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Original Research

Research on the Resilience Evaluation of Rural Ecological Landscapes in the Context of Desertification Prevention and Control: a Case Study of Yueyaquan Village in Gansu Province

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Abstract

The China Desertification Ecological Restoration Project has effectively curbed the problem of soil desertification in Northwest China, and improved the ecological environment and landscape pattern of the Dunhuang Desertification Control Area. As the birthplace of Dunhuang culture, the ecological landscape of Yueyaquan Village shows strong sensitivity to disturbances, and in order to improve the ecological landscape resilience, an ecological landscape resilience evaluation system for desertification control villages was constructed from three levels: ecosystem, engineering system, and cultural traditions, and the results show that: (1) villages in the context of desertification control are difficult to resist the damages brought by natural disasters, and therefore the ability to resist determines the key factor of the ecological landscape resilience of villages. resilience level. (2) Through the empirical analysis of the ecological landscape system, engineering system and cultural system of Yueyaquan Village, it is found that the engineering system of the village has high resilience, the ecosystem resilience is average, and the resilience of the cultural system is weak, which reduces ecosystem resilience. The research results can guide subsequent improvement strategies for ecological landscape construction and provide new thoughts and ideas for rural environmental renovation and resilience enhancement.

Keywords: resilient ecological, desertification management, rural landscape, ecological rehabilitation

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Introduction

Degraded lands are characterized by arid, semi-arid, and partly semi-humid regions, where the surface layer consists of sandy and gravelly soils [1]. These lands are predominantly affected by natural factors, such as drought, water scarcity, wind, and geological effects. Additionally, anthropogenic factors, including overgrazing, excessive deforestation, overexploitation of water resources, and irrational land use, contribute to the loss of vegetation cover [2, 3]. This exposure of the soil surface leads to the formation of wind-eroded soil under specific climatic conditions. The primary surface layer of degraded land is composed of sandy and gravelly soils resulting from wind erosion. Furthermore, the combined effects of global climate change, geological factors, and unsustainable land practices have worsened land siltation, particularly due to increased urbanization and rapid social productivity growth in recent years. As of 2016, approximately 17.93% of Chinese territory and 19.81% of the land area are at risk of sandblasting [4]. The rapid spread of sandblasting poses a significant threat to China's ecological security, farmland quality, living environment, and sustainable economic and social development. Therefore, it is crucial to take immediate action to combat desertification and ensure its effective control. Desertification is a significant issue that China is currently grappling with. This problem poses a serious threat to China's economic and social development due to its extensive reach and the substantial damage it causes [5-6]. Deserts are areas where the ground is entirely covered with sand, vegetation is scarce, rainfall is minimal, and the air is dry. China's desert area spans approximately 700,000 km^2, or 1.28 million km^2 when including the Gobi Desert, which alone covers over 500,000 km^2 [7]. This accounts for roughly 13% of the country's total land area. The Northwest Arid Zone of China, home to eight major deserts, represents the most concentrated desert region in the country. Despite these challenges, China has made commendable efforts to combat desertification, yielding positive results. According to the findings of the Sixth National Survey on Desertification and Sandification, the national desertified and sandy land area has consistently decreased over four monitoring periods [8, 9]. It is projected that between 2019 and 2023, the desertified land area will decrease by 50,000 square kilometres, and the sandy land area will decrease by 43,300 square kilometres. However, the vast rural areas of north-west China encounter various challenges, such as the arduous task of consolidating governance efforts and the lack of long-term sustainability [10]. These issues arise primarily from the detrimental effects of desertification and conflicts arising from human-land interactions.

In 2017, the Chinese government introduced a new approach to managing rural environments in areas affected by desertification. They proposed a rural revitalization strategy with the goal of modernizing agriculture, improving rural areas, and enhancing living conditions [11, 12]. Rural landscape ecology encompasses ecological, technical, and socio-cultural aspects, aiming to provide a suitable living environment and promote sustainable and diverse development. However, villages developed in desertification control areas pose a significant threat to the landscape pattern of rural human-land systems, as they are susceptible to external influences [13]. Hence, it is crucial to study how to enhance the rural landscape in cold and arid regions, considering ecological, social, and environmental factors. The concept of "resilience," introduced by Canadian ecologist Holling in 1973, offers a new perspective on studying the adaptability and recovery ability of rural landscapes in desertified lands [14]. Resilience has gradually been incorporated into landscape planning and risk management to identify potential risks and maintain the operational capacity of landscape systems. It refers to the ecosystem's capacity to recover rapidly without collapsing in the face of disturbance. In recent years, the vulnerability of rural areas in reservoir regions has become increasingly evident due to global climate change and the frequency of natural disasters. Assessing landscape resilience by considering potential risks and systemic resilience of landscape systems can effectively evaluate the effectiveness of managing rock desertification. Moreover, it can enhance the response of village systems to land degradation in desertified areas by optimizing coordination of landscape patches based on the principles of landscape ecology [15, 16]. Therefore, it holds great potential as an effective measure for desertification management.

Currently, research on landscape resilience is steadily increasing, with a focus on defining and characterizing resilient landscapes, as well as exploring their relationship with climate and implementing effective management strategies. However, the complex nature of factors influencing landscape resilience has resulted in a limited number of empirical studies assessing it. Quantitative assessments of rural resilience often overlook the crucial role of rural landscape resilience in overall rural development [17, 18]. These assessments predominantly concentrate on dynamic changes in village livelihoods and individual resilience adaptability. Therefore, there is a pressing need for a comprehensive assessment framework that specifically addresses the resilience of desertified rural landscapes. This framework should analyze the systemic adaptability and resilience of human-land landscape systems in the face of natural disaster disturbancesl environments. In this study, an analytical framework has been developed to enhance the resilience of rural landscapes in desertified regions, focusing on the context of desertification in cold and arid areas [19, 20]. The framework is based on the concept of resilience proposed by the United Nations International Agency for the Reduction of Disaster Risk [21]. To validate this framework, an empirical study was conducted in Yueyaquan village, located in Dunhuang City, Gansu Province.

