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PENILAIAN GEOSIT DANAU RAKIHAN MENGGUNAKAN MODEL PENILAIAN GEOSIT YANG DIMODIFIKASI DAN RISET TINDAKAN PARTISIPATIF

ASSESSMENT OF THE RAKIHAN LAKE GEOSITE USING MODIFIED GEOSITE ASSESSMENT MODEL AND THE PARTICIPATORY ACTION RESEARCH

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Abstrak

Danau Rakihan yang terletak di Kabupaten Ogan Komering Ulu Selatan, Provinsi Sumatra Selatan, memiliki potensi sebagai geosite yang dapat dikembangkan dalam konteks geowisata. Penelitian ini bertujuan untuk menilai kondisi dan tingkat kelayakan Danau Rakihan sebagai geosite menggunakan pendekatan kuantitatif *Modified Geosite Assessment Model* (M-GAM) sebagai metode utama, yang diverifikasi melalui pendekatan kualitatif *Participatory Action Research* (PAR) sebagai metode pendukung. Hasil penilaian M-GAM menunjukkan bahwa Danau Rakihan berada pada matriks Z21 dengan nilai total sebesar 4,97 (*Main Value*) dan 4,24 (*Additional Value*), yang termasuk dalam kategori rendah. Temuan kuantitatif tersebut selanjutnya diverifikasi melalui metode PAR, yang menunjukkan adanya kesesuaian antara hasil M-GAM dengan keluhan masyarakat dan pengelola terkait kondisi geosite. Hasil pengkodean wawancara informan mengungkapkan bahwa aspek perlindungan, fungsionalitas, dan fasilitas merupakan prioritas utama yang perlu diperhatikan apabila dilakukan pengembangan geowisata di Danau Rakihan. Validitas temuan kualitatif diperkuat oleh hasil observasi lapangan peneliti, yang membuktikan kesesuaian antara pernyataan responden dan informan dengan kondisi aktual di lapangan melalui dokumentasi foto dan wawancara. Integrasi metode M-GAM dan PAR menunjukkan konsistensi antara hasil kuantitatif dan kualitatif, serta menegaskan bahwa rendahnya nilai M-GAM merepresentasikan kondisi aktual geosite yang masih memerlukan perbaikan mendasar sebelum dikembangkan sebagai kawasan geowisata.

Kata kunci: Danau Rakihan, Konservasi Lokal, *Modified Geosite Assessment Model*, *Participatory Action Research*, Sumatra Selatan

Abstract

Lake Rakihan, located in South Ogan Komering Ulu Regency, South Sumatra Province, has the potential to be developed as a geosite in the context of geotourism. This study aims to assess the condition and feasibility of Lake Rakihan as a geosite using the Modified Geosite Assessment Model (M-GAM) quantitative approach as the main method, verified through the Participatory Action Research (PAR) qualitative approach as a supporting method. The M-GAM assessment results show that Lake Rakihan is in the Z21 matrix with a total score of 4.97 (Main Value) and 4.24 (Additional Value), which is classified as low. These quantitative findings were further verified through the PAR method, which showed consistency between the M-GAM results and the complaints of the community and managers regarding the condition of the geosite. The results of coding the informant interviews revealed that the aspects of protection, functionality, and facilities are the main priorities that need to be considered when developing geotourism at Lake Rakihan. The validity of the qualitative findings was reinforced by the results of the researchers' field observations, which proved the consistency between the statements of the respondents and informants and the actual conditions in the field through photo documentation and interviews. The integration of the M-GAM and PAR methods shows consistency between quantitative and qualitative results and confirms that the low M-GAM score represents the actual condition of the geosite, which still requires fundamental improvements before it can be developed as a geotourism area.

Keywords: Lake Rakihan, Local Conservation, Modified Geosite Assessment Model, Participatory Action Research, South Sumatra

I. INTRODUCTION

Lake Rakihan is located in Ulu Danau Village, South OKU Regency, South Sumatra Province. Geographically, Lake Rakihan is located at coordinates 4°27'00.49"S 103°33'57.10"E (Figure 1), Lake Rakihan is the second largest lake in South Sumatra [1]. Based on Geological Map of Lake Rakihan 1:3.600 (Figure 2) [2], Lake Rakihan was formed during the Quaternary period. Lake Rakihan is part of an ancient volcano that has an Andesite-Basalt Volcanic Unit (Qv) Formation with tuff, lapilli, breccia, andesite, and scoria lithology.

