




Geotourism Potential for Sustainable Geotourism Development at Phou Pha Marn, Khammouane Province, Laos

Phomsanh Chantharangson^{1,*} , Kethsa Nanthavongdouangsy²,
Vongphet Sihapanya³, Li Bo⁴, Khamson Lattayot⁵

¹ *Kunming University of Science and Technology, China*

² *Department of Ecotourism, National University of Laos, Laos*

³ *Department of Ecotourism, National University of Laos, Laos*

⁴ *Faculty of Land Resource Engineering, Kunming University of Science and Technology, China*

⁵ *Deputy Division Management for Concession, Department of Geology and Minerals, Vientiane, Laos*

Corresponding Author's E-mail: c.phomsanh@gmail.com

Original Article

Received:

25-Nov-2024

Revised:

18-Apr-2025

Accepted:

13-May-2025

Published Online:

28-Jul-2025

© 2025 The Author(s). Published by the OICC Press under the terms of the [CC BY 4.0 Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/), which permits use, distribution and reproduction in any medium, provided the original work is properly cited

Abstract

Phou Pha Marn, located in Khammouane Province, Laos, is a karst landscape of notable geological and geomorphological interest. This study assesses its geotourism potential through the application of the Modified Geosite Assessment Model (M-GAM), integrating expert-based and visitor-oriented evaluation criteria. Five representative geosites, including Konglor Cave, Karst Tower Ridge, and the Nam Dene doline field, were assessed for their scientific, educational, aesthetic, and touristic values. The results indicate that Konglor Cave scored highest overall (0.75), with outstanding scientific and educational value, while Karst Tower Ridge demonstrated exceptional aesthetic appeal (0.90). Despite moderate infrastructure scores, the area exhibits high geoheritage potential due to its diverse karst features, cultural associations, and landscape integrity. Comparative insights from successful geotourism models in Albania, Serbia, Vietnam, and Malaysia further inform the development framework. The study concludes with strategic recommendations for sustainable geotourism planning, infrastructure enhancement, and community-based geoheritage conservation, positioning Phou Pha Marn as a strong candidate for future geotourism initiatives in Southeast Asia.

Keywords: Geotourism, Phou Pha Marn, Karst, Geoheritage, Sustainability

Introduction

Phou Pha Marn, situated in the karst-dominated terrain of Khammouane Province, Laos, is a region of exceptional geoheritage significance. The area is characterized by extensive karst morphologies, including prominent limestone peaks, do-

lines, speleological systems, and subterranean hydrological networks. These geomorphological features are the result of prolonged carbonate dissolution processes under tropical climatic conditions, creating a landscape of high scientific, aesthetic, and educational value. Additionally, the site harbors a diverse array of ecosystems interwoven

with cultural practices unique to the region, further enhancing its geotourism potential.

Geotourism, as a subdiscipline of sustainable tourism, integrates the promotion of geoheritage with environmental stewardship and cultural appreciation. Globally, geotourism has demonstrated its capacity to enhance regional development while maintaining geoconservation goals. For instance, Thethi National Park in Albania exemplifies how geosites can serve as pivotal assets for regional tourism, fostering socio-economic growth and conservation awareness. Similarly, the Danube region in Serbia underscores the importance of systematic geosite assessment frameworks, such as the Modified Geosite Assessment Model (M-GAM), to identify, evaluate, and manage sites for sustainable tourism.

This study aims to investigate the geotourism potential of Phou Pha Marn, drawing insights from comparable international examples from Albania, Serbia, Malaysia, Vietnam, and China, to inform locally appropriate development strategies. Given the region's geological richness and socio-economic context, this research provides evidence-based recommendations for promoting Phou Pha Marn as a sustainable geotourism destination while ensuring the long-term conservation of its geoheritage.

Literature Review

Geotourism Principles

Geotourism is a specialized form of tourism that emphasizes the exploration, education, and appreciation of geological formations and processes. It involves the sustainable management of geosites, locations of geological, geomorphological, or paleontological significance, while contributing to the conservation of geoheritage and fostering local socio-economic development (Shekhar *et al.* 2019). Geotourism extends beyond the simple observation of natural landscapes; it aims to educate

the public about geological processes and to highlight the scientific, cultural, and environmental significance of geological features (Farsani 2012).

Central to geotourism is the concept of geoheritage, which refers to the natural geological features that have scientific, educational, aesthetic, and cultural value. Geoheritage conservation is essential for maintaining the integrity of geosites, especially in areas with fragile ecosystems, such as karst landscapes, which are prone to degradation from unsustainable tourism practices (Matsusha 2020). Geosites are irreplaceable resources that offer insights into Earth's history and evolution. Hence, sustainable management practices are crucial to ensure the long-term conservation of these geological features while enhancing public understanding and appreciation.

Geosite Assessment Models

To evaluate the geotourism potential of an area, several models have been developed to assess the scientific, aesthetic, and educational value of geosites, as well as their potential for sustainable tourism development. One such model is the Modified Geosite Assessment Model (M-GAM), which has been applied in karst regions like the Homolje area in eastern Serbia. M-GAM integrates geological significance with tourism potential by assessing geosites based on factors such as scientific research value, rarity, geomorphological features, accessibility, and visitor experience (Antić and Tomić 2017). This framework also emphasizes the importance of carrying capacity, the ability of a geosite to withstand tourist activities without significant degradation of its scientific or aesthetic value (Crofts *et al.* 2015).

In the context of Phou Pha Marn, applying geosite assessment models like M-GAM would enable the identification of key geological features with high geotourism potential, such as distinctive karst formations, caves, and paleontological sites.

These sites could then be managed and promoted through sustainable tourism initiatives that balance geoheritage conservation with the development of local tourism infrastructure.

