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Quantitative evaluation of geosites in the Lang Son UNESCO global geopark



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ABSTRACT

A quantitative evaluation of geosites in the Lang Son UNESCO Global Geopark (Vietnam) is urgently needed to provide objective evidence for conservation prioritization and sustainable geotourism planning. This study aims to quantitatively assess the geotourism value of 19 selected geoheritage sites within the Lang Son UNESCO Global Geopark. By integrating secondary data, spatial distribution analysis, and primary data collected through expert interviews and field surveys conducted within the geopark, the research applies the Geosite Assessment Model (GAM). The model is structured as a 9-field matrix, allowing the classification of geosites according to appropriate development orientations based on two main groups of values: (1) Main Values (maximum 12 points), including scientific/educational value (VSE), aesthetic/landscape value (VSA), and protection level (VPr); and (2) Additional Values (maximum 15 points), including functional value (VFn) and touristic value (VTr). The results indicate that the Main Values (VSE + VSA + VPr) of the evaluated geosites are relatively uniform (average ≈ 8.0 points), while the Additional Values (VFn + VTr) exhibit a wider variation (3.75–13.75 points), which plays a decisive role in distinguishing between the Z_{33} , Z_{32} , and Z_{21} groups. This demonstrates that, beyond their inherent geological and scientific significance, factors such as infrastructure, promotional activities, and community-based tourism management are crucial in enhancing the overall value of geosites within the context of sustainable geotourism development. The GAM results not only help identify the geosites that should be prioritized for conservation and development (Z_{33} , Z_{32}) but also highlight the groups requiring functional and touristic enhancement (Z_{23} , Z_{22} , Z_{21}). These findings provide a scientific foundation for local authorities and tourism enterprises to design more effective strategies for the sustainable utilization of geoheritage resources within the Lang Son UNESCO Global Geopark, thereby contributing to the socio-economic development of Lang Son Province.

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1. Introduction

Geoheritage represents an important natural resource that can bring significant socio-economic benefits. Worldwide, numerous studies have focused on assessing its potential; however, practical models for the sustainable exploitation of this resource are still not fully understood. Research on geoheritage has contributed to shaping a dynamic direction in modern geological science. Although most studies have concentrated on issues of geoconservation and geotourism, the relationship between geoheritage and resource management policies at international, national, and local scales has also received increasing attention (Erikstad, 2013; Navarro et al., 2022; Ruban, 2010).

In particular, geoheritage is now widely recognized as an essential natural resource for science, education, and tourism (Brocx & Semeniuk, 2019; Henriques et al., 2022), offering clear socio-economic benefits (Brilha et al., 2018; Gray, 2018). Geoheritage resources are preserved within geological environments and can be regarded as renewable when exploited rationally and sustainably. Various methodological approaches have been proposed to assess geoheritage in specific territories, including semi-quantitative geological evaluation (Brilha, 2016; Gray, 2008), ecosystem conservation monitoring (Kubalíková, 2020; Reverte et al., 2020), and tourism potential mapping (Chrobak et al., 2021; De Sena et al., 2022). All these approaches have proven to be rational and effective for addressing specific tasks in defined regions or case studies, primarily focusing on selected aspects of geoheritage assessment and enhancing the efficiency of its sustainable utilization.

The research and evaluation of the geotourism value of geoheritage sites within the Lang Son UNESCO Global Geopark are of both theoretical and practical significance. Theoretically, this study provides a scientific foundation for identifying, quantifying, and classifying the values of geoheritage, thereby contributing to strategic orientations for sustainable conservation and utilization. In the current context, as Lang Son has recently been recognized by UNESCO as a Global Geopark, the assessment of geotourism value plays a crucial role in identifying sites with high potential for development into educational, experiential, and research-based tourism products. From a practical

perspective, the assessment results offer quantitative data to support spatial planning for geotourism, enhance management capacity, and promote the image of Lang Son as a "living geological museum" of Northeastern Vietnam.

2. Literature Review

Geotourism research is a multidisciplinary activity that encompasses the identification, evaluation, and valorization of geoheritage sites as well as the assessment of their potential for geotourism development. Evaluating both an entire territory and its individual geosites is a key factor in determining tourism potential; moreover, it plays a particularly important role in future geotourism management and heritage conservation. Globally, numerous scholars have addressed the issue of assessing geoheritage values as a foundation for geotourism development.

Pralong (2005) was among the first to propose a set of criteria for quantifying and evaluating the potential of geomorphological sites. Applied to glacial, karstic, and hydrological landforms in the regions of Chamonix Mont-Blanc (Haute-Savoie, France) and Crans - Montana - Sierre (Valais, Switzerland), the model defined touristic value based on four groups of criteria: aesthetic, scientific, cultural/historical, and economic. Reynard et al. (2007) integrated two groups of parameters: scientific and additional values in assessing geomorphological heritage in the Adula National Park (Ticino, Switzerland) and the geo-cultural heritage of the Trient area (Valais, Switzerland). Gónra and Golonka (2010) employed three groups of parameters - scientific, locational, and additional values to evaluate the Neogene volcanic geomorphology of the Vtáčnik Mountains (Western Carpathians, Slovakia).