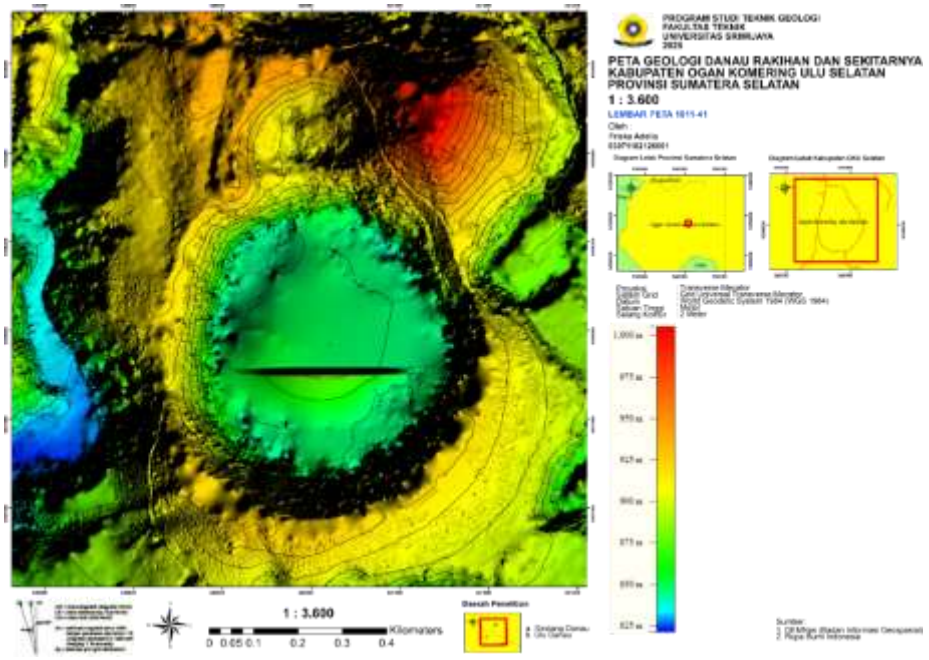

Figure 1. Digital elevation model map of Lake Rakihan

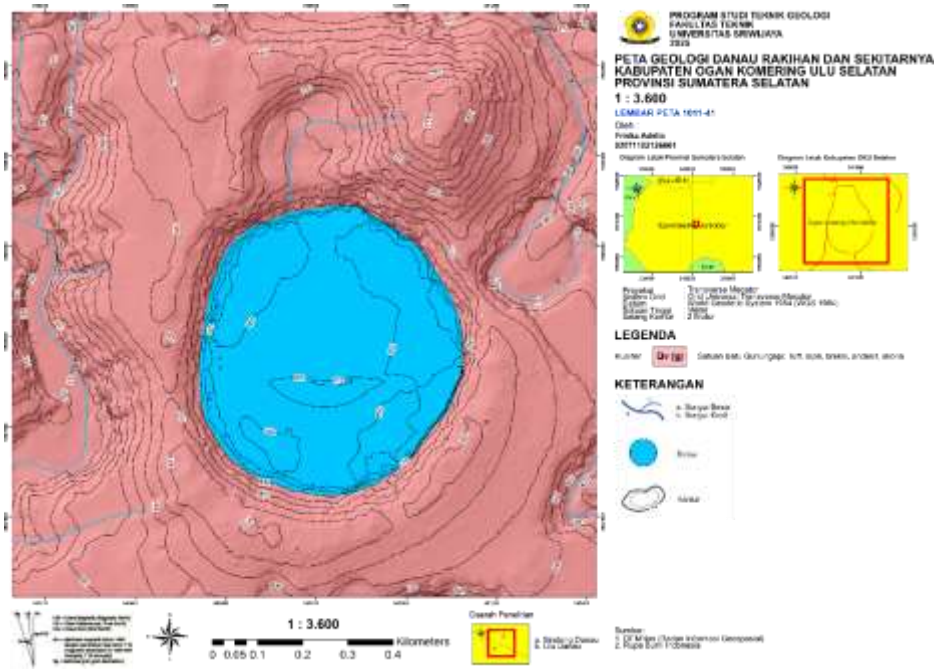

Figure 2. Geological map of Lake Rakihan

Lake Rakihan has great potential to be designated as a geoheritage site due to its educational, aesthetic, economic, conservation, and cultural value (Figure 3). If these values can be fulfilled, a geosite can be

designated as geoheritage, in accordance with the concept of geoheritage, which is geological diversity (geodiversity), biological diversity (biodiversity), and cultural diversity [3].

Figure 3. Panoramic view of Lake Rakihan from the viewpoint

In developing geosites, there are several challenges that must be addressed, namely:

a) Weak government and institutions: this is a major challenge because it results in weak management structures, inconsistent management standards, and a lack of formal institutional support to ensure the continuity of geosite development in terms of conservation, education, and tourism [4].
b) Infrastructure and accessibility: the absence or inadequacy of infrastructure and accessibility will hinder the development of a geosite because it will be difficult to visit [5].
c) Limited human resource capacity in understanding geosites: the lack of knowledge and understanding among the community is one of the challenges in developing geosites, as the community will be the main actors in conservation and education, which will ultimately boost their economy through geopark-based tourism activities [6].
d) Conservation challenges and environmental change: several studies show that without proper conservation management, a geosite can be threatened by environmental change and human activity [7].
e) Economic challenges and optimization of local economic benefits: The availability of sustainable funding for facility development, conservation, and promotion of geosites is a major challenge. Dependence on government budgets without an inclusive financing strategy will hinder the progress of geosites as tourist destinations [4]. Although the economic potential of geosites is quite high, the inability to effectively monetize geotourism potential can prevent the community from immediately feeling the benefits, which can lead to a decline in social support [8].

One effective method to determine the responsibilities, principles, and functions of the government, local authorities, managers, and the community in the management of conservation areas is collaborative management [9]. The government is very important in continuing the development of geosites because the Minister of Energy and Mineral Resources (ESDM) handles the management of geological sites [10]. However, local governments have not yet succeeded in establishing an effective mechanism for managing geological sites. Managers and local communities expect local governments to follow up on the division of authority, roles, and functions between local governments and managers so that geosite development can be continued by the central government, which can then improve the socio-economic welfare of the local area without conflict.

The purpose and contribution of this research to regional development is to preserve Lake Rakihan as a geotourism destination. In this study, the author used two methods, quantitative and qualitative. The quantitative method used was the Modified Geosite Assessment Model (M-GAM) method, which was first introduced by Vujičić et al. (2011) [11] then modified by Tomić & Božić (2014) [12] and remains the standard in geosite modification research, which has proven effective to date, as applied by Pál & Albert (2021) [13]. By combining these two methods, the imbalance of perspectives between researchers and the community will be minimized, so that the community can express their opinions regarding the significance of each problem they face with the M-

GAM indicator [14]. The concept of developing the Rakihan Lake geosite adopts the three-pillar framework used in geopark development in accordance with Presidential Regulation No. 9 of 2019, which states that the management of geopark development is carried out between the central government, local government, and stakeholders through three pillars, namely conservation, education, and sustainable economy. This orientation focuses on meeting the social and economic needs of local communities while still striving to protect the landscape as a place for developing local cultural identity [15].

Furthermore, in qualitative research, the author uses the Participatory Action Research (PAR), a collaborative methodology that integrates research, education, and action for change with the aim of collaboration, empowerment, and concrete action to address social transformation [16]. By using PAR, communities are taught to think critically about the social issues they face and to strengthen and bridge the gaps between local wisdom and scientific knowledge. Academics or researchers act as facilitators who help the community analyze problems and plan actions. This creates equal collaboration, where scientific data is combined with the experience and traditional knowledge of the community [17]. Through PAR, it is hoped that an autonomous governance system will be formed that provides positive benefits for all stakeholders [9] and can change the situation, increase knowledge, and improve the community's ability to understand and improve the conditions they face [18].

This study aims to obtain the results of the M-GAM quantitative method assessment, which is then verified through the PAR qualitative approach. In this study, the application of PAR is limited to the initial stage without implementation of action, so that it functions as supporting data and a verification instrument to ensure that the M-GAM values produced are valid and represent actual field conditions, as well as a basis for evaluation for further research development.

II. LITERATURE REVIEW

A. Formation Process of Lake Rakihan

Lake Rakihan is interpreted to have been formed by a volcanic eruption [19], which was explosive in nature, ejecting pyroclastic material onto the earth surface in the form of boulders. Later, when volcanic activity ceased, a crater lake was formed. Because crater lakes are formed by explosive eruptions that destroy the summit of a volcano, creating a depression that becomes impermeable (waterproof), it is then filled with alkaline rainwater. There are several unique geological features, such as rock formations, lakes, waterfalls, hot springs, and springs, which are the main attractions for tourists seeking educational and adventurous experiences.

B. Tourism Development Concept

Geotourism development is understood as a conceptual and applied approach that aims to utilize the potential of a region's geological resources as tourist attractions while upholding the principles of sustainability. Unlike conventional nature tourism, geotourism places geological heritage (geoheritage) and geological diversity (geodiversity) as key elements in the formation of tourist attractions, rather than merely as complementary elements. In literature, geotourism is defined as a type of tourism activity that focuses on geological and landscape aspects with the aim of supporting the development of sustainable tourism through increasing understanding of geological processes and the relationship between abiotic, biotic, and local cultural elements. This approach enables the development of tourism that is integrative and comprehensive, as it not only emphasizes visual appeal but also prioritizes scientific and interpretive values related to the geological history and landscape dynamics of an area [20].

The concept of geotourism development also emphasizes the importance of interaction between environmental, cultural, and economic components so that geotourism destinations are not only visually appealing but also provide educational experiences that enrich visitors' knowledge, while promoting local economic growth through responsible tourism activities. This concept aligns with the sustainable tourism development approach, where environmental conservation is an important part of livelihoods and its benefits are enjoyed by the local community without damaging or depleting the natural resources that are the main attractions of tourism [21]. This is in line with what is being developed at the Lake Rakihan geosite. The Lake Rakihan geosite is one of the assets in South Sumatra, but it faces several problems, such as limited knowledge among the local community, a lack of attention to infrastructure and accessibility, and a lack of government emphasis on the development of this geosite, all of which can hinder the development of a geosite. The following is an explanation of the assessment of tourist attractions

referring to the six variables of the geotourism box concept (Figure 4) [22]:

a) Observable geological or geomorphological processes and activities.
b) Existing landforms, landscapes, earth surfaces, and rock outcrops.
c) Tourism, this element is an important variable in increasing tourist visits and their management.
d) Geobasic, basic science and earth science are fundamental to understanding the forms and processes of geological events.
e) Geohistory, an explanation of the geological history of a destination area.
f) Geo +, becomes a supporting factor for geotourism activities from legends, history and culture, society, as well as flora and fauna at a geological site.