Research on the Sustainability of Desertification-Affected Areas for Ecological Enhancement in Yueyaquan Village emphasizes ecological equilibrium strategies. Furthermore, it underscores that desertification constitutes a worldwide concern. Drawing from Yueyaquan Village's experiences in desertification mitigation, collaborative sharing and intensified international cooperation are advocated to collectively confront desertification challenges and advance global ecological amelioration.

Yueyaquan Village in Gansu serves as a representative case for investigating ecological resilience in the context of global desertification prevention and control. Despite its typical desert environment and strong attraction to thousands of tourists visiting for Dunhuang culture, the village faces significant pressures on its ecological, engineering, and cultural systems. The survey data obtained can effectively address the threats posed by desertification disasters and the influx of tourists, thus enhancing the village's disaster preparedness. These challenges are not unique to Yueyaquan Village alone, as many villages in desert environments worldwide confront similar issues. Therefore, there is a pressing need for a universal, straightforward, and scientifically sound approach to bolster resilience. Conducting research on this type of ecological resilience can provide valuable insights for the sustainable ecological landscape management of other tourist villages in desert regions across the globe.

Experimental

Framework for evaluating the resilience of rural ecological landscapes in the desertification management area of Yueyaquan Village.

Resilience, originally defined and applied in the field of ecology by Holling, encapsulates the remarkable ability of a system to maintain its fundamental functions and structure in the face of disruptions and pressures [22]. This concept serves as a crucial tool for understanding complex adaptive systems and underpins a wide range of research efforts exploring the interaction between human and natural systems [23]. For instance, Connell has proposed an assessment framework for resilience that extends its application to land management, food security, and agro-ecosystems. Similarly, Adger's work delves into the intricate relationship between society and ecosystems, introducing the concept of socio-ecological resilience and conducting empirical investigations [24, 25]. Within this domain, scientists effectively grasp and evaluate resilience across three key dimensions: buffering capacity, self-organizing capacity, and learning capacity.

Kusumastuti has developed a framework for assessing the resilience of disaster-prone areas to natural hazards, defining resilience as the ratio of preparedness indicators to pressures indicators. Her research focuses on the social and environmental recovery of complex villages, with the eventual implementation of spatial planning [26]. Due to the unique environmental challenges of desertification in Yueyaquan Village, located in Gansu Province, the villages' ability to prevent and control desertification impacts the degree of destruction caused by soil erosion and desertification in rural landscapes. pressures indicators plays a crucial role in the resilience of the village's ecological landscape, referring to the sensitivity and low adaptive capacity of the village's own system, which makes the landscape susceptible to external disturbances. Therefore, this paper defines the ecological landscape resilience of Yueyaquan Village as the ratio of the desertification control index to the pressures indicators. As Equation (1)

$$\text{Resilience Index(I)}=\frac{Preparedness\ Index(Xi)}{\text{Pressures}\ Index(Yi)} \quad (1)$$

The resilience index (I) represents the resilience of the desertified rural ecological landscape and is calculated as the ratio of the readiness index of the rural landscape to its own pressures index in response to desertification. When RI is greater than 1, it signifies that the rural landscape has the ability to withstand the pressures of desertification. This is achieved through a combination of ecosystem and human interventions in response to the threat of desertification. It indicates that the natural resources, social organization, and engineering construction within the landscape can effectively cope with the disturbances caused by desertification, showcasing strong resilience. On the other hand, when RI is less than 1, it suggests that the control measures for desertification are insufficient to handle external pressures, leading to weak resilience in rural landscapes.

This research constructs an evaluation system for rural landscape resilience, considering three essential aspects: rural ecosystems, engineering and construction systems, and sociocultural systems. From field surveys, Yueyaquan Village is frequently affected by desertification disasters, leading to sandstorms that inundate farmland, cause casualties among villagers, and damage houses. Monitoring ecosystem indicators can enhance the ecosystem and landscape stability, reducing the occurrence of disasters. To achieve this, ecological pattern and management indicators should be established. The allure of Dunhuang culture attracts tourists from around the world, resulting in a significant population influx that demands more robust engineering system services. By enhancing the monitoring of engineering system indicators, we can improve tourists' experiences and minimize ecological pollution caused by tourism. These indicators should focus on building facilities, water-saving facilities, fire-fighting facilities, road facilities, and sand control facilities. Furthermore, global climate change has intensified in recent years, affecting Dunhuang cultural relics through temperature, humidity, and natural disasters. Local people often lack awareness of cultural protection, leading to significant damage and even disappearance of cultural heritage. To comprehensively protect the cultural relics of Yueyaquan Village and ensure cultural system sustainability and development, monitoring indicators should be established for cultural disaster erosion and cultural landscape protection. It investigates the ability of rural landscapes in these dimensions to prevent and control desertification, thereby resisting disturbance pressures [27, 28]. The resilience formula elucidates that the preparedness of the rural landscape for desertification determines its level of resilience, providing a quantitative explanation for implementing desertification control measures [29]. Assessing the resilience of desertified rural landscapes aims to identify the threats and opportunities they face in relation to desertification. By comprehending the ecological pressures on rural landscapes, the functions of their systems, and their intricate interactions, it establishes a foundation for enhancing the resilience of rural ecological landscapes and serves as a basis for their improvement [30].

Research Methodology

Research Area

The desertified area in northwest China presents one of the most severe desertification hazards in the country, primarily due to its unique geographical location. Situated far from the sea, deep within the continental interior, it experiences low rainfall and high evaporation rates. Yueyaquan Village is located in the westernmost part of the Hexi Corridor, bordering Dunhuang City and the Kumtag Desert. Its geographical coordinates range from 92°13′ to 95°30′ east longitude and 39°40′ to 41°35′ north latitude. The total land area of Yueyaquan Village is 2.67 x 104 km^2, with the oasis area covering 1,400 km^2, representing only 4.5% of the overall territory [31-32]. According to the desertification assessment report, the prevalent types of desertification in Yueyaquan Village include mobile sand, semi-fixed sand, fixed sand, and Gobi, covering a total area of 1.97 x 106 km^2, accounting for 73.2% of the monitored region [33].

