RESEARCH ARTICLE

Ecological security and economic development of tourist attractions based on space-time evolution in the context of big data

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In recent years, the rapid development of tourism has raised concerns about the sustainability of ecological security and economic growth in tourist attractions. Addressing the balance between environmental protection and economic development has become a pressing issue. This study explored the relationship between ecological security and economic development of tourist attractions through the lens of space-time evolution in the context of big data. Utilizing comprehensive datasets collected from major tourist destinations between 2010 and 2020, the study employed advanced big data paralytics and space-time analysis tools to construct indices for both ecological security and economic development. The results revealed a positive correlation between improved ecological security and economic growth, highlighting that integrating ecological protection with economic development was crucial for sustainable tourism. The study proposed strategies to foster this coordination such as promoting sustainable tourism practices, establishing ecological compensation mechanisms, and leveraging science and technology for effective scenic area management and policy formulation. This research provided the potential to guide policymakers and stakeholders in making informed decisions that ensured the dual advancement of environmental sustainability and economic prosperity. Future research should delve into the application of big data and advanced analytics to enhance the management of tourist attractions, achieving a harmonious balance between ecological and economic objectives.

Keywords: tourist attractions; ecological security; economic development; space-time evolution; big data.

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Introduction

In the context of the current era of big data, tourism as an important part of the global economy is undergoing unprecedented changes. The application of big data technology enables the tourism industry to collect and analyze a large amount of tourist behavior data, traffic data, and environmental data in real time to more accurately understand and predict the dynamic changes in the tourism market. However, there are often contradictions between the rapid development of tourist attractions and the sustainability of resources and environment, especially the increasingly prominent ecological security problem, which has become a key factor restricting the healthy development of tourism. The interaction and influence between economic development and ecological security of tourist attractions, especially in the dimension of spatial and temporal change, are still lacking in in-depth and systematic research. The research on ecological security and economic development of tourist attractions based on temporal and spatial evolution can not only provide scientific decision support for the management of tourist attractions, but also be the key to realize the strategy of sustainable development of tourism. There have been some studies in the field of ecological security and economic development of tourist attractions, covering a variety of aspects from ecological footprint and sustainability assessment to the coordinated development of ecological economy. Researchers mainly focused on how to promote economic growth through tourism development while protecting and optimizing the ecological environment. Lee *et al*. pointed out that tourism development, economic complexity, and national security had significant impacts on the ecological footprint and emphasized the pressure that tourism development might cause on the ecosystem and the importance of comprehensive management [1]. Sun *et al*. analyzed China's ecological and economic security through dynamic evaluation methods and proposed the correlation between ecological security and economic development and discussed the dynamic changes and influencing factors of the two [2]. Zhu *et al*. discussed the economic development model of eco-city in their research, pointing out that ecological security was a key factor to promote sustainable regional economic development [3]. In addition, Li *et al*. assessed the benefits of economic security and environmental protection, demonstrating the balance between environmental protection measures and economic benefits from the perspective of sustainable development and technological eco-environment [4].

Hai *et al*. demonstrated the application of big data in water resource allocation through a game model of river ecohydrological evolution, emphasizing the actual benefits of data analysis in ecological protection [5]. Further, Yang *et al*. used reliable neural network integration and big data analysis to provide forecasts for future ecological and economic development through a new coordinated forecast model of environment and economy [6]. Karaszewski *et al*. discussed the application of blockchain technology in public sector management including security and energy efficiency, which were essential to improve the transparency and efficiency of data processing [7], while Hu *et al*. demonstrated how to maintain ecological security in the process of rapid urbanization through a case study on the balance between urban expansion and ecological security [8]. Kirilchuk *et al*. explored the concept implementation of sustainable ecological and economic development from the perspectives of Russia and China, respectively, and the strategies for constructing and optimizing ecological security pattern in rapidly urbanizing areas [9, 10].

