project, promoted the karez irrigation system. These historical figures are most distinctly characterized by their pragmatic spirit and unwavering loyalty to national interests. Their philosophies and methodologies of water management have exerted a profound influence on later periods, elevating technical practices into a model of political governance. By integrating engineering wisdom and dedication into the legacy of Chinese water civilization, their efforts offer enduring historical insights for contemporary water resource management in arid regions.

Diverse expressions of water-inspired folk literature and art

Literary and artistic heritage embodies the symbolic connection between "water-ecology-culture", vividly mirroring the reverence, admiration and existential yearnings cherished by inhabitants of arid and semi-arid regions for water. which is dominated by the expression of spirituality, provides a reference and guidance for the development and aesthetics of our art today (Zhang, 2021). Along the Silk Road, an extensive implicit cultural landscape revolves around water embracing myths, proverbs and poetry. This landscape has fused into local communities' values and artistic expressions, forging timeless and spaceless cultural bonds.

Preliminary field surveys have documented 111 literary and artistic works focused on water culture. Covering key categories like poetry, murals and novels, these works explore themes including ecological sustainability, allegorical eulogies of water and character cultivation. Water holds a central place in Chinese mythological narratives. Major mountains and rivers often take on divine personifications such as river gods, dragon kings and flood-control heroes. These figures carry the collective memory of how successive dynasties shaped political and cultural landscapes through water governance (Chau, 2005; Ge, 2011). Specific instances include the *Kunlun Mountain Flood Legend* which preserves collective memories of glacial meltwater disasters; the "Jiaohe" imagery in Tang dynasty frontier poetry that frequently links to hardship and warfare thus reflecting garrison soldiers' experiences of extreme hydrological and climatic conditions; and folk tales such as *Measuring Canal Water* and *Water is as Precious as Oil*. These tales use humor to convey community norms and ethical principles surrounding water conservation and equitable distribution.

Such heritage not only depicts natural hydrological phenomena but also represents a significant cultural construction of the relationship between people, water, and land. It provides a vivid vehicle for understanding the ecological concepts and social identity of ethnic groups along the Silk Road.

In-depth interviews on community ecology, livelihood, and cultural perceptions

Based on in-depth interviews conducted in the regions of Turpan, Kashgar, Hotan, etc in 2023, this study reveals that community perceptions of Water Heritage Systems of Xinjiang are multi-dimensional and complex, collectively highlighting the contemporary tensions and underlying values embedded within this heritage system.

First, water-heritage landscapes—karez systems, ancient canals and reservoirs—still irrigate fields, sustain settlements and buffer the ecosystem, yet their performance is slipping as structures age, farmland spreads and water becomes scarcer, pushing maintenance costs onto local households (Zhao, 2024). Interviews show that the customary Mirab arrangement, a community-run scheme for joint upkeep and fair allocation of water, together with family-level maintenance routines, survives but is increasingly stretched.

Overexploitation or neglect can both jeopardize the healthy continuity of traditional karez systems, a phenomenon observed internationally with shared challenges (Khan et al., 2015; Xu, 2025). For instance, Interviewee A mentioned that communal repairs are still organized, but also noted a critical lack of resources and labor, citing insufficient funds and the outmigration of youth (Interview transcript, 13 July 2023). Several interviewees noted that many karez channels now carry less water or have run dry altogether, shrinking the area that once depended on them for irrigation. Meanwhile, farming costs continue to rise. Payments for pumped water, fertilizers and hired labor have surged sharply, eating into the profits growers can still anticipate. As their profit margins narrow, more farmland is left fallow, undermining the karez system's long-standing role as the backbone of local agriculture.

Second, the transformation of the water resource system has profoundly altered human-water relationships and community spaces. This shift is commonly described as a process of pragmatic necessity (Reyxit, 2016). Interviewee D recounted the transition from water abundance to scarcity, noting the ineffectiveness of traditional water-locating knowledge under current conditions (Interview transcript, 24 August 2023). Even after open channels and reservoirs run dry, the trees left in the adjoining shelterbelts still offer

shaded spots where people meet daily to talk, rest, and swap news. This shows the karez heritage is valued not just for moving water, but for shaping a distinctive settlement landscape and the social ties that go with it.

Finally, as a cultural emblem and social tie, the Water Heritage Systems of Xinjiang are widely valued, exposing the central tension between safeguarding them and promoting growth. Interviewees repeatedly called the karez the “lifeline of the oasis” and the bedrock of home, an identity woven through family memory and local attachment. One participant traced how the channel had sustained several generations, voicing a profound bond. A cultural officer likewise framed it as a key marker of local identity (Interview transcript, 2 July 2023). Yet the same community couples sentiment with pragmatism: while eager to see the network revived and ready to supply labour if assisted, they warn against sweeping, unrealistic development schemes (Zhang and Chen, 2023). They press for measured growth and place-based protection, urging that still-working karez be conserved first and then used in ways matched to realistic resource audits.