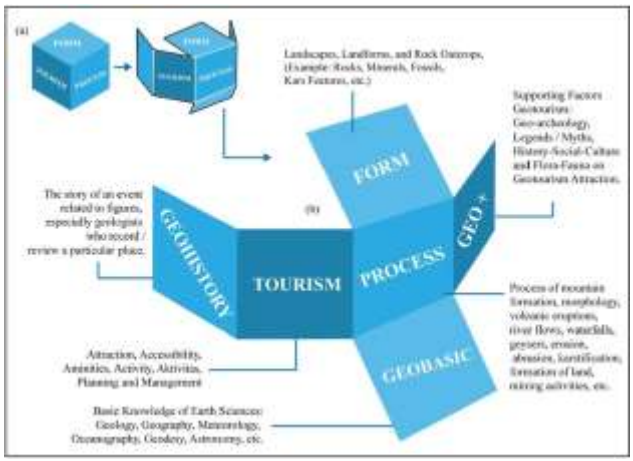

Figure 4. Geotourism box concept

C. Principles of geotourism

The principles of geotourism are the conceptual basis for the development of geology-based tourism, which emphasizes a balance between the utilization of geological resources, conservation, education, and the empowerment of local communities. The following are principles that must be considered when developing geotourism [21]-[23]:

1) Geologically based
2) Sustainable
3) Geologically informative
4) Locally beneficial
5) Tourist satisfaction

III. RESEARCH METHOD

A. Modified Geosite Assessment Model (M-GAM)

The Modified Geosite Assessment Model (M-GAM) method is a tool used in this study as an assessment model that produces more accurate and realistic assessment results regarding the geotourism potential of a geosite by considering market demand and visitor experience [12], with the aim of incorporating tourists' opinions on the importance of indicators in the assessment process, which previously only reflected the experts' point of view, known as the Geosite Assessment Model (GAM) [11]. M-GAM maintains the basic structure of GAM, which consists of two main indicators, namely Main Value (MV) and Additional Value (AV), which are divided into 12 and 15 sub-indicators (Table 1), the Main Values (MV) is divided into three sub-indicators, namely Scientific/Educational Values (VSE), Scenic/Aesthetic Values (VSA), and Protection Values (VPr). Furthermore, in the second component the Additional Values (AV) is divided into two sub-indicators, namely Functional Values (VFn) and Touristic Values (VTr). The application of M-GAM in the study area shows that limitations in supporting facilities, such as damaged roads, inadequate sanitation facilities, lack of places of worship and lodging, and a lack of restaurants, have a significant impact on functional and tourism values. In addition, protection aspects are still dominated by local governments, while public understanding of the scientific value of geosites remains limited. Thus, the scope of M-GAM in this study focuses on assessing the existing conditions of geosites, while its limitations lie in the suboptimal facilities, participatory management, and level of geoscience literacy among the community, which affect the overall assessment results.

Table 1. The structure of Modified Geosite Assessment Model (M-GAM)

No.	Indicators/Sub Indicators (SI)	Description
Main Values (MV)		
	Scientific/Educational Values (VSE)	
1	Rarity ($SIMV_1$)	Number of closest identical sites
2	Representative ($SIMV_2$)	Didactic and exemplary charateristics of the site due to its own quality and general configuration

No.	Indicators/Sub Indicators (SI)	Description
Main Values (*MV*)		
	Scientific/Educational Values (*VSE*)	
3	Knowledge on geoscientific issues ($SIMV_3$)	Number of written papers in acknowledge journals, thesis, presentations, and other publications
4	Level of interpretation ($SIMV_4$)	Level of interpretative possibilities on geological and geomorphologic processes, phenomenon and shapes and level of scientific knowledge
	Scenic/Aesthetic Values (*VSA*)	
5	Viewpoints ($SIMV_5$)	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
6	Surface ($SIMV_6$)	Whole surface of the site, each site is considered in quantitative relation to the other sites
7	Surrounding landscape and nature ($SIMV_7$)	Panoramic view quality, presence of water and vegetation, absence of human induced deterioration, vicinity of urban area, etc.
8	Environmental fitting of sites ($SIMV_8$)	Level of contrast to the nature, contrast of colors, appearance of shapes, etc.
	Protection Values (*VPr*)	
9	Current condition ($SIMV_9$)	Current state of geosite
10	Protection level ($SIMV_{10}$)	Protection by local or regional groups, national government, international organizations, etc.
11	Vulnerability ($SIMV_{11}$)	Vulnerability level of geosite
12	Suitable number of visitors ($SIMV_{12}$)	Proposed number of visitors on the site at the same time, according to surface area, vulnerability, and current state of geosite
Additional Values (*AV*)		
	Functional Values (*VFn*)	
13	Accessibility ($SIAV_1$)	Possibilities of approaching to the site
14	Additional natural values ($SIAV_2$)	Number of additional natural values in the radius of 5 km
15	Anthropogenic values ($SIAV_3$)	Number of additional anthropogenic values in the radius of 5 km
16	Vicinity of emissive centers ($SIAV_4$)	Closeness of emissive centers
17	Vicinity of important road network ($SIAV_5$)	Closeness of important road networks in the radius of 20 km
18	Additional functional values ($SIAV_6$)	Parking lots, gas stations, mechanics, etc.
	Touristic Values (*VTr*)	
19	Promotion ($SIAV_7$)	Level and number of promotional resources
20	Organized visits ($SIAV_8$)	Annual number of organized visits to the geosite
21	Vicinity of visitors' centers ($SIAV_9$)	Closeness of visitor center to the geosite
22	Interpretative panels ($SIAV_{10}$)	Interpretative characteristics of text and graphics, material quality, size, fitting to surroundings, etc.
23	Number of visitors ($SIAV_{11}$)	Annual number of visitors
24	Infrastructure ($SIAV_{12}$)	Level of additional infrastructure for tourist (pedestrian pathways, resting places, garbage cans, toilets, etc.)
25	Tour guide service ($SIAV_{13}$)	If exists, expertise level, knowledge of foreign language, interpretative skills, etc.
26	Hostelry service ($SIAV_{14}$)	Hostelry service close to geosite
27	Restaurant service ($SIAV_{15}$)	Restaurant service close to geosite

