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Study on the Relationship between Economic Growth in Zhanyi District and Vegetation Slope Protection along the Guiyang-Kunming Railway

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Abstract: This paper takes the vegetation slope protection project along the Guiyang-Kunming Railway (Zhanyi-Kunming section) as the research object. Based on high-resolution remote sensing image data from 2008 to 2022, it quantitatively analyzes the spatiotemporal evolution of vegetation coverage on rock slopes following soil spray-seeding. The study finds that despite an extreme drought in 2011, the Normalized Difference Vegetation Index (NDVI) in the study area showed an overall trend of continuous improvement starting in 2013 and stabilized after 2016, indicating the significant effectiveness of the vegetation slope protection technology. Furthermore, by integrating economic growth data from the adjacent Zhanyi District, the research demonstrates a dynamic synergistic relationship between economic growth and ecological protection: the relationship between economic development and vegetation coverage is not simply positive or negative but is dynamic and complex. The average NDVI shows a weak correlation with the economic development of Zhanyi District, whereas the trend of NDVI change exhibits a strong correlation with it. Vegetation slope protection is not merely a technical measure but also a crucial investment in ecological capital. By constructing ecological security barriers, shaping linear green landscape corridors, and optimizing the living environment, it directly enhances the ecological asset value and attractiveness of the areas along the railway.

1. Introduction

Ecosystem conservation and economic prosperity together form critical pillars of sustainable development [1]. However, ecosystem degradation caused by economic growth, or the economic compensation paid for environmental protection and restoration, can significantly deplete the foundation for sustainable development. Consequently, global sustainability is increasingly challenged by the complex and dynamic interactions between economic and environmental systems [2]. A general lack of deep consideration of causal relationships in policy-making processes is one of the key reasons behind the limited effectiveness of sustainable development policies.

The impact of vegetation change on economic growth also warrants attention. Existing research has predominantly focused on the ecological processes triggered by vegetation change [3-6], while relatively less attention has been paid to its socioeconomic consequences. Vegetation slope protection can realize the value of ecological products, promote the integration of tourism and tertiary industries, and thereby generate comprehensive social benefits [7]. From a micro-mechanistic perspective, vegetation slope protection generally enhances soil and vegetation growth through the addition of peat and water-retaining agents.

Peat, rich in organic matter, significantly increases the organic matter content in soil when added, thereby improving the physical structure of the fill soil. It has strong water-retaining capacity, absorbing and storing large amounts of moisture, which helps maintain soil moisture during dry periods and partially stores water. Peat improves soil aeration and drainage while providing long-term nutrients essential for plant growth. Water-retaining agents are composed of high-molecular polymers that absorb and retain substantial amounts of water, thereby enhancing the soil's water-holding capacity. They form a sponge-like structure in the soil, effectively absorbing and releasing moisture. These agents reduce water evaporation and deep percolation, keeping moisture around plant roots for longer periods and minimizing water loss. The presence of water-retaining agents helps improve soil stability, reduces soil compaction, and promotes root development [8, 9]. Advanced ecological slope protection materials themselves offer advantages such as effective protection, strong durability, and low cost. A one-time investment yields long-term benefits, reducing the need for repeated maintenance expenses.

It is noteworthy that current research has not yet fully revealed the causal links between regional economic growth and specific ecological engineering projects. In reality, there exists synergistic potential for mutual promotion between economic growth and vegetation restoration. Through technological innovation and the development of a green economy, deep integration of infrastructure construction and ecological restoration can be promoted, ultimately achieving a “win-win” scenario of both economic and ecological benefits.