In conclusion, community perceptions reveal that Water Heritage of Xinjiang is at a critical juncture, transitioning from a dominant productive infrastructure to a complex cultural-ecological heritage. Yet, if only the financial costs and benefits are considered, rehabilitation is often not competitive with drilling new boreholes (Goes et al., 2017). Its future survival depends not only on technical restoration but, more crucially, on establishing a synergistic governance mechanism that can effectively balance ecological conservation, cultural transmission, community well-being, and economic benefits (Xu, 2025).

Constructing a synergistic revitalization mechanism: The Turpan case

Building upon the previous analysis of heritage value, community perception, and ecological wisdom, this chapter takes the Turpan Karez system as a case study to construct a synergistic revitalization mechanism for “Water Heritage Conservation-Rural Revitalization” centered on “ecology first, culture-led, and community benefit.” This mechanism aims to transcend singular engineering or tourism development approaches. Through systematic interventions, it seeks to transform the multifaceted values of the karez into a comprehensive driving force for regional sustainable development.

At the level of ecological environment protection and restoration, the mechanism emphasizes treating the karez as critical ecological infrastructure. Conservation practices should not be limited to dredging and desilting but must be integrated with watershed ecological restoration, promotion of water-saving agriculture, and dynamic groundwater monitoring (Hao et al., 2025). This is to preserve its core functions of regulating the oasis microclimate and safeguarding biodiversity, thereby strengthening the baseline of regional ecological security.

Regarding the development of cultural and tourism integration, the mechanism advocates “revitalization through utilization, in a moderate and orderly manner.” Guided by the principle of “protecting the tangible, inheriting the intangible, and developing the industrial,” it proposes designing in-depth cultural experience products (such as ecological research tours and intangible cultural heritage performances) and creating a “Karez+” public brand. The key lies in directing tourist flows, converting cultural appeal into industrial value-added capacity, while simultaneously using planning controls and visitor management to prevent the negative impacts of over-commercialization and spatial congestion on the heritage itself and community life.

In terms of fostering community well-being, the mechanism focuses on benefit-sharing and stakeholder empowerment. By improving rural infrastructure, optimizing public spaces represented by features like the water storage ponds and establishing community participation systems such as “Water Heritage Stewards,” it ensures that development dividends reach local residents. The core objective is to enable residents to become the main participants, beneficiaries, and evaluators in heritage conservation and utilization. This ensures that heritage revitalization genuinely contributes to improving living environments, enhancing livelihood capabilities, and strengthening cultural identity, ultimately achieving a “triple-win” scenario for ecology, livelihoods, and community life.

Discussion

This study employed an integrated methodology combining historical document analysis, systematic field surveys, and spatial analysis to systematically identify and construct a framework for the water-cultural heritage along the Xinjiang section of the Silk Road. This work accomplishes more than a mere census and inventory of heritage items; more importantly, through a “texts-field” mutual verification research pathway, it deeply excavates the institutional traditions and composite wisdom of arid-land adaptation embodied within the heritage.

From texts to field: identification, systematization, and the mining of composite wisdom in water cultural heritage

The research reveals that historical documents (e.g., Records of Waterways in the Western Regions, Illustrated Gazetteer of Xinjiang) are far from static records; rather, they function as dynamic living archives of “institutional heritage.” The documented hydraulic engineering technologies and water allocation systems (such as the “ditch-head system” and “rotational water distribution by day”), together with the material remains observed in the field (e.g., ancient urban water supply systems, channel relics) and persisting intangible practices (community water management institutions, water-drawing ritual customs), form a robust chain of mutual evidence. This unveils that water management in arid regions constitutes a socio-technical system integrating technology, institutions, and community covenants, whose core logic is a historically validated wisdom of adaptive governance (Özçalik, 2022).

This study examines the heritage framework holistically, analyzing its composite wisdom through three interrelated dimensions: how production adapts to the environment, how society self-organizes, and how ecological balance is sustained. The adaptive intelligence of “determining fields by water and regulating output by water” is reflected in the integration of diverse hydraulic engineering with refined agricultural models, enabling efficient resource use and sustained output under arid conditions. Water resources not only shape the spatial layout of settlements but also deeply influence the organization of public life—the “settling by water” spatial pattern and the “gathering because of water” social relations together transform scarce water resources and rich culture into a generative grammar of collective space.