Rocha et al. (2014) proposed a theoretical framework for quantitative assessment of geoheritage and geomorphological sites, incorporating both scientific value and their potential for educational and touristic use. This framework was subsequently applied to several studies on mining and industrial tourism (Aysan Güreter et al., 2019; Albani et al., 2020). Artugyan (2017) applied the model proposed by Pralong (2005) to evaluate geomorphological features of the Anina karst area (Banat Mountains, Romania), including karst springs, caves, gorges, and plateaus.

This study highlighted the significance of geomorphological heritage in promoting public awareness, engaging local authorities, and enhancing appreciation of natural features for local development. In that research, the value of geoheritage was determined through the assessment of aesthetic, scientific, cultural/historical, and economic criteria. Pourahmad et al. (2018), in assessing the potential for geotourism and environmental development on Qeshm Island (Iran), applied an evaluative approach to identify the potential of each site based on geomorphological criteria, namely aesthetic, scientific, cultural, and economic values. The findings revealed that although the sites possess high geomorphological, aesthetic, and scientific value, their overall scores were reduced due to limited accessibility, remoteness from major centers, and low local awareness of geotourism concepts.

All of the aforementioned studies and scientific publications indicate that the assessment of geoheritage values and the enhancement of geoheritage utilization efficiency within geoparks and geomorphologically significant landscapes represent an emerging research direction in contemporary global geoscience. This topic has increasingly attracted the attention of many scholars, particularly in the context of growing public awareness of environmental protection and the conservation of geoheritage in particular, as well as tangible cultural and natural heritage in general.

Among the various geoheritage assessment frameworks discussed above, the Geosite Assessment Model (GAM) is particularly suitable for this study because it simultaneously evaluates both intrinsic geological values and tourism-related attributes, which are essential for the development of a newly designated UNESCO Global Geopark such as Lang Son. The model provides a transparent, quantitative scoring system and a matrix-based classification that allow for clear prioritization of geosites for conservation and geotourism development. Furthermore, GAM has been widely applied in karst regions and geoparks with similar geological and management contexts, demonstrating its reliability and relevance for supporting evidence-based planning in Lang Son.

3. Research Methodology

The Geosite Assessment Model (GAM) provides a framework for ranking various thematic groups of values, classified into two fundamental categories - main values and additional values, while simultaneously evaluating key aspects such as geological value, landscape and ecological value, historical-archaeological value, and touristic value. The overall score for each site is determined through a standardized rating scale. By conducting a comparative analysis of the results obtained, the model allows for the identification of which factors within the analyzed value groups require greater attention and improved management in the future to enhance the attractiveness of geosites to visitors. The GAM model was proposed by Vujičić et al. (2011), building upon numerous earlier studies in the field of quantitative geoheritage assessment and management (Hose, 1997; 2011; Pralong, 2005; Reynard et al., 2007). It consists of two principal groups of indicators: Main Values (MV) and Additional Values (AV), the details of which are presented in Table 1.

The Main Values (MV) arise from the intrinsic natural characteristics of each geosite and include three groups of indicators: scientific/educational value (VSE), scenic/aesthetic value (VSA), and protection status (VPr). The Additional Values (AV), on the other hand, are shaped by human influence and adaptation - attributes created by people to facilitate visitor use and experience. These comprise two groups of indicators: functional value (VF_n) and touristic value (VTr) (Vujičić et al., 2011). In total, the model incorporates 12 primary indicators (MV) and 15 secondary indicators (AV), each evaluated on a five-level scoring scale of 0, 0.25, 0.5, 0.75, and 1. Accordingly, the GAM value for each site is determined using the following equation (Hrnjak et al., 2013):

$$GAM = MV + AV \quad (1)$$

Where:

$$MV = VSE + VSA + VPr \quad (2)$$

$$AV = VF_n + VTr \quad (3)$$

which means,

Table 1. The structure of geosite assessment model (GAM) (Vujičić et al., 2011).