Table 2. Weight values of M-GAM

Sub-Indicators	Description				
	0,00	**0,25**	**0,50**	**0,75**	**1,00**
$SIMV_1$	Common	Regional	National	International	The only occurence
$SIMV_2$	None	Low	Moderate	High	Utmost
$SIMV_3$	None	Local publications	Regional publications	High publications	International publications
$SIMV_4$	None	Moderate level of processes but hard to explain to non experts	Good example of processes but hard to explain to non expert	Moderate level of processes but easy to explain to common visitor	Good example of processes and easy to explain to common visitor
$SIMV_5$	None	1	2 to 3	4 to 6	More than 6
$SIMV_6$	Small	-	Medium	-	Large
$SIMV_7$	-	Low	Medium	High	Utmost
$SIMV_8$	Unfitting	-	Neutral	-	Fitting
$SIMV_9$	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
$SIMV_{10}$	None	Local	Regional	National	International
$SIMV_{11}$	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
$SIMV_{12}$	0	0 to 10	10 to 20	20 to 50	More than 50
$SIAV_1$	Inaccessible	Low (on foot with special equipment and expert guide tours)	Medium (by bicycle and other means of manpowered transport)	High (by car)	Utmost (by bus)
$SIAV_2$	None	1	2 to 3	4 to 6	More than 6
$SIAV_3$	None	1	2 to 3	4 to 6	More than 6
$SIAV_4$	More than 100 km	100 to 50 km	50 to 25 km	25 to 5 km	Less than 5 km
$SIAV_5$	None	Local	Regional	National	International
$SIAV_6$	None	Low	Medium	High	Utmost
$SIAV_7$	None	Local	Regional	National	International
$SIAV_8$	None	Less than 12 per year	12 to 24 per year	24 to 48 per year	More than 48 per year
$SIAV_9$	More than 50 km	50 to 20 km	20 to 5 km	5 to 1 km	Less than 1 km
$SIAV_{10}$	None	Low quality	Medium quality	High quality	Utmost quality
$SIAV_{11}$	None	Low (less than 5000)	Medium (5001-10.000)	High (10.001-100.000)	Utmost (more than 100.000)
$SIAV_{12}$	None	Low	Medium	High	Utmost
$SIAV_{13}$	None	Low	Medium	High	Utmost

Sub-Indicators	Description				
	0,00	**0,25**	**0,50**	**0,75**	**1,00**
$SIAV_{14}$	More than 50 km	50-25 km	25-10 km	10-5 km	Less than 5 km
$SIAV_{15}$	More than 25 km	25-10 km	10-5 km	5-1 km	Less than 1 km

The M-GAM method is the most objective because it not only takes into account the opinions of experts but also the views of visitors towards the geosite to consider the needs and interests that affect the value and potential of geotourism destinations. The following are ways to implement the M-GAM method [12]:

a. Questionnaire: a questionnaire is needed to measure perceptions, levels of geo-education knowledge, visitor or resident behavior, and the level of importance of aspects necessary for geosite development. The questionnaire in this study uses a likert scale, which provides quantitative data that can be analyzed statistically. [13].
b. Expert validation: expert validation is intended to ensure that the questionnaire data is appropriate in terms of content and practical for the local context. Expert validation is necessary because it is strategic in nature, as the quality of the data obtained and the reliability of the research inferences depend heavily on validation by experts in the field.

Each M-GAM indicator consists of 27 sub-indicators that will be converted into questions that can be understood by visitors, local governments, and administrators around Lake Rakihan in the form of a questionnaire. In total, there are 12 Main Value (MV) sub-indicators and 15 Additional Value (AV) sub-indicators, which are ranked from 0.00 to 1.00, which can define GAM in a simple equation as follows:

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

In which:
MV = Main Values
AV = Additional values
The two equations can be written as:

$$MV = VSE + VSA + VP_r\,, \quad (2)$$
$$AV = VF_n + VT_r\,, \quad (3)$$

In which:
VSE = Scientific/Educational Values
VSA = Aesthetic/Scenic Values
VP_r = Protection Values
VF_n = Functional Values
VT_r = Touristic Values

Furthermore, the M-GAM method does not only rely on expert opinions, but also provides opportunities for visitors to express their opinions on each sub-indicator in the modeling, which is referred to as the Important Factor (Im). After that, the Important Factor (Im) is multiplied by the value given by the expert and done for each sub-indicator ($SIMV_1$ and $SIAV_1$), Then the modified GAM equation is defined and presented in the following form:

$$M - GAM = Im(GAM) = Im(MV + AV)\,, \quad (4)$$

Next, the research results are entered into the M-GAM matrix. In this process, the values are calculated by inputting all the geosite calculation values. The Additional Value (***AV***) and Main Value (***MV***) are located in the X and Y fields of the M-GAM matrix. In geosite development, this matrix aids in mapping and drawing conclusions (Figure 5). Then, (Table 3) shows that the assessment of Main Value (***MV***) and Additional Value (***AV***) produces the M-GAM value matrix.

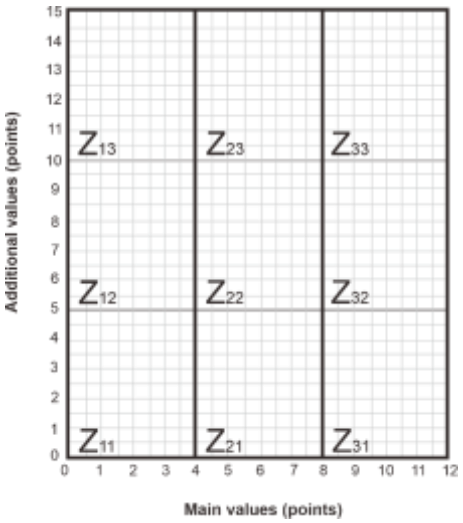

Figure 5. Value matrix of M-GAM

Table 3. Matrix description of M-GAM

Desc.	Main Value	Additional Value
Z11	Low	Low
Z12	Low	Medium
Z13	Low	High

Desc.	Main Value	Additional Value
Z21	Medium	Low
Z22	Medium	Medium
Z23	Medium	High
Z31	High	Low
Z32	High	Medium
Z33	High	High

B. Participatory Action Research (PAR)

Participatory Action Research (PAR) is a qualitative research and social intervention that is cyclical and collaborative in nature. Its purpose is not only to understand problems, but also to create change and sustainability in conservation areas. The following is the PAR cycle [17]:

1. Planning: researchers carry out planning, such as what problems will be faced by involving participants (the community, administrators, and local government).
2. Action: researchers carry out the prepared plan.
3. Observation: researchers review during the course of the action.
4. Reflecting: analyze and evaluate all processes and results of actions that have been taken.

When conducting research using the PAR method, several techniques are needed to ensure the validity and reliability of the data. Here are some techniques that are commonly used:

a. Field observation: Field observation aims to collect primary data on the condition of the geosite, starting from its scientific/educational value, aesthetic value, conservation value, functional value, and touristic value (field conditions, access, signs of damage, etc.).
b. Focus Group Discussion (FGD): FGD is needed to reveal perceptions, local knowledge, problems faced, and geoeducation needs. FGD also helps to find solutions and mutual agreements by discussing in depth the agreements that researchers and participants want to reach [24].
c. Interviews: Interviews are just as important as FGDs. Interviews also help find solutions and mutual agreements by discussing in depth the agreements desired by researchers and informants.

The following are the steps involved in analyzing data using the thematic analysis model [25]:

1) Understanding research data: researchers delve into data by reading transcripts, listening to recordings, or reviewing notes to gain a deep understanding.
2) Coding: systematically encoding data by identifying and labeling responses to questions. This process helps organize information into meaningful groups while ensuring that important details are not overlooked.
3) Finding themes: researchers look at the connections between codes and organize larger groups to represent specific concepts or meanings in the data. This process considers how the codes form meaningful patterns and answer the research questions.
4) Evaluating themes: examining themes that correspond to the codes. Researchers combine, change, or delete themes that are considered to have no clear connection to the research questions.
5) Conclusion: in the final stage, researchers provide an analysis of the themes and link them back to direct quotes from the interview results, connecting them to supporting documents or literature, and explaining how the themes answer the research questions.