Comparative Case Studies and International Perspectives

Sustainable geotourism is not only concerned with geoheritage protection but also with community engagement and the integration of local stakeholders in decision-making processes (Tavares *et al.* 2015). Successful case studies, such as those in Thethi National Park (Albania) and the Danube region of Serbia, highlight the importance of community-based geotourism planning. These areas have effectively combined conservation efforts with community development, ensuring that local communities benefit economically from tourism while preserving their geoheritage (Dollma 2019). Additionally, these models emphasize the need for visitor management strategies that limit tourism pressure on sensitive geosites, thereby maintaining the integrity of the geological features for future generations (Schutte 2009).

This theoretical framework underscores the necessity of integrating sustainable development principles into the geotourism planning process for Phou Pha Marn. By applying these established models and incorporating best practices from other successful geotourism destinations, it is possible to develop strategies that support both the conservation of Phou Pha Marn's geoheritage and its potential as a sustainable tourism destination. Case studies from both Europe and Southeast Asia demonstrate diverse approaches to integrating geological conservation, education, and sustainable tourism.

The Thethi National Park in Albania, located in an Alpine karst environment, demonstrates how geosite inventory, interpretive signage, and eco-tourism infrastructure can be developed with com-

munity engagement to promote conservation-oriented tourism. The park features well-preserved limestone gorges, caves, and traditional villages adapted to geotourism strategies that preserve both geological and cultural values.

In the Homolje region and Danube corridor of eastern Serbia, the integration of karst features such as karst springs, caves, and sinkholes into tourism trails has been reinforced through geosite assessments and educational tools (Miljkovic *et al.* 2023; Ertekin and Ulugergerli 2022). These regions have successfully employed participatory tourism models and local interpretative planning based on geodiversity mapping.

The Langkawi UNESCO Global Geopark in Malaysia represents a tropical karst setting where limestone landforms have been integrated with geotrails, geoeducation centers, and community-based geotourism (Komoo & Patzak 2008). The geopark emphasizes public awareness of geological processes through accessible interpretation, zoning strategies, and small-scale tourism enterprises led by locals.

The Dong Van Karst Plateau Geopark in Vietnam, a high-altitude limestone region, showcases transdisciplinary management linking geological heritage with ethnic minority culture, traditional settlements, and geopark education (Tran *et al.* 2022). Its co-management structure, combining governmental, scientific, and community stakeholders, offers a model for decentralized and inclusive geoheritage governance.

In China, the Leye-Fengshan UNESCO Global Geopark is known for its giant karst tiankengs and subterranean hydrological networks. The site integrates scientific research with tourism through cave exploration, geological museums, and strict conservation zoning (Fang *et al.* 2024). Its focus on scientific-tourism synergies offers a model for balancing karst fragility and touristic demand.

Lastly, the Batur Geopark in Indonesia, although a volcanic system, illustrates how geotourism can be leveraged through thematic storytelling, local livelihoods, and volcanic hazard education (Agastya *et al.* 2021). The park integrates community identity with natural heritage, reinforcing the use of narrative-driven geotourism applicable to karst settings with cultural overlays.

These global examples highlight the relevance of

combining geosite assessment methodologies, interpretation planning, participatory governance, and conservation zoning. Such strategies provide a framework for Phou Pha Marn to adapt international best practices to its own geomorphological and socio-economic context.

A summary of comparative geotourism strategies relevant to Phou Pha Marn is provided in Table 1.

Table 1. Comparative Geotourism Strategies in Karst and Geoheritage Regions.

No.	Geopark/Region	Country	Geological Setting	Strategic Focus	Relevance to Phou Pha Marn
1	Thethi National Park	Albania	Alpine Karst	Geosite inventory, trail development, local infrastructure, community engagement	Demonstrates low-impact tourism infrastructure in mountainous karst regions; valuable for trail planning and interpretation
2	Danube & Homolje Region	Serbia	Limestone karst with springs, sinkholes, caves	Geosite evaluation (M-GAM), aesthetic classification, educational signage	M-GAM-based assessment and participatory ecotourism approaches are directly applicable
3	Langkawi UNESCO Global Geopark	Malaysia	Tropical Karst Island	Geo-interpretation centers, geotrails, local entrepreneurship	Offers a tropical karst model with strong community-based tourism and interpretation frameworks
4	Dong Van Karst Plateau Geopark	Vietnam	Highland Karst Plateau	Ethnocultural integration, co-management governance, heritage villages	Illustrates successful integration of geological and cultural narratives with decentralized management
5	Leye-Fengshan UNESCO Global Geopark	China	Deep Karst (Tiankengs, caves)	Scientific-tourism synergy, zoned conservation, cave tourism	Useful model for developing speleotourism and managing high-value karst landscapes through zoning
6	Batur UNESCO Global Geopark	Indonesia	Volcanic System	Hazard education, thematic geotourism, community identity	Provides an adaptable model for narrative-based tourism and local empowerment, though based in a non-karst setting

Method

Geographic Location

Phou Pha Marn is situated in the southeastern part of Khammouane Province, central Laos, located within the Annamite Mountain Range, a region that extends along the Lao-Vietnamese border. The area lies approximately at 17°45' N latitude and 106°45' E longitude, characterized by steep, rugged topography and a rich diversity of karst formations. The karst landscapes of Phou Pha Marn span approximately 1,200 square kilometers and are a prominent feature of the region's geography, distinguished by limestone outcrops, paleokarst formations, and river gorges. Phou Pha Marn is located within Khammouane Province, Laos, as shown in Fig. 1.

Geological Background

Phou Pha Marn's geological landscape is predominantly formed by limestone of the Cambrian to Permian age, which is part of the extensive Indochina karst system that spans Laos, Vietnam, Thailand, and Cambodia. This karstification is the

result of millions of years of geological processes, including sedimentation, tectonic uplift, and chemical weathering. Over time, the dissolution of the calcareous rocks by slightly acidic water has created distinctive features such as karst towers, caves, limestone plateaus, and sinkholes. Notable geological structures in the area include the Phou Pha Marn Cave and several deep, subterranean river systems that are vital for both scientific research and potential geotourism activities.