Indicators/ Subindicators	Description	Grades (0-1)				
		0	0.25	0.5	0.75	1
Scientific/Educational value (VSE)		0	0.25	0.5	0.75	1
Rarity	Number of closest identical sites.	Common	Regional	National	International	The only occurrence
Representativeness	Didactic and exemplary characteristics of the site due to its own quality and general configuration.	None	Low	Moderate	High	Utmost
Knowledge on geoscientific issues	Number of written papers in acknowledged journals, thesis, presentations and other publications.	None	Local publications	Regional publications	National publications	International publications
Level of interpretation	Level of interpretive possibilities on geological and geomorphologic processes, phenomena and shapes and level of scientific knowledge.	None	Moderate level of processes but hard to explain to non experts	Good example of processes but hard to explain to non experts	Moderate level of processes but easy to explain to common visitor	Good example of processes and easy to explain to common visitor
Scenic/Aesthetic (VSA)		0	0.25	0.5	0.75	1
Viewpoints	Number of viewpoints accessible by a pedestrian pathway. Each must present a particular angle of view and be situated less than 1 km from the site.	None	1	2÷3	4÷6	More than 6
Surface	Whole surface of the site. Each site is considered in quantitative relation to other sites.	Small	-	Medium	-	Large
Surrounding landscape and nature	Panoramic view quality, presence of water and vegetation, absence of human-induced deterioration, vicinity of urban area, etc.	-	Low	Medium	High	Utmost
Environmental fitting of sites	Level of contrast to the nature, contrast of colors, appearance of shapes, etc.	Unfitting		Neutral		Fitting
Protection (VPr)		0	0.25	0.5	0.75	1
Current condition	Current state of geosite.	Totally damaged (as a result of human activities)	Highly damaged (as a result of natural processes)	Medium damaged (with essential geomorphologic features preserved)	Slightly damaged	No damage
Protection level	Protection by local or regional groups, national government, international organizations, etc.	None	Local	Regional	National	International
Vulnerability	Vulnerability level of geosite.	Irreversible (with possibility of total loss)	High (could be easily damaged)	Medium (could be damaged by natural processes or human activities)	Low (could be damaged only by human activities)	None
Suitable number of visitors	Proposed number of visitors on the site at the same time, according to surface area, vulnerability and current state of geosite.	0	1÷10	11÷20	21÷50	More than 50

Indicators/ Subindicators	Description	Grades (0-1)				
		0	0.25	0.5	0.75	1
Functional (VF _n)						
Accessibility	Possibilities of approaching to the site.	Inaccessible	Low (on foot with special equipment and expert guide tours)	Medium (by bicycle and other means of man-powered transport)	High (by car)	Utmost (by bus)
Additional natural values	Number of additional natural values in the in radius of 5 km (geosites also included).	None	1	2÷3	4÷6	More than 6
Additional anthropogenic values	Number of additional anthropogenic values in the in radius of 5 km.	None	1	2÷3	4÷6	More than 6
Vicinity of emissive centers	Closeness of emissive centers.	More than 100 km	100÷50 km	50÷25 km	25÷5 km	Less than 5 km
Vicinity of important road network	Closeness of important road networks in the in radius of 20 km.	None	Local	Regional	National	International
Additional functional values	Parking lots, gas stations, mechanics, etc.	None	Low	Medium	High	Utmost
Touristic values (VTr)		0	0.25	0.5	0.75	1
Promotion	Level and number of promotional resources.	None	Local	Regional	National	International
Organized visits	Annual number of organized visits to the geosite.	None	Less than 12 per year	12÷24 per year	24÷48 per year	More than 48 per year
Vicinity of visitors center	Closeness of visitor center to the geosite.	More than 50 km	50÷20 km	20÷5 km	5÷1 km	Less than 1 km
Interpretative panels	Interpretative characteristics of text and graphics, material quality, size, fitting to surroundings, etc.	None	Low quality	Medium quality	High quality	Utmost quality
Number of visitors	Annual number of visitors.	None	Low (less than 5000)	Medium (5001÷10.000)	High (10.001÷100.000)	Utmost (more than 100.000)
Tourism infrastructure	Level of additional infrastructure for tourist (pedestrian pathways, resting places, garbage cans, toilets, wellsprings etc.).	None	Low	Medium	High	Utmost
Tour guide service	If exists, expertise level, knowledge of foreign language(s), interpretative skills, etc.	None	Low	Medium	High	Utmost
Hostelry service	Hostelry service close to geosite.	More than 50 km	25÷50 km	10÷25 km	5÷10 km	Less than 5 km
Restaurant service	Restaurant service close to geosite.	More than 25 km	10÷25 km	10÷5 km	1÷5 km	Less than 1 km

$$MV = VSE + VSA + VPr = \sum_{i=1}^{12} SIMV_i$$

$$(0 \leq SIMV_i \leq 1)$$

$$AV = VF_n + VTr = \sum_{j=1}^{15} SIAV_j$$

$$(0 \leq SIAV_j \leq 1)$$

To graphically represent the assessment results, a GAM matrix is constructed and divided

into 9 fields (zones) using a grid, denoted Z(ij), where i,j = 1, 2, 3. The matrix consists of two axes: the X-axis (MV) representing Main Values and the Y-axis (AV) representing Additional Values. Each axis is subdivided into four value intervals along the X-axis and five along the Y-axis, forming a grid of nine distinct zones.