In qualitative research, data validity testing can be conducted to examine data validity. Data validity testing includes credibility, transferability, dependability, and confirmability tests [26]. Researchers use data validity testing with credibility tests. The technique used is triangulation. Triangulation in data validity testing can be interpreted as checking data from source triangulation, technique triangulation, and time triangulation [26]. The following are the types of triangulations used by researchers:

A. Source triangulation: to test the validity of the data by examining data from various sources. In this study, the researcher obtained data from primary sources (interviews with informants) and secondary sources (various documents related to the research subject).
B. Technique Triangulation: to test the validity of data by comparing data using different techniques for the same source. Data was collected through interviews and verified through observation and documentation.

In this study, the PAR elements used as supporting methods include:

a) Active participation of the community and managers as co-researchers in qualitative data collection.
b) Identification of problems based on local social experiences and contexts.
c) Collaborative and reflective data analysis through thematic coding of interviews.

d) Data triangulation through interviews, field observations, and documentation to increase the validity of the findings.

This approach is in line with the PAR principle that emphasizes cooperation between researchers and communities in understanding real issues and connecting contextual knowledge with M-GAM quantitative findings.

IV. RESULT AND DISCUSSION

To manage the data from the geotourism potential questionnaire in the research area, a survey was conducted in the form of a questionnaire and field observations in September 2025 on visitors, local government, and geosite managers in the Lake Rakihan area. The questionnaire consisted of 27 questions/sub-indicators, and each respondent was asked to assess the importance of each sub-indicator using a likert scale, consisting of five points with values ranging from 0.00 to 1.00 (0.00 = not important; 0.25 = less important; 0.50 = quite important; 0.75 = important; 1.00 = very important). A total of 40 visitors, 8 local government officials, and 3 administrators filled out the questionnaire. Table 4 shows the calculation of the GAM and M-GAM values. Table 5, Table 6, and Figure 6 show the final assessment results obtained using both versions of the method.

Table 4. Results of the geosite assessment and respondent assessment of Lake Rakihan Geosite by using M-GAM method

No.	Sub-Indicators	Values given by experts	Im	Total
Main Values (MV)				
	Scientific/Educational Values (VSE)			
1	Rarity ($SIMV_1$)	0.50	0.79	0.39
2	Representative ($SIMV_2$)	0.75	0.24	0.18
3	Knowledge on geoscientific issues ($SIMV_3$)	1.00	0.25	0.25
4	Level of interpretation ($SIMV_4$)	0.25	0.33	0.08
	Scenic/Aesthetic Values (VSA)			
5	Viewpoints ($SIMV_5$)	0.75	0.45	0.33
6	Surface ($SIMV_6$)	1.00	0.55	0.55
7	Surrounding landscape and nature ($SIMV_7$)	0.75	0.71	0.53
8	Environmental fitting of sites ($SIMV_8$)	1.00	0.76	0.76
	Protection Values (VPr)			
9	Current condition ($SIMV_9$)	1.00	0.73	0.73
10	Protection level ($SIMV_{10}$)	0.50	0.71	0.35
11	Vulnerability ($SIMV_{11}$)	0.50	0.85	0.42
12	Suitable number of visitors ($SIMV_{12}$)	0.50	0.76	0.38
Additional Values (AV)				
	Functional Values (VFn)			
13	Accessibility ($SIAV_1$)	0.50	0.78	0.39
14	Additional natural values ($SIAV_2$)	0.50	0.25	0.12
15	Anthropogenic values ($SIAV_3$)	1.00	0.78	0.78
16	Vicinity of emissive centers ($SIAV_4$)	0.25	0.75	0.18
17	Vicinity of important road network ($SIAV_5$)	1.00	0.79	0.79
18	Additional functional values ($SIAV_6$)	0.25	0.77	0.19
	Touristic Values (VTr)			
19	Promotion ($SIAV_7$)	0.50	0.80	0.40
20	Organized visits ($SIAV_8$)	0.25	0.79	0.19
21	Vicinity of visitors centers ($SIAV_9$)	0.00	0.75	0.00

No.	Sub-Indicators	Values given by experts	*Im*	Total
22	Interpretative panels ($SIAV_{10}$)	0.00	0.65	0.00
23	Number of visitors ($SIAV_{11}$)	0.25	0.78	0.19
24	Infrastructure ($SIAV_{12}$)	0.25	0.80	0.20
25	Tour guide service ($SIAV_{13}$)	0.25	0.75	0.18
26	Hostelry service ($SIAV_{14}$)	0.00	0.68	0.00
27	Restaurant service ($SIAV_{15}$)	0.75	0.80	0.60

Table 5. Ranking results for Rakihan Lake Geosite using GAM

Label Geosite	Main Values (*MV*)		Additional Values (*AV*)		Matrix
	VSE + VSA + VPr	∑	VFn + VTr	∑	
Danau Rakihan	1,50 + 3,50 + 2,50	7,50	3,50 + 2,25	5,75	Z22

Table 6. Ranking results for Rakihan Lake Geosite using M-GAM

Label Geosite	Main Values (*MV*)		Additional Values (*AV*)		Matrix
	VSE + VSA + VPr	∑	VFn + VTr	∑	
Danau Rakihan	0,90 + 2.18 + 1.89	4.97	2.46 + 1.78	4.24	Z21

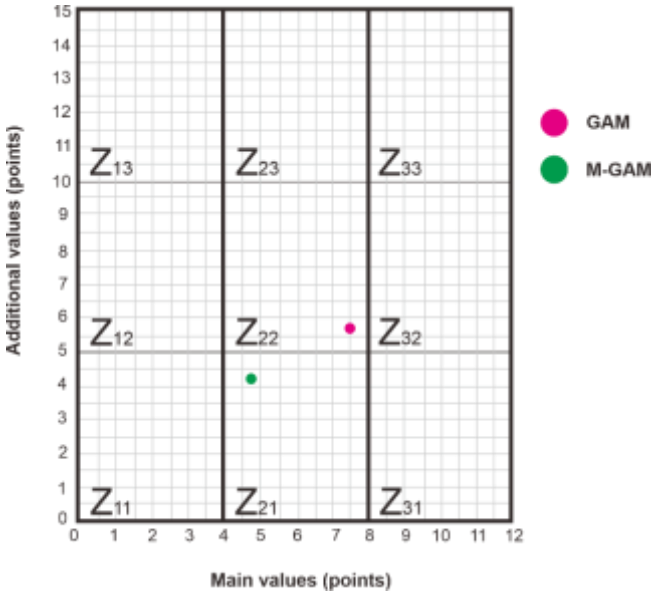

Figure 6. The position of the Rakihan Lake geosite evaluated in the GAM and M-GAM matrix

In the first sub-indicator, Scientific/Educational Value (VSE), it can be seen how the importance ranking of some of these indicators, as determined by tourists, can significantly change the final assessment results. This sub-indicator shows that the value given by experts is significantly greater than the Importance Factor (Im). This indicates a perception gap, where tourists may fail to fully understand the geological aspects. Therefore, there is a need to improve geo-education in the local area to bridge the significant difference in the values assigned.

Next, in the second sub-indicator, namely Scenic/Aesthetic Value (VSA) in the sub-indicators. For example, ($SIMV_7$) is rated by tourists as an Important Factor ($Im = 0.71$) and ($SIMV_8$), is rated by tourists as an Important Factor ($Im = 0.76$) which

means that this sub-indicator plays a significant role in tourists' choice of places to visit. This is also relevant to the value given by experts multiplied by the Importance Factor (Im) assessed by tourists, the results are quite similar, so there is no significant change. However, looking at other sub-indicators in the Scenic/Aesthetic Values (VSA) shows significant differences in $SIMV_5$ and $SIMV_6$. It can be seen how the value given by tourists multiplied by the value given by experts greatly affects the final result.

