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Water Resource Management in the Hani Terraced Agroecosystem from an Ethnoecological Perspective: A Postprint

Authors: Yang Jingbiao, Xia Jianxin, Feng Jinchao, Guo Luo, Shi Sha, Xue Dayuan

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Abstract

As one of the typical models of mountain agriculture, the Hani terraced fields have become a World Cultural Heritage site and a Globally Important Agricultural Heritage System due to their long history and cultural landscape. The success of the Hani terraced field agricultural ecosystem lies in effective water resource management, yet a comprehensive analysis of its institutional construction and ecological cultural connotation remains to be perfected. Based on an ethnoecological perspective and integrating theories and methods from natural and social sciences such as ecology and ethnology, this study interprets the institutional construction of water resource management and its ecological cultural connotation in the Hani terraced fields. Research indicates that the Hani community has perfectly solved the challenge of uneven spatiotemporal distribution of water resources through institutional construction centered on water conservation and allocation, while the ecological cultural system built upon the pillars of migration culture, religious culture, customary law, and traditional knowledge constitutes the ecological cultural connotation that safeguards the construction and effective implementation of water resource management institutions. The institutional construction and ecological cultural concepts of water resource management in the Hani terraced fields hold important reference value for addressing climate change, promoting sustainable agricultural development, and perfecting the theoretical system of water resource management institutions in China.

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Full Text

Water Resource Management in the Hani Rice Terraces Agro-Ecosystem from an Ethnoecological Perspective

YANG Jingbiao, XIA Jianxin, FENG Jinchao, GUO Luo, SHI Sha, XUE Dayuan College of Life and Environmental Sciences, Minzu University of China, Beijing 100081, China*

Abstract

The Hani Rice Terraces represent a typical model of mountain agriculture and have been successfully inscribed on the UNESCO World Heritage List and designated as a Globally Important Agricultural Heritage System (GIAHS) by the FAO due to their long history and cultural landscape values. Previous studies have demonstrated that the success of the Hani Rice Terraces agro-ecosystem lies in its effective water resource management. However, a comprehensive analysis of the institutional construction and ecological cultural connotations underlying this management system remains incomplete. From an ethnoecological perspective, this study integrates theories and methods from ecology, ethnology, and other disciplines to analyze the institutional framework and cultural dimensions of water resource management in the Hani terraces. The results indicate that the Hani community has established a water resource management system centered on two core elements—conservation and distribution—that effectively addresses the challenge of temporally and spatially uneven water distribution. Furthermore, an ecological culture institution supported by migration culture, religious culture, customary law, and traditional knowledge provides the cultural foundation that ensures the establishment and effective implementation of the water resource management system. This research offers valuable insights for adapting to climate change, promoting sustainable agricultural development, and improving theoretical frameworks for water resource management systems in China.

Keywords: Hani Rice Terraces; ethnoecology; water resource management; traditional knowledge; customary law

1. Study Area Overview

This study focuses on Xinjie Town, Panzhihua Township, and Niujiaozhai Township in the Hani Rice Terraces protected area of Yuanyang County, Honghe Hani and Yi Autonomous Prefecture, Yunnan Province. This region encompasses the core protected area of the Honghe Hani Rice Terraces cultural landscape World Heritage site, where the terrace ecosystem remains intact and representative. Xinjie Town and Panzhihua Township include important scenic areas such as

Bada and Laohuzui, while Niujiaozhai Township serves as a major grain production area.

The study area is located in the southern Ailao Mountains and features deeply incised mountainous terrain with almost no flat land, with slopes generally exceeding 15°. The region has a mountainous monsoon climate characterized by distinct dry and rainy seasons and vertical climate zones. According to meteorological data from Yuanyang County Station (located in Xinjie Town) and various observation sites, the area has an average annual temperature of 16.4°C, with 180 days per year above 20.6°C and 1,770 hours of annual sunshine. Average annual precipitation is 1,397.6 mm, with 1,184.1 mm (84.8%) falling during the rainy season. The total area of the research region is 417.65 km², accounting for 19.1% of Yuanyang County' s territory and 28.5% of its terrace area.

Geographically, Xinjie Town is situated in central Yuanyang County (102°40 -102°53 E, 23°03 -23°14 N), with elevations ranging from 685 m to 2,878.3 m. Panzhihua Township lies in southern Yuanyang County (102°38 -102°49 E, 23°01 -23°06 N), with elevations between 480 m and 2,149.8 m. Niujiaozhai Township is in western Yuanyang County (102°38 -102°42 E, 23°03 -23°11 N), with elevations from 650 m to 2,662 m. In 2011, the region' s total grain output was 23,551 tons with a per capita grain possession of 360 kg. The total cultivated land area was 4,089.53 hectares, with grain output of 13,970 tons and per capita possession of 420 kg.