Depending on the evaluated level, each geosite's total score is plotted within a specific zone, clearly defining its position according to the two main assessment dimensions: Main Values (MV) and Additional Values (AV). This positioning reflects

the overall “tourism value” of the geosite (Figure 1). The calculation results displayed on the GAM matrix make it possible to identify both the strengths and weaknesses of each evaluated site, thereby clarifying the causes of variation and suggesting corresponding management or development strategies. Moreover, this spatial classification enables the recognition of high-potential geosites - particularly those located in Zone Z_{33} - as priority areas for economic and social investment, where favorable mechanisms and policies can be established to attract investors in the tourism sector, thereby contributing to the socio-economic development of the local region.

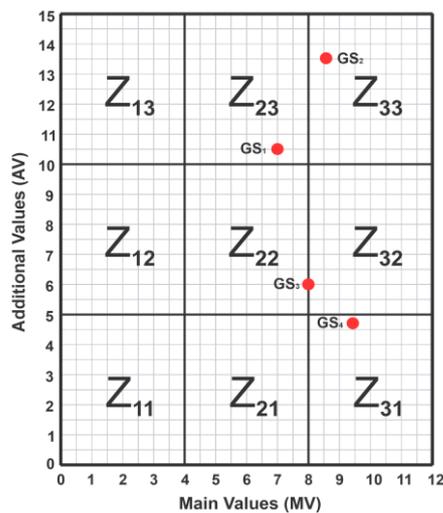


Figure 1. Position of geosites in GAM matrix.

4. Regional settings and geosites inventory

The Lang Son UNESCO Global Geopark is located in northeastern Vietnam, encompassing the entire administrative territories of Bac Son, Chi Lang, Huu Lung, Loc Binh, and Van Quan districts, the city of Lang Son, and parts of Binh Gia and Cao Loc districts, with a total area of approximately 4,842.58 km² (Figure 2). From a geological perspective, the Lang Son UNESCO Global Geopark stands out as an “open-air museum” that records over 500 million years of Earth’s history, reflected through ancient limestone formations, shallow-marine sedimentary layers, traces of magmatic activity, tectonic faults, and an extensive system of karst caves. The karstification process, in combination with topographical, climatic, and hydrological conditions, has produced an impressive network of large limestone caves characterized by diverse and well-preserved stalactites and stalagmites.

Representative geoheritage sites within the geopark, such as the Dong Lam Magic Valley, the Ammonite World, the Mau Son Panorama, the Tham Khuyen Cave, and the Binh Gia Sinkhole - not only illustrate a long geological evolution but also embody high aesthetic, educational, and scientific value. In particular, several sites preserve evidence of ancient marine fossils and paleoenvironments, documenting geological changes from the Paleozoic to the Cenozoic eras. In addition, the geopark’s unique geomorphological and landscape features -

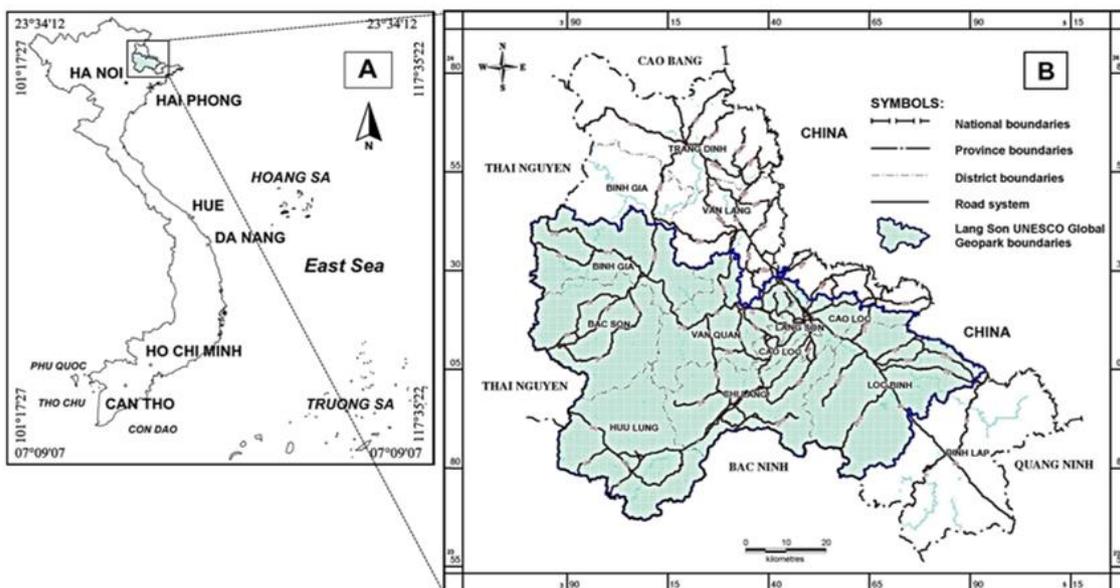


Figure 2. Location of the study area in Vietnam (A); Study area location map (B).

including flooded karst valleys, tower-shaped weathering surfaces, sinkholes, and underground cave systems - enhance its potential for ecotourism, geotourism, and environmental education, making Lang Son an outstanding example of the integration between geoh heritage conservation and sustainable tourism development in Vietnam.