2. Overview of the Study Area

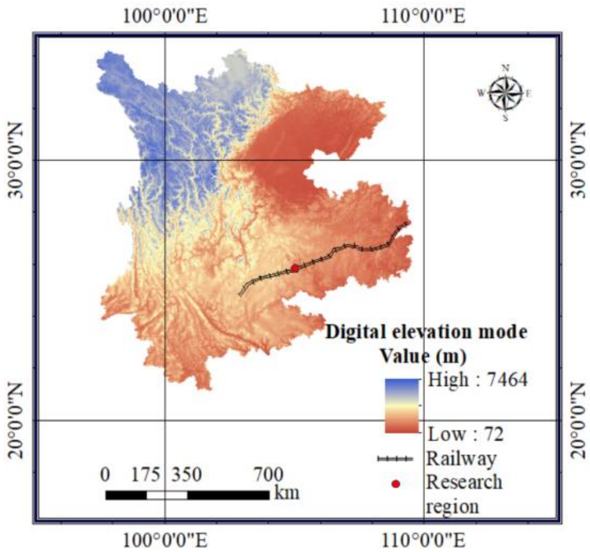


Fig. 1 Location and Elevation of the Study Area

The study area is located in eastern Yunnan Province, with the field test site situated along the Guiyang-Kunming Railway section between Zhanyi and Kunming. This region belongs to the hilly denudation landform of the Yunnan-Guizhou Plateau, as shown in Fig. 1. The railway runs along the edge of the broad and gentle section of the Huangniwan U-shaped river valley. The bedrock of the slope primarily consists of mudstone and shale from the Upper Silurian Guandi Formation (S_3g), which is a weakly water-bearing stratum containing only fissure water in the bedrock. The slope residual cohesive soil contains a small amount of pore phreatic water. Surface water mainly consists of seasonal gully water, with flow varying according to seasonal changes.

The slope vegetation adopted a combination of grasses and shrubs dominated by Bermuda grass, with grass seeds sprayed and shrub seedlings transplanted. The construction process for the field test was as follows: clearing and leveling the slope → drilling → installing anchor rods → laying and fixing wire mesh → mixing fill soil → spraying fill soil → planting shrub seedlings → preliminary maintenance. Fig. 2(a) shows the on-site spraying process, while Fig. 2(b) depicts the growth condition of slope vegetation in autumn, four years after the completion of the slope project.

(a) On-site Spraying for Vegetation Slope Protection

(b) 4 Years After Vegetation Slope Protection

Fig. 2 Vegetation Slope Protection Treatment Technology

3. Spatiotemporal Evolution Patterns of NDVI

Normalized Difference Vegetation Index (NDVI) is a commonly used indicator in remote sensing monitoring for assessing vegetation coverage and health status. Its calculation formula is:

$$\mathrm{NDVI}=\frac{\mathrm{NIR\text{-}R}}{\mathrm{NIR+R}} \tag{1}$$

Where the near-infrared band reflectance is denoted as NIR, and the red band reflectance is denoted as R. The NDVI value ranges from -1 to 1, with higher values typically indicating denser vegetation. This index serves as a standardized method for assessing vegetation health: higher NDVI values generally correspond to healthier vegetation, while lower values reflect sparse or absent vegetation.

The NDVI data used in this study were sourced from the Geographic Remote Sensing Ecological Network platform (http://www.gisrs.cn), with a spatial resolution of 30 m and a temporal coverage from 2008 to 2022, with one dataset per year. Within the study area, NDVI values primarily ranged from -0.02 to 1. NDVI values along the linear project and in the central urban areas were generally lower, while areas with richer forest cover in the periphery of the urban region often reached NDVI values as high as 0.99, as shown in Fig. 3. Notably, in 2011, the railway area experienced severe drought, leading to widespread vegetation die-off, with NDVI values along the route dropping to between 0.11 and 0.92. Following the return to normal climatic conditions, the vegetation health in this region gradually improved thereafter.