Despite the wealth of theoretical and empirical research supporting the correlation between ecological security and economic development, there remains a critical need to explore and optimize the specific applications and effects in various regions. This study addressed the pressing issue of balancing ecological protection with economic growth in tourist attractions, a challenge exacerbated by the rapid development of tourism and its impact on environmental sustainability, to systematically analyze the spatiotemporal evolution of ecological security and economic development in tourist attractions using big data technology. By constructing comprehensive indices for both ecological security and economic growth, this study aimed to uncover the intricate relationships and dependencies between these two dimensions [11]. A multi-faceted methodology that integrated advanced big data analytics and spatiotemporal analysis tools was adopted to analyze the data collected from major tourist destinations over a decade, encompassing environmental, economic, and tourist behavior metrics. This robust methodological framework allowed for a nuanced understanding of how ecological and economic variables interact and evolve [12]. By promoting the use of big data and advanced analytics, this research paved the way for more informed and adaptive management strategies that could be tailored to specific regional contexts, ultimately contributing to the sustainable development of tourist attractions and other environmentally sensitive areas [13].

Materials and methods

Data resource and analysis

All data used in this study covered the period from 2010 to 2020. The ecological security scores were derived from a comprehensive index system that integrated multiple environmental indicators from the National Environmental Monitoring Center (https://www.cnemc.cn/). Economic data including tourism revenue and employment statistics were obtained from the National Bureau of Statistics (https://www.stats.gov.cn/english/) and the Ministry of Culture and Tourism (https://www.mct.gov.cn/). The visitor behavior data were collected from major online travel platforms and social media analytics, offering real-time insights into tourist activities and preferences. The indicators included water quality index (WQI), air quality index (AQI), soil erosion rate (SER), species diversity index (SDI), number of endemic species (NES), habitat destruction degree (HDD), tourist density (TD), environmental management investment (EMI), and pollution emissions (PE). Each indicator was standardized and weighted based on its relative importance, as determined by expert consultation and statistical analysis. The weighted sum of these indicators was used to calculate the integrated ecological security index (ESI) for each tourist attraction. Advanced data processing and analysis were conducted using Hadoop (https://hadoop.apache.org/) for big data handling, Spark (https://spark.apache.org/) for real-time analytics, and machine learning algorithms like Random Forest (https://www.stat.berkeley.edu/~breiman/RandomForests/) for prediction and pattern recognition. The computational environment included high-performance computing clusters equipped with Intel Xeon E5-2698 v4 processors and NVIDIA Tesla V100 GPUs. Python 3.8 (https://www.python.org/) with libraries of TensorFlow (https://www.tensorflow.org/), Scikit-learn (https://scikit-learn.org/), and Pandas (https://pandas.pydata.org/) were used for machine learning and data manipulation.

Construction of ecological security index system of tourist attractions

A multi-level framework was adopted to cover multiple dimensions from physical environment to biodiversity and then to human activities. This system could be quantified by an integrated ESI with the consideration of the impact of several key indicators [14, 15]. Physical environmental indicators included WQI, AQI, and SER. These indicators reflected the basic environmental conditions of scenic spots and were crucial for assessing ecological safety. Biodiversity indicators included NES, SDI, and HDD, which enabled assessment of the potential impact of tourism activities on biodiversity. Human activity indicators included TD, EMI, and PE to assess the pressure of human activities on ecosystems. The integrated ESI could be calculated using the weighted summation formula below.

$$ESI = w_1 \cdot (WQI) + w_2 \cdot (AQI) + w_3 \cdot (SER) + w_4 \cdot (NES) + w_5 \cdot (SDI) + w_6 \cdot (HDD) + w_7 \cdot (TD) + w_8 \cdot (EMI) + w_9 \cdot (PE) \quad (1)$$

where $w_1, w_2, \ldots, w_9$ were the weight of each indicator, which reflected the relative importance of each indicator in assessing ecological security and was usually determined based on expert opinions and actual survey data. The ecological security status of tourist attractions could then be systematically assessed, and scientific basis could be provided for formulating relevant policies and management measures. The establishment of the index system also helped to continuously monitor and improve the ecological environment of tourist attractions.

