

Article

Evaluating Scientific Tourism of Geoheritage: An Empirical Study of Fangshan Global Geopark in Beijing

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Abstract: Scientific tourism (ScT) of geoheritage serves as a crucial approach to ensuring the protection of natural heritage. Establishing a comprehensive evaluation system to guide the exploration of ScT in geoheritage is essential. This study adheres to principles of comprehensiveness by integrating both qualitative and quantitative methods, ensuring operability, authenticity, and scientific rigor. It employs the analytic hierarchy process, expert consultation method, and fuzzy mathematical evaluation method to construct an evaluation index system. This system encompasses four dimensions: ScT of geoheritage resources, practices and construction related to ScT, auxiliary conditions for exploration, and ecological environment construction. The study uses Fangshan Global Geopark in Beijing as a case study for empirical analysis. The findings indicate that the constructed evaluation system effectively captures key factors influencing the exploration of the ScT of geoheritage. Fangshan Global Geopark demonstrates commendable performance in terms of its ScT of geoheritage resources as well as practices and construction. But it has limitations regarding auxiliary conditions for exploration and ecological environment construction. This study provides theoretical underpinnings and policy recommendations for the exploration of the ScT of geoheritage.

Keywords: exploration evaluation; Fangshan Global Geopark; geoheritage; index system; scientific tourism



Citation: Zhu, Z.; Liu, J.; Zhu, H.; Zhao, W. Evaluating Scientific Tourism of Geoheritage: An Empirical Study of Fangshan Global Geopark in Beijing. *Land* **2024**, *13*, 2119. <https://doi.org/10.3390/land13122119>

Academic Editor: Theo van der Sluis

Received: 5 November 2024

Revised: 30 November 2024

Accepted: 5 December 2024

Published: 6 December 2024



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1. Introduction

Geoheritage serves as a vital repository of natural heritage [1], encompassing a wealth of geoheritage and information about Earth's history, which possess significant scientific, educational, and cultural value [2]. These natural heritage sites not only document the extensive evolution of our planet over billions of years—containing tectonic movements, volcanic activities, and glacial erosion—but also harbor abundant mineral resources, fossils of ancient organisms, and distinctive geological landscape features [3]. Held in Beijing, China, in 1996, during the 30th International Geological Congress, the United Nations Educational, Scientific and Cultural Organization (UNESCO) Division of Earth Sciences and the International Union of Geological Sciences were tasked with initiating the “Global Geopark” initiative. This initiative aims to enhance the protection of global geoheritage. The term “Geopark” was first introduced in this context in Beijing. Consequently, geoparks are recognized as essential locations for preserving Earth's heritage while facilitating the study of geoheritage processes and their impacts [4]. In 2004, UNESCO formally established the Global Geoparks Network with a core mission to not only safeguard these invaluable geoheritage sites but also to enhance public awareness of their significance within both the ecological environment and human civilization through scientific research and education [5]. As of August 2024, there are 213 member geoparks worldwide, spanning across 48 countries. China's development in this area has been particularly rapid, boasting 47 geoparks and becoming the largest member country globally. In an era where

global environmental changes are increasingly pronounced, the protection and sustainable exploration of geoheritage have become especially urgent and vital.

With the enhancement of public awareness of environmental protection and scientific literacy, scientific tourism (ScT), as a form of tourism that integrates education and experience, has emerged as a prominent topic in tourism research [6]. ScT combines education with experiential learning, focusing on the dissemination of scientific knowledge as its core component. It emphasizes active participation in the field and interactive experiences designed to stimulate tourists' interest in learning and foster a spirit of scientific inquiry [7]. This form of tourism covers a variety of tourist destinations such as scientific attractions, nature reserves, and geoheritage, where tourists can conduct scientific exploration and study [8]. Different from traditional tourism, the purpose of ScT is not only leisure and entertainment, but more importantly, through interaction and participation, tourists can learn scientific knowledge in practice [9]. A geopark is a geoheritage conservation area recognized by organizations such as UNESCO. It serves not only to protect and showcase geoheritage but also fulfills multiple functions, including the promotion of local economies, scientific research, education, and sustainable tourism. The primary objective of a geopark is to enhance public awareness regarding the protection of geoheritage through scientific inquiry, educational initiatives, and tourism activities while fostering the development of local communities [10]. Under the influence of ScT as well as the global emphasis on natural heritage protection and eco-tourism development in recent years, geoheritage, as natural outdoor laboratories, has become an ideal place for ScT [11]. Through the interaction between tourists and the natural environment, ScT of geoheritage can enhance visitors' awareness of the importance of respecting and protecting nature [12], aligning closely with the globally advocated concept of sustainable tourism [13]. Simultaneously, the implementation of the ScT of geoheritage represents a harmonious integration of scientific education and social welfare initiatives [14]. Many geoheritage sites have established a complete system of ScT interpretation and have effectively promoted the dissemination of scientific knowledge by holding various ScT activities. For instance, the Zhangjiajie Global Geopark in China, renowned for its distinctive karst landforms, has developed a rich array of ScT education programs. This initiative has attracted a significant number of domestic and international tourists, establishing the park as a model for the ScT of geoheritage. However, with the growth of tourism comes the challenge of balancing ecological protection with tourism exploration. Additionally, designing a scientific and effective suitability evaluation index system to assess the exploration potential of the ScT of geoheritage remains a complex issue that requires resolution.

This study aims to elucidate the primary advantages and challenges associated with the integration of geoheritage protection and ScT practices while also offering viable recommendations for sustainable development. The study is conducted in four stages. First, a comprehensive evaluation framework for the exploration of the ScT of geoheritage is established based on relevant literature, expert consultations, and the analytic hierarchy process (AHP) method. Second, the evaluation methods and scoring criteria are defined using the fuzzy mathematical evaluation method. Third, a comprehensive assessment of the ScT of geoheritage exploration within Fangshan Global Geopark is performed to validate the rationality and practicality of the evaluation index system. Finally, the results are synthesized to offer practical recommendations for integrating geoheritage protection with ScT initiatives. Theoretically, this research enriches the relevant measurement methods pertaining to the exploration of the ScT of geoheritage. Practically, the findings presented in this paper can serve as a reference for advancing ScT in other geoheritage at home and abroad and hold significant practical guiding implications.

2. Literature Review

2.1. Research on the ScT of Geoheritage

In recent years, the exploration of the ScT of geoheritage has garnered considerable attention, with research addressing several critical dimensions. Key areas of study include

the classification and valuation of resources, product development, and interpretation systems, as well as the educational impacts and satisfaction levels experienced by tourists. The resources encompassed within geoheritage exhibit a complex and diverse nature, necessitating scientific and rational classification as a prerequisite for their effective development and management. For instance, Poiraud A et al. conducted a comprehensive survey of geoheritage in the Vercors region, identifying five significant resource areas pertinent to ScT initiatives [14]. The assessment of resource value is a crucial approach to unlocking their potential and emphasizing the distinctive features of tourism. Academic inquiry in this domain encompasses various dimensions, including scientific value [15], esthetic value, ecological value [16], cultural and historical significance, educational and popular science relevance, as well as economic and social impact. Furthermore, it addresses aspects related to sustainable development and management practices. Migon et al. analyzed the European Geopark Network through four key perspectives: science, education, functionality, and tourism [17]. The development of ScT products within geoheritage sites represents a vital link in transforming resource advantages into both tourism attractiveness and economic value [18]. It serves as an essential approach to achieving the objectives of science popularization education [19]. Zouros' analysis of successful experiences at the Aegean Geopark in Greece indicates that establishing a natural museum can significantly enhance its attractiveness to tourists [20]. The ScT explanation system is designed to convey professional scientific knowledge to visitors while simultaneously improving their own literacy. This system incorporates various methods, including language, imagery, demonstrations, and interactive elements [21]. Scholars categorize the components of the ScT explanation system into three main aspects: the object of explanation, the method of explanation, and the audience for explanation. With advancements in technology, contemporary research has increasingly focused on integrating traditional commentary techniques with innovative technologies to improve tourist engagement and interactivity [22]. The educational perceptions and satisfaction level of tourists serve as direct indicators of the effectiveness of ScT in geoheritage activities. The academic community has developed a scale for analyzing educational perception [23] and has evaluated tourist satisfaction in order to enhance the appeal of tourist destinations [24]. In addition, many studies have emphasized the collaborative role of communities in the ScT of geoheritage [25]. Within this context, communities assume various roles that can stimulate the development of new tourist attractions while further enhancing environmental protection efforts [26]. Furthermore, advancements of the ScT of geoheritage contribute to improving community quality and fostering sustainable development within the local economy [27].