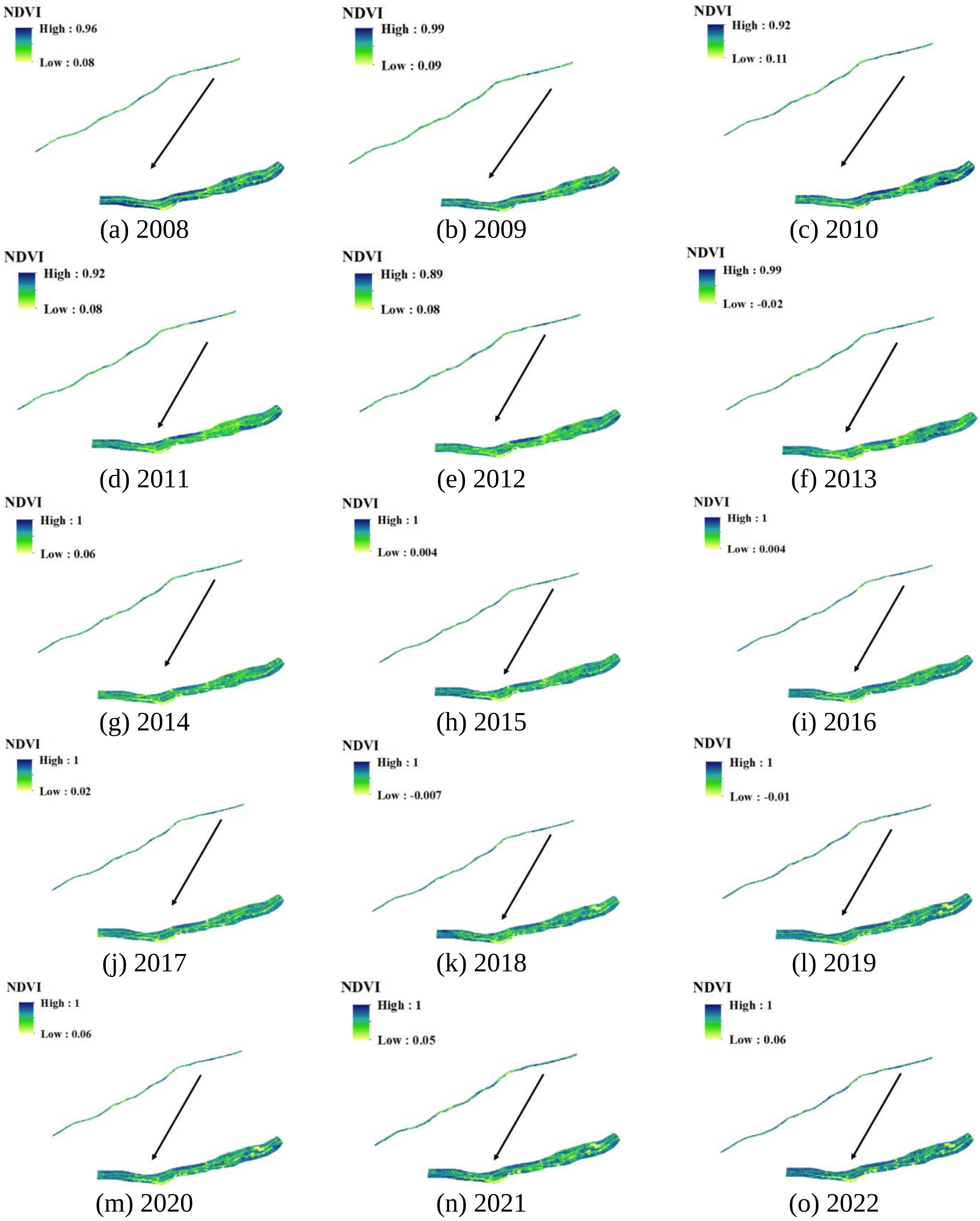
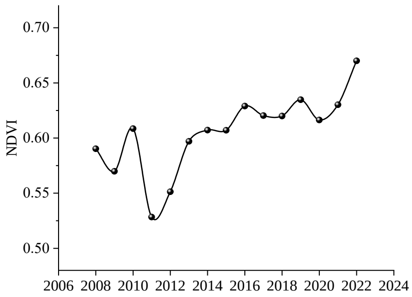


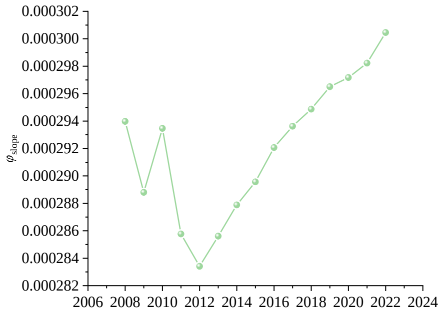
Fig. 3 Evolution Pattern of NDVI in the Zhanyi–Kunming Section of the Guiyang–Kunming Railway

Furthermore, this study calculated the 15-year average NDVI values for 20 engineering sites, as shown in Fig. 4(a). Except for the severe drought in 2011, the region predominantly featured sparse herbaceous vegetation. Overall, the NDVI trend was positive, showing a gradual and steady increase. NDVI values rose from a range of 0.145–0.712 (2008) to 0.165–0.771 (2016). Since 2016, the NDVI levels at the study sites have gradually stabilized at a relatively healthy state, reaching 0.67 by 2022.

Univariate regression trend analysis is a method used to perform regression analysis on a set of variables that change over time. In this study, φ_{slope} was defined to predict future trends, as shown in Eq. (2). According to the results of the univariate regression trend analysis, as illustrated in Fig. 4(b), the φ_{slope} values for the 20 rock-cut slopes in the study area over the past 15 years, following the completion and operation of the Guiyang-Kunming Railway, ranged from 0.000283 to 0.0003. Based on the classification in Table 1, these values all fall into the category of "minor improvement," indicating a consistent trend of slight annual enhancement in vegetation.



(a) Average Value of NDVI



(b) Univariate Regression Trend Analysis of NDVI

Fig. 4 NDVI Analysis and Prediction for the Zhanyi to Kunming Section of the Guiyang-Kunming Railway

$$\varphi_{\text{slope}} = \frac{n\sum_{i=1}^{n}(i \times \text{NDVI}_i) - \sum_{i=1}^{n} i \times \sum_{i=1}^{n} \text{NDVI}_i}{n\sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} i)^2} \tag{2}$$

where n represents the total number of years; NDVI_i denotes the average NDVI value for the i-th year; and φ_{slope} is the slope of the trend line is used to determine the changing trend of NDVI. The classification criteria for φ_{slope} are detailed in Table 1.