Application of big data technology in ecological security data acquisition and analysis

Big data technology is widely used in the data acquisition and analysis of ecological security in tourist attractions, especially in the processing and analysis of large-scale environmental monitoring data, which plays a key role. Big data technology integrates data from various sources, such as satellite remote sensing data, geographic information system (GIS) data, environmental monitoring site data, and user-generated content on social media and online platforms, to provide comprehensive data support for ecological security assessment [16]. A common analysis method was to build a comprehensive data analysis model that automatically collected and collated data from different data sources using machine learning algorithms for prediction and pattern recognition. The random forest algorithm was used to predict the potential impact of tourism activities on the ecological environment as follows.

$$Y = f(X_1, X_2, \ldots, X_n) + \varepsilon \quad (2)$$

where Y was the prediction result of ecological security status. $X_1, X_2, \ldots, X_n$ were the input environmental monitoring and human activity indicators such as air quality, water quality, land use type, tourist flow. ε was the error term. Big data analysis also involved time series analysis, which was used to track the changing trend of the environmental quality of scenic spots. The model was shown as follows.

$$Y_t = \alpha + \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + \ldots + \beta_p Y_{t-p} + \varepsilon_t \quad (3)$$

where Y_t was the ecological security index at time t. α and $\beta_1, \beta_2, \ldots, \beta_p$ were the model parameters. ε_t was the error term that changed with time. This model could effectively process and analyze the huge data set and realize the real-time monitoring and prediction of the ecological security state of tourist attractions to provide decision support for timely policy making and environmental management.

Application of space-time evolution in ecological security assessment of tourist attractions

The application of temporal and spatial evolution plays an important role in understanding and predicting environmental changes. By integrating temporal and spatial data, dynamic models could be built to observe and analyze changes in ecological security indicators over time and space to identify potential environmental risks and trends in ecological degradation, while assessing the long-term impact of tourism activities on ecosystems [17]. The commonly used spatiotemporal model was the spatial autoregressive model, which could handle the autocorrelation of spatial data, through that the ecological security state of a region could be affected by the state of neighboring regions as shown below.

$$Y = \rho WY + X\beta + \varepsilon \quad (4)$$

where Y was the vector of ecological security indicators. ρ was the spatial autocorrelation coefficient. W was the spatial weight matrix, describing the spatial relationship between various regions. X was other covariables that affected ecological security. β was the regression coefficient. ε was the error term. The application of spatiotemporal geographical weighted regression allowed the model parameters to vary spatially, thus capturing the impact of geographical location on ecological security more accurately. The model was shown as follows.

$$Y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{n} \beta_k(u_i, v_i) X_{ik} + \varepsilon_i \quad (5)$$

where Y_i was the ecological security index of the i site. (u_i, v_i) was the spatial coordinate of the site. X_{ik} was the impact factor. $\beta_0(u_i, v_i)$ was the parameter of the site i, which changed in the spatial position. ε_i was the error term. Through these models, this research could analyze in detail how the ecological security status of tourist attractions changed with the passage of time and space to provide more targeted strategies and measures for scenic spot management and ecological protection.

Construction of economic development index system of tourist attractions

In the construction of economic development index system of tourist attractions, the key was to incorporate multi-dimensional economic factors into the evaluation framework to fully reflect the economic vitality and development potential of scenic spots. This system included direct economic indicators, indirect economic indicators, and potential economic indicators to measure the contribution of tourist attractions to the local and related economy. Direct economic indicators mainly included tourism revenue (TR), tourist spending (TC), and employment opportunities (JE), which directly reflected the contribution of tourism activities to the economy of scenic spots. Indirect economic indicators were related to tourism-driven growth of related industries (IG) and tax contribution (TCR), which helped to assess the driving effect of tourist attractions on the surrounding economy. Potential economic indicators included return on investment (ROI) and tourism growth potential (TGP), which predicted the future economic growth prospects of the scenic area. The composite economic development index (EDI) was calculated as follows.

$$EDI = w_1 \cdot TR + w_2 \cdot TC + w_3 \cdot JE + w_4 \cdot IG + w_5 \cdot TCR + w_6 \cdot ROI + w_7 \cdot TGP \quad (6)$$

where $w_1, w_2, \ldots, w_7$ were the weights of each indicator, which was determined according to the relative importance of each indicator in economic assessment, usually relying on expert assessment and practical experience. Through this index system, the economic development level of tourist attractions could be evaluated quantitatively, and data support could be provided for policy formulation, resource allocation, and optimal management. The establishment of this system also provided a tool for continuous monitoring of economic performance and adjustment of development strategies.