2. Data Sources and Methods

2.1 Data Sources Basic data for this study were derived from the Second National Land Survey reports, including *Land Use Status (2006)* and *Yunnan Province Yuanyang County Forest Resources (2011)*, which provide data on forest area, cultivated land, and village construction land. These data were verified through field surveys and interviews.

2.2 Key Informant Interviews Semi-structured interviews were conducted with relevant officials from the Yuanyang County Government Office, Land and Resources Bureau, Ethnic and Religious Affairs Bureau, Terraces Management Bureau, County Chronicles Office, township governments, as well as village committee members and villagers.

2.3 Participatory Rural Appraisal Participatory Rural Appraisal (PRA) methods were employed, inviting villagers (direct users and managers of various natural resources), village committees or villagers (managers and decision-makers for general village affairs, typically respected elders who play important roles in coordinating and decision-making), religious clergy (Migu and Mopi, who play important roles in village and household rituals), and local county and township government staff (outsiders who can significantly influence village affairs) to participate in the assessment. This approach helped identify the positions and roles of various stakeholders in water resource management [4].

3. Water Resource Management System in the Hani Rice Terraces

Uneven temporal and spatial distribution of water resources is the primary challenge facing water resource management in China [15], and the Hani Rice Terraces agro-ecosystem is no exception. Temporal unevenness results from the region' s monsoon climate, with over 84% of annual precipitation concentrated in the rainy season, while spatial unevenness is attributed to significant elevation differences in the mountainous terrain. To address this challenge, the Hani community has established a water resource management system centered on conservation and distribution, ensuring the stability and sustainability of the terrace agro-ecosystem. Water conservation management primarily solves temporal distribution issues, while water allocation management addresses spatial distribution challenges [4].

3.1 Water Resource Conservation Management The Hani Rice Terraces represent both a typical agroforestry ecosystem and an artificial wetland system. Water conservation mainly includes forest water storage, reservoir/pond storage, and terrace water storage.

Forest Water Storage: Forests, their understory vegetation, and soils have exceptional water conservation capacity [17]. The average soil water storage capacity in the Hani terrace ecosystem' s forests reaches 2,589 m^3/hm^2, with soil retention storage of 2,173 m^3/hm^2. The forest area in the three townships of the study region is 16,605.85 hm^2, providing a perennial water conservation volume of 56,259,000 m^3 and a maximum storage capacity of up to 160,358,000 m^3.

Reservoir and Pond Storage: Hani communities have constructed numerous ponds within or at the edges of forests, and a series of reservoirs have been built under government leadership. Due to the large number of existing ponds in the Hani terrace ecosystem forests, it is difficult to calculate their storage capacity; therefore, this study uses only reservoir capacity as the basis. The study area concentrates all reservoir capacity in Yuanyang County, with a total capacity of 7.044 million m^3. Since actual reservoir/pond storage would be higher [4], these facilities store water during the rainy season, intercept surface runoff, prevent flash floods, and provide water sources during the dry season [18].

Terrace Water Storage: The Hani terraces themselves constitute a massive invisible reservoir. Terrace ridges are generally 0.4 m high, with water depth typically maintained at 0.2 m. Calculating only the water surface area of 8,016.76 hm^2 of terraces, the perennial water retention volume is 16,033,500 m^3, with maximum storage capacity reaching 32,067,000 m^3.

The Background of Reservoirs and Pools in Research Area

The total perennial water conservation volume of forests, reservoirs/ponds, and terraces in the study area is 95,770,000 m^3, which ensures constant water availability throughout the year and enables the Hani terrace agro-ecosystem to

successfully resist extreme drought conditions. The maximum storage capacity of 139,136,000 m^3 allows the terraces to effectively mitigate potential flood disasters from heavy rainfall. Through water conservation management, the Hani terrace agro-ecosystem maximizes water resource preservation during the rainy season and ensures continuous water supply during the dry season [4].

3.2 Water Resource Distribution Management The Hani community attaches great importance to water resources, viewing them as property, and has established a comprehensive water resource distribution management system [4]. This system primarily includes ditch management and allocation institutions.

Ditch Management: The Hani terrace ecosystem features numerous and intricate ditches that not only channel water from mountain forests to the terraces but also connect streams with terraces, terraces with other terraces, and terraces with river valleys, forming smooth water flow channels. Through ditch management, water resources are delivered to terraces and villages, solving spatial distribution unevenness while effectively eliminating hazards such as landslides and floods. The crisscrossing ditches also serve as flood drainage channels during the rainy season. The Hani people have established long-term ditch management mechanisms through customary laws and village regulations developed through long-term production practices, ensuring effective water resource utilization [4].