The karst topography found in Phou Pha Marn has been shaped by tectonic activity and geomorphological processes, creating dramatic cliffs and limestone ridges that dominate the landscape. The area's complex geological history also reflects significant episodes of hydrothermal activity and tectonic movements associated with the Southeast Asian seismic zone, which continues to shape the region's landscape. These processes are responsible for the geomorphological diversity that characterizes the area, including limestone escarpments, gullies, and stalactite formations.

Cultural and Ecological Significance

Phou Pha Marn is not only of geological importance but also holds cultural and ecological significance. The region is home to indigenous Khmu and Lao Loum communities, whose traditional livelihoods are closely tied to the land and its natural resources. These communities practice agriculture, fishing, and forestry, and their cultural beliefs are deeply intertwined with the landforms and natural features of the region. For instance, local legends often relate to the caves and mountains, which are seen as sacred or spiritual sites, enhancing the cultural value of the area for geotourism.

Ecologically, Phou Pha Marn is part of a larger biodiversity hotspot within Lao PDR, recognized for its faunal and floral diversity, some of which include endangered species such as the Indochinese tiger and the Asian elephant. The forested re-



Figure 1. Location of Phou Pha Marn in Khammouane Province, Laos

gions surrounding the karst formations contribute to the region's rich biodiversity, supporting ecosystem services such as soil stabilization, water filtration, and carbon sequestration. The combination of geological uniqueness and biodiversity provides significant opportunities for eco-tourism, nature-based tourism, and, importantly, geotourism.

Phou Pha Marn is also located near the Phou Hin Poun National Protected Area, which adds an extra layer of conservation value to the region. This area is designated for its biodiversity conservation and ecotourism development, providing a legal framework for the management and sustainable use of its resources. The proximity of Phou Pha Marn to this protected area underscores the potential for integrating geoconservation efforts with sustainable tourism strategies.

The integration of geological heritage and cultural landscapes in Phou Pha Marn presents a unique opportunity for developing a sustainable geotourism model. However, the region faces significant challenges related to infrastructure development, capacity building, and tourism management. These challenges underscore the need for strategic planning and geosite assessment to ensure that the development of geotourism does not negatively impact the area's delicate geological and ecological systems.

Data Collection Methods

To comprehensively evaluate the geotourism potential of Phou Pha Marn, Khammouane Province, a multifaceted research approach is implemented, integrating field-based observations and remote sensing technologies along with qualitative stakeholder feedback and comparative analysis with established geotourism models. The methodological framework encompasses the following key components:

- **Geosite Identification:**

Geosite identification at Phou Pha Marn is carried out through a combination of systematic field surveys and remote sensing. Field surveys involve on-the-ground mapping of prominent geological features such as karst towers, limestone cliffs, caves, and underground river systems. The key geological structures are cataloged based on their scientific, aesthetic, and educational significance. These field observations are supplemented by geospatial data obtained from satellite imagery and LiDAR (Light Detection and Ranging) technologies, to facilitate the detailed mapping of the terrain and identification of geological formations that may not be easily accessible by ground surveys (Jones & Hobbs 2021).

The integration of remote sensing tools, particularly high-resolution satellite imagery, allows for the precise delineation of geosites across the rugged, karstic topography of Phou Pha Marn. These tools provide detailed topographic maps and reveal hidden geosites, such as cave systems or subterranean water features, crucial for enhancing the spatial accuracy of geological mapping.

- **Geosite Assessment Models and Application to Phou Pha Marn:**

The Modified Geosite Assessment Model (M-GAM) is a semi-quantitative method used to evaluate the overall value of geosites for geotourism purposes. It builds upon earlier models by incorporating not only scientific, educational, and aesthetic criteria, but also functional and accessibility factors, including visitor safety, interpretive infrastructure, and local participation. The M-GAM includes both expert-based values (main values) and visitor-based values (additional values), allowing for a more holistic appraisal of geoheritage.

Each geosite is evaluated using 12 main criteria (e.g., scientific importance, rarity, representative-

ness, integrity, aesthetic value, accessibility, safety, observation conditions, interpretive potential) and 12 additional criteria (e.g., promotion, interpretative panels, local products, tourist infrastructure, stakeholder involvement). Following Ertekin & Ulugergerli (2022), values are scored between 0 and 1, and the final M-GAM score is computed through a weighted matrix. For example, a karst cave with high scientific value, moderate accessi-

bility, and basic interpretive signage might score 0.8 in scientific value, 0.6 in accessibility, and 0.5 in education, resulting in a balanced potential for geotourism development.

The interpretation of the M-GAM score ranges used to classify geotourism potential in this study is detailed in Table 2.

Table 2. Interpretation of M-GAM Score Ranges

No.	Score Range	Interpretation	Meaning
1	0.00 – 0.29	Low	Indicates very limited value or suitability for geotourism development.
2	0.30 – 0.59	Moderate (Basic)	Shows average value with potential, but with some limitations.
3	0.60 – 0.79	High	Reflects strong potential and important value for tourism and education.
4	0.80 – 1.00	Very High / Exceptional	Denotes outstanding significance and high readiness for geotourism use.

In other cases, for example in the Danube region, sedimentary formations, river terraces, and karstic features were evaluated using M-GAM to assess their potential for tourism development, while considering the capacity of each site to withstand visitor impact without compromising its geological integrity (Tomić *et al.* 2020). A similar approach, which assesses carrying capacity and visitor management strategies, is particularly relevant for Phou Pha Marn, given the vulnerability of its karst formations to overexploitation from poorly managed tourism.

The SWOT matrix, a strategic planning tool, can also be adapted to Phou Pha Marn to assess internal and external factors affecting geotourism development. By identifying strengths (e.g., the region's rich geological heritage), weaknesses (e.g., limited infrastructure and insufficient local capacity), opportunities (e.g., potential for local community

involvement and eco-tourism development), and threats (e.g., environmental degradation due to unregulated tourism), this model provides a systematic way to develop sustainable tourism strategies that mitigate risks and maximize socio-economic benefits (Díaz-López *et al.* 2021). For instance, the Homolje region's successful integration of geoconservation with community-driven tourism provides a useful reference for Phou Pha Marn, where local communities could play a central role in the stewardship of the geoheritage while benefiting economically from sustainable tourism activities (Antić and Tomić 2017).