The evaluation of the ScT of geoheritage not only enhances the academic community's understanding of the intrinsic value of geoheritage resources but also provides a scientific foundation for effective management and sustainable development practices. Currently, research on tourism evaluation in geoheritage primarily concentrates on aspects such as resource protection, benefits derived from tourism development, and environmental impacts. For instance, a quantitative evaluation of 17 geoheritage sites in Viana do Castelo (northwestern Portugal) revealed that six exhibited significant potential for tourism and educational purposes [28]. The SWOT analysis of the Xiangxi Global Geopark and Zhangye-Danxia Geopark in Gansu Province highlights their significant potential for the ScT of geoheritage [12]. The development prospects and environmental challenges of the Kizilcahamam-Camlidere geopark in Turkey are systematically analyzed using visual analysis, SWOT analysis, surveys, work of focus group, etc. [29]. At the same time, Farsani et al. evaluated the connectivity between the European Geoparks Network and the UNESCO Global Geoparks Network to establish an academic foundation for the ScT of geoheritage and knowledge exchange [5]. To summarize, the majority of existing research on the ScT of geoheritage primarily concentrates on the singular aspects of geoheritage resources and their educational value. There is a notable lack of in-depth discussion regarding the comprehensive suitability evaluation for the exploration of ScT in these areas. Furthermore, empirical analyses focusing on the evaluation of specific geoheritage are relatively scarce,

resulting in weak references for further study. Concurrently, while some scholars have proposed various evaluation models and methods, these approaches often fall short in terms of comprehensiveness, with few established indicators specifically addressing ScT of geoheritage. Therefore, this study proposes a comprehensive evaluation index system to better measure the exploration of the ScT of geoheritage. By providing a standardized approach, this framework facilitates the comparison and analysis of various geoheritage sites worldwide, thereby promoting sustainable tourism practices and contributing to the preservation of geoheritage.

2.2. Framework of Evaluation Index System

The indicator evaluation method means evaluating the attributes of an object or many objects with different indicators [30]. The process of selecting indicators has undergone the following steps (Figure 1). To ensure the scientific rigor, practicality, and comprehensiveness of the index system, the selection of evaluation indicators should adhere to the following five principles [31]: (1) comprehensiveness; (2) a combination of qualitative and quantitative approaches [32]; (3) operability [33]; (4) authenticity; (5) scientific principles.

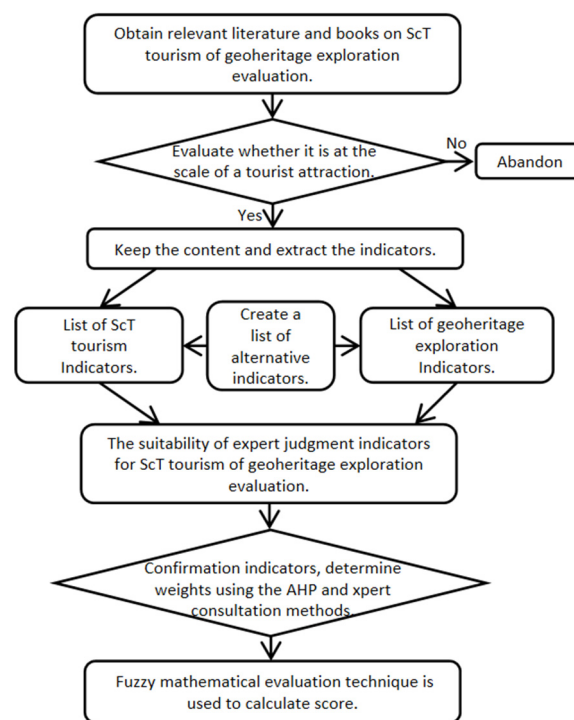


Figure 1. Flowchart for establishing the evaluation indicator system.

2.2.1. Selection of Indicators

There is no general agreement on a standard evaluation index system of the ScT of geoheritage value at present. Based on relevant research results and features of the ScT of geoheritage [34], this study constructs the evaluation index system from four factors: ScT resources in geoheritage (B1), practices and construction related to ScT (B2), auxiliary conditions for exploration (B3), ecological environment construction (B4) (Table 1). This study aims to develop a comprehensive evaluation framework designed to assess the ScT potential of geoheritage sites on a global scale. The proposed model is intended for application across a diverse array of geoheritage sites and geoparks, irrespective of their geographical location, and can be utilized to evaluate the scientific and educational value of geoheritage relics for tourism purposes.

Table 1. Evaluation index system for the ScT of geoheritage.

Dimension(B) /Level 2	Weight	Factor(C)/ Level 3	Weight	Attribute(D)/Level 4	Weight
Resources for the ScT of geoheritage B1	0.32	Geoheritage feature C1	0.33	Classification of geoheritage D1	0.44
				Geoheritage typicality D2	0.39
				Scale of geoheritage remains D3	0.17
		Resource value C2	0.67	Ornamental value D4	0.13
				Environmental value D5	0.12
				Scientific value D6	0.38
				Cultural value D7	0.37
Practices and construction related to ScT B2	0.41	ScT practice C3	0.50	Clear theme D8	0.20
				Attractiveness of novelty D9	0.10
				ScT sign system D10	0.38
				The guide explains the content of ScT D11	0.32
		ScT capacity building C4	0.50	Popularization of science D12	0.23
				ScT activities D13	0.18
				Training days ScT D14	0.16
Auxiliary conditions for exploration B3	0.15	Development condition C5	0.36	Construction of ScT education base D15	0.43
				Scenic spot level D16	0.36
				Distance from central city D17	0.24
				Connect with the surrounding attractions D18	0.12
		Social environment C6	0.19	Suitable travel period D19	0.28
				Local economic level D20	0.38
				Government policy D21	0.36
				Tourism investment D22	0.16
		Tourist market C7	0.45	Local attitude D23	0.10
				Tourist growth rate D24	0.55
Ecological environment construction B4	0.12	Ecological security C8	0.33	Age structure of tourists D25	0.21
				Tourist source structure D26	0.24
				Geoheritage disaster D27	0.50
		Environmental quality C9	0.67	Meteorological disaster D28	0.25
				Species invasion D29	0.25
				Greening level D30	0.52
				Negative oxygen ion content D31	0.34
				Surface water quality D32	0.14

First and foremost, the resources for the ScT of geoheritage serve as the foundation of the exploration evaluation system, encompass the following: geoheritage feature (C1) and resource value (C2). The design of indicators is conducted in accordance with relevant standards outlined in “Technical Requirements for National Geopark Planning” (Ministry of Land and Resources, 2016 No. 83) and “Technical Requirements for Geological Heritage Investigation”. In terms of geoheritage characteristics, the evaluation system has established indicators such as classification of geoheritage (D1), geoheritage typicality (D2), and scale of geoheritage remains (D3) [35]. Resource value is assessed through four dimensions: ornamental value (D4), environmental value (D5), scientific value (D6), and cultural value (D7) [36]. This multifaceted approach ensures that geoheritage resources not only hold significant importance for scientific research and public education but also offer a high-quality viewing experience and rich cultural connotation [37].