Beyond its rich natural heritage, the Lang Son UNESCO Global Geopark also preserves a diverse layer of cultural and historical sediments, closely associated with the long-standing traditions of the Tay, Nung, Dao, and Kinh ethnic communities. The harmonious integration of geological, ecological, and cultural heritage has made Lang Son a model of sustainable geotourism development in Vietnam, contributing to raising public awareness of resource conservation, promoting scientific and educational values, and advancing the goals of sustainable development in alignment with the UNESCO Global

Geoparks Network framework. The subjects of evaluation in this study are 19 geoh heritage sites within the Lang Son UNESCO Global Geopark. Among them, 15 sites have already been integrated into four official geotourism routes, specifically:

- Route 1 - "Experience the Realm of Mountain and Forest": GS₁ - GS₃
- Route 2 - "Journey to the Realm of Heaven": GS₄ - GS₇
- Route 3 - "Enjoy the Realm of Earth": GS₈ - GS₁₀
- Route 4 - "Way to the Realm of Water": GS₁₁ - GS₁₅

In addition, four newly identified geosites (GS₁₆-GS₁₉) were discovered during the subsequent research and field surveys. These sites possess significant scientific information value and high potential for tourism development, as illustrated in Figure 3.

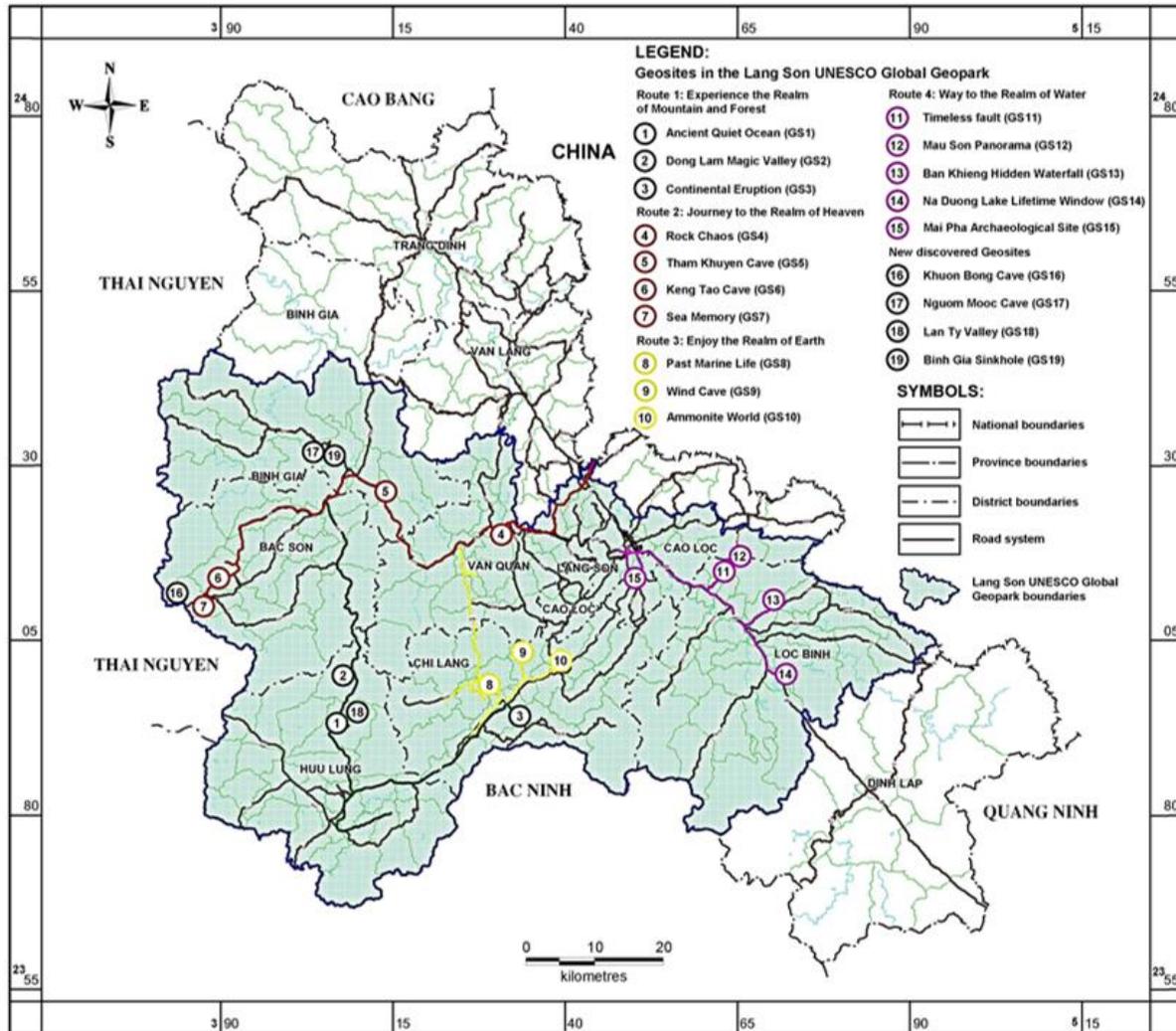


Figure 3. Location of Lang Son UNESCO Global Geopark with disposition of proposed geosites.