We also employ the Geosite Evaluation Model (GEM), as applied in Thethi, which highlighted the region's key karst features, such as caves and mountain ranges, and helped develop a balanced approach that addressed both the protection of geosites and the enhancement of local tourism

infrastructure (Dollma 2019). Similarly, applying GEM or a hybrid assessment approach for Phou Pha Marn could provide a rigorous, scientific evaluation of its karst features, guiding the development of sustainable tourism initiatives that prioritize conservation and enhance the site's accessibility to tourists.

- **Stakeholder Input:**

In addition to the geosites' scientific evaluation, qualitative data is collected through interviews and focus groups with key stakeholders, including local communities, government officials, and tourists. This qualitative approach captures a range of perspectives on the potential for sustainable geotourism development. Interviews with local communities assess how they perceive the environmental, social, and economic impacts of geotourism. Emphasis is placed on gathering insights regarding traditional ecological knowledge, cultural significance, and community-driven tourism opportunities.

Engagement with government representatives provides an understanding of the existing regulatory frameworks, policy initiatives, and tourism infrastructure available for the promotion of sustainable geotourism. Interviews with tourists help gauge interest in visiting geosites and understand the factors influencing their decision-making processes, such as access, environmental awareness, and educational programs available at potential geosites.

- **Comparative Framework:**

Case studies from regions such as Thethi National Park (Albania) and the Danube Region (Serbia), which have successfully integrated geoheritage assessments into their tourism development strategies, serve as benchmarks. These regions have utilized geosite evaluations to promote sustainable tourism, balancing Geoheritage conservation with economic development. The Homolje Aea case

study in eastern Serbia provides additional insights into the integration of community involvement and geoheritage conservation in the development of geotourism, particularly in regions with complex karst topography.

Results

Geosite Assessment Results and Classification

Five representative geosites within the Phou Pha Marn area were evaluated using the Modified Geosite Assessment Model (M-GAM). The integrated results are presented in Table 3, which combines both the evaluation scores and classification attributes for a holistic overview of each geosite.

These evaluation values were selected to capture both the inherent significance of each geosite and its practical readiness for tourism. Scientific, educational, and aesthetic values reflect the natural and interpretive qualities that make a site meaningful for learning and appreciation. Accessibility and tourism infrastructure assess how well a site can accommodate and engage visitors. Together, these values provide a balanced framework for identifying geosites that are not only important but also feasible for sustainable geotourism development.

The integrated assessment and classification approach provides a comprehensive overview of the geosites within Phou Pha Marn. The Konglor Cave System emerged as the most significant site, with high scores across scientific, educational, and aesthetic dimensions. In contrast, sites like the Limestone Pavement Area and Dolines showed moderate scores, suggesting the need for focused development to enhance their tourism readiness.

Geotourism Potential:

The karst towers and limestone ridges of Phou Pha Marn are particularly significant due to their striking visual appearance, formed by millennia of erosion and dissolution processes, making them

Table 3. Integrated Geosite Evaluation and Classification of Phou Pha Marn

No.	Geosite Name	Geosite Type	Key Features	Scientific Value	Educational Value	Aesthetic Value	Accessibility	Tourism Infrastructure	Total Score	Geotourism Potential
1	Konglor Cave System	Karst Cave / Speleological	Large limestone cave with underground river, stalactites, and speleothems	0.9	0.85	0.8	0.6	0.55	0.75	High
2	Karst Tower Ridge (Pha Luang)	Structural Karst	Steep limestone pinnacles and cliffs formed by differential erosion	0.8	0.7	0.9	0.5	0.4	0.72	Moderate to High
3	Dolines of Phou Pha Marn	Surface Karst Depression	Collapse features indicating subsurface voids and dissolution processes	0.75	0.65	0.6	0.45	0.35	0.6	Moderate
4	Rock Shelter with Petroforms	Geocultural / Geoarchaeological	Karst overhang with local spiritual significance and lithic structures	0.65	0.8	0.5	0.7	0.3	0.65	Moderate
5	Limestone Pavement Area	Erosional Surface Karst	Extensive exposure of jointed limestone bedrock with visible solution features	0.7	0.6	0.55	0.6	0.3	0.6	Moderate

key sites for geological education and geotourism. Furthermore, the cave systems present a unique opportunity for spelunking and subterranean exploration, drawing attention to paleoclimate reconstructions, hydrological processes, and karst aquifers. The subterranean rivers that flow through the karst formations could become focal points for geotourism, allowing for study and engagement in

hydrological systems, which could offer critical insights into karst hydrology and aquifer management.

Ecologically, Phou Pha Marn lies within the Annamite Mountain Range, a recognized biodiversity hotspot. The region's tropical rainforests and wetland habitats provide a home to numerous en-

demic species and rare fauna, such as the Indochinese tiger and Asian elephant, which contribute to the site's ecological value. The integration of geological and ecological assets presents significant opportunities for eco-geotourism, where tourists can explore both the geological formations and the rich biodiversity of the region. This combination facilitates educational opportunities related to sustainable resource management and the interdependence between geology and ecosystem conservation. Activities such as wildlife tours, bird watching, and eco-trekking can be incorporated, enhancing the visitor's understanding of the link between geological processes and ecological dynamics.

In addition to its geological and ecological importance, Phou Pha Marn holds significant cultural relevance. The local Khmu and Lao communi-

ties have long considered the karst formations and caves sacred, embedding them deeply in the region's cultural landscape. The area's spiritual significance is tied to local myths and practices, which present unique opportunities for cultural interpretation alongside geological exploration. These aspects can be integrated into geocultural tourism, where visitors experience the convergence of geology, ecology, and culture, thus promoting a holistic tourism model. The cultural component can be leveraged by developing interpretive programs that emphasize both the geological heritage and cultural traditions surrounding the region's sacred geosites.