Second, practices and construction related to ScT exemplify the tangible achievements of the geoheritage in fulfilling its educational functions. This can be categorized into two sub-groups: ScT practice (C3) and ScT capacity building (C4). The design index is grounded in the “Management Measures for the National Science Popularization Base of Natural Resources (Trial)” and the “Application Conditions for Identifying the National Science Popularization Education Base”. In the realm of ScT, various indexes are used to evaluate

the quality of activities within geoheritage and tourist engagement. These indexes include clear theme (D8), attractiveness of novelty (D9), ScT sign system (D10), and the guide explains the content of ScT (D11) [38]. To assess the quality of ScT activities and visitor engagement in geoheritage, it is essential to focus on the geoheritage's overall capacity for science communication. This includes aspects such as popularization of science (D12), ScT activities (D13), training days for ScT (D14), and construction of ScT education base (D15) [20].

The auxiliary conditions for exploration serve as a crucial guarantee influencing the success of such initiatives within geoheritage. The index was established in accordance with the Standard of rating for quality of tourist attractions (GB/T17775-2003) [39] and relevant literature [40]. It includes the following: development condition (C5), social environment (C6), and tourist market (C7). The auxiliary conditions encompass the following: scenic spot level (D16), distance from central city (D17), connect with the surrounding attractions (D18), and suitable travel period (D19). These elements are essential to ensure that the geoheritage offers excellent accessibility and convenient tourist facilities [41]. The social environment reflects the influence and support of the geoheritage within its region by evaluating factors such as local economic level (D20), government policy (D21), tourism investment (D22), and local attitude (D23). Among these factors, local attitudes play a crucial role in the exploration of the ScT of geoheritage [42]. However, currently, the perspectives of locals are frequently overlooked. Therefore, this paper incorporates the evaluation index of local attitudes [43]. The market appeal and potential exploration opportunities of geoheritage are assessed through the tourist growth rate (D24), age structure of tourists (D25), and tourist source structure (D26).

Finally, ecological environment construction plays a fundamental and supportive role in the exploration of the ScT of geoheritage [44]. The ecological environment construction index is formulated based on a review of the pertinent literature [45] and the Environmental Protection Industry Standard of the People's Republic of China. This section encompasses two dimensions: ecological security (C8) and environmental quality (C9). Ecological security indicators—such as geoheritage disaster (D27), meteorological disaster (D28), and species invasion (D29)—are employed to evaluate the ecological risks encountered by geoheritage. These indicators facilitate the formulation of effective disaster prevention and mitigation strategies for management agencies. Environmental quality is assessed through various metrics that reflect the ecological health of the ScT of geoheritage, including greening levels (D30), negative oxygen ion content (D31), and surface water quality (D32). These evaluations ensure that tourism exploration does not adversely impact the ScT of the geoheritage's ecosystem.

2.2.2. Calculation of Weights

In this study, the analytic hierarchy process (AHP) is used to calculate the weight of each index [46]. The specific steps are outlined as follows: First, an expert evaluation table is designed based on the evaluation index system for the ScT of geoheritage. Researchers extended invitations to 10 experts via email in September 2024 and 8 experts responded to the email and participated. The experts have the following profile: five years or more of research experience in heritage protection, tourism management, and tourism planning; currently work in universities or scientific research institutions or planning companies, and all have doctor's degrees [47] (Table 2). The experts employed a reciprocal scale method to conduct pairwise comparisons and score each layer of indicators. The scale descriptions for the reciprocal scale method are presented in Table 3.

In the process of research, considering that many comparison items may affect the subjective judgment of experts, the number of comparison items is 7 ± 2 . Taking 9 factors as an example, the scale from 1 to 9 is used to express the relative differences among the factors. In the process of pin-two comparison, a total of $n(n - 1)/2$ judgments are needed to ensure that sufficient information is collected and the importance of each indicator is scientifically ranked. This study adopts a multi-expert independent scaling method, where each element

is evaluated using multiple judgment matrices. As a result, it becomes crucial to aggregate these diverse judgments effectively. Following the principle that the minority should adhere to the majority, the study selects the mode of the eight expert ratings as the final value. In cases where multiple modes exist, the average of these modes is computed. If no mode is present, the arithmetic mean of all expert scores is used. Ultimately, this process leads to a definitive judgment matrix. Through the pairwise comparison results, the weights of each index are calculated, and the importance comparison matrix is presented [48] (Table 4).

Table 2. Experts' profile.

		No. of Experts
Gender	Male	3
	Female	5
	Total	8
Specialized field	Heritage protection	3
	Tourism management	3
	Tourism planning	2
	Total	8
Experience in relevant fields	5–10 years	2
	10–20 years	3
	20–25 years	2
	Above 25 years	1
	Total	8

Table 3. Scale description.

Implication	Scale Value
The C_i element has the same effect as the C_j element	1
The C_i elements have a slightly stronger effect than the C_j element	3
The C_i element has a stronger influence than the C_j element	5
The C_i element has a much stronger influence than the C_j element	7
The C_i element has a Completely stronger influence than the C_j element	9
The influence ratio of the C_i element to the C_j element lies within the two adjacent levels mentioned above	2, 4, 6, 8
The influence ratio of element C_i on element C_j is represented by the reciprocal of the value a_{ij} mentioned above	1, 1/2, ..., 1/9

Table 4. Dimensions/level 2 index weights.

	B1	B2	B3	B4	W_i
B1	1	0.5	3	3	0.32
B2	2	1	3	2	0.41
B3	1/3	1/3	1	2	0.15
B4	1/3	1/2	1/2	1	0.12

Then, the normalized summation method is used to normalize the columns of the judgment matrix, and the maximum eigenroot of the judgment matrix is 4.22, and the CI value is 0.08. According to the query of the RI table, the corresponding RI value is 0.88, and the consistency ratio of the judgment matrix is calculated as $CR = CI/RI = 0.08 < 0.1$, indicating that the weight of the indicator has high reliability (Table 5). The calculation results show that among the first-level indicators, practices and construction related to ScT has the highest weight, accounting for 0.41, followed by resources for the ScT of geoheritage, accounting for 0.32; auxiliary conditions for exploration have a weight of 0.15,

and ecological environment construction has a relatively low weight, accounting for 0.12. The weights of the factors and attributes were also calculated according to the above steps and passed the consistency test. The variable weight distribution is shown in Table 5.

Table 5. AHP method test results.

Results of the Consistency Test				
Maximum Eigenvalue	CI value	RI value	CR value	Consistency test result
4.22	0.07	0.88	0.08	passed

3. Methodology

3.1. Evaluation Criteria

The measurement of the evaluation index is a crucial aspect in ensuring the scientific rigor and objectivity of evaluation outcomes. These measurements can generally be categorized into two types: One type is based on objective standards, wherein data are derived from authoritative sources such as relevant national standards, statistical yearbooks, official website bulletins, and other credible data repositories. Measurements obtained through these means exhibit high levels of objectivity. The second type involves subjective evaluation, which gathers qualitative data from appropriate survey subjects using methods such as questionnaires (Table 6). The questionnaires designed for both tourists and residents can be found in Appendices A and B.

Table 6. ScT of geoheritage index measurement and methods.

Attribute(D)/Level 4	Measure and Method	Attribute(D)/Level 4	Measure and Method
Classification of geoheritage	Technical requirements for geoheritage survey	Distance from central city	Distance from the nearest central city
Geoheritage typicality	Technical requirements for geoheritage survey	Connect with the surrounding attractions	Courtesy of geoheritage
Scale of geoheritage remains	Courtesy of geoheritage	Suitable travel period	Courtesy of geoheritage
Ornamental value	GB/T17775-2003 [39]; visitor questionnaire	Local economic level	Per capita GDP; data inquiry
Environmental value	GB/T17775-2003 [39]; visitor questionnaire	Government policy	Data inquiry
Scientific value	GB/T17775-2003 [39]; visitor questionnaire	Tourism investment	Data inquiry
Cultural value	GB/T17775-2003 [39]; visitor questionnaire	Local attitude	Resident questionnaire
Clear theme	Visitor questionnaire	Tourist growth rate	Courtesy of geoheritage
Attractiveness of novelty	Visitor questionnaire	Age structure of tourists	Proportion of tourists under 40 years old
ScT sign system	Number of ScT commentary boards	Tourist source structure	Courtesy of geoheritage; proportion of domestic and foreign tourists
The guide explains the content of ScT	GB/T17775-2003 [39]; Visitor questionnaire	Geoheritage disaster	Number of hidden geoheritage hazards in the region
Popularization of science	Courtesy of geoheritage	Meteorological disaster	Number of hidden points of meteorological disasters in the geoheritage

Table 6. Cont.