A summary of the 19 geosites, grouped into five thematic clusters, is presented in Table 2, with representative illustrative photographs shown in Figure 4. The clustering was carried out based on the geological, geomorphological, paleontological, and landscape characteristics of each area, reflecting both the diversity and integrity of the geoheritage system. Each cluster represents a distinct stage or process in Earth's geological evolution,

simultaneously demonstrating the interconnection between scientific, aesthetic, and touristic values. This summary table not only highlights the unique features of each site but also serves as a scientific foundation for the GAM-based evaluation of geotourism value, supporting the planning of sustainable development and the integration of interconnected geotourism routes across the entire geopark.

Table 2. Preliminary list of geosites in the Lang Son UNESCO Global Geopark with description.

Label	Geosite Name	Description
Cluster 1 - Tectonic and Paleo-marine Heritage (Huu Lung - Bac Son area)		
GS ₁	Ancient Quiet Ocean	A representative stratigraphic section of limestone-siliceous sediments containing Devonian shallow-marine fossils, providing clear evidence of an ancient ocean that once covered the Lang Son region. It holds high scientific value for stratigraphic and paleontological studies of northeastern Vietnam.
GS ₂	Dong Lam Magic Valley	The intersection between ancient and neotectonic fault systems, clearly visible on the surface morphology. It has strong scientific value for illustrating the tectonic evolution of northeastern Vietnam.
GS ₃	Continental Eruption	A remnant of Mesozoic volcanic activity, comprising basaltic flows interbedded with sediments. It represents intraplate magmatic processes during the evolution of the regional geological structure.
GS ₄	Rock Chaos	An assemblage of heavily weathered limestone blocks sculpted into striking shapes, serving as a vivid example of karst surface dissolution combined with erosional and fluvial dynamics.
Cluster 2 - Cave and Archaeological Heritage (Binh Gia - Van Quan area)		
GS ₅	Tham Khuyen Cave	One of Vietnam's most significant prehistoric sites, where fossilized human teeth of <i>Homo erectus</i> were discovered (~475,000 years BP). The site bears dual geological and archaeological importance.
GS ₆	Keng Tao Cave	A typical karst cave system with stalactites, stalagmites, and ancient collapse structures, illustrating the deep-stage evolution of karstification. It has strong potential for geotourism and educational activities.
GS ₇	Sea Memory	A fossil-bearing sedimentary outcrop with brachiopods and crinoids, evidencing shallow-marine environments during the Devonian-Carboniferous periods and marking ancient continental margin evolution.
GS ₈	Past Marine Life	A thick limestone unit rich in fossil corals and algal remains, reflecting Devonian biogenic activity and marine biodiversity evolution. It offers high scientific and educational significance.
GS ₉	Wind Cave	A ventilated karst cave developed along fault zones, characterized by strong natural airflows and unique microclimatic conditions, illustrating structural control in karst formation.
Cluster 3 - Structural and Stratigraphic Heritage (Chi Lang - Cao Loc area)		
GS ₁₀	Ammonite World	A fossiliferous marine sequence rich in ammonites and cephalopods, vividly recording the evolution of marine invertebrates. It is a type locality for paleontological and educational geotourism.
GS ₁₁	Timeless fault	The intersection between ancient and neotectonic fault systems, clearly visible on the surface morphology. It has strong scientific value for illustrating the tectonic evolution of northeastern Vietnam.
Cluster 4 - Mountain and Geo-ecological Heritage (Mau Son - Loc Binh area)		
GS ₁₂	Mau Son Panorama	A large granitic intrusion forming the highest mountain massif in northeastern Vietnam (altitude ~1,500m). It is notable for its tectonic, climatic, and biodiversity values.
GS ₁₃	Ban Khieng Hidden Waterfall	A multi-tiered waterfall formed by fault activity and differential erosion, exemplifying fluvial-tectonic interaction in a mountainous setting.
GS ₁₄	Na Duong Lake Lifetime Window	The Na Duong basin is a treasure of paleontological wonders from the Eocene period, 40 million years ago. Around 35 million years ago, this lake knew its more fascinating moment with a rich ecosystem hosting a variety of unique paleontological species (clams, mollusks, snails, fish, etc.). Some of these species were discovered here for the first time.
Cluster 5 - Cultural and Archaeological Heritage (Lang Son - Huu Lung area)		
GS ₁₅	Mai Pha Archaeological Site	An ancient human settlement area within a low karst terrain, demonstrating the close link between prehistoric human adaptation and geological environment. It holds both geoarchaeological and cultural value.
GS ₁₆	Khuon Bong Cave	A large karst cave containing ancient sediments and archaeological remains, valuable for studying shallow karst development and early human occupation.
GS ₁₇	Nguom Mooc Cave	A karst cave in the Binh Gia - Mong An area, featuring stalactites and fossil-bearing sediments. It has high scientific and geotouristic potential for field education.