Table 1 NDVI Trend

Classification	Trend
$\varphi_{\text{slope}} \le -0.0091$	Severe Degradation
$-0.009 \le \varphi_{\text{slope}} \le -0.0046$	Moderate Degradation
$-0.0045 \le \varphi_{\text{slope}} \le -0.0010$	Slight Degradation
$-0.0009 \le \varphi_{\text{slope}} \le -0.0009$	No Significant Change
$0.0010 \le \varphi_{\text{slope}} \le 0.0045$	Slight Improvement
$0.0046 \le \varphi_{\text{slope}} \le 0.0090$	Moderate Improvement
$\varphi_{\text{slope}} \ge 0.0091$	Significant Improvement

4. Analysis of the Relationship between Economic Growth and NDVI in Zhanyi District

The modernization of transportation infrastructure not only serves as an engine for regional economic growth but also acts as a critical lever for promoting the green transformation of development models. This paper takes the area along the Guiyang-Kunming Railway as a case study, examining its developmental journey from reliance on traditional conventional-speed railways to entering the high-speed rail era. It further focuses on analyzing how eco-friendly construction approaches, represented by “vegetation slope protection,” enhance the environmental foundation and ultimately translate into a key pathway for boosting regional economic vitality.

Rapid Growth and Structural Optimization in Zhanyi District: Between 2008 and 2022, the GDP of Zhanyi District demonstrated sustained and rapid growth, with its total size more than quadrupling. Specifically, GDP increased from 12.33 billion yuan in 2011 to 39.55 billion yuan in 2022, representing an approximate 2.2-fold growth over the course of more than a decade, as shown in Fig. 5.

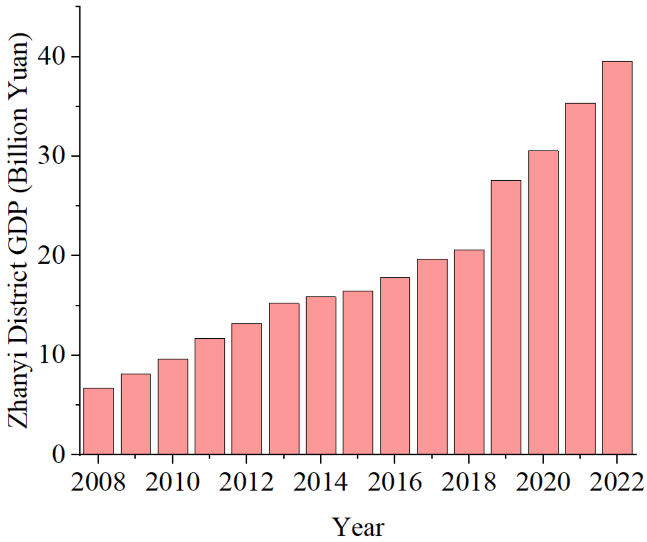


Fig. 5 GDP of Zhanyi District

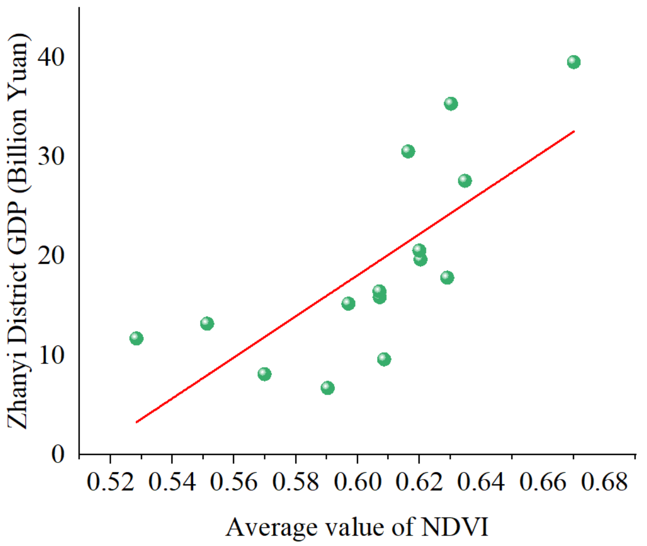


Fig. 6 Relationship between the Economy of Zhanyi District and the Average NDVI

The relationship between economic development and vegetation coverage is usually not a simple positive or negative correlation, but rather dynamic and complex, as illustrated in Fig. 6. The correlation fit between the average NDVI and the economy of Zhanyi District is only 0.53. This can be attributed to the shift in the development philosophy of Zhanyi District:

1) Potential Pressure Period: During the early stages of rapid industrialization and urbanization, economic activities such as the expansion of construction land and resource extraction may directly

occupy or damage vegetation, exerting certain pressure on the ecological environment.