Attribute(D)/Level 4	Measure and Method	Attribute(D)/Level 4	Measure and Method
ScT activities	Courtesy of geoheritage	Species invasion	The number of species invasion danger spots in the area
Training days for ScT	Courtesy of geoheritage	Greening level	Green area of scenic spot
Construction of ScT education base	Courtesy of geoheritage	Negative oxygen ion content	Negative oxygen ion content
Scenic spot level	Courtesy of geoheritage	Surface water quality	GB/T3838-2002 [49]; Courtesy of geoheritage

3.2. Scoring Criteria for the ScT of Geoheritage

In this study, a fuzzy mathematics scoring system [50] is employed to assign scores to various indices of the ScT of geoheritage. The scoring scale for the indices ranges from 0 to 5 points [51]. It is divided into five sections, as shown in Table 7. Each interval corresponds to distinct performance levels of various indices, aimed at quantifying the current state of the ScT of geoheritage. The scoring criteria for each index are primarily established based on the following national standards and technical specifications: “Standard of rating for quality of tourist attractions” (GB/T17775-2003) [39], “Technical Requirements for the Preparation of National Geopark Planning” (Document No. 83 of 2016), “Quality of Tour-Guide Service” (GB/T15971-1995) [52], “Technical Requirements for Geological Heritage Investigation”, and “Application Conditions for the Identification of National Science Popularization Education Base”.

Table 7. Grading criteria for the indicators.

Attribute(D)/Level 4	Evaluation Criteria				
	5	4	3	2	1
Classification of geoheritage	World-class	National-class	Provincial-class	City- and county-class	No class
Geoheritage typicality	Extremely high	High	Normal	Lower	Low
Scale of geological remains	Maximum	Tremendous	Large	Normal	Small
Ornamental value	Extremely high	High	Normal	Lower	Low
Environmental value	Extremely high	High	Normal	Lower	Low
Scientific value	Extremely high	High	Normal	Lower	Low
Cultural value	Extremely high	High	Normal	Lower	Low
Clear theme	Very strong	Strong	Normal	Lower	Low
Attractiveness of novelty	Very strong	Strong	Normal	Lower	Low
ScT sign system/each	≥ 50	40~50	30~40	20~30	<20
The guide explains the content of ScT	Extremely high	High	Normal	Lower	Low
Popularization of science	Tremendous	Larger	Normal	Lesser	Small
ScT activities/time	≥ 15	14~10	6~9	3~5	<3
Training days for ScT/day	≥ 18	15~18	10~15	5~10	<5

Table 7. Cont.

Attribute(D)/Level 4	Evaluation Criteria				
	5	4	3	2	1
Construction of ScT education base	At the national level, there exist geological museums and popular science tourism routes.	At the provincial level, there exist geological museums and popular science tourism routes.	At the provincial level, there exist geological museums or popular science tourism routes.	At the city and county level, there exist geological museums or popular science tourism routes.	There exist geological museums or popular science tourism routes.
Scenic spot level	World-class	National-class	Provincial-class	City- and county-class	No class
Distance from central city/km	≤ 50	51~100	101~200	201~250	>250
Connect with the surrounding attractions	Very strong	Strong	Normal	Lower	Low
Suitable travel period/day	≥ 300	250~299	150~249	100~149	<100
Local economic level/RMB	$\geq 150,000$	100,000~14,999	80,000~99,999	70,000~89,999	<70,000
Government policy	A lot of	More	Normal	Less	Seldom
Tourism investment	≥ 45	40~44	35~40	30~35	≤ 30
Local attitude	Quite agree with	Be in favor of	Normal	More opposed to	Oppose
Tourist growth rate	≥ 25	20~24	15~19	10~14	<10
Age structure of tourists/%	≥ 50	40~49	30~39	20~29	<20
Tourist source structure/%	Equilibrium at home and abroad	There are some foreign tourists	From all over the country	Local and nearby provinces	Mainly local
Geoheritage disaster	Very light	Lighter	Normal	Heavier	Seriousness
Meteorological disaster	Very light	Lighter	Normal	Heavier	Seriousness
Species invasion	0	1~2	3~5	6~7	>7
Greening level	First-level	Second-level	Third-level	Fall below level 3	Non-greening
Negative oxygen ion content/(each/cm ³)	$\geq 50,000$	10,000~49,999	3000~9999	1000~2999	<1000
Surface water quality	First-level	Second-level	Third-level	Fall below level 3	Contaminate

Note: Includes the total number of youth summer (winter) camps, popular science research initiatives, social practice activities, and popular science reports, among others.

In order to systematically assess the exploration level of the ScT of geoheritage, this model evaluates each index using a scientifically grounded membership degree scoring method and a multi-objective linear weighted function approach. The specific steps for model construction and operation are as follows:

- (1) **Membership Score of Quantitative Index.** The membership score of a quantitative index is determined based on objective data derived from the quantitative indicators. A membership degree scoring method is employed to evaluate these indicators. When an indicator's score falls within a specific interval, the membership degree for that interval is assigned a value of 1, while all other intervals receive a membership degree of 0. The interval with a membership degree of 1 signifies the optimal performance level for the index. Simultaneously, each index is allocated a corresponding score value according to the defined range of its respective score intervals. This allocation reflects variations in performance levels across different indices.
- (2) **Treatment of Qualitative Indicators.** For qualitative indicators that are challenging to quantify using objective data, evaluation primarily relies on data obtained through

questionnaire (Appendices A and B) surveys. Based on various levels of indicators—such as tourist satisfaction, interest in ScT activities, and the guide explains the content of ScT—statistical analysis is conducted on the survey results to calculate scores for each qualitative index.

- (3) Application of the Multi-Objective Linear Weighted Function Method [32]. To evaluate the overall suitability of the ScT of geoheritage, this study employs the fuzzy mathematics scoring system weighting function method to aggregate all relevant indicators. Initially, based on expert assessments and established standards, this study determines the weight for each indicator to ensure that their relative importance is accurately represented. Subsequently, a linear weighting model is used to combine the scores from both quantitative and qualitative indicators, resulting in a final evaluation. The outcomes of this model range from 0 to 5, with variable scores falling into distinct intervals that reflect varying performance levels of the ScT of geoheritage.

$$A = \sum_{h=1}^p \left[\sum_{j=1}^m \left(\sum_{i=1}^q D_i W_i \right) \cdot C_j \right] \cdot B_h \quad (1)$$

In Formula (1): A represents the total score for the evaluation of the ScT of geoheritage exploration; D_i denotes the score of the i -th attribute indicator; W_i indicates the weight of the i -th attribute indicator within its respective indicator layer; C_j refers to the weight of the j -th factors indicator in that same layer; and B_h signifies the weight of the h -th dimension at this level. The variable p represents the number of dimension indicators, which is set to 4 in this model; m denotes the number of factor indicators, fixed at 9 in this model; and n stands for the number of attribute indicators, established as 32 in this model.