Yueyaquan Village has a history spanning 2,000 years and is renowned as a world-class tourist attraction, notably featuring the UNESCO World Heritage Site, the Mogao Grottoes [34]. However, in recent decades, the village has experienced aggravated desertification due to natural factors such as drought, wind, and sand, as well as human activities. This has significantly impacted the local ecological environment and various aspects of people's livelihoods and productivity.

This research focuses on empirical analysis conducted in Yueyaquan Village, located in Dunhuang City, China, utilizing a framework centered around desertification resilience analysis. The village, named after the Yueyaquan River, is situated within the Dunhuang watershed and is a part of the nationally recognized tourist attraction, Mingsha Mountain. The annual rainfall in the region is 42.2 mm, accompanied by high evapotranspiration of 2505 mm, indicative of a typical continental arid climate [35, 36]. The area experiences frequent storms and sandstorms, with prevailing east and northwest winds throughout the year. Covering an area of approximately 2,000 hectares, Yueyaquan Village primarily consists of cultivated land, accounting for 94 percent of the total area. Mingsha Mountain exhibits a terrain characterized by low hills and wind-blown sediments, with the degree of waviness primarily influenced by the underlying rock surface [37, 38]. The landscape bears traces of ancient terrain and features modern wind and sand geomorphology. The surrounding area of Yueyaquan generally exhibits higher elevations in the south and lower elevations in the north. The southern part is characterized by the hilly terrain of Mingsha Mountain, while the northern part encompasses a flat alluvial and lacustrine plain, serving as the location of Yueyaquan Village. As the region's tourism industry grows, the demand for water resources increases, necessitating groundwater extraction to maintain a balance between supply and demand. Consequently, the declining groundwater level has emerged as a significant factor limiting the ecological environment in the region. Additionally, the development of the tourism sector has resulted in the abandonment of farms by local farmers, leading to the encroachment of desertification on arable land. With the support of both central and local governments, Dunhuang has influenced the trajectory of desertification, leading to some improvement in the extent of desertified land. This progress can be attributed to major ecological restoration projects, such as artificial afforestation, land sealing and management, the conversion of farmland back to forests, the establishment of nature reserves, and the development of related infrastructure projects, including highways and airports [39]. (Fig. 1)

Data Source

Questionnaires

In June 2023, the research team conducted an investigation in Yueyaquan Village, focusing on three key aspects: ecology, technology, and social culture. The study commenced with interviews involving a total of 56 individuals, including four cadres and 52 villagers. Among them, there were nine village cadres, with an average interview duration of 3.5 hours, and 43 villagers, with an average interview duration of 2 hours. These interviews aimed to gather information on the village's industrial structure, arable land, as well as the publicity, protection, and organizational activities related to soil and water conservation and desertification prevention in Yueyaquan Village. Subsequently, the team interviewed three professionals from the Sand Control Institute to gain insights into the ecological and

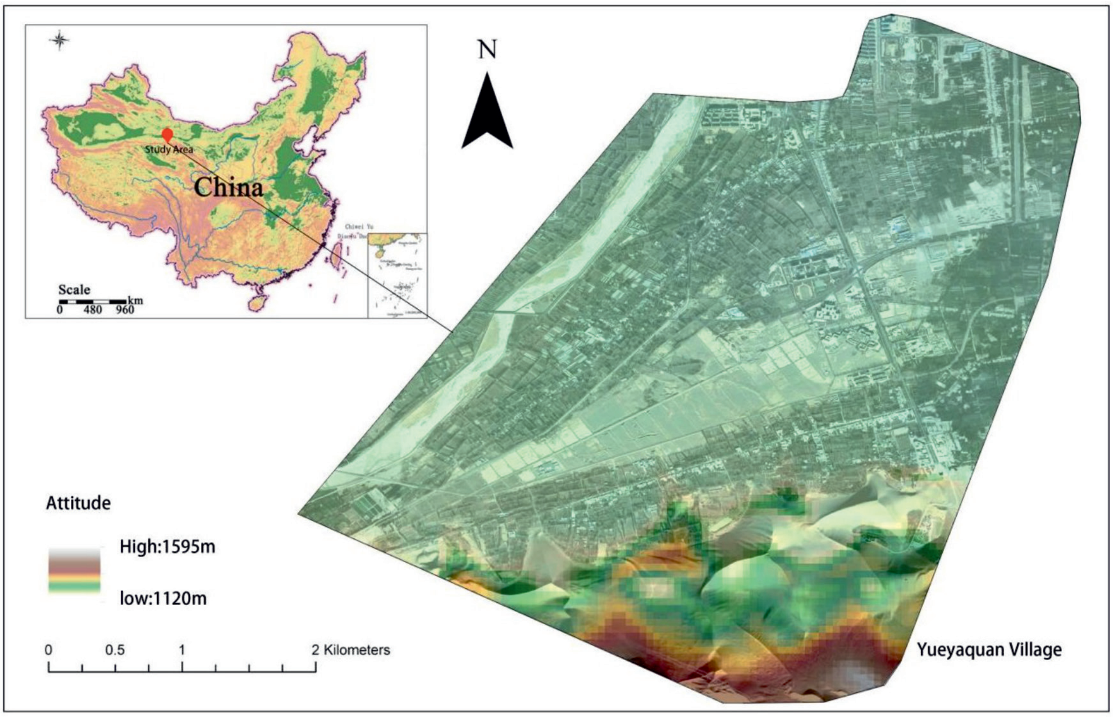

Fig. 1. The location map of Yueyaquan Village.

engineering measures implemented for sand control and assess their recent effectiveness. Specific data on sand control were also collected. The statistical findings, combined with the interview results, serve as indicators for assessing the village's preparedness and vulnerability to desertification in Yueyaquan. Based on the survey data, a final index score is calculated using a five-level assessment scale: very low (1), low (2), medium (3), high (4), and very high (5). This comprehensive assessment provides a thorough understanding of the village's preparedness and vulnerability to desertification.