GS18	Lan Ty Valley	The central landscape of Lang Son Geopark, composed of karst valleys, hills, and lakes, showcasing outstanding aesthetic, ecological, and geotouristic value. It functions as the core tourism nucleus of the geopark.
GS19	Binh Gia Sinkhole	One of the largest sinkholes in northern Vietnam (diameter >80 m, depth ~50 m), a prime example of ancient karst collapse processes. It is an exceptional site for geoadventure tourism and geomorphological research.

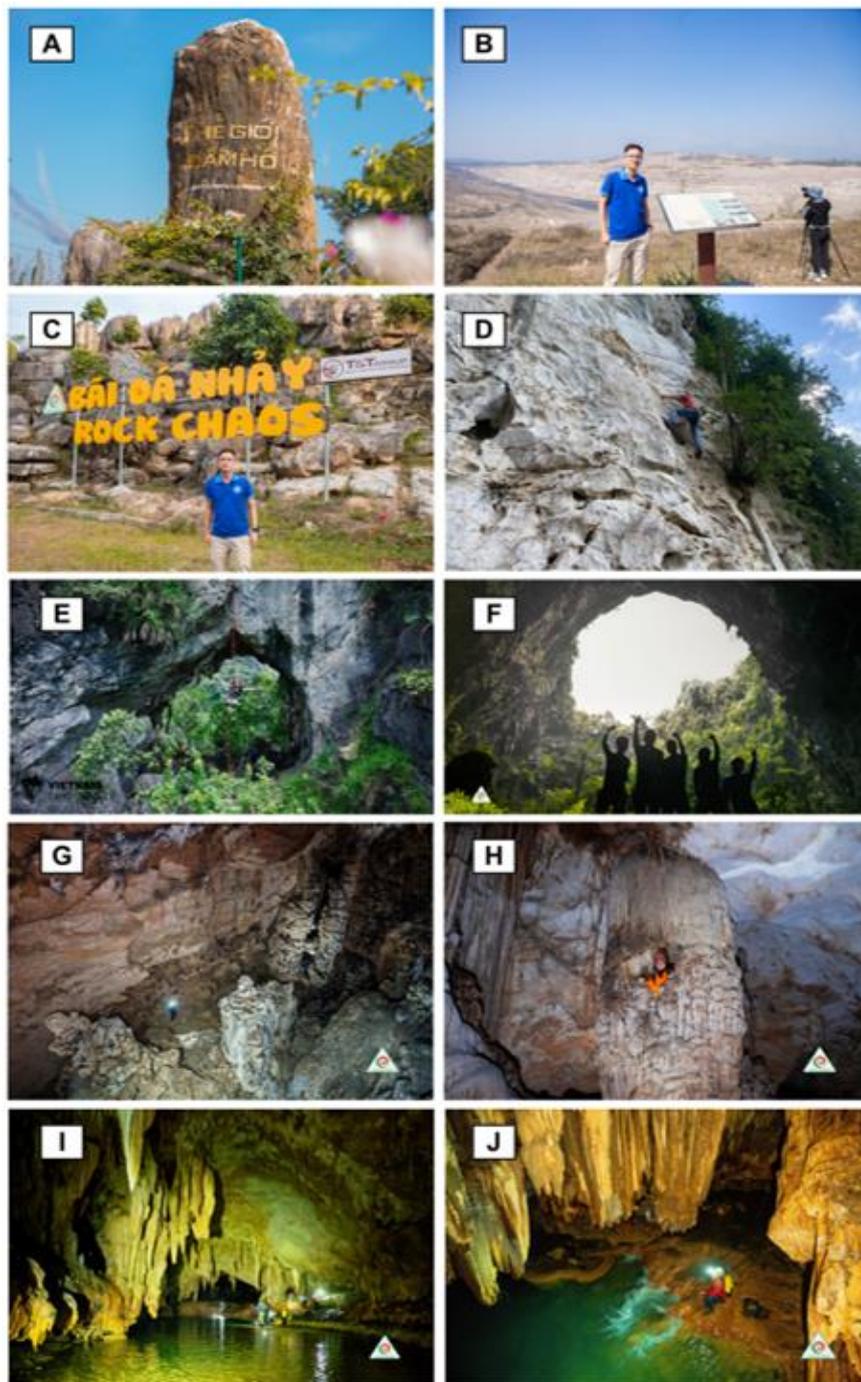


Figure 4. Some of the geosites in the Lang Son UNESCO Global Geopark. (A,B) - Na Duong Lake Lifetime Window (GS14); (C) - Rock Chaos (GS4); (D) - Participate in the rock-climbing experience at Na Lay Mountain - Bac Son (source: author); (E) - Lan Ty Valley (GS18) (source: Vietnam Expeditions); (F) - Binh Gia Sinkhole (GS19); (G,H) - Nguom Mooc Cave (GS17); (I,J) - Khuon Bong Cave (GS16) (source: Lang Son Geopark).