3.3. The Empirical Evaluation

3.3.1. Study Area

Fangshan World Geopark is located at the confluence of the Taihang Mountains and the Yanshan Mountains. This geopark is situated in the southwest of Beijing, encompassing the Fangshan District of Beijing and Laiyuan and Laishui Counties in Hebei Province. It is approximately 50 to 100 km away from the city center of Beijing. The main part of the park stretches 130.80 km from east to west (from Liangxiang in Fangshan District in the east to Baishi Mountain in Baoding City, Hebei Province, in the west) and 75.09 km from north to south (from Baihua Mountain in Fangshan District in the north to Zhangfang Town in Fangshan District in the south), with a total area of 953.95 square kilometers. Its geographical coordinates are between $114^{\circ}36'48''$ and $116^{\circ}08'16''$ east longitude and between $39^{\circ}09'57''$ and $39^{\circ}43'08''$ north latitude, with an elevation ranging from 26 m to 2161 m (Figure 2). Fangshan Global Geopark represents a mountainous and hilly region that has undergone significant geoheritage uplift due to the Mesozoic Yanshan movement, followed by further elevation during the Cenozoic Himalayan orogeny. The geomorphology of this area is diverse, featuring a sequence from northwest to southeast that includes medium mountains, low mountains, hills, tablelands, and alluvial plains. Various landforms such as river valleys, terraces, depressions, sand dunes, and riverine floodplains are distributed throughout the park. Fangshan Global Geopark contains typical representative geoheritage formations of large karst caves found in temperate, semi-arid, and semi-humid regions across northern China and even globally. This park is designated due to its unique geological features, including the well-preserved karst landscapes, ancient limestone formations, human origin ruins, and evidence of tectonic activities that provide valuable scientific insight into Earth's geological history, such as the Peking Man Site at Zhoukoudian, Shihua Cave group, Shidu Yesanpo, and Fangshan Global Geopark Museum. These geoheritage landscapes exhibit characteristics such as typicality, rarity, naturalness and primitiveness, systematic integrity, and esthetic beauty. This area is often referred to as “the cradle of geoheritage science” (Table 8).

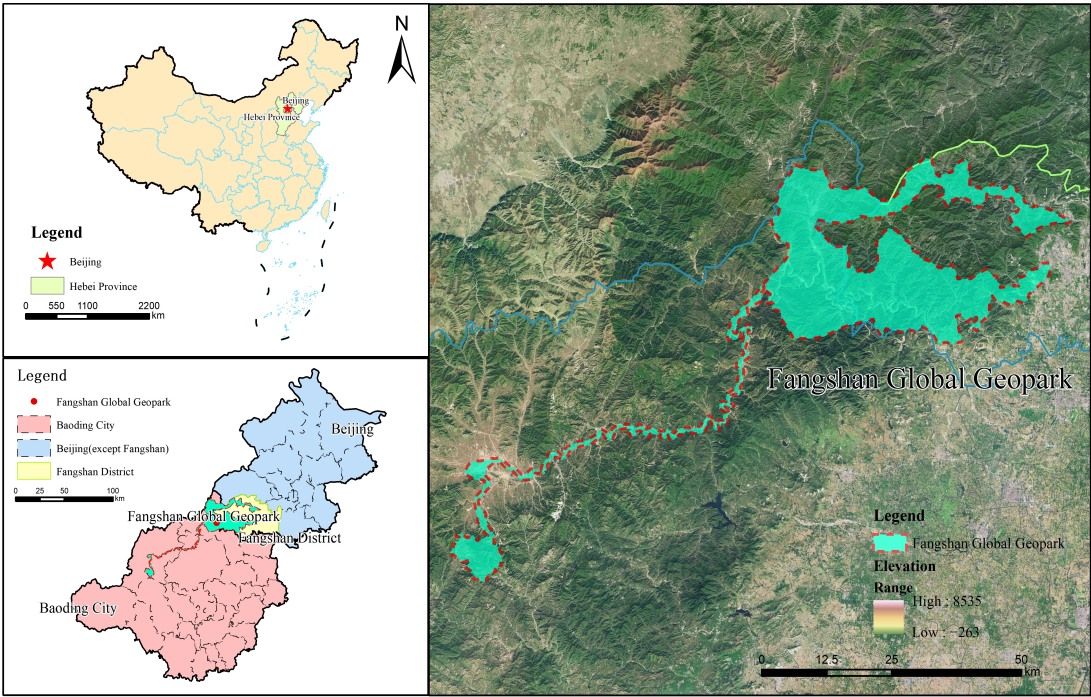


Figure 2. Location map of Fangshan Global Geopark.

From a historical perspective, Fangshan Global Geopark has significantly contributed to the advancement and exploration of geoheritage [53]. In 1996, during the 30th International Geological Congress held in Beijing, members of the UNESCO Department of Geosciences and the International Union of Geological Sciences first proposed the concept of a “global geopark” while visiting the Peking Man site in Zhoukoudian, Fangshan. Geoparks are established to safeguard and showcase geoheritage sites that possess considerable scientific value and educational importance. Consequently, the Peking Man Site is recognized as the “birthplace of the global geopark concept”. Between 2001 and 2004, Shihuadong, Baishi Mountain, Shidu, and Yesanpo were successively designated as national geoparks. In 2006, at the second Global Geopark Congress, Fangshan Geopark received official approval from UNESCO. In December 2012, Fangshan Global Geopark was recognized by the China Association for Science and Technology as a national science popularization education base. Furthermore, in September 2016, it was awarded the “Best Practice Award” by UNESCO Global Geoparks. To date, Fangshan Global Geopark has continued to conduct resource surveys and enhance its ScT initiatives while actively promoting collaboration with universities to further strengthen its educational functions [54] (Figure 3).

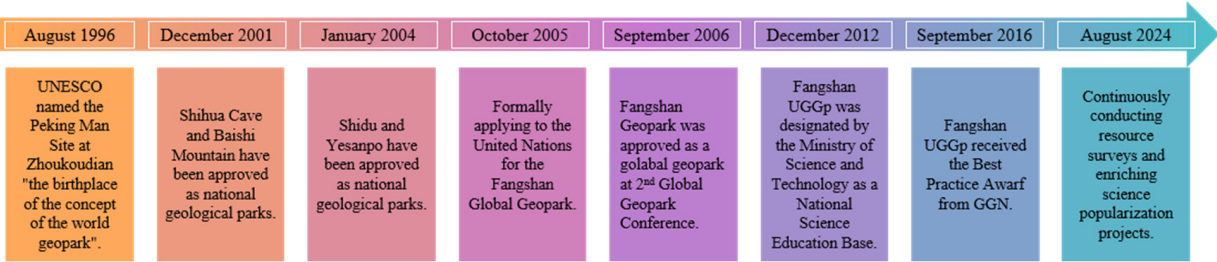


Figure 3. Historical development of Fangshan Global Geopark.

Table 8. Introduction to the main attractions of Fangshan Global Geopark.

Significant ScT of Geoheritage Relics and Attractions	Brief Introduction	Figures of the Main Attractions
Peking Man Site at Zhoukoudian	The Peking Man Site at Zhoukoudian, which preserves three generations of ancient human fossils, is a significant location for the study of human evolution.	
Shihua Cave group	The Shihua Cave group features stalactites and stalagmites of various shapes and sizes, along with other cave formations. These geological relics represent diverse chemical sedimentary forms and are underground karst temples created by unique geoheritage conditions in northern China.	
Shidu Yesanpo	The surface karst landscape of Shidu Yesanpo exemplifies the semi-arid and semi-humid temperate tectonic erosion karst landscape typical of northern China. The formation process of the Yanshan-type intracontinental orogenic belt, coupled with intense tectonic activities during the Mesozoic era, has made this region an attractive destination for tourists.	
Fangshan Global Geopark Museum	The Fangshan Global Geopark Museum comprises six halls, which include the Science Popularization Education and Research Exchange Center as well as the 4D Dynamic Film Hall. Adjacent to the museum is an 18,000 square meter science popularization square.	