Application of big data technology in economic data acquisition and analysis of tourist attractions

The application of big data technology made full use of various data sources including online transaction records, tourist behavior data, social media interaction, and mobile positioning data to provide in-depth insights into economic activities in tourist attractions. These technologies made it possible to collect and analyze large amounts of data in real time, thereby monitoring economic activity and trends on an almost real-time basis. Big data analysis frameworks, such as Hadoop and Spark, were adopted to process and analyze large-scale data sets. Predictive model, such as linear regression model, was built to predict future tourist flows and economic gains with the formula below.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + ò \quad (7)$$

where Y was the economic output variable such as tourism income. $X_1, X_2 \ldots X_n$ were a series of predictive variables such as the number of historical tourists, the impact of holidays, average consumption. $\beta_0, \beta_1, \ldots, \beta_n$ were the model parameters. ò was the error term. Machine learning techniques such as decision trees, support vector machines (SVM), and neural networks were also used for pattern recognition and trend prediction, which could capture complex nonlinear relationships and interaction effects more accurately and improve the accuracy of prediction. The economic activities of tourist attractions could be deeply monitored and analyzed through these data analysis technologies to optimize the allocation of resources, improve the economic benefits of tourist attractions, and provide support for decision-making.

Application of spatiotemporal evolution in economic development assessment of tourist attractions

The application of spatiotemporal evolution allowed the analysis of the changes of economic activities over time and geographical space, which was crucial for understanding how the economic performance of scenic spots varied over time and in different regions, especially in terms of strategic adjustments to promote regional economic development. Spatiotemporal autoregressive model, which combined the advantages of time series analysis and spatial data analysis to adapt to the spatiotemporal characteristics of tourism economic data was adopted as below.

$$Y_{t,i} = \rho W Y_{t,i} + \phi Y_{t-1,i} + X_{t,i}\beta + \epsilon_{t,i} \quad (8)$$

where $Y_{t,i}$ was the economic indicators in time t and position i. ρ and ϕ were spatial and temporal autoregressive coefficients, respectively. W was spatial weight matrice. $X_{t,i}$ was the other influencing factor such as policy changes and market demand. β was coefficient vector. $\epsilon_{t,i}$ was error term. Spatiotemporal geographical weighted regression was also used in this study, which considered the local changes of parameters in space and could more accurately capture the local characteristics of economic development in different regions. The model was calculated as follows.

$$Y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{n} \beta_k(u_i, v_i) X_{ik} + \epsilon_i \quad (9)$$

where Y_i was the economic development index of the location i. (u_i, v_i) was the spatial coordinate of the location. X_{ik} was the impact factor. $\beta_0(u_i, v_i)$ was the parameter of the location i, which varied spatially. ϵ_i was the error term. Through these models, the influence of time and space could be comprehensively considered to analyze and predict the economic development trend of tourist attractions and provide scientific basis for tourism management and policy formulation.

Results and discussion

The correlation between ecological security and economic development

The data points and regression fitting lines between ecological security score and economic growth rate demonstrated a positive correlation trend (Figure 1). The results showed that the ecological security score gradually increased from 70.35 to 87.47, while the economic growth rate also increased from 3.12% to 5.63%. The results indicated that, while the ecological security score was improving, the economic growth rate also showed an upward trend. The regression line equation was obtained as y = $0.35x - 17.74$, where the slope of 0.35 indicated that every unit increased in the ecological security score increased the economic growth rate by 35%. This relationship reflected that a good ecological environment could attract more tourists and investment, promote the development of tourism and related industries, and thus drive the overall economic growth. This analysis not only helped to understand the intrinsic relationship between ecological protection and economic development, but also provided data support for formulating relevant policies and implementing sustainable development strategies.

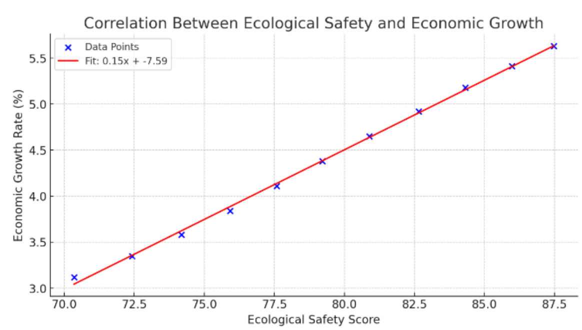

Figure 1. Relationship between ecological security score and economic growth rate.