The ditch construction in Hani terraces fully utilizes topographic advantages and follows contour lines, reducing earthwork while preventing soil erosion [4]. In Yuanyang County, there were 1949 骨干沟渠 (main ditches) in 1949, with total length reaching 123.98 km by 2005. The effective irrigation area is 6,000 hm^2, drought- and flood-resistant area is 3,188.26 hm^2, and actual irrigation area is 8,213 hm^2, accounting for 39.77% of total terrace area.

Ditch management is reflected in two aspects: property rights and daily maintenance. Based on the long-standing Tusi system, most main ditches were constructed by local Tusi who mobilized labor, with ownership belonging to the Tusi. Farmers had to pay grain as water fees according to their output. Some main ditches were collectively excavated by one or several villages and belonged to these villages collectively. Field ditches were dug by villagers themselves and belonged to individuals. After the founding of the People' s Republic of China, particularly following land reform, ditches formerly owned by Tusi became collectively owned, with each village inheriting management and usage rights for traditionally utilized ditches. Locally government-built ditches are managed by relevant villages [4].

The Background of Irrigation Canals and Ditches in Research Area

The Hani community has established a "ditch head" system. Ditch heads are responsible for daily ditch maintenance, supervising water distribution, and reporting water theft or disputes to the Tusi or village heads for resolution. Only morally upright individuals can serve as ditch heads, a position that carries both remuneration and honor. Ditch heads can serve consecutive terms or be elected

annually, with satisfaction determining reappointment [19-20]. The river chief system implemented nationwide in 2017 shares many similarities with the Hani ditch head system.

Allocation System: The water allocation system is the foundation of the Hani community' s water resource distribution, embodying principles of fairness and justice. Wooden-notch water division is applied in two contexts: between villages and within villages. Inter-village allocation is based on the proportion of labor and materials contributed during main ditch construction, with wooden notches set at village junctions to control water flow to each village. Intra-village allocation among households follows similar rules. The fairness of this system lies in the matching of water volume with terrace area, as villages/households with less labor contribution typically have smaller terrace areas in agricultural societies. The Hani community has established strict customary laws to maintain the authority of the wooden-notch system. Blockages caused by natural factors (e.g., fallen leaves) require maintenance, while deliberate alteration of notch width, blocking outlets, or moving wooden bars to harm others' interests results in fines or other penalties [20]. Wooden-notch division ensures minimum water requirements for all terraces during water scarcity periods and drought seasons, significantly reducing water allocation conflicts [4].

4. Cultural Connotations of Water Resource Management in the Hani Rice Terraces

The success of the Hani terrace water resource management system lies in its rich cultural connotations, primarily manifested in a cultural system supported by migration culture, religious culture, customary law, and traditional knowledge.

4.1 Migration Culture Numerous oral migration epics preserved to this day, such as *Hani Ape Cong Popo* and *Yaniya Gazanga*, document the Hani people' s long migration history [21-22]. Through prolonged migration, the Hani adapted to diverse natural environments and interacted with multiple ethnic cultures, eventually settling in mid-mountain areas unsuitable for large-scale agriculture and developing highly adaptive farming cultures [23]. Avoiding inter-ethnic wars and intra-ethnic conflicts over land resources was undoubtedly a major factor driving Hani migration [22]. The "fenzhai" system—where new villages are established when the round-trip to the farthest terraces exceeds half a day —controls village population size and represents a continuation of migration culture [24]. Among 28 natural villages, 26 have populations under 500, with the advantage of facilitating public affairs and natural resource management while preventing overexploitation through rational spatial distribution.

4.2 Religious Culture The Hani people practice primitive nature-based religion, with animism as its ideological foundation and soul immortality and divine protection as its core beliefs, forming a system of spirit worship and ecological ethics emphasizing harmony between humans and nature [25]. Nature worship

objects are extensive, with forest worship being most important [20]. Besides celestial bodies and flora/fauna, the Hani deify rice and other elements, with this concept of harmony permeating daily production and life, playing a crucial role in maintaining the stability of the Hani terrace agro-ecosystem [4].

4.3 Customary Law The Hani have a long tradition of customary law—behavioral norms with de facto legal validity, independent of state law, based on social authority and organizations with certain coercive power. Although not codified, customary law is implemented through clan relationships, village meetings, and other mechanisms, enforced not through violent coercion but through cultural identity and belief factors [26]. Villages are the basic units for customary law generation and implementation. While many Hani villages have formulated written village regulations based on national laws, these are not widely understood by villagers and essentially function as customary law, demonstrating the vitality of customary law in Hani communities, particularly in forest protection and ditch management [26].