3.3.2. Data Collection

The research data were primarily gathered through field studies, questionnaires, and pertinent statistical information. The survey was conducted from August to September 2024. The data processing is divided into two main parts. The objective indicator evaluation has already explained the data acquisition method in the previous text (Table 6). Subjective evaluation indicators: A total of 30 tourists (Appendix A) and 15 local residents (Appendix B) participated in the questionnaire survey. The basic information of the respondents is presented in Table 9. The investigation has been approved by the Fangshan Global Geopark Management Committee. All interviewees were asked for oral approval before conducting the survey. In the survey, researchers distributed questionnaires to both tourists and local residents, requesting them to indicate their recognized scores in order to determine their overall ratings. For the resident questionnaire, 15 people will score

and then add up 4 questions to obtain the average value. Subsequently, the researchers performed a statistical analysis on these scores and calculated the average values to derive the scoring results for each indicator. Finally, multiplying the average score by the weight can obtain the weighted score. D4–D9, D11, and D12 are calculated by 30 tourists. D23 is calculated by 15 local residents. In the investigation, it was found that Fangshan Global Geopark lacks statistics on the number of training days dedicated to ScT. Through interviews and inquiries, the annual training days for five docents were determined, from which an average value was calculated to derive the D14 index score. Notably, three employees reported training days exceeding 18, while two employees indicated their training days fell within the range of 6 to 9.

Table 9. Demographic characteristics of the experimental samples.

Item	Type	Frequency	
		Tourists	Local Residents
Gender	Man	12	10
	Woman	18	5
Age	≤19	4	0
	20–29	8	5
	30–39	3	7
	40–49	5	2
	50–59	9	1
	≥60	1	0
Educational level	Junior high school or below	0	2
	High school and vocational school	6	5
	College and undergraduate degree	20	8
	Graduate student	4	0
Average monthly income	≤2000	4	0
	2001–3000	2	4
	3001–5000	9	4
	>5000	15	7

4. Results

The results revealed that Fangshan Global Geopark possesses significant strengths in terms of its geoheritage resources and potential for ScT. Through the aforementioned calculation and evaluation process, the results pertaining to the exploration of ScT in Fangshan Global Geopark have been obtained, as illustrated in the accompanying Table 10. The score for ScT exploration in Fangshan Global Geopark is 4.17, indicating significant potential for growth in this sector. However, there is a need to strengthen training for ScT guides, brand attraction for tourist sites, and infrastructure for transportation. Empirical analysis has substantiated the scientific validity and practical relevance of the evaluation index framework.

Table 10. Evaluation results of ScT exploration in Fangshan Global Geopark.

Dimension(B) /Level 2	Score	Factor(C)/ Level 3	Score	Attribute(D)/Level 4	Score
Resources for the ScT of geoheritage B1	1.54	Geoheritage feature C1	1.55	Classification of geoheritage D1	2.11
				Geoheritage typicality D2	1.79
				Scale of geoheritage remains D3	0.78
		Resource value C2	3.26	Ornamental value D4	0.64
				Environmental value D5	0.58
				Scientific value D6	1.90
				Cultural value D7	1.75

Table 10. Cont.

Dimension(B) /Level 2	Score	Factor(C)/ Level 3	Score	Attribute(D)/Level 4	Score
Practices and construction related to scientific tourism B2	1.96	Scientific practice C3	2.44	Clear theme D8	0.97
				Attractiveness of novelty D9	0.49
				ScT sign system D10	1.82
				The guide explains the content of ScT D11	1.59
		Scientific capacity building C4	2.35	Popularization of science D12	1.10
				ScT activities D13	0.86
				Training days for ScT D14	0.67
				Construction of ScT education base D15	2.06
Auxiliary conditions for exploration B3	0.67	Development condition C6	1.44	Scenic spot level D16	1.58
				Distance from central city D17	0.72
				Connect with the surrounding attractions D18	0.46
				Suitable travel period D19	1.23
		Social environment C7	0.92	Local economic level D20	1.82
				Government policy D21	1.73
				Tourism investment D22	0.80
				Local attitude D23	0.48
Ecological environment construction B4	0.55	Ecological security C8	1.52	Tourist growth rate D24	2.53
				Age structure of tourists D25	1.01
				Tourist source structure D26	1.10
				Geoheritage disaster D27	2.10
		Environmental quality C9	3.10	Meteorological disaster D28	1.25
				Species invasion D29	1.25
				Greening level D30	2.29
				Negative oxygen ion content D31	1.70
				Surface water quality D32	0.64

Note: The scores presented in the table reflect the values obtained after applying the respective weights to each indicator.

4.1. Analysis of Resources for the ScT of Geoheritage

The comprehensive score for the resources for the ScT of geoheritage in Fangshan Global Geopark is 4.81 points, indicating exceptional resource characteristics and value. The geoheritage feature (C1) received a score of 4.68, while the resource value (C2) achieved a score of 4.87. There are seven relevant attribute indicators, all scoring above 4.60 points: specifically, they scored 4.80, 4.60, 4.60, 4.90, 4.87, 5.00, and 4.73 points, respectively. The evaluation results presented above indicate that Fangshan Global Geopark possesses significant attributes as a resource for ScT and has a robust resource base conducive to the exploration of such tourism. This result is attributed to the geopark's strategic location at the intersection of the Yanshan and Taihang tectonic belts, making it one of the quintessential regions within the global meso-Cenozoic intracontinental (intraplate) orogenic belt. The area's abundant geoheritage relics not only hold substantial scientific research value but also provide critical support for promoting ScT. For instance, the remnants of the Yanshan-type intracontinental orogenic belt provide a striking illustration of the significant tectonomagmatic activity that characterized the Mesozoic era and fully embody its position as the "cradle" of geoheritage science. These geoheritage resources provide a solid foundation for local science education and tourism exploration and show strong scientific and cultural value (Table 8).

4.2. Analysis of Practices and Construction Related to ScT

The evaluation results of the practice and construction of ScT in Fangshan Global Geopark indicate a score of 4.79 points, reflecting a high level of engagement in ScT initiatives. Specifically, the score for ScT practice is 4.87, while the score for ScT capacity

building stands at 4.70. The evaluation encompasses a total of eight indicators across three levels, with scores recorded as follows: 4.87, 4.87, 4.80, 4.97, 4.80, 4.80, 4.20, and 4.80.

Through field investigations, it has been observed that Fangshan Global Geopark excels in the implementation and exploration of ScT. The guides employ vivid and engaging language, complemented by various auxiliary tools such as flashlights, which significantly improve tourists' sense of participation and interest in learning (Figure 4). The ScT sign system is relatively comprehensive, adequately addressing tourists' needs for self-guided tours and educational experiences. The promotion of ScT within this area is notably active; diverse media platforms disseminate information about the scenic region, such as WeChat, the internet, Weibo, etc. Additionally, the park offers a wide array of ScT activities tailored for different age groups, including parent–child adventure tours and specialized routes for elderly visitors. The Fangshan Global Geopark Museum stands out as one of the largest geopark museums globally (Table 8), featuring advanced exhibition methods and an extensive collection of resources. This indicates a high level of construction regarding its role as a base for ScT education. Nevertheless, it is noteworthy that the score for ScT training remains relatively low due to insufficient tour guide training days. This lack may result in inadequate professional depth in explanatory content and responsiveness to varying tourist needs. In addition, there remains a necessity to incorporate digital facilities such as electronic guide maps and audio explanations to further enrich the learning experience.

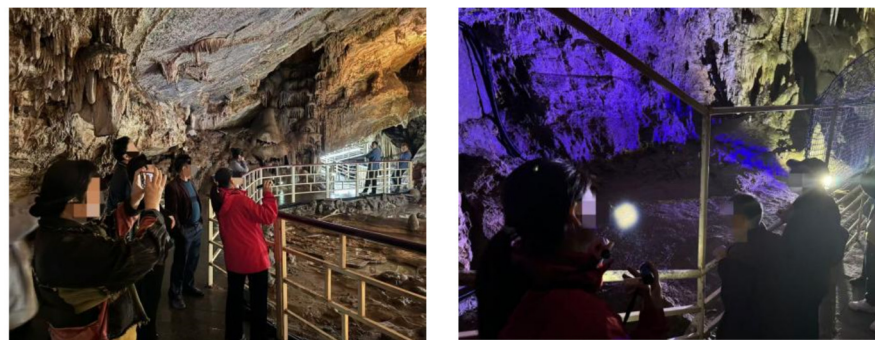


Figure 4. Tourists take a scientific tour in Fangshan Global Geopark.