Notable geological formations characteristic of Phou Pha Marn's karst landscape is depicted in Fig. 2.

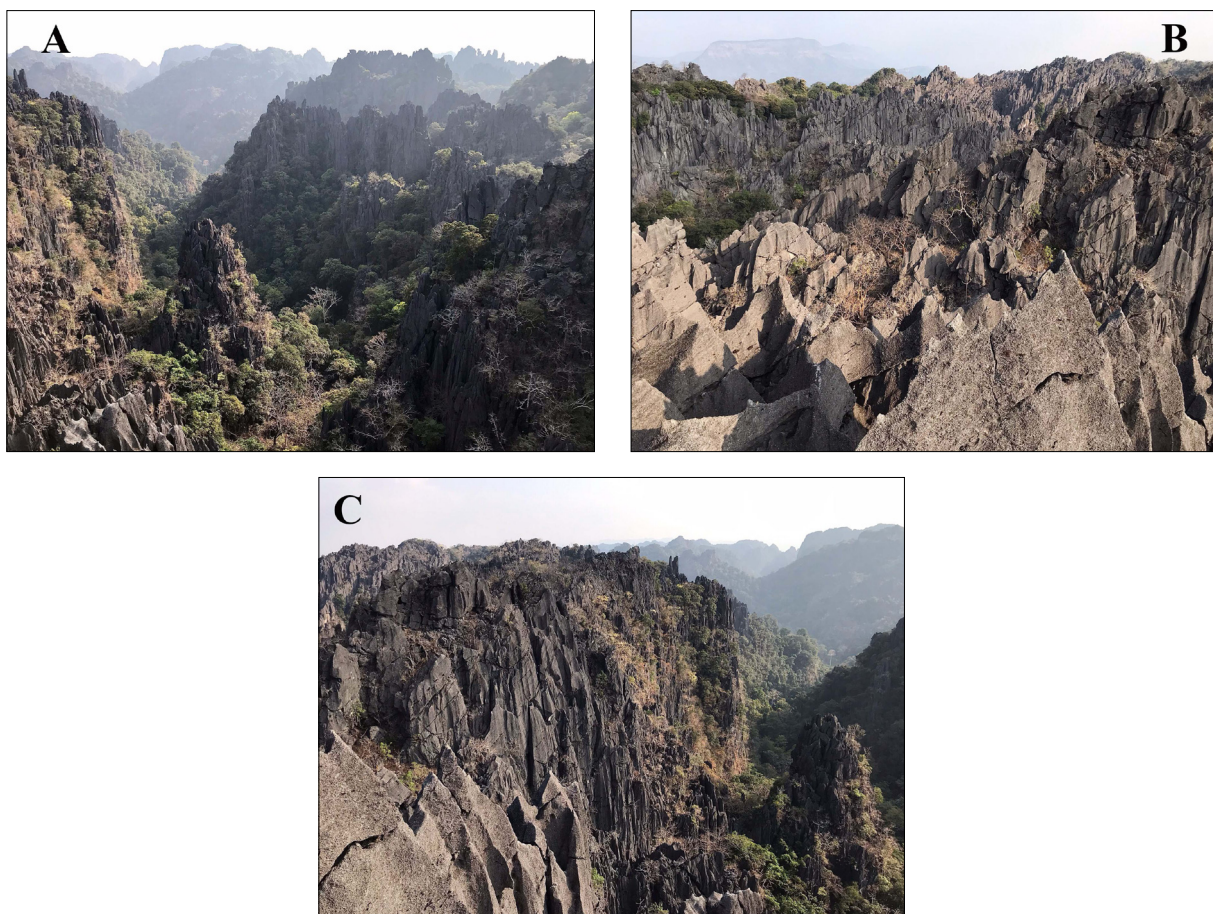


Figure 2. (A, B, C) Karst towers and limestone ridges are characteristic of the Phou Pha Marn landscape.

However, despite the geotourism potential, Phou Pha Marn faces substantial challenges, particularly in infrastructure development. The current state of accessibility to the site remains limited, with underdeveloped transport networks and a lack of tourist facilities. These issues hinder the region's ability to fully capitalize on its geotourism potential. To address these barriers, the development of eco-friendly infrastructure such as sustainable transport systems, environmentally conscious accommodation options, and visitor centers that provide educational programs on geoheritage and ecological conservation will be essential.

A successful development strategy for Phou Pha Marn's geotourism potential will require a sustainability framework that integrates environmental conservation, community involvement, and economic development. Lessons learned from other geotourism initiatives, such as those implemented in the Danube region and the Homolje area, can be adapted to fit the unique characteristics of Phou

Pha Marn. These models highlight the importance of developing geoheritage assessments and visitor management strategies that prioritize the conservation of both geosites and the surrounding ecosystems. Furthermore, strategies that promote community engagement and ensure that the local population benefits from geotourism development will be critical to ensuring the region's long-term sustainability.

Challenges Identified

Challenges include underdeveloped infrastructure, lack of awareness, insufficient local capacity, and environmental sustainability concerns. These issues are similar to those encountered in other regions with geotourism potential, necessitating targeted interventions to ensure long-term success and geoheritage conservation.

A detailed overview of key challenges identified in this study is summarized in Table 4.