Assessment Indicators

Rural landscapes in desertified areas possess unique local characteristics. However, the current landscape resilience evaluation index systems are mainly tailored to urban areas and may not be suitable for assessing the resilience of rural landscapes in desertified regions. To address this gap, this study constructs an evaluation index system that specifically considers the local characteristics of desertified rural areas. The system is based on a theoretical framework of evaluation and incorporates three dimensions: ecosystem, engineering system, and cultural system. By accounting for the distinctive attributes of desertified rural areas, this index system aims to provide a comprehensive assessment of landscape resilience in these specific contexts [40]. (Table 1 and Table 2)

The ecosystem plays a crucial role in the rural landscape, offering not only aesthetic value but also climate regulation, environmental pollution mitigation, and air purification. When the rural landscape system faces external disturbances, a well-functioning ecosystem can serve as a mitigating factor against disasters. In this study, the assessment of ecosystem quality focuses on two aspects: ecological pattern and ecological governance [41]. An effective ecological pattern can generate a high-quality landscape effect and provide resilience against disasters such as soil desertification, thereby enhancing the landscape's preparedness for potential hazards. The objective

Table 1. Assessment Indicators of disaster preparedness of rural landscapes in Desertification Prevention and Control.

First-Level Indicators	Second-Level Indicators	Third-Level Indicators	Indicator Score Description
Ecological system preparedness	Ecological pattern	Ratio of green space	0-20% (1), 21%-30% (2), 31%-40% (3), 41%-50%, More than 50% (5)
		Diversity of species	Species of plants in the region 3 (1), 5 (2), 7 (3), 10 (4), More than 15 (5)
	Ecological governance	Percentage of desertified land	0-20% (1), 21%-30% (2), 31%-40% (3), 41%-50%, More than 50% (5)

Table 1. Continued.

Engineering system preparedness	Building facilities	Building structure	The proportion of brick or reinforced concrete structure: less than: ≤50% (1), 51%-60% (2), 61%-70% (3), 71%-80% (4), More than 81% (5)
		Proportion of new houses built in the last decade	≤40% (1), 41%-50% (2), 51%-60% (3), 61%-70% (4), More than 71% (5)
	Water conservation facility	Number of new water reservoirs repaired in the last three years	0 (1), 1 (2), 2 (3), 3 (4), More than 4 (5)
	Fire protection facilities	Fire station service radius	More than 6 km^2 (1), 4-6 km2 (2), 3-4 km^2 (3), 2-3 km^2 (4), Less than 1 km^2 (5)
	Road engineering	Proportion of concrete roads	≤50% (1), 51%-60% (2), 61%-70% (3), 71%-80% (4), More than 81% (5)
		Road supporting facilities	0 (1), 1-2 (2), 3 (3), 4 (4), More than 5 (5)
	Mechanical desert control	Number of sand retaining walls	0 (1), 1-2 (2), 3 (3), 4 (4), More than 5 (5)
Culture system preparedness	Erosion of cultural disasters	Number of systems for the protection of sites developed per year	0 (1), 1-2 (2), 3 (3), 4 (4), More than 5 (5)
		Yearly training	0 (1), 1-2 (2), 3 (3), 4 (4), More than 5 (5)
		Number of times per year that knowledge of Dunhuang culture is promoted	0 (1), 1-2 (2), 3 (3), 4 (4), More than 5 (5)
	Cultural landscape protection	Establishment of Dunhuang Cultural Reserve	0 (1), 1-2 (2), 3 (3), 4 (4), More than 5 (5)
		Awareness of cultural protection	≤50% (1), 51%-60% (2), 61%-70% (3), 71%-80% (4), More than 81% (5)

Table 2. Assessment indicators of rural landscape pressures in Desertification Prevention and Control.

First-Level Indicators	Second-Level Indicators	Third-Level Indicators	Indicator Score Description
Ecological system pressures	Irrigation pressures	The proportion of crops requiring large amounts of water	0-20% (1), 21%-30% (2), 31%-40% (3), 41%-50%, More than 50% (5)
	Sand stabilisation pressures	Proportion of invasive alien plants	0-20% (1), 21%-30% (2), 31%-40% (3), 41%-50%, More than 50% (5)
	Soil sanding pressure	Proportion of soil desertification	0-5% (1), 10%-15% (2), 15%-20% (3), 20%-25%, More than 26% (5)
Engineering system pressures	Building instability	Old buildings with security risks	0 (1), 1-2 (2), 3-4 (3), 4-5 (4), More than 6 (5)
	Water supply pressure	Annual water supply and drainage facilities failure days	0 (1), 1-2 (2), 3 (3), 4 (4), More than 5 (5)
	Fire fighting pressure	Frequency of failure of fire protection facilities in the past years	10 (1), 10-15 (2), 15-20 (3), 20-25 (4), More than 2 (5)
	Desert control pressure	Number of sand walls damaged in the past year	0 (1), 1-2 (2), 3 (3), 4 (4), More than 5 (5)
	Road sensitivity	Annual frequency of road failure	0 (1), 1-2 (2), 3 (3), 4 (4), More than 5 (5)
Culture system pressures	Cultural resource loss	Number of damages to Dunhuang sites in the past year	0 (1), 1-2 (2), 3 (3), 4 (4), More than 5 (5)
	Disaster sensitivity	Setting of disaster sensitive area	0 (1), 1-2 (2), 3 (3), 4 (4), More than 5 (5)

is to mitigate the threats posed by disasters like sandstorms to the rural landscape and ensure the safety of villagers' lives and property by improving the vegetation cover in the area. This paper evaluates the current state of ecosystem resilience in rural areas, specifically addressing the ecological pressure dimension. The ecological balance in rural areas is affected, and ecosystem resilience is weakened when there is severe soil desertification or a high proportion of water-intensive crops. To safeguard soil and water conservation and maintain the ecological integrity of rural areas, the implementation of wind and sand control plants is crucial. With desertification, various plant species face endangerment and extinction, resulting in biodiversity loss and an imbalance in the ecosystem. This diminishes the resilience of the rural landscape system to external influences.