Implications of the spatiotemporal evolution analysis for the relationship between ecological security and economic development

The results of spatiotemporal evolution analysis,

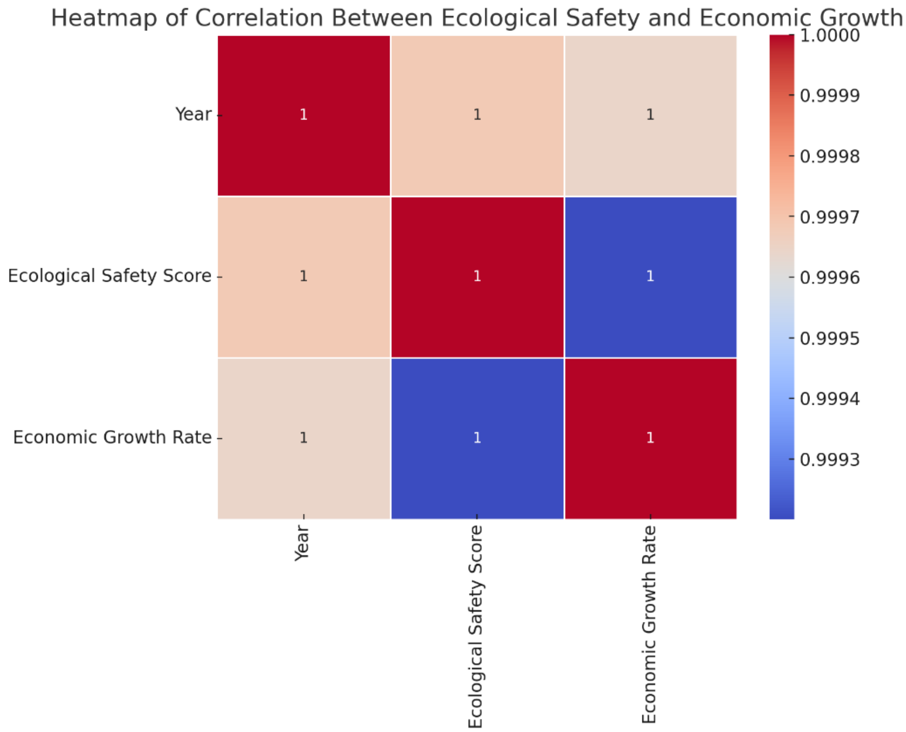

Figure 2. Correlation heat map of ecological security score and economic growth rate.

especially the correlation between ecological security and economic development of tourist attractions, could provide more specific guidance for management and decision-making. The results showed that, with the improvement of ecological security scores, economic growth rates also showed a corresponding increase, which suggested that investing in ecological protection and improvement measures not only contributed to the continuous improvement of the environment, but also promoted economic development. The strong correlation between ecological security and economic growth demonstrated the correlation coefficient close to 1, which indicated a strong positive correlation and suggested that improving ecological security was a key factor in promoting economic growth. The heat maps showed complex relationships between ecological security scores and economic growth, providing policymakers with a visual analytical tool to identify and enhance synergies between ecological protection and economic development (Figure 2). The results highlighted the important impact of ecological security on economic development and emphasized the importance of implementing sustainable tourism strategies. By maintaining ecological security, tourist attractions could maintain their natural and cultural attractiveness and further realize the growth of economic benefits, which was crucial for the long-term development of the regional economy and communities. This analysis provided valuable insights into the management and policymaking of tourist attractions, highlighting the need for ecological protection and economic development strategies to move in tandem to ensure the sustainability of tourism while promoting economic growth. This integrated approach would help to develop more effective management strategies to ensure that tourist attractions could achieve the maximum economic benefits while protecting the ecology.

The coordinated development strategy of ecological security and economic development

The coordination between ecological security and economic development is the key to the sustainable development of tourist attractions.

To achieve this goal, a comprehensive strategy must be adopted to promote economic growth while protecting and improving the ecological environment.