Table 4. Key Challenges for Geotourism Development at Phou Pha Marn

No.	Challenge	Description	Comparable Cases	Potential Solutions
1)	Infrastructure Deficiencies	Inadequate transportation systems and the absence of basic tourism amenities hinder access to geosites.	Thethi National Park, Albania; Danube Region, Serbia.	Develop sustainable transport infrastructure, improve road conditions, and create eco-friendly accommodations.
2)	Lack of Awareness	Limited recognition of Phou Pha Marn's geological and ecological significance reduces its attractiveness as a geotourism destination.	Danube Region, Serbia; Homolje, Serbia.	Increase visibility through targeted marketing campaigns and collaborations with international geotourism platforms.
3)	Capacity Building Needs	Local communities and tourism operators lack knowledge and skills in sustainable tourism management and geoheritage conservation.	Homolje Area, Serbia; Thethi National Park, Albania.	Provide capacity-building programs focused on geoheritage conservation, tourism management, and hospitality.
4)	Environmental Risks	Over-tourism could lead to degradation of fragile karst ecosystems and geosites without proper monitoring and management.	Thethi National Park, Albania; Homolje Area, Serbia.	Implement visitor management strategies, including limits on visitor numbers, eco-tourism practices, and environmental monitoring.

1) Infrastructure Deficiencies

Road networks are poorly maintained, and transportation access to key geosites is limited, especially during the rainy season when landslides and erosion can obstruct access. Furthermore, the area lacks essential tourist infrastructure, such as interpretive centers, visitor signage, and eco-lodging facilities, which are critical to providing an immersive and educational geotourism experience. Similar challenges have been encountered in other geotourism hotspots, such as Thethi National Park in Albania, where poor infrastructure has limited visitor access to key karst features and cultural landscapes.

To overcome these infrastructure deficiencies, it is essential to develop sustainable tourism infrastructure that prioritizes eco-friendly transport solutions and ensures minimal environmental impact. Establishing well-maintained roads and creating facilities such as educational visitor centers, sustainable accommodations, and interpretive trails would enhance accessibility and contribute to a more holistic tourism experience.

2) Lack of Awareness

Despite its rich karst formations, cave systems, and biodiversity, the area is relatively unknown to both international tourists and local communities. This lack of awareness diminishes the potential for geotourism development, as potential visitors are unaware of the geological significance of the region. This issue has been observed in other regions, such as the Danube region of Serbia, where underutilized geosites remained largely unknown despite their potential.

To address this issue, targeted promotion and marketing strategies are necessary. Utilizing digital media platforms, collaborations with geotourism organizations, and educational outreach can help raise awareness about Phou Pha Marn's geoheritage. Informing the local population and tourists

about the region's geological features will increase its appeal as a geotourism destination.

3) Capacity Building Needs

To maximize the potential of geotourism, it is imperative to invest in capacity building for local communities and tourism stakeholders. Many local residents and operators lack the necessary knowledge and skills to manage tourism sustainably or to engage in effective geoheritage conservation practices. This gap in knowledge and skills can impede the development of geotourism in the area, as local communities may be ill-prepared to accommodate increasing tourist numbers or properly protect the fragile karst ecosystems. This challenge has been noted in the Homolje area of Serbia, where a lack of local engagement in geotourism led to a slow pace of development.

To enhance local capacity, comprehensive training programs focused on sustainable tourism practices, geoheritage management, and environmental stewardship should be implemented. Workshops and educational initiatives aimed at local tourism operators and residents can improve their understanding of geotourism principles and empower them to participate actively in its development.

4) Environmental Risks

Phou Pha Marn's karst landscapes and other geological features are highly vulnerable to the negative impacts of over-tourism. Without proper management, increased visitation can lead to erosion, soil degradation, and loss of biodiversity in the region. These environmental risks have been observed in other geotourism destinations, such as Albania, where poorly managed tourist activities led to significant environmental damage.

To mitigate these risks, it is essential to implement a comprehensive visitor management strategy. This strategy should include measures such as limiting the number of visitors to particularly

fragile geosites, enforcing eco-tourism practices, and establishing protected areas around sensitive geological features. Environmental education programs for tourists can also raise awareness of the importance of conserving geoheritage and encourage responsible behavior among visitors.

In conclusion, Phou Pha Marn has significant geological potential that can be leveraged for sustainable geotourism development. However, overcoming the challenges of infrastructure deficiencies, low awareness, insufficient capacity, and environmental sustainability will require coordinated efforts from local stakeholders, governmental bodies, and the geotourism industry. By addressing these challenges through targeted strategies and best practices derived from successful geotourism models in other regions, Phou Pha Marn can develop as a leading destination for sustainable geotourism that balances conservation with economic growth.

Strategic recommendations for sustainable geotourism development in Phou Pha Marn are summarized in Table 5.

1) Development of Eco-friendly Infrastructure

The implementation of eco-tourism infrastructure is essential to minimize the environmental footprint of growing tourist activities while enhancing the visitor experience. Drawing inspiration from Thethi National Park's development of eco-lodges, visitor centers, and low-impact trails, Phou Pha Marn could benefit from the construction of sustainable buildings that utilize locally sourced materials and energy-efficient technologies. The use of solar power, rainwater harvesting, and biodegradable waste management systems would align with global sustainable tourism practices. Additionally, interpretive signage, geological trail systems, and viewpoints designed to highlight karst landscapes and cave systems would not only

Table 5. Proposed Geotourism Development Strategies for Phou Pha Marn

No.	Strategy	Description	Reference Model	Expected Outcome
1)	Eco-friendly Infrastructure	Development of low-impact, energy-efficient buildings and interpretive trails to highlight karst landscapes.	Thethi National Park (Albania)	Conservation of natural heritage, reduced environmental footprint.
2)	Digital Promotion and Awareness	Implementation of virtual tours, geolocation apps, and social media campaigns to increase global visibility.	Homolje Area (Serbia)	Increased international tourist flow, enhanced geoheritage awareness.
3)	Educational and Capacity Building	Development of community-based educational programs on sustainable tourism and geoheritage conservation.	Thethi National Park (Albania)	Empowerment of local communities, improved interpretation skills.
4)	Global Geotourism Partnerships	Establish partnerships with international geotourism organizations for certification and funding.	UNESCO Global Geoparks, Global Geotourism Network	Enhanced credibility, international partnerships, access to funding.

enhance visitors' understanding of the area's geological significance but also encourage a deeper appreciation for its natural heritage.