Engineered systems refer to the utilization of facilities or technical means to mitigate the adverse effects of disasters. In the context of disaster preparedness, this study analyzes engineered systems from five perspectives: buildings, water conservation, firefighting, roads, and wind and sand control. When faced with natural disasters, robust and stable buildings can serve as shelters, showcasing their capacity for disaster preparedness. Hydraulic facilities effectively address water scarcity issues in the desert region of Dunhuang. Reservoirs store water during periods of abundance, ensuring its availability during times of scarcity. Well-developed fire-fighting facilities effectively manage potential safety hazards and enhance the disaster prevention capacity of the rural landscape system. Furthermore, a well-developed road network enhances the disaster preparedness of the rural landscape system by facilitating the quick location of emergency shelters. Maintaining and improving wind and sand defenses reduce the impact of sandstorms on the city and prevent the countryside from being overwhelmed by sand and dust [42]. The resilience of engineering systems is analyzed using indicators such as building imbalance, water scarcity pressure, fire-fighting capacity, wind and sand defense readiness, and frequency of road failures. Building imbalance refers to the presence of old and potentially hazardous houses in rural areas that would be severely affected during disasters, resulting in significant personal and property losses. A water shortage or failure of water supply facilities can significantly impact farmland irrigation. Insufficient water supply or facility failures not only affect farmland irrigation but can also lead to the malfunctioning of fire-fighting facilities, diminishing their effectiveness and subsequently reducing the resilience of the rural landscape system. Moreover, an inadequate road system hampers the speed at which people can evacuate during disasters, resulting in increased damage to the rural landscape system. Dunhuang boasts a world-renowned heritage of cave art and culture that spans nearly 2,000 years. Every year, millions of tourists visit Dunhuang to immerse themselves in its cultural allure. The cultural system primarily encompasses the prevention of cultural encroachment and the protection of local cultural heritage. During the examination process, it was observed that local villagers still exhibit insufficient awareness regarding cultural preservation. Hence, there is a need for the local government to continually develop systems that regulate villagers' behavior. Regular training for government management personnel can also raise awareness among locals and tourists alike about the cultural significance of Dunhuang, guiding visitor behavior and thereby bolstering the resilience of the cultural system. A significant aspect influencing the recovery of the cultural system is the loss of cultural resources and the occurrence of cultural disasters. This study assesses the resilience of the cultural system from two perspectives: the loss of cultural resources and susceptibility to cultural disasters. The loss of cultural resources refers to the frequency of cultural damage to protected and visited sites, where the damage is irreversible and undermines the resilience of the cultural system. Cultural disaster sensitivity relates to the progressive disappearance of site areas over time and the irreversible loss of cultural heritage, leading to a weakened resilience of the cultural system.

Data Processing

Methodology for Calculating Indicator Weights

Step 1 involves achieving matrix capture, where the weight assigned to each indicator reflects its contribution to the objective. This process serves as a vital bridge for establishing correlations among factors within the indicator system and is crucial for assessing ecosystem resilience. The hierarchical analysis method is primarily employed in this assessment [43]. To determine the weights of the indicators, a two-by-two comparative judgment matrix is constructed, and the relative importance of each pair of indicators is compared using expert judgment. When constructing the judgment matrix, it is necessary to compare the importance of two elements, A_i and A_j, based on a specific criterion and assign corresponding values. The value assigned, a_{ij}, is calculated as A_i divided by A_j, and the resulting judgment matrix $A = (a_{ij})n*n$ represents the degree of importance using a scale of 1-5 to indicate the relative importance.

Significance	Scale	Connotation
$a_{ij} = A_i/A_j$	1	A_i and A_j equally importance
	2	Compared A_i with A_j, marginally importance
	3	Compared A_i with A_j, patent importance
	4	Compared A_i with A_j, high importance
	5	Compared A_i with A_j, utmost importance

The influence matrix is analyzed to explore the interrelationships between elements and determine the degree of influence of each element on others. This analysis forms the basis for constructing a comprehensive evaluation model of ecological resilience and determining the weight of each element within the system [44].

Step 2: Calculation of the Specification Effect Matrix. Programmability, also referred to as data standardization and specification, involves a straightforward mathematical transformation of diverse indicator data. This transformation effectively addresses issues related to indicator scale and magnitude, enabling the comparative analysis of data across indicators. In this study, we adopt the widely used maximum-minimum normalization method, which operates based on the following principle: Numerous dimensionless methods for data exist. To mitigate the influence of different measurement units and magnitudes, the original data is transformed using the maximum and minimum values of the variables. This transformation yields data within the range of (1, 5), thereby modifying the weights of the variables in the analysis. X'_{ij} for preparedness system,as equation (2). Y'_{ij} for pressure system,as equation (3). Z'_{ij} for preparedness system and pressure system,as equation (4).

$$X'_{ij} = \frac{x_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})} \tag{2}$$

$$Y'_{ij} = \frac{Y_{ij} - \min(Y_{ij})}{\max(Y_{ij}) - \min(Y_{ij})} \tag{3}$$

$$Z'_{ij} = \frac{Z_{ij} - \min(Z_{ij})}{\max(Z_{ij}) - \min(Z_{ij})} \tag{4}$$

To capture the spatial distribution of ecological resilience in the study area and monitor changes in ecological resilience over time, this study employed dimensionless processing for both spatial and temporal analysis. For the spatial dimension, the village indicators were monitored over nearly a year and normalized using the maximum-minimum value. X'_{ij} represents the dimensionless value of the jth-year indicators for the ith village, while X_{ij} represents the initial value. For the temporal analysis, the village indicators were monitored over nearly a year and normalized using the maximum-minimum value. X_{ij} represents the dimensionless value of the ith indicator for the jth township, while X_{ij} represents the initial value. Additionally, the maximum [$\max(X_{ij})$] and minimum [$\min(X_{ij})$] values were determined for each index.