2) Restoration and Coordinated Development Period: With the growing awareness of environmental protection and the transition to a high-quality development stage, the development model undergoes a transformation.

However, in the analysis of the correlation between the NDVI trend and the GDP of Zhanyi District, it is evident that the relationship between the NDVI trend and the GDP satisfies a certain nonlinear pattern, as shown in Eq. (3). From the perspectives of policies and concepts, it is clear that addressing railway hazards through vegetation slope protection has been adopted as a measure.

1) In terms of policies: In recent years, railway construction in Yunnan has integrated ecological protection throughout the entire process, such as implementing specialized greening initiatives and creating green corridors.

2) In terms of structural optimization: The development of low-carbon governance helps reduce energy consumption and emissions.

3) In terms of industrial upgrading: The shift of economic focus from high-energy-consuming and potentially ecologically damaging traditional resource extraction to eco-friendly industries like tourism, commerce, and high technology fundamentally alleviates pressure on vegetation.

Therefore, the NDVI trend exhibits a nonlinear positive correlation with the GDP growth of the region, as illustrated in Fig. 7.

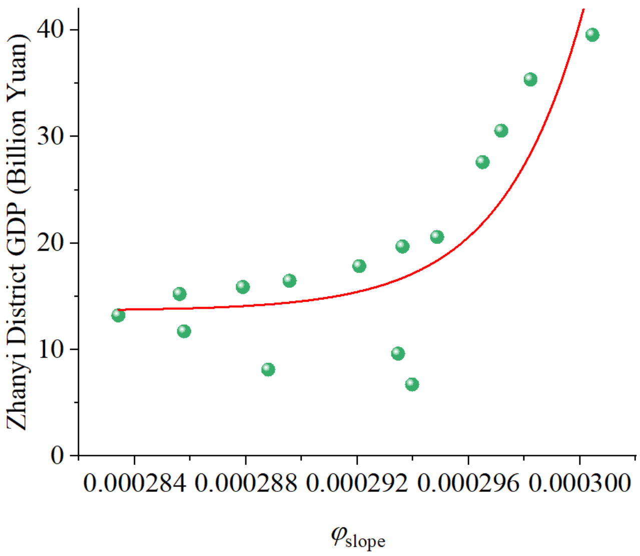


Fig. 7 Correlation Analysis Between NDVI Trend and GDP of Zhanyi District

$$GDP=A_1 e^{-\frac{\varphi_{slope}}{t_1}}+y_0,\quad R=0.72 \tag{3}$$

In the equation, A_1、t_1 and y_0 are fitting parameters, with values of $1\times e^{-42}$、$-2.9\times e^{-6}$ and 13.66, respectively. The units of A_1 and y_0 are billion yuan, while t_1 is dimensionless.

5. Conclusion

Based on the vegetation slope protection project along the Zhanyi-Kunming section of the Guiyang-Kunming Railway, this study utilized remote sensing technology to quantitatively analyze the spatiotemporal evolution characteristics of vegetation cover over nearly 15 years following soil spraying on 20 rock-cut slopes across different spatial and temporal scales. The main conclusions drawn are as follows:

(1) The vegetation slope protection project implemented along the Guiyang-Kunming Railway has withstood the test of time. Remote sensing data indicate that after initial fluctuations, such as the drought in 2011, the NDVI in the soil-sprayed areas has shown a continuous and stable slight improvement trend since 2013. The gradual healthy succession of the slope vegetation community confirms the long-term effectiveness and adaptability of this ecological restoration technology.

(2) The relationship between economic development and vegetation coverage is typically not a simple positive or negative correlation but rather dynamic and complex. While the average NDVI shows a weak correlation with the economic development of Zhanyi District, the trend of NDVI changes exhibits a strong correlation with it. The shifts in the NDVI trend in Zhanyi District reflect broader transformations in policy, structure, and industrial upgrading.

(3) The correlation between NDVI and the economic development of Zhanyi District reveals the mechanism for transforming “ecological assets” into “economic returns.” This provides a solid foundation for developing green industries such as tourism and wellness, as well as attracting high-end talent and investment, thereby facilitating the intrinsic conversion of ecological benefits into socio-economic benefits.

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