4.3. Analysis of Auxiliary Conditions for Exploration

The overall score of the auxiliary conditions for ScT in Fangshan Global Geopark is 4.44, which is the lowest among the four factors in Dimension (B). Among them, the scores of development conditions, social environment, and tourist market are 3.99, 4.83, and 4.64, respectively, all of which are relatively low. There is a total of 11 attribute indicators, and the scores are 4.40, 3.00, 3.80, 4.40, 4.80, 4.80, 5.00, 4.80, 4.60, 4.80, and 4.60, respectively.

First and foremost, Fangshan Global Geopark is currently designated as a AAA scenic spot in China, which reflects a relatively low status in terms of tourism appeal and brand recognition. The geoheritage is distant from the urban area of Beijing, which poses an additional challenge; public transportation requires approximately 3–4 h. There are few surrounding attractions, and the connectivity between these sites is weak. This lack of integration further diminishes tourists' willingness to visit. However, Fangshan Global Geopark boasts an extended suitable tourism period. For instance, the Yinhu Cave maintains a stable year-round temperature of approximately 13 °C, making it ideal for visitors throughout all seasons. From a social environment perspective, Fangshan Global Geopark is situated in Beijing, the capital city with a high per capita GDP and robust tourism demand. This creates a solid foundation and promising prospects for ScT. Furthermore, the government strongly supports ScT; significant investments are evident through initiatives such as free admission to numerous parks and museums and regular provision of complimentary guided tours. Additionally, local residents exhibit a positive attitude toward the advancement of ScT within the geopark. The local residents hold the view that the ScT initiative not only facilitates the dissemination of scientific knowledge

but also fosters economic development. In terms of tourist demographics, there has been a notable increase in visitor numbers due to the public's growing interest in spiritual and cultural experiences. The primary tourists include young students and organized tour groups; however, family travelers and adventure enthusiasts also represent a considerable segment. The majority of visitors originate domestically; nonetheless, there exists a small influx of international tourists, primarily from Southeast Asia as well as Europe and North America.

4.4. Analysis of Ecological Environment Construction

The overall score of ecological environment construction conditions is 4.62. Among them, the ecological safety score is 4.60, and the environmental quality score is 4.63. The scores of the three indexes are 4.20, 5.00, 5.00, 4.40, 5.00, and 4.60, respectively, and the scores of geoheritage hazards, greening level, and surface water quality were relatively low.

First and foremost, the score for geoheritage disaster is low. This is primarily due to certain geoheritage hazard risks present in some scenic spots within the park, particularly at the Shihua Cavern scenic area. To ensure tourist safety, access to this area is permitted only under the guidance of a qualified tour guide. Furthermore, although the park is currently undergoing exploration and construction, its location within a temperate monsoon climate zone characterized by four distinct seasons results in meteorological disasters and species invasions being relatively uncommon. In cases of extreme weather conditions, advance warnings will be issued to safeguard tourists' well-being. There is an issue regarding the uneven distribution of greening levels. This is particularly evident in areas dominated by geoheritage landscapes, where insufficient artificial greening in the surrounding regions has led to a low overall score. The air quality in the scenic area is exceptional, particularly within the Shidu-Yesanpo region, where the concentration of negative oxygen ions reaches as high as 5000/cm³. This phenomenon has earned it the designation of a "natural oxygen bar". The overall assessment of surface water quality indicates that it is good and meets national evaluation standards. The health of the water within the park contributes to maintaining ecological balance throughout the area and enhances the appeal of its natural landscape.

5. Discussion

5.1. Theoretical Implications

This study makes a significant theoretical contribution to the field of ScT, primarily through the application and exploration of an evaluation index system specifically designed for the ScT of geoheritage. Previous research has predominantly focused on the macro-analysis of ScT [55], with limited in-depth exploration of the distinctive role that geoheritage relics play within this domain [56]. Furthermore, there is a notable deficiency in studies addressing residents' attitudes combined with tourist questionnaires, resulting in an incomplete understanding of geoheritage impact on ScT [43]. To address this gap, our research broadened its scope to encompass the exploration of ScT at natural heritage destinations by conducting a comprehensive analysis of China's Popular Science Statistics, relevant literature, and national standards. Ultimately, this study established a systematic framework for an evaluation index system tailored to the ScT of geoheritage. This framework encompasses multiple dimensions, including ScT of geoheritage resources, practices and construction related to ScT, auxiliary conditions for exploration, and ecological environment construction. The establishment of this theoretical framework not only enriches existing theories surrounding ScT but also offers new insights for more profound investigations into geoheritage initiatives.

Also, this study presents important theoretical contributions in terms of heritage tourism [57]. By examining both the uniqueness and significance of geoheritage sites [58], this study enhances our understanding of heritage tourism while underscoring these sites' roles as vital conduits for scientific education and dissemination. The proposed index system serves as a novel theoretical foundation for assessing the scientific value associated with geoheritage in terms of its educational potential and tourist engagement opportunities.

These theoretical advancements not only facilitate progress within the realm of geoheritage tourism research [59] but also promote recognition regarding the multifaceted functions that such sites serve in scientific outreach and experiential learning contexts.

5.2. Practical Implications

5.2.1. Evaluation Framework

The ScT of geoheritage evaluation framework established in this paper holds significant practical importance. First, the framework serves as a systematic evaluation tool for the exploration and management of geoheritage, effectively measuring its value within the context of tourism. This comprehensive assessment not only aids in identifying and safeguarding critical geoheritage resources but also provides a scientific foundation for policymakers and managers to optimize resource allocation and management strategies. Second, the multi-dimensional indicators incorporated within the framework offer specific guidance tailored to various stakeholders. Whether addressing government agencies, tourism operators, or local communities, all parties can develop actionable plans based on these indicators. This inclusive approach fosters participation from diverse groups and promotes the sustainable utilization and conservation of geoheritage. Finally, implementing this evaluation framework enhances public awareness regarding geoheritage while elevating its appeal as a scientific tourist attraction. Consequently, it encourages support and engagement from all sectors of society in efforts to protect our invaluable geoheritage resources.

5.2.2. Suggestions for Fangshan Global Geopark

First, it is important to emphasize the uniqueness and scarcity of ScT resources. The geoheritage resources within Fangshan Global Geopark possess not only significant scientific research value but also considerable esthetic and educational importance. Therefore, it is recommended that the exploration of ScT deeply explores the academic connotations of these resources while integrating their esthetic values to establish a highly recognizable and attractive ScT brand. For instance, in addition to conventional landscape displays, there should be an incorporation of cutting-edge scientific research findings through specialized lectures, academic exhibitions, and digital presentations [60]. This approach will effectively communicate the academic background and ongoing research related to geoheritage to visitors.

Second, it is essential to enhance the scientific literacy of employees. The effectiveness of ScT largely depends on the learning experiences of tourists, which are closely linked to the professional competence of docents and related practitioners. It is recommended to build a comprehensive and systematic training mechanism that not only updates basic geological knowledge but also emphasizes the improvement of science communication techniques. By collaborating with research institutions, experts should be invited to conduct regular professional training sessions and exchanges for interpreters and managers [61]. This approach will ensure that they can accurately and thoroughly convey complex scientific concepts while adapting their interpretation methods according to the cognitive levels of diverse tourist groups, thereby enhancing the educational value of tourism.

Third, it is necessary to incorporate advanced scientific and technological methods to diversify the forms of ScT. Technology increasingly plays a pivotal role in enhancing the experience of ScT. It is recommended to integrate cutting-edge technologies such as augmented reality (AR), virtual reality (VR), and holographic projection to create an immersive interactive experience for visitors [62]. For instance, utilizing virtual reality technology can effectively recreate ancient geoheritage evolution processes, allowing visitors to “witness” the Earth’s transformations over billions of years. Furthermore, interactive digital products should be developed so that tourists can access real-time information about geoheritage relics through smart devices during their visit. This approach not only enhances engagement but also increases interest and participation in the tourism experience.