Step 3: Derivation of the Total Impact Matrix. The comprehensive index method is extensively employed in ecological environment assessment. It utilizes dimensionless results to calculate the local ecosystem resilience within the study area through specific weighting operations. This calculation enables the assessment of the ecological environment's health, which holds significant importance for evaluating ecological environment changes and implementing effective ecological management practices. In this study, the comprehensive index method was employed to construct the ecological resilience evaluation model for the study area, allowing for the evaluation of its ecological resilience [45]. The formula for the comprehensive evaluation of ecological resilience is as follows:E for ecological system,as equation (5). S for engineering system,as equation (6). C for culture system, as equation (7). we, ws, and wc denote the weight values of each indicator in the second indicator layer. w_{ei}, w_{si}, and w_{ci} represent the weight values of the ith indicator in the third indicator layer relative to all indicators in that layer. x_{ei}, x_{si}, and x_{ci} signify the normalized values of the ith indicator in the third indicator layer.

$$E = \sum_{i=1}^{n} W_{ei} \cdot Z_{ei} \tag{5}$$

$$S = \sum_{i=1}^{n} W_{si} \cdot Z_{si} \tag{6}$$

$$C = \sum_{i=1}^{n} W_{ci} \cdot Z_{ci} \tag{7}$$

Conclusions

Ecological Resilience Assessment

Yueyaquan Village serves as a critical transitional area between the urban space of Dunhuang City and the expansive desert space, playing a vital role in maintaining environmental stability in the urban region. The village exhibits a readiness score of 2.01 and an ecological pressure score of 1.97. The resilience score slightly surpasses the ecological pressure score, indicating that the village's ecological landscape system maintains an acceptable level of resilience during daily monitoring. However, the village's ecosystem is susceptible to collapse in the event of natural disasters like "sandstorms." The ecosystem resilience score is 1.05.In the ecosystem preparedness index, the disaster preparedness indices for Ecological Patterns and Ecological Governance are scored as 2.01 and 1.97, respectively. These scores reflect the performance of "ecological pattern" and "ecological governance" in terms of their disaster preparedness capability. The scores range from 1 (extremely poor) to 5 (excellent), with Ecological Governance demonstrating a stronger disaster preparedness capability. To address the challenges posed by the local desert environment, Yueyaquan Village has implemented various measures, including sand control, reforestation, and the development of ecological management infrastructure such as wind and sand control structures, high-standard farmland, and water diversion canals. However, the arid climate, limited water supply, and high temperatures in the desert region present obstacles to afforestation and the survival of plant species. Consequently, the ecological pattern readiness of Yueyaquan Village remains weak. To address the issue of water scarcity in desert farming, the village government is promoting the cultivation of drought-resistant and low-nutrient crops such as grapes, plums, apricots, and early pears. Additionally, they are encouraging the adoption of water-saving irrigation methods. The development of tourism in Dunhuang, coupled with the exacerbation of global warming, poses a growing threat to the village's ecological environment. This has led to an accelerated rate of soil desertification and increased challenges and risks in its management. In response, the local government is actively engaging in cooperative negotiations to involve more organizations in sand control efforts. They are also seeking increased capital investment to expand forested areas for sand control and enhance tourist supervision. The ecological environment of Yueyaquan Village requires further enhancement to build resilience against natural disasters. Based on the evaluation results, two measures can be implemented to improve the ecological resilience of the village: (1) Reducing the cultivation area of water-intensive crops and promoting the production of specialized agricultural products that can increase farmers' income without compromising the ecosystem's disaster preparedness capacity. (2) Strengthening sand control efforts by implementing policies that encourage the participation of various stakeholders and increasing tourist supervision in scenic areas. These measures will contribute to the overall improvement of Yueyaquan Village's ecological resilience and ensure its ability to withstand and recover from potential environmental challenges (Table 3).

Engineering Resilience Assessment

The engineering system evaluation of Yueyaquan Village reveals notable findings. The preparedness and stress scores are 1.12 and 0.81, respectively. Importantly, the engineering system exhibits a higher resilience than stress, signifying its robustness. With a resilience score of 1.24, the facilities in Yueyaquan Village demonstrate a commendable level of resilience. Notably, the "road project" obtains a score of 4, while the "water conservation project" and "fire extinguishing facilities" each achieve a score of 2. Similarly, the "wind and sand prevention" project also earns a score of 4. These scores reflect the village's investment in essential infrastructure, especially considering its recent development in tourism and economic growth. Yueyaquan Village has undergone a significant transformation over the years. The landscape now showcases newly constructed concrete medical, commercial, and school buildings. Moreover, the village boasts comprehensive basic service facilities, well-organized landscaping, and meticulously planned road networks. These advancements are the result of the village's flourishing tourism industry and economic upliftment. Located within the desert hinterland, Yueyaquan Village faces challenging environmental conditions. The area experiences minimal annual rainfall, measuring less than 42.2 mm, coupled with high temperatures and evaporation rates. Consequently, water resources remain scarce, compelling the reliance on groundwater sources due to their limited availability. Unfortunately, recent tourism growth has heightened water scarcity issues, leading to frequent water shortages and difficulties in meeting the local water demands. This explains the low resilience score for the Water Conservation Project. Additionally, the village encounters obstacles in terms of fire safety preparedness. The "Disaster Preparedness of Fire Fighting Facilities" receives a low score due to the significant service radius of over 5 km^2. This substantial coverage area poses challenges in promptly responding to emergencies, resulting in potential loss of life and property. On a positive note, the village excels in wind and sand protection resilience. The government's construction of sand barriers along the desert-town border has proven highly effective. These barriers provide substantial protection against desert wind and sand, contributing to the village's high resilience score in this regard. At the pressure level on the engineering system of Yueyaquan Village, "building instability" receives a score of 1 point, while "water supply pressure," "fire protection pressure," "wind and sand control equipment pressure," and "road pressure" each score 3, 3, 4, and 2 points, respectively. The occurrence of "building instability" and "road damage" is infrequent in the village. With a focus on tourism development, Yueyaquan Village has undergone reconstruction in recent years, resulting in the demolition of old buildings and the construction of new ones that provide improved resistance against wind and sand threats. Furthermore, the village's roads are well-equipped, primarily catering to small and medium-sized tourist vehicles, resulting in negligible pressure

Table 3. Yueyaquan Village ecological resilience assessment results.