(1) Promotion of sustainable tourism practices

Promoting sustainable tourism practice was an effective way to realize the coordination between ecological security and economic development of tourist attractions, which included the development of environmentally friendly tourism activities such as ecotourism, agritourism, and cultural tourism to encourage visitors participating the conservation of natural resources and respecting local cultures. Implementing strict visitor management policies and limiting the number of visitors to reduce pressure on the fragile ecological environment was another key strategy to protect the ecological environment. Developing sustainable tourism also required increasing the participation of local communities. By training residents to participate in tourism business operations, it would provide employment opportunities and directly benefit them from tourism, thereby enhancing community support for ecological conservation projects. Enhancing environmental education and publicity to raise awareness of the importance of ecological protection among tourists and local residents was also an important part of promoting sustainable tourism practices.

(2) Establishment of ecological compensation mechanism

The establishment of ecological compensation mechanism was another key strategy to balance tourism development and ecological protection needs. Ecological compensation referred to the provision of compensation for those individuals or groups who beard additional costs or loss economic benefits in ecological protection actions and ensured that they were reasonably compensated for economic losses caused by ecological protection. Tax breaks or direct financial grants could be given to areas that restricted development to protect the ecology. Ecological compensation could also be implemented through the payment of ecological services such as payments to communities that maintained the health of forests and wetlands, which served to regulate the climate, maintain water quality, and provide biodiversity. Through such a mechanism, local communities were encouraged to participate in ecological protection to maintain the long-term sustainable use of tourism resources.

(3) The application of science and technology in ecological protection and economic development

The use of modern technology such as remote sensing, GIS, and big data analysis could effectively monitor and manage the ecological environment of tourist attractions. These technologies could provide real-time data to help managers understand ecological changes in a timely manner, prevent environmental risks, and optimize resource allocation to improve the efficiency of economic operations. Technology could also play a role by facilitating the development of emerging tourism products such as immersive tourism experiences provided by virtual reality and augmented reality technology to attract more tourists. Digital marketing tools could help tourist attractions more effectively reach the target market and enhance market competitiveness. Science and technology not only improved the ability of ecological protection, but also created new economic growth points, and was an important force to promote the coordination of ecological security and economic development. Through the implementation of these strategies, tourist attractions could realize the sustainable protection of ecological environment and the steady growth of economy to ensure the realization of sustainable development goals.

Prospects

This research field still has extensive development space and deepening direction in future studies. With the further development and application expansion of big data technology, more advanced analytical tools and models will be introduced into the research of ecological security and economic development of tourist attractions, which will further improve the accuracy and efficiency of research and make the processing of complex data more refined and efficient. In particular, the integration of machine learning and artificial intelligence technologies will provide more powerful predictive capabilities and decision support for analyzing the spatiotemporal evolution of tourist attractions. Future research should focus more on the integration of multiple disciplines such as combining theories and methods from the fields of ecology, economics, geographic information systems (GIS), and sociology to form a more comprehensive research framework. This interdisciplinary research method can further explore the interaction and complex mechanism between ecological security and economic development. The importance of empirical research should also be emphasized. By conducting case studies in different types and scales of tourist attractions, the theoretical model can be verified and refined, and the universal applicability and practical value of the research results can be enhanced. With the continuous changes of global climate and environmental policies, the research on ecological security and economic development of tourist attractions should constantly adapt to these external changes, and constantly update and adjust related management strategies and development models.

Conclusion

Under the background of big data, the study on the ecological security and economic development of tourist attractions by using the space-time evolution could not only reveal the correlations, but also provide scientific data support and decision-making basis for the sustainable development of tourist attractions. The research showed that there was a positive correlation between ecological security and economic development, indicating that the improvement of ecological security was often accompanied by the acceleration of economic development. This finding highlighted the importance of ecological conservation and the need to integrate ecological and economic objectives in the development strategy of tourist attractions. By constructing a spatiotemporal evolution model of ecological security and economic development of tourist attractions, this study provided a new perspective and method for assessing and predicting the dynamic changes in these two aspects. The proposed method could help managers better understand and predict the changing trend of tourist attractions in different time and spatial scales to formulate more effective management measures and development strategies. To promote the long-term healthy development of tourist attractions, it was recommended to strengthen ecological safety management and stimulate the potential of economic development. Through the implementation of scientific data analysis and space-time evolution model, the relationship between the two could be more effectively balanced to ensure that the economic interests and ecological environment of tourist attractions were optimized and promoted simultaneously.

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