Furthermore, in the third sub-indicator, namely Protection Values (VPr) this sub-indicator shows harmony between the values given by experts and those given by tourists. However, the high values assigned by experts should not be considered entirely realistic for assessment purposes, as some sub-indicators are of very little significance to tourists and do not really influence their decisions when choosing which geosites to visit. The alignment of values in this sub-indicator indicates that the need for conservation and protection of sites is not only recognized technically by experts, but is also considered equally important by users (stakeholders) through a participatory process [9]. This means that action strategies and site management must prioritize conservation area efforts supported by local managers to ensure the sustainability of geological site protection.

In Additional Values (AV) has two sub-indicators, namely Functional Values (VFn) and Touristic Values (VTr). Functional Values (VFn) has several assessment gaps, for example $SIAV_2, SIAV_4, SIAV_6$ between the values given by experts and those given by tourists, which can affect the final multiplication result. However, not all Functional Values (VFn) are equally important to tourists.

Furthermore, Touristic Values (VTr), shows that the values assigned by experts and tourists have a significant impact. This is additional evidence that we cannot rely solely on the opinions of experts, who represent just one segment of tourists visiting attractions. Ignoring other segments and their opinions results in a GAM that is neither objective nor accurate compared to the modified version (M-GAM).

To draw conclusions about geosite development, the final research results were then entered into a modified geosite assessment model matrix. From the data obtained, it was found that the process of assigning a total score to the Rakihan Lake geosite in the M-GAM matrix is at Z21 (Figure 6). According to the M-GAM assessment and the results of the PAR taken by experts and tourists, the Rakihan Lake geosite still has a significant lack of geological information, inadequate infrastructure, limited accessibility (only accessible by motorbike), minimal parking space which limits the number of visitors, and a lack of facilities such as an information center, interpretive panels, and no accommodation. The geosite admnistrator also explained that he wants the local government to follow up on the development of this geosite in any way possible (promotion, visitor comfort facilities, funding, etc.).

The results of the GAM and M-GAM assessments are presented in the form of visualizations of geosite zoning and development potential (Figure 7 and Figure 8). Based on the graphs and matrix, Protection Values (VPr has the highest percentage, but there is still a need to improve facilities such as additional functional facilities (fuel stations, etc.). The lowest value from the GAM and M-GAM assessments is the Scientific/Educational Value (VSE), Looking at Table 6, the values given by tourists and experts are not consistent. The scores given by tourists tend to be lower than those given by experts ($SIMV_2$, $SIMV_3$, dan $SIMV_4$). This proves that the Scientific/Educational Value (VSE) needs to be prioritized in the development of this geosite, followed by other values.

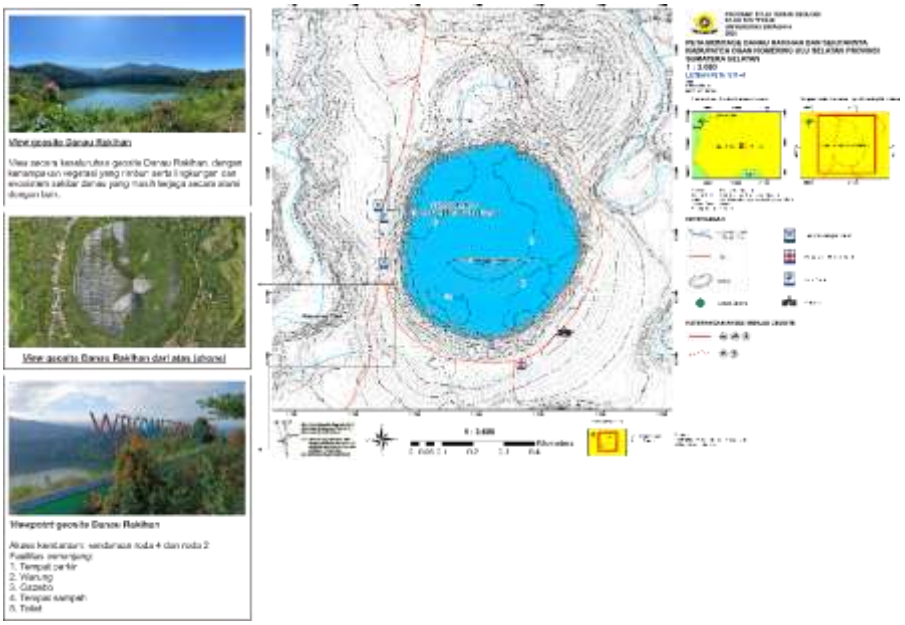

Figure 7. Visualization of Rakihan Lake Geosite with montage map

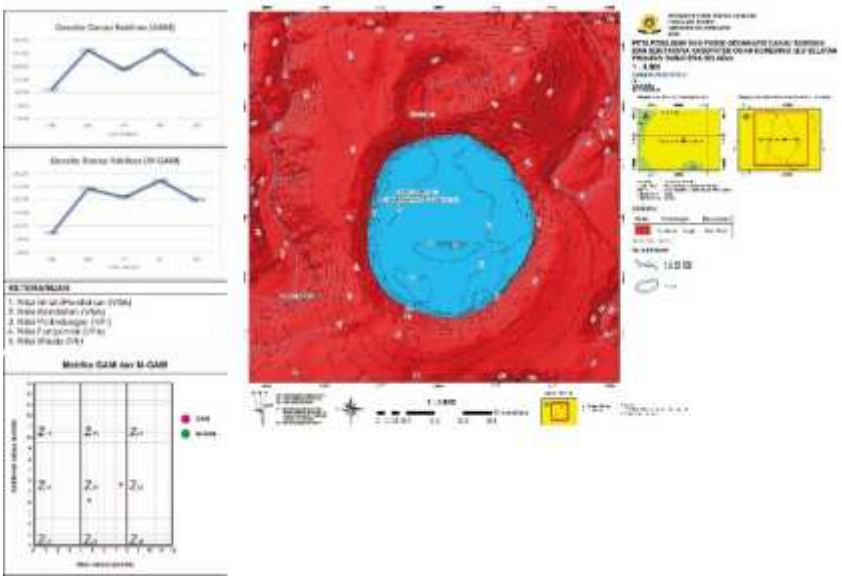

Figure 8. Assessment Map and Geographic Position of Lake Rakihan

The following are the characteristics of the informants in this study (Table 7), consisting of six people, including two local government officials, two managers, and two visitors to the Lake Rakihan geosite. The characteristics shown include name, age, gender, and occupation. Names are used as identifiers, age and gender provide demographic information, and occupation provides context for each informant's background.

Table 7. Informant characteristics

Name	Age	Gender	Position
Arexa	26-30	Male	Administrator
Bobi Sastra	36-40	Male	Visitor
Elon	>40	Male	Administrator
Rima Raiu Lailfa	15-20	Female	Visitor
Syahriasi Rajri	>40	Male	Local Government
Zita Datul Aini	21-25	Female	Local Government

Data collection was conducted over a period of approximately one month to answer the research questions and focus. Through interviews, observations, and secondary data searches, various data were collected to support the answers to the questions that had been formulated. The data were

processed using a thematic analysis approach to the interview results from six informants. The Code column is the result of grouping data coded based on themes, topics, ideas, or concepts relevant to the research focus. Then, the N column shows the number of findings identified from the interview transcripts. The Category column represents the sub-indicators of this study, which further detail the main indicators. The Theme column includes the main indicators that are the focus of the research and the main dimensions of analysis in the data interpretation process: innovation, communication channels, time, social systems, and barriers. The data presented is formulated based on the themes and categories obtained from the informants' answers and related to the findings of observations and supporting documents (Table 8).