These infrastructures should also focus on preserving the integrity of Phou Pha Marn's karst ecosystems by adhering to sustainable construction practices and involving local communities in the process to ensure that the infrastructure supports both ecological conservation and economic development.

2) Leveraging Digital Tools for Promotion and Awareness

One of the most impactful strategies for promoting Phou Pha Marn is through digital platforms. Like the Homolje area in Serbia, Phou Pha Marn can harness virtual tours, interactive websites, and social media campaigns to increase awareness about its geoh heritage. The implementation of geo-location apps could provide interactive, real-time navigation tools for tourists, offering detailed information on geosites, such as limestone karst formations, sinkholes, and cave systems. Such tools could also offer educational materials on the formation of these features and their ecological significance, enhancing the overall visitor experience while contributing to geo-education.

The creation of a digital geoh heritage repository that catalogs the area's geosites with high-resolution imagery and geological descriptions would serve as a resource for both researchers and tourists. This approach could substantially increase international interest and drive global tourism to Phou Pha Marn, positioning it as a leading geotourism destination in Southeast Asia.

3) Educational and Capacity Building Programs

Similar to the capacity-building initiatives in Thethi National Park, Phou Pha Marn can implement training programs aimed at developing the

skills of local communities, tourism operators, and guides. These programs would focus on the principles of geoh heritage conservation, the interpretation of karst geology, and the promotion of sustainable tourism practices. Local guides could receive specialized training in scientific interpretation of the area's geological formations, enabling them to provide in-depth educational experiences for visitors. Furthermore, local communities can be trained in hospitality and tourism management to ensure that they can effectively participate in the geotourism industry.

The creation of school-based educational programs and geological workshops for students, both locally and internationally, could foster greater awareness of the region's geological significance while also instilling a sense of pride and responsibility among the local population for their geoh heritage. These initiatives would ensure that geotourism development is not only sustainable but also inclusive, benefiting both the local economy and the conservation of the area's natural resources.

4) Collaboration with Global Geotourism Networks

Phou Pha Marn can greatly benefit from partnerships with international geotourism organizations such as UNESCO Global Geoparks and the Global Geotourism Network (GGN). These collaborations would provide access to funding opportunities, technical expertise, and global networks, while also ensuring that the development process adheres to international best practices. The area could also pursue geopark certification, which would not only improve its reputation but also provide an official designation that emphasizes the region's importance as a geosites hub. Such recognition would increase its appeal to the growing ecotourism market and attract tourists interested in exploring the geological diversity of Southeast Asia.

By joining geotourism networks and collaborating with research institutions, Phou Pha Marn could also facilitate scientific studies and academic exchanges related to karst systems and geoheritage management. These relationships would enhance the scientific value of the area and ensure that the development of geotourism is scientifically informed and contextually relevant to the region's unique geological features.

Discussion

The application of the Modified Geosite Assessment Model (M-GAM) revealed that Phou Pha Marn hosts several geosites with moderate to high geotourism potential. Our results affirm the region's classification as a geotourism candidate area with multi-dimensional value, yet they also reveal disparities in infrastructure and accessibility, which scored relatively low across all sites (e.g., 0.40 - 0.60). This gap underlines the need for infrastructure investment aligned with conservation goals.

When compared to established models such as Thethi National Park (Albania) and Homolje region (Serbia), Phou Pha Marn demonstrates similar geological appeal and cultural context but remains in a nascent stage of geotourism planning. In Albania, geosites are supported by interpretation panels, trail systems, and local tourism cooperatives, while Serbia's Homolje region has successfully integrated M-GAM results into community-based ecotourism strategies. Phou Pha Marn's M-GAM scores fall within a comparable range for scientific and aesthetic values, but lag in terms of infrastructure and organized interpretive planning, indicating a gap that policy and management interventions could bridge.

From a policy perspective, the M-GAM analysis provides a valuable evidence base for regional planning. Scores for tourism infrastructure and accessibility suggest a need for zoning strategies

that focus investment on high-potential geosites (e.g., Konglor Cave, Karst Tower Ridge) while maintaining ecological integrity. Furthermore, involving local communities in tourism services, interpretation, and guiding can align development with conservation, echoing the participatory models seen in Dong Van (Vietnam) and Langkawi (Malaysia).

This study also underscores the importance of integrating geotourism into Laos's protected area management framework. By using M-GAM and international benchmarking, stakeholders can prioritize capacity building, establish interpretive infrastructure, and promote Phou Pha Marn as a destination that supports both heritage conservation and socio-economic growth. Future research should expand the geosite inventory across the broader Phou Hin Pha Nam karst complex, incorporate stakeholder-based M-GAM scoring, and evaluate long-term impacts of geotourism on community livelihoods and karst ecosystem resilience.

Conclusions

Phou Pha Marn, situated in Khammouane Province, Laos, represents an exceptional site for geotourism development due to its geological significance, ecological diversity, and cultural heritage. The area's karst landscape, shaped by extensive carbonate dissolution over millions of years, features prominent limestone towers, sinkholes, and cave systems that are geologically significant and aesthetically remarkable. These formations serve as valuable resources for scientific research, education, and tourism, showcasing the dynamic interactions of geological and geomorphological processes.

The ecological aspects of Phou Pha Marn further enhance its geotourism potential. The region supports a variety of biodiverse ecosystems, including endemic and endangered species, which coexist within the fragile karst environment. This

biodiversity underscores the need to integrate geoconservation with eco-tourism to ensure the sustainability of the site's natural resources.

Culturally, Phou Pha Marn is deeply intertwined with the traditions of local communities. The karst formations hold spiritual and cultural significance, making the region an exemplary model for geo-cultural tourism, where geology and cultural heritage converge. This integration provides a unique platform for promoting geo-education and fostering a connection between visitors and the region's geological and cultural narratives.

Despite its outstanding potential, Phou Pha Marn faces significant challenges, including underdeveloped infrastructure, insufficient public awareness, and the need for capacity building among local stakeholders. Addressing these issues is critical for transforming the area into a sustainable geotourism destination. The implementation of eco-friendly infrastructure targeted digital promotion, and educational initiatives can help overcome these barriers while ensuring the conservation of the area's fragile karst environment.