4.4 Traditional Knowledge Traditional knowledge (also called traditional ecological knowledge or indigenous knowledge) refers to the experiences, practices, and knowledge created and accumulated by indigenous peoples and local communities regarding biodiversity conservation and sustainable use [27-32]. The Hani have rich traditional knowledge that plays important roles in maintaining terrace ecosystem balance and promoting agricultural production [33].

Land Resource Management: Hani land management is evident in two aspects: (1) creating the forest-village-terrace-water system through comprehensive utilization of climate, hydrology, and soil; and (2) rational classification management of land use types. Using current national land use classification standards, land types in the study area include cultivated land, orchard, forest, grassland, construction land, transportation land, water areas, and other land. The overall proportions are 34.28%, 4.17%, 43.88%, 2.80%, 1.87%, 0.82%, 0.65%, and 11.53%, respectively. Cultivated land is divided into paddy fields (terraces with year-round water, accounting for 45.81% of total land area, slightly exceeding forest area) and dry land (sloping fields and non-perennial terraces, mostly terrace ridges). Maintaining such a high proportion of cultivated land in mountainous areas is closely related to rational layout of various land use types, particularly forest distribution and water conservation management [4].

Traditional Forest Management: Hani forest management includes strict protection and sustainable utilization. Sacred forest culture and customary law are important means for strict forest protection. Each Hani village has at least one sacred forest protected by customary law. Despite policy impacts that reduced Yuanyang County' s forest coverage from 56% in the 1950s to 11.6% in the 1980s, sacred forests were largely preserved, ensuring structural and functional integrity of the terrace ecosystem [4]. Sustainable utilization involves functional zoning of forests for economic, social, and ecological purposes, with

targeted management of canopy and understory vegetation. Forests are divided into sacred forests and water source forests based on ecological function, and into village collective forests and household contract forests based on ownership, with the latter providing timber, fuelwood, and non-timber forest products [4,34].

Status of Land-Use Type on Administrative Village in Research Areas

Agricultural Biodiversity Conservation: Agricultural biodiversity is crucial for Hani community socioeconomic development and terrace ecosystem balance [35]. Its richness is manifested in: (1) crop diversity—Yuanyang County grows 152 crop species including 89 food crops, providing diverse food sources and enabling intercropping to maximize limited land resources; and (2) rice variety diversity—Yuanyang grew 195 traditional rice varieties in the 1990s, with 48 currently planted (including 34 traditional varieties). These diverse germplasm resources adapt to different elevations and conditions, with traditional varieties growing above 1,400 m while hybrid rice is limited to below 1,400 m, effectively preventing and resisting extreme weather events [4].

Phenological Calendar: Timing is critical in agriculture as adverse climate conditions at any growth stage can cause yield loss. The Hani use a phenological calendar system developed through long-term terrace farming experience, observing natural phenological changes to schedule farming activities, rituals, and daily life. The calendar divides the year into three seasons: cold, warm, and rainy, with 360 days for production and 5 days for festivals [20]. This traditional calendar effectively avoids damage from climate anomalies, particularly important in mountainous areas where microclimates vary significantly over short distances due to elevation and topography [4].

5. Discussion

Mountain agriculture can be broadly categorized into slash-and-burn/shifting cultivation, slope/terrace dryland farming, and terrace rice cultivation, with terrace rice cultivation having the highest output efficiency [37]. While shifting cultivation is limited by declining fertility and slope/terrace dryland farming by water constraints, terrace rice cultivation effectively solves both problems. The success of the Hani terrace agro-ecosystem benefits from its unique geographic and climatic environment, with effective water resource management being key. However, the institutional construction and cultural connotations of water management are equally important and closely related to local communities' traditional knowledge.

Besides the Hani terraces, other renowned terrace systems include Ziquejie Terraces in Hunan, Longji Terraces in Guangxi, Congjiang Terraces in Guizhou, and the Banauwe Rice Terraces in the Philippines [38-39]. The Banauwe Terraces were inscribed as World Heritage in 1995 but faced large-scale destruction due to deforestation-induced soil erosion, giant earthworm damage, and younger generations changing livelihoods, leading to their inclusion on the endangered heritage list [40]. After years of effort by government agencies and local com-

munities, they have been revitalized [41-42], demonstrating both the sensitivity of mountain agro-ecosystems and the resilience and adaptability of local traditional knowledge.

Facing unprecedented economic development, social-cultural transformation, and global climate change, mountain agriculture and all agro-ecosystems confront complex challenges: rapid livelihood changes, strong external cultural impacts, accelerated tourism development, and intensifying climate change [43]. The Hani terrace agro-ecosystem may serve as a model, with traditional knowledge potentially playing more important roles, while ethnoecology—using interdisciplinary theoretical approaches and multi-dimensional perspectives—may provide an effective pathway forward.

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