By systematically identifying, classifying and interpreting scattered records and field evidence, the study converts the ‘local water wisdom’ of the Silk Road into a framework that can be analysed and mapped. This gives an empirical basis for grasping how people along the route once adapted to their environment and turns Traditional Ecological Wisdom into a practical resource (Memon et al., 2017). The result is a historically

grounded set of pointers for managing scarce water, protecting ecosystems and reviving communities in today's arid lands.

Cultural-tourism integration as a synergistic pathway: opportunities, risks, and a re-examination from a community perspective

Drawing on community interview data, this study identifies a distinct “double-edged sword” effect of tourism development on heritage revitalization. Tourism, on one side, can secure funding and public attention for heritage conservation while reinforcing local cultural identity. For instance, residents recognizing the karez as a “symbol of home”. On the other side, insights from community interviews also alert to accompanying risks: heightened pressure on water resources, cultural performativity and uneven benefit distribution (Pueppke, 2021). The “Karez+” model advanced here is more than tourism appended to an ancient system. It weaves spatial planning into themed routes, blends business around eco-science travel, and entrusts heritage stewards drawn from the community. By keeping growth measured and ensuring residents lead in benefit distribution, the framework tries to steer clear of the de-localization and social fragmentation that frequently shadow heritage tourism.

From local heritage to regional strategic resource: elevating the role of water-cultural heritage in the “Cultural Enrichment of Xinjiang”

Spatial analysis shows that water-cultural heritage sites cluster along the Silk Road corridor, implying their origin owes as much to long-distance cultural contact and technology transfer as to local ecological adaptation (Yan et al., 2025). Framing karez and similar systems within the “Silk Road Cultural Belt” and the “Chinese National Community” lifts their meaning from local ecological know-how to a symbol of regional identity and inter-civilizational dialogue. This shift helps secure policy backing and funds under the “cultural enrichment of Xinjiang” initiative, while also moving conservation beyond technical fixes to become a concrete means of fostering ethnic interaction, exchange and integration, ultimately strengthening cultural confidence.

Methodological innovation and theoretical extension: the “Rediscovery” of heritage from a social-ecological systems perspective

This study employs a mixed-methods approach, particularly the integration of GIS spatial analysis and in-depth interviews. This not only systematically identifies the types and distribution of heritage but also reveals the underlying socio-ecological interactive logic. The results section shows that the karez system possesses ecological functions such as microclimate regulation and support for agricultural biodiversity at a micro scale, while at the community level, it carries collective memory, social networks, and cultural identity. This supports the theoretical proposition of viewing water-cultural heritage as a “social-ecological system” and resonates with the international trend in heritage studies towards “liveliness” and “systematicity” (Wang, 2018). Recent studies indicate that research on Nature-based Solutions addressing societal challenges such as water security remains peripheral on a global scale (Dunlop et al., 2024). Building on this, the synergistic pathway of “heritage conservation-community governance-industrial revitalization” proposed in this study can be regarded as a form of heritage-based ecological engineering, providing a culturally sensitive practical example for implementing Nature-based Solutions (NbS) in arid regions.

Conclusion

This study, focusing on the water-cultural heritage of the Xinjiang section of the Silk Road, particularly the Turpan Karez system, has successfully constructed and elucidated a synergistic revitalization mechanism linking “ecological conservation, cultural transmission, community development, and industrial revitalization (Meng and Wang, 2022).” The main conclusions are as follows:

Focusing on the water-cultural heritage of the Xinjiang Silk Road, this interdisciplinary study yields three key conclusions. First, this heritage forms a comprehensive tangible-intangible system, spatially clustered along the Tianshan Corridor, which reflects and reinforced the historical water-road coupling. Second, hydraulic systems like the karez transcend mere technical adaptations; they are complex social-ecological systems integrating ecology, governance, and identity, whose sustainability hinges on synergistic maintenance of these functions. Third, we propose a “Karez+” synergistic revitalization model, guided by “ecology as the foundation, culture as the thread, and community as the core.” This model, operationalized through themed routes and participatory mechanisms, offers an actionable “Turpan Paradigm” for heritage-led rural revitalization, with potential for wider arid-region application.

This study proposes a framework linking water-cultural heritage with rural revitalization, yet limitations remain. Future work should: (1) Establish long-term monitoring to quantify the hydrologic, livelihood, and cultural impacts of this model for adaptive management; (2) Develop smart management platforms using digital twin and AR technologies for integrated heritage monitoring and visitor engagement; (3) Conduct cross-regional comparative studies in areas like Southern Xinjiang to refine scalable frameworks applicable to holistic and systematic conservation and utilization of Silk Road water culture. The ultimate aim is to ensure heritage evolves sustainably in modern society. Realizing this depends on continued research, inclusive governance, and community wisdom.

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