Second-Level Indicators	Weights	Score	Third-Level Indicators	Score	Evaluation Attribute	Ecological Resilience
Ecological pattern	0.153	3	Ratio of green space	4	Xei = 2.11	E = 1.07
			Diversity of species	3		
Ecological governance	0.167	5	Percentage of desertified land	5		
Irrigation pressures	0.189	3	The proportion of crops requiring large amounts of water	5	Yei = 1.97	
Sand stabilisation pressures	0.158	5	Proportion of invasive alien plants	4		
Soil sanding pressure	0.168	3	Proportion of soil desertification	3		

on the road infrastructure. However, the village frequently experiences water shortages, leading to an inadequacy of underground water resources to sustain the growing number of tourists. As a consequence, the "water supply pressure" is substantially high, often resulting in water supply facilities running out of water or malfunctioning, leading to frequent incidents. The elevated score for "Fire Fighting Facility Stress" stems from the lack of regular maintenance of fire fighting facilities in the village. Consequently, these facilities are either non-operational or damaged following accidents. Similarly, the high score for "Sand Control Equipment Stress" is a consequence of the frequent occurrence of sandstorms and other natural disasters in recent years, which have inflicted severe damage to the sand control equipment. Moreover, the equipment necessitates continual updating and upgrading to remain effective. Overall, despite the improvements made to the infrastructure and external landscape of Yueyaquan Village during the rapid development of the tourism economy, the resilience of the engineering system can be enhanced by addressing the village's water scarcity issues and fortifying the engineering facilities to withstand severe natural disasters. The proposed specific measures to be implemented include: (1) Constructing water diversion and storage projects to address water scarcity concerns. This involves establishing clear classification standards for surface and underground water usage while ensuring a reliable water supply for both villagers and tourists. (2) Reprogramming the layout of firefighting facilities within the village is crucial. This entails increasing the quantity of various types of firefighting facilities and establishing a regular maintenance mechanism. This will ensure the timely and uninterrupted functionality of firefighting equipment. In summary, the recommended measures consist of constructing water diversion and storage projects to meet water demands, along with reprogramming the layout of firefighting facilities, augmenting their quantity, and implementing a maintenance mechanism to guarantee their efficient operation (Table 4).

Cultural Resilience Assessment

The assessment of the cultural system in Yueyaquan Village reveals important findings. The preparedness score for the cultural system is 0.95, whereas the pressure score is 1.12. Notably, the preparedness score is below 1, indicating insufficient cultural preparedness within the village. This reflects a lack of awareness among villagers regarding cultural heritage protection and inadequate local promotion of desertification prevention and control. The resilience score for the cultural system is 0.89. Specifically, "cultural disaster erosion" receives a score of 2, while "cultural landscape protection" obtains a score of 3. Although Yueyaquan Village conducts annual Dunhuang culture promotion and desertification disaster prevention activities, the current efforts of inheriting and promoting traditional culture prove inadequate. For instance, events like the "social fire" and "Buddha bathing" festivals primarily involve and attract elderly participants. The absence of young people's

Table 4. Yueyaquan Village engineering resilience assessment results.

Second-Level Indicators	Weights	Score	Third-Level Indicators	Score	Evaluation Attribute	Engineering Resilience
Building facilities	0.102	5	Number of new water reservoirs repaired in the last three years	5	Xsi = 1.12	S = 1.38
			Fire station service radius	3		
Water conservation facility	0.075	2	Proportion of concrete roads	2		
Fire protection facilities	0.056	2	Road supporting facilities	2		
Road engineering	0.077	4	Number of sand retaining walls	3		
			Number of new water reservoirs repaired in the last three years	5		
Mechanical desert control	0.065	4	Fire station service radius	4		
Building instability	0.091	1	Old buildings with security risks	1	Ysi = 0.81	
Water supply pressure	0.071	3	Annual water supply and drainage facilities failure days	3		
Fire fighting pressure	0.075	3	Frequency of failure of fire protection facilities in the past years	3		
Desert control pressure	0.069	4	Number of sand walls damaged in the past year	4		
Road sensitivity	0.092	2	Annual frequency of road failure	2		

involvement hampers the promotion and innovation of traditional culture, leading to a cultural divide. At the level of cultural system pressure, Yueyaquan Village scores 4 for "loss of cultural resources" and 3 for "disaster sensitivity" The increasing number of tourists in the village, coupled with the worsening climate conditions, raises the likelihood of damage to cultural heritage. Consequently, natural disasters have become more frequent, resulting in the accelerated destruction of cultural heritage. Moreover, intensified archaeological work in recent years has identified additional areas prone to disasters. In conclusion, the assessment emphasizes the need for enhancing cultural preparedness and raising awareness of cultural heritage protection among the villagers. Additionally, promoting the active participation of young people in traditional cultural activities is essential for their preservation and innovation. Addressing the increasing pressure on the cultural system, particularly the loss of cultural resources and heightened disaster sensitivity, is crucial to prevent further damage to the village's cultural heritage. However, research indicates that the community has yet to implement measures for the protection of certain caves, posing a safety hazard. In order to evaluate the findings, two measures are necessary to enhance the cultural resilience of Yueyaquan Village: (1) Implement hierarchical management of cultural heritage, including the regulation of tourism development intensity and the strengthening of tourism supervision. (2) Foster research in various aspects of Dunhuang culture, actively engage young individuals in cultural and artistic innovation related to Dunhuang, involve them in campaigns for desertification disaster prevention, and explore the economic benefits derived from Dunhuang's traditional culture. These measures will contribute to the safeguarding of cultural heritage, ensure sustainable tourism practices, encourage the active participation of the younger generation in cultural preservation and innovation, and harness the economic potential of Dunhuang's rich traditional culture (Table 5).