Finally, it is fundamental to promote regional coordination and the exploration of multi-scenic linkages. Fangshan Global Geopark should enhance collaboration with surrounding scenic areas that are rich in natural resources, as well as other national geoparks, to establish a strategy for coordinated regional development. This can be achieved by creating cross-regional and interdisciplinary tourism routes, integrating ScT resources from various scenic spots, and strengthening the environmental infrastructure of these locations. Simultaneously, active participation in national-level ScT publicity initiatives is crucial. Leveraging the influence of the national geopark network will facilitate communication among tourists visiting different scenic spots [63]. This approach aims to foster a virtuous cycle of resource sharing and mutual tourist flow, ultimately leading to coordinated development and a win-win situation for regional ScT.

6. Conclusions and Limitations

6.1. Conclusions

This study developed and applied an evaluation framework for assessing the ScT of geoheritage. This evaluation index system includes four dimensions, nine factors, and thirty-two attributes that collectively reflect the critical factors influencing the exploration of the ScT of geoheritage. Compared to existing studies, this study adopts a more integrative approach by incorporating dimensions that reflect both the scientific and practical aspects of tourism in geoheritage sites. These dimensions, which encompass both scientific and practical considerations, provide a more nuanced understanding of the complexities inherent in the ScT of geoheritage. In contrast to existing frameworks that frequently concentrate on isolated aspects of geoheritage or tourism, this study adopts a holistic perspective that recognizes the interconnections among geoheritage significance, tourism infrastructure, educational outreach, and sustainable development.

Through a case study of Fangshan Global Geopark, this study identified its unique strengths in geoheritage resources and key challenges in development. The results provide valuable insights and practical recommendations, fulfilling the objectives outlined at the outset of the study. The application of this model to the Fangshan Global Geopark illustrates its efficacy as a tool for evaluating the scientific tourism potential of geoheritage sites. Importantly, the framework developed in this study is not limited to the Fangshan case but offers a flexible and adaptable model for assessing ScT potential in other geoparks worldwide. Future research should explore the adaptability of this model to a wider range of geoparks and cultural landscapes, assessing how it can be fine-tuned to reflect regional differences in geological heritage, local development priorities, and tourism management practices. This could lead to the refinement of the framework's components, ensuring that it remains relevant and applicable in diverse settings.

In addition, the evaluation index system explored in this study demonstrates significant adaptability and flexibility. In addition to the practical contributions, this study also offers insights into the challenges and opportunities associated with the sustainable development of the ScT of geoheritage. The framework emphasizes a balance between educational outreach, ecological sustainability, and economic viability, which could inspire further interdisciplinary research. By bridging theoretical and empirical research, this study contributes to the growing body of knowledge on ScT and its role in promoting both heritage conservation and public understanding of geoheritage resources. Future studies could benefit from incorporating diverse stakeholder perspectives to enrich the evaluation framework. Additionally, longitudinal analyses could assess how scientific tourism initiatives impact the sustainability of geoheritage sites over time, providing valuable insights into the dynamic interplay between conservation and development.

6.2. Limitations

Although this paper establishes a relatively comprehensive evaluation index system for the exploration of the ScT of geoheritage, it is not without its limitations. First, regarding weight allocation and subjective assessment, an overreliance on expert evaluations and

questionnaires may introduce certain biases into the findings [64]. However, this is also an inevitable aspect of such methods. In future studies, the introduction of more quantitative analysis methods, in conjunction with big data technology, could mitigate human interference factors and further enhance the objectivity and accuracy of evaluation results. Second, this paper selects Fangshan Global Geopark as a case study to preliminarily assess the validity and rationality of the proposed system. However, to further evaluate the universality and operability of this system, subsequent research should broaden its empirical scope by including a diverse range of geoheritage sites for analysis. This approach will not only validate the applicability of the system across different environments but also provide a more robust practical foundation for optimizing it.

Author Contributions: Conceptualization, Z.Z. and J.L.; methodology, Z.Z., J.L. and H.Z.; validation, Z.Z. and W.Z.; formal analysis Z.Z. and H.Z.; investigation, Z.Z. and W.Z.; resources, Z.Z. and W.Z.; data curation, Z.Z., J.L. and H.Z.; writing—original draft preparation, Z.Z., J.L., H.Z. and W.Z.; writing—review and editing, Z.Z., J.L., H.Z. and W.Z.; visualization, Z.Z. and W.Z.; supervision, J.L. and H.Z.; project administration, Z.Z. and W.Z.; Figure provided, Z.Z. and W.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Key Research and Development Program of China, grant number 2024YFF0809303.

Data Availability Statement: The data sets used and/or analyzed during the current study are available from Zehui Zhu on reasonable request, and her email address is zhuzehui2022@126.com.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Survey questionnaire on evaluating scientific tourism of geoheritage in Fangshan Global Geopark

Dear Friend,

Greetings! In order to enhance the high-quality exploration of Scientific tourism within the Fangshan Global Geopark, we sincerely request your valuable insights despite your busy schedule. This survey will be conducted anonymously, and all information provided will be treated with strict confidentiality and utilized solely for research purposes.

Thank you!

Part I: In accordance with the Scientific tourism’s value of Fangshan Global Geopark, please indicate your level of agreement by marking a “√”.

Value of Scientific Tourism Resources	Extremely High	High	Normal	Lower	Low
Appreciation value					
Environmental value					
Scientific value					
Cultural value					

Value of Scientific Tourism Practice	Extremely High	High	Normal	Lower	Low
Clear theme					
Attractiveness of novelty					
The guide explains the content of ScT					

Part II: Basic personal information

1. Your age: ____; your gender: ① male, ② female; your nationality is _____;
2. Your educational level: ① junior high school or below, ② high school and vocational school, ③ college and undergraduate degree, ④ graduate student;

3. Your average monthly income (yuan): ① ≤ 2000 , ② 2001–3000, ③ 3001–5000, ④ > 5000 ;
 4. Your occupation: ① civil servant, ② enterprise and public institution staff, ③ professional/cultural and educational technical personnel, ④ service, sales, and commercial personnel, ⑤ worker, ⑥ farmer, ⑦ soldier, ⑧ student, ⑨ retiree, ⑩ other occupation_____.

Appendix B

Survey questionnaire on evaluating scientific tourism of geoheritage in Fangshan Global Geopark

Dear Friend,

Greetings! In order to enhance the high-quality exploration of Scientific tourism within the Fangshan Global Geopark, we sincerely request your valuable insights despite your busy schedule. This survey will be conducted anonymously, and all information provided will be treated with strict confidentiality and utilized solely for research purposes.

Thank you!

Part I: In accordance with the scientific tourism exploration of Fangshan Global Geopark, please indicate your level of agreement by marking a “√”.

Resident Attitude	Quite Agree with	Be in Favor of	Normal	More Opposed to	Oppose
Are you interested in participating in the ScT of Fangshan Global Geopark?					
Do you support conducting more Scientific tourism activities within the geopark?					
Do you think Scientific tourism in geoparks can help enhance public scientific knowledge and environmental awareness?					
Do you think the development of Scientific tourism in geoparks can drive local economic growth?					

Part II: Personal basic information

1. Your age: _____; your gender: ①male, ②female; your nationality is _____;
 2. Your educational level: ① junior high school or below, ② high school and vocational school, ③ college and undergraduate degree, ④ graduate student;
 3. Your average monthly income (yuan): ① ≤ 2000 , ② 2001–3000, ③ 3001–5000, ④ > 5000 ;
 4. Your occupation: ① civil servant, ② enterprise and public institution staff, ③ professional/cultural and educational technical personnel, ④ service, sales, and commercial personnel, ⑤ worker, ⑥ farmer, ⑦ soldier, ⑧ student, ⑨ retiree, ⑩ other occupation_____.

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