Table 8. Coding of informant interview results

Theme	Category	Code	N
Protection	Current situation	Very good	5
		Preserving culture	5
		Maintaining compatibility	5
	Authority role	Government	14
		Society	2
		Admnistrator	2
	Protection efforts	Do not litter	1
		Build community	2
Functional	Accessibility	Accessible only by motorcycle and on foot	2
		Roads around the geosite	5
	Additional functionality	Lack of parking spaces	13
Facilities	Accommodation	Providing accommodation	4
	Infrastructure	Place of worship	1
		Gazebo	1
		Toilet	1
		Lack of viewpoints	6
		Boat	1
	Services	Improved	13
		Restaurant	6
		Tour guide	4
		Information center	2
		Interpretive panel	5
		Promotion	4

In developing PAR-based geosites, the focus should be on collaboration between researchers, local communities, local governments, and managers to bring about real change, such as improvements in conservation, geo-education, facilities, and sustainable management strategies.

Several issues have been identified after processing PAR data using interview results. Issues at a geosite involve researchers and stakeholders. This is felt by stakeholders and seen directly by researchers, as stated by Mr. Elon, the administrator of Lake Rakihan, who said:

> "I also hope that a gazebo can be built near the lake, not just the one above it. Some of the roads are damaged, the toilets need roof repairs, and there is no prayer room or mosque at all. That's why I want to build these things, but again, there is no funding [...]." (Interview on Tuesday, October 21, 2025).

This shows that some complaints were directly felt by the administrator and confirmed in the field by researchers. Not only the facilities, but also the functional value of the geosite was lacking.

> "Parking space for cars is still limited, although there should be enough space underneath because there is enough space for motorcycles. However, it gets quite full-on big days. Actually, there is a lot of empty land that could be used as parking space for cars, but there is no funding to improve the land [...]." (Interview on Tuesday, October 21, 2025).

Then, Mr. Arexa, the administrator of Lake Rakihan felt the same way.

> "It is very important for parking lots. At some tourist attractions that I manage, the only way to reach the tourist attraction is by motorcycle or on foot." (Interview on Tuesday, October 7, 2025).

Not only felt by the administrators of Lake Rakihan, but also felt by Rima Raiu Lailfa as a visitor to Lake Rakihan.

> "But as far as I know, the ducks (boats) can no longer be used [...]." (Interview on Sunday, September 21, 2025).

The following are some examples of complaints received from administrators and visitors (Figure 9).

Researchers sought to observe firsthand any evidence in the field that was lacking in terms of the aspects needed to develop a geosite. This greatly affects the appeal of a geosite if it has several shortcomings in terms of value. Lake Rakihan is still well preserved in terms of its environment, but this protection must continue in order to preserve and promote the existing geological heritage.

Figure 9. The condition of the parking lot near the Rakihan Lake geosite (a), the condition of the parking lot near the Rakihan Lake geosite viewpoint (b), the condition of the toilets (c), the condition of unusable boats and the absence of a place of worship near the Rakihan Lake geosite (d)

Referring to the data obtained through interviews and observations above; the researchers reprocessed and presented the results as follows (Figure 10):

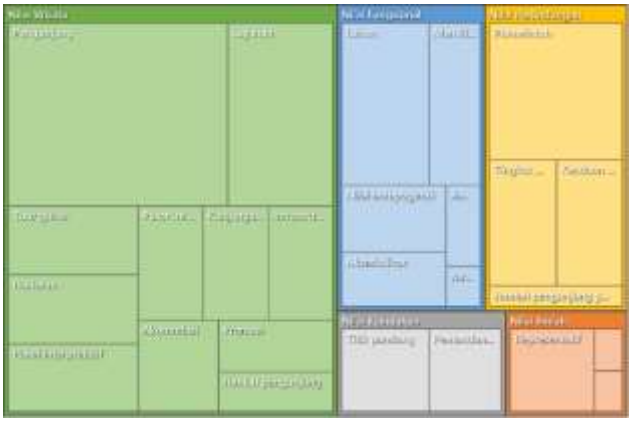

Figure 10. Hierarchy Chart Tree Map Model related to keywords

Based on the Hierarchy Chart Tree Map Model analysis (Figure 10), the most frequently mentioned theme in interviews regarding the development potential of Lake Rakihan geosite was dominated by Tourism Value, followed by Functional Value, Protection Value, Scenic/Aesthetic Value, and Scientific Value. Tourism Value includes discussions in the following order: visitors, services, tour guides, restaurants, interpretive panels, information centers, organized visits, infrastructure, accommodation, promotion, and number of visitors. The community needs and prioritizes these discussions, as evidenced by researchers who conducted direct field observations in Ulu Danau Village, South OKU Regency, South Sumatra, which proved that there are still many shortcomings in Lake Rakihan geotourism, as seen from several values such as ($SIAV_9$), ($SIAV_{10}$), dan ($SIAV_{14}$) (Table 4), that such a service does not exist. The interview was supported by a questionnaire filled out by the community, which was then processed using the M-GAM method, showing that the community does need such a service. The following is a summary made in a mind map of several obstacles experienced by informants obtained from the interview (Figure 11).

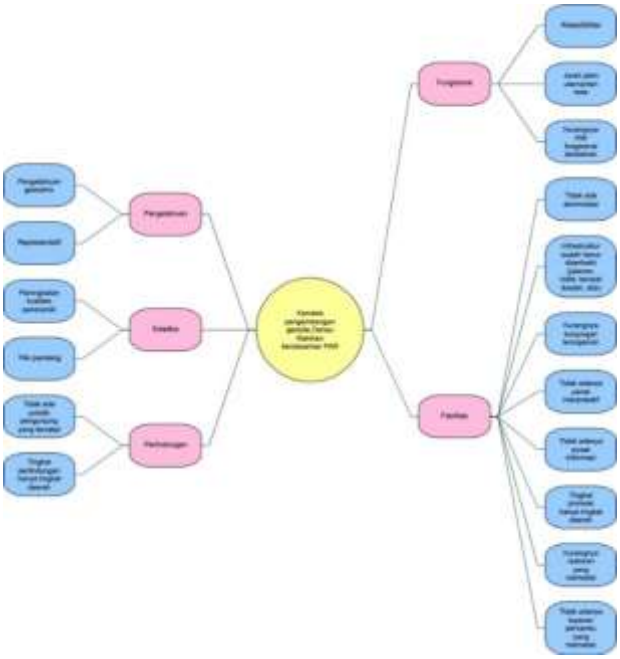

Figure 11. Mind Map of obstacles in the development of the Rakihan Lake geosite

The image above illustrates the obstacles directly experienced by the informants. In terms of knowledge, they feel a lack of geoscience knowledge because they are more familiar with their cultural values. In terms of aesthetics, they feel the need to improve the quality of the panoramic view, such as the completeness of objects, clear contrast, sharpness, and viewpoint. In terms of protection, there is no record of the number of visitors and the level of protection is only at the regional level. In terms of functionality, there is a lack of accessibility, the distance to the main road or city still needs to be considered, and there is a lack of additional functional value. Finally, in terms of facilities, they feel that there are shortcomings in several areas, such as the lack of accommodation, the need to improve infrastructure, the lack of organized visits, the absence of interpretive panels, the lack of an information center, the fact that promotion is only at the regional level, the lack of adequate restaurants, and the absence of adequate guide services. The negative impact of halting the development of a geosite has serious consequences, such as physical degradation and the risk of permanent loss of these assets, social conflicts (community losses or land conflicts), and safety risks. Researchers have an important role in overseeing geological education for the community by informing them about their geological heritage. From an aesthetic perspective, Lake Rakihan only has one viewpoint, which will have an impact when there are large numbers of visitors and the geotourism site's capacity is inadequate, as stated by Mr. Arexa, the administrator of Lake Rakihan geotourism:

> "Every Sunday and on public holidays, visitors flock to Lake Rakihan tourist spot [...]." (Interview on Tuesday, October 7, 2025).