Resilience Assessment of Rural Landscape in Yueyaquan Village

In conclusion, Yueyaquan Village exhibits resilience and pressure scores of 4.18 and 3.90, respectively, indicating a greater resilience than pressure. The landscape of Yueyaquan Village is in good condition, as evident from its landscape resilience score of 1.52. This score, greater than 1, signifies the village's landscape possesses robust resilience against natural disasters. The landscape system's structure can effectively withstand external disturbances and inherent limitations. To assess the resilience of the ecosystem, engineering system, and cultural system, the ratio of their respective resilience and pressure scores was calculated. For the landscape of Yueyaquan Village, the resilience scores were determined as follows: 1.07 for the engineering system, 1.38 for the ecosystem, and 0.84 for the cultural system. These findings indicate that the engineering system of the landscape exhibits the highest resilience, followed by the ecosystem. However, the cultural system's resilience is insufficient, suggesting the need for improvement. Overall, Yueyaquan Village demonstrates commendable resilience in its landscape, particularly in the engineering system and ecosystem domains. However, efforts should focus on enhancing the resilience of the cultural system to ensure its alignment with the village's overall sustainability and protection against potential challenges. (Table 6)

Discussion

Through an analysis of the resilience of the rural landscape in Yueyaquan Village, we have discovered that the desert villages in Dunhuang, Gansu have cultivated a distinctive socio-economic and cultural system. This system has thrived due to the growth of tourism, fostering the preservation and evolution of rural cultures. However, environmental challenges such as drought, water scarcity, and severe desertification have constrained the village's progress. Thankfully, the Dunhuang Desertification Prevention and Control

Table 5. Yueyaquan Village cultural resilience assessment results.

Second-Level Indicators	Weights	Score	Third-Level Indicators	Score	Evaluation Attribute	Cultural Resilience
Erosion of cultural disasters	0.171	2	Number of systems for the protection of sites developed per year	2	Xci = 0.95	C = 0.84
			Yearly training	2		
			Number of times per year that knowledge of Dunhuang culture is promoted	2		
Cultural landscape protection	0.154	3	Establishment of Dunhuang Cultural Reserve	3		
			Awareness of cultural protection	4		
Cultural resource loss	0.151	4	Number of damages to Dunhuang sites in year	4	Yci = 1.12	
Disaster sensitivity	0.197	3	Setting of disaster sensitive area	3		

Table 6. Yueyaquan Village ecological landscape resilience assessment results.

	Ecological Resilience	Engineering Resilience	Cultural Resilience	Total
Xi	2.11	1.12	0.95	4.18
Yi	1.97	0.81	1.12	3.90
I	1.07			

Project, initiated by the Chinese government, has mitigated the environmental issues faced by Yueyaquan Village [46]. The cultural vitality of Yueyaquan Village is of paramount importance, as its decline would result in the loss of artistic creations by older generations and erode the traditional folklore that has endured for two millennia. Therefore, efforts to preserve and innovate culture should also be reflected in the village's external landscape. Based on the findings of this study, it is imperative to develop appropriate strategies that foster the integrated development of Yueyaquan Village's landscape system in the future [47-48]. These strategies will contribute to the harmonious growth of the village, bolster its resilience, and ensure the preservation and innovation of its cultural heritage.

Intelligent remote sensing and big data analysis technologies are employed for monitoring and managing desertification and ecological patterns in Yueyaquan Village. They also facilitate dynamic management of engineering systems and cultural landscape preservation practices. These efforts significantly bolster the village's ecological restoration capacity. Further platform refinement will enable researchers and nations in other desertified regions to more effectively utilize this approach for safeguarding natural ecosystems, prioritizing cultural heritage resource conservation, and strengthening regional governance capabilities.

Summary

A comprehensive ecological landscape resilience evaluation index system was established for Yueyaquan Village, China, based on the principles of resilience and the resilience of rural ecological landscapes. The evaluation focused on three key aspects: ecology, engineering, and culture. In terms of the preparedness of the rural landscape in Yueyaquan Village, its ability to mitigate negative impacts during disturbances was considered. The ecological system plays a crucial role in buffering the effects of sandstorm disasters and alleviating the environmental pressures resulting from the influx of tourists. The engineering system effectively reduces damages caused by natural disasters while safeguarding village houses and roads. The cultural system is dedicated to preserving village traditions and cultural heritage, with the values of local villagers serving as the driving force and direction for sustainable rural tourism development. Given the influence of external cultures, it is vital to foster the fusion of diverse cultural qualities and development concepts to promote the growth of local culture. Furthermore, comprehensive measures, such as widespread education, systematic supervision, and regional science popularization, should be employed to strengthen cultural awareness among villagers and tourists. These efforts aim to underscore the importance of culture and encourage broader participation in cultural preservation. By employing this evaluation index system and implementing various strategies, Yueyaquan Village can enhance its ecological landscape resilience and ensure the sustainable development and protection of its unique rural environment and cultural heritage.

The research findings indicate that within the three levels of ecosystem, engineering system, and cultural system, the engineering system in Yueyaquan Village achieved the highest score of 1.38. This signifies that despite the challenging local ecological conditions, the layout of the engineering system effectively enhances the local ecological landscape, compensates for ecosystem deficiencies, and strengthens overall resilience. Following closely is the ecological system with a score of 1.07, slightly surpassing 1, indicating a relatively stable situation achieved through ecological pattern layout and management measures. However, in the event of a natural disaster, the ecological environment is vulnerable and susceptible to severe damage. Therefore, the village is currently undergoing a structural transformation stage in the development of the ecological environment. The ecological structure exhibits a singular characteristic, necessitating the establishment of measures to promote ecological diversity, including the introduction of drought-resistant and soil-poor plants, and the protection of the desert oasis. The research findings reveal that within the three levels of ecosystem, engineering system, and cultural system, Yueyaquan Village's engineering system attained the highest score of 1.38. This highlights its ability to enhance the local ecological landscape, address ecosystem limitations, and strengthen overall resilience, despite challenging local ecological conditions. In close proximity is the ecological system with a score of 1.07, slightly surpassing 1, indicating a relatively stable state achieved through strategic ecological pattern layout and effective management measures. However, the ecological environment remains vulnerable to severe damage in the event of a natural disaster. Consequently, the village is currently in a stage of structural transformation in its ecological development. The ecological structure exhibits a homogeneous characteristic, emphasizing the need for measures to promote ecological diversity.

This includes introducing drought-resistant and soil-poor plants and prioritizing the preservation of the desert oasis.

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Conflict of Interest

The authors declare no conflict of interest.

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