factors, remain limited. Conversely, the Z_{23} group (GS₁₃, GS₁₅, GS₁₆) has a lower MV average (~ 7.25) but a higher AV average (~ 11.33). These sites benefit from good infrastructure, supportive socio-cultural contexts, and accessible tourism services, although their scientific significance or protection level is relatively modest. The Z_{22} group (GS₄, GS₇, GS₈, GS₉, GS₁₇) presents balanced yet moderate values for both MV and AV (~ 7.0 each), yielding an overall GAM score of approximately 14 points. This group can be regarded as “transitional geosites” - locations with moderate tourism potential that could be enhanced through better interpretation, accessibility improvements, and the addition of visitor services.

Finally, the Z_{21} group (GS₃, GS₁₁) records the lowest values, with MV averaging 5.5 points, AV averaging 4.25, and a total GAM score of ~ 9.75 . These sites are typically small in scale, difficult to access, and have received little to no investment for geotourism purposes, reflecting their current peripheral role in the geopark’s overall tourism framework.

These data indicate that the differences among the groups stem not only from their intrinsic geological values but are particularly pronounced in the component of Additional Values ($V_{Fn} + V_{Tr}$). The geosites located within the Dong Lam - Lan Ty - Mau Son cluster demonstrate both high Main Values ($\approx 9.5 \div 10.75$) and outstanding Additional Values (≥ 11.25), reflecting a harmonious integration of distinctive landscapes, scientific significance, and well-developed community-based tourism infrastructure. These sites should therefore be prioritized for conservation, promotion, and sustainable tourism development. In contrast, sites such as GS₃, GS₁₁, and some within the Z_{22} field show moderate Main Values ($\approx 7 \div 7.5$) but lower Additional Values ($\approx 5 \div 7.75$), revealing key limitations in accessibility, infrastructure, and promotional activities. Hence, the GAM assessment results not only help identify geoheritage sites that require priority conservation and development (groups Z_{33} and Z_{32}) but also highlight the groups that should focus on improving functional and touristic aspects (groups Z_{23} , Z_{22} , and Z_{21}). These findings provide an essential scientific basis for strategic planning toward sustainable geotourism development within the Lang Son UNESCO Global Geopark.

6. Conclusions and Recommendations

The quantitative assessment of the geotourism value of 19 geoheritage sites within the Lang Son UNESCO Global Geopark, conducted using the Geosite Assessment Model (GAM), reveals a clear differentiation in overall values among the study areas. The total GAM scores range from $9.0 \div 24.5$, with the very high-value group (Z_{33}) comprising Dong Lam Magic Valley (GS₂), Ammonite World (GS₁₀), Mau Son Panorama (GS₁₂), Na Duong Lake Lifetime Window (GS₁₄), and Lan Ty Valley (GS₁₈). These are the core sites distinguished by their outstanding scientific, aesthetic, and educational values, supported by well-developed infrastructure, tourism services, and high accessibility. In contrast, the low-value group (Z_{21}), including Continental Eruption (GS₃) and Timeless fault (GS₁₁), mainly demonstrates scientific significance but remains limited in scale, accessibility, and tourism development potential.

Detailed analysis shows that the Main Values (VSE + VSA + VPr) of the geosites are relatively uniform (average ≈ 8.0 points), whereas the Additional Values ($V_{Fn} + V_{Tr}$) exhibit greater variability (3.75 -13.75 points), playing a decisive role in distinguishing between the Z_{33} , Z_{32} , and Z_{21} groups. This finding suggests that, beyond their inherent geological and scientific importance, infrastructure, promotional activities, and community-based tourism management are key factors enhancing the overall value of the sites within the framework of sustainable geotourism development.

Based on these findings, the authors propose the following recommendations:

- (1) Prioritize conservation and development of Z_{33} - Z_{32} group sites as “core zones” for educational, research, and international geotourism activities;
- (2) Invest in infrastructure, interpretation panels, and tourism services for geosites with medium potential (Z_{23} - Z_{22} groups), particularly in the Chi Lang - Binh Gia area;
- (3) Enhance communication, train local guides, and integrate geoscience education programs in schools to promote heritage awareness and community engagement;
- (4) Continue improving the quantitative geoheritage database, incorporating GIS and multi-criteria decision models (MCDM, AHP) to support future planning, conservation, and sustainable

development of the Lang Son UNESCO Global Geopark.

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Contributions of authors

An Manh Do - designed the study, conducted field surveys, performed the GAM model evaluation, and wrote the article; Son Viet Phan, Thoa Thi Hoang - collected and synthesized secondary data; Hien Thanh Thi Pham, Thao Thanh Thi Nguyen - methodology and database.

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