Furthermore, in terms of protection (Protection Value), Rakihan Lake geotourism does not count the number of visitors each year, and the level of protection is still at the regional level, which will trigger undesirable things for visitors. Due to the lack of firm action to follow up on this, some people still litter (Figure 12). However, Mr. Arexa, as the admnistrator, emphasized that undesirable things should not happen, such as:

> "Do not litter, do not pick plants or cut down trees in tourist areas, and maintain good manners and respect local customs and culture." (Interview on Tuesday, October 7, 2025).

Figure 12. Evidence of littering

Furthermore, in terms of functionality (Functional Value), there are several complaints such as poor accessibility, the distance from the main road to the geotourism site is still inadequate, and a lack of security such as the absence of fences to protect visitors (Figure 13). and the functional value is still lacking, such as a fuel station, parking area, repair shop, and so on (Figures 9a and 9b).

Figure 13. The safety level of Lake Rakihan geotourism

Success in PAR is not only measured by the completion of field research and obtaining interview results, but researchers must also act as a bridge between the community or managers and local or central government to follow up on the development of a geosite. To develop a geosite using PAR, researchers must involve the local community as co-researchers in the development of this geosite, so that they have a sense of ownership and responsibility for its preservation and development. After conducting a PAR analysis, a summary of the challenges and solutions regarding the development of the Lake Rakihan geosite was obtained (Table 9).

Table 9. Results of the analysis of challenges and handling of the development of the Rakihan Lake geosite

Challenges	Solutions
Low public awareness of the concept of geosites	Participatory education and outreach, involving junior high and high school students, communities such as youth organizations, and geosite managers
Lack of human resources	Local human resources training was established to become geotourism guides, geotourism conservation services, and to create official institutions specifically for geoheritage conservation
Limited infrastructure and accessibility	Developing plans for access strategies, routes, necessary facilities (in accordance with the geosite development concept and the constraints they face), and environmental impact control
Risks of environmental degradation, overexploitation	Use conservation principles, visitation limits, visitor education (through guides and interpretative panels), environmental monitoring, and geosite surveillance systems
Dependence on external parties (government or foreign entities)	In addition to building knowledge within the community, foster community independence, establish local governance, and diversify the local economy (tourism, education, and research) to bring direct benefits to the community

Compared to similar lake geosites in Indonesia, Lake Rakihan is very similar to Lake Kelimutu, located in Ende Regency, Flores Island, East Nusa Tenggara Province. Based on a review of scientific literature, the comparison between Lake Rakihan and Lake Kelimutu in the northeast of the Sukaria Caldera shows that both are volcanic lakes formed by the explosive eruption of Mount Kelimutu. From northwest to southeast, they are Acidic Crater Lake (TAM), Active Hydrothermal Crater Lake (TIN), and Acidic Volcanic Crater Lake (TAP). [27]. Similarly, based on geomorphological map analysis, Lake Rakihan has volcanic landforms in the form of Cinder Cone, Nester Crater I, and Nested Crater II. Lake Kelimutu and Lake Rakihan are significant because they contain scientific records, geological formations, and specific landscapes that provide evidence of geological events in the past [28].

The Rakihan Lake geosite has excellent geo-educational resource potential for physical geography learning. Students can conduct research using several tools commonly used for mapping, such as GPS, compasses, Google Earth, geospatial applications, and drones. Students can study the geosite directly or in the classroom. This interactive visualization can make learning more interesting and motivate students to become more involved in understanding the concepts of geography [29]. Students can understand the diversity of geological features such as igneous and pyroclastic rocks, geological structures, landscapes, and volcanic processes that can serve as natural laboratories for studying lithospheric materials. Field learning using geosites can enhance understanding of Earth dynamics, rock formation processes, and landscape changes in spatial and temporal contexts. However, several challenges must be overcome to optimize the implementation of geoeducation, such as a lack of educational facilities, adequate training for teachers, accessibility issues, and the inadequate integration of geoeducation content into the formal curriculum [30].

V. CLOSURE

A. Conclusion

The results of the assessment using the Modified Geosite Assessment Model (M-GAM) method show that the research location is in zone Z21 with a total score of 4.97 and 4.24, which is classified as low. These low scores are reinforced by the finding that several M-GAM sub-indicators received a score of zero, which was given based on the researchers' assessment and confirmed through field observations. In addition, the assessment of all Touristic Value (VTr) sub-indicators showed a very small contribution compared to other value groups, indicating the weakness of the tourism aspect at the research site. These quantitative findings were further verified through a qualitative Participatory Action Research (PAR) approach, which showed consistency between the M-GAM results and the complaints of the community and managers regarding the protection, functionality, and facilities of the geosite. The results of coding the informant interviews in PAR confirmed that the aspects of protection, functionality, and facilities are the main priorities that need to be considered when developing geotourism. The validity of these qualitative findings was reinforced by the results of the researcher's observations, which showed consistency between the statements of respondents and informants and the actual conditions in the field, as evidenced by photo documentation and interview results. Thus, the integration of the M-GAM and PAR methods shows consistency between the quantitative assessment results and qualitative findings, and confirms that the low M-GAM score reflects the actual conditions of the geosite, which still requires serious attention in terms of protection and management for the sustainable development of the Lake Rakihan geotourism area.

B. Recommendation

The development of the Rakihan Lake geosite needs to be supported by the local and central governments. The solution is to maintain consistency among all parties, conduct intensive socialization and focus group discussions, and support geo-education activities so that the development of the Rakihan Lake geosite can proceed based on scientific knowledge and local culture, and provide optimal benefits for all parties involved.

The Rakihan Lake Geosite is capable of creating prosperity for both the communities surrounding Rakihan Lake and the managers of Rakihan Lake or the local government itself, as well as actively involving the community in the development of the Rakihan Lake geological site, thereby enabling the achievement of the principles of sustainable geopark development, namely the three pillars of conservation, education, and sustainable economy.

Based on the overall research results with the aim of continuing the development of the Rakihan Lake geosite, it is recommended to develop a participatory geo-education module involving local communities, educational institutions, and geosite managers as a means of increasing earth literacy and awareness of the importance of geosite preservation. This module can be developed using an experiential learning approach in the field to foster a deep understanding of geological processes and conservation values. In addition, community-based conservation policies need to be implemented that place the community as the main actor in the sustainable management and protection of geological resources. This policy is expected to encourage active community participation in preserving geosites while providing economic benefits through the development of sustainable geotourism. A collaborative approach between the government, academics, and managers is key to the successful implementation of these recommendations in achieving a balance between educational, conservation, and productive aspects in geosite areas.

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