In conclusion, the geotourism potential of Phou Pha Marn provides an opportunity to establish it as a leading destination for sustainable tourism in Southeast Asia. A strategic approach that prioritizes geoheritage conservation, promotes scientific research and engages local communities will not only preserve the geological and ecological integrity of the area but also contribute to its socio-economic development.

Acknowledgments

The authors express their profound gratitude to the local authorities of Khammouane Province for their invaluable support and facilitation during the field investigations at Phou Pha Marn. Their assistance in grant-

ing access to geosites and providing logistical support was critical to the successful completion of this research. The authors also extend their appreciation to academic advisors and colleagues for their expert guidance, constructive critiques, and contributions that significantly enriched the scientific rigor of this study. Finally, we are deeply indebted to the local communities of Phou Pha Marn for sharing their traditional knowledge and cultural perspectives, which provided essential context for understanding the interplay between geological heritage and cultural significance. Their collaboration underscores the importance of integrating community engagement into sustainable geotourism development frameworks.

Authors' Contribution

Phomsanh Chantharangson designed the study, conducted the fieldwork, performed the data analysis, and led the manuscript writing. Li Bo supervised the project and revised the manuscript. Kethsa Nanthavongdouangsy contributed to data collection and helped write the 27 early sections. Vongphet Sihapanya provided field support and assisted in drafting the descriptive sections. Khamson Lathayot contributed to mapping and visual data preparation.

Conflict of Interest

The authors declare that there are no conflicts of interest, financial or non-financial, related to this research.

References

- Agastya IBO, Meiva PS, Satya Y, Rinjani P, Cahyadi P (2021, December). The Potential and Challenges of Batur UNESCO Global Geopark as a Place for Volcanic Learning and Geological History in Bali Based on SWOT Analysis. In Proceedings Joint Convention Bandung.
- Antić A, Tomić N (2017). Geoheritage and geotourism potential of the Homolje area (eastern Serbia). *Acta Geoturistica*: 8(2): 67-78. <https://doi.org/10.1515/agta-2017-0007>
- Crofts R, Gordon JE, Santucci VL (2015). Geoconservation in protected areas. In *Protected area governance and management*. 531-568. <https://doi.org/10.22459/pagm.04.2015.18>
- Díaz-López C, Carpio M, Martín-Morales M, Zamorano M (2021). Defining strategies to adopt Level (s) for bringing buildings into the circular economy. A case study of Spain. *Journal of Cleaner Production*. 287: 125048. <https://doi.org/10.1016/j.jclepro.2020.125048>
- Dollma M (2019). Geotourism potential of Thethi National Park (Albania). *International Journal of Geoheritage and Parks*. 7(2), 85-90. <https://doi.org/10.1016/j.ijgeop.2019.05.002>
- Ertekin C, Ulugergerli EU (2022). Geoelectrical survey over perched aquifers in the northern part of Upper Sakarya River Basin, Türkiye. *Journal of Groundwater Science and Engineering*. 10(4): 335-352.
- Fang W, Gou GR, Cheung LT, Fok L, Chow AS, Zhang K (2024). An Investigation of Willingness to Pay for Geopark Management and Conservation: A Case Study of Geotourists in the Greater China Region. *Resources*. 13(2): 24. <https://doi.org/10.3390/resources13020024>
- Farsani NT (2012). Sustainable tourism in geoparks through geotourism and networking (Doctoral dissertation, Universidade de Aveiro (Portugal)).
- Jones L, Hobbs P (2021). The application of terrestrial LiDAR for geohazard mapping, monitoring and modelling in the British Geological Survey. *Remote Sensing*: 13(3): 395. <https://doi.org/10.3390/rs13030395>
- Komoo I, Patzak M (2008). Global geoparks network: An integrated approach for heritage conservation and sustainable use. Southeast and East Asia Geoheritage Conservation, Leman, MS, Reedman, A and Chen, SP, eds. *Bangi: LESTARI UKM*, 1-13.
- Matshusa K (2020). The potential for geotourism at the Kruger National Park for social sustainability. University of Johannesburg (South Africa). Doctor of Philosophy (PHD), University of Johannesburg
- Miljkovic B, Bjelajac D (2023). Geoheritage promotion towards sustainable tourism: "Kučaj-Beljanica Mountains" National Park in the Homolje Area (Eastern Serbia). *Tourism in Southern and Eastern Europe*.... 7:283-295. <https://doi.org/10.20867/tosee.07.19>
- Schutte IC (2009). A strategic management plan for the sustainable development of geotourism in South Africa (Doctoral dissertation, North-West University, Potchefstroom Campus).
- Shekhar S, Kumar P, Chauhan G, Thakkar MG (2019). Conservation and sustainable development of geoheritage, geopark, and geotourism: a case study of Cenozoic successions of Western Kutch, India. *Geoheritage*. 11(4): 1475-1488. <https://doi.org/10.1007/s12371-019-00362-5>
- Tavares AO, Henriques MH, Domingos A, Bala A (2015). Community involvement in geoconservation: a conceptual approach based on the geoheritage of South Angola. *Sustainability*. 7(5): 4893-4918. <https://doi.org/10.3390/su7054893>
- Tomić N, Marković SB, Antić A, Tešić D (2020). Exploring the potential for geotour-

ism development in the Danube region of Serbia. *International Journal of Geoheritage and Parks*. 8(2): 123-139. <https://doi.org/10.1016/j.ijgeop.2020.05.001>

Tran DA, Goeppert N, Palmer AN, Goldscheider N (2022). Development and structure of karstification of the Dong Van Karst Plateau UNESCO Global Geopark, North Vietnam based on cave survey data. *International Journal of Earth Sciences*. 111(5): 1573-1592. <https://doi.org/10.1007/s00531-022-02190-5>