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Geosite Potential Assessment Using the Modified Geosite Assessment Method (M-GAM) in North Musi Rawas Regency

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ABSTRACT

This study assesses the geosite potential of two emerging geotourism locations Rayo Lake and Sosokan Waterfall in North Musi Rawas Regency using the Modified Geosite Assessment Method (M-GAM). The research aims to address the limited empirical application of M-GAM in developing geotourism regions of Indonesia, thereby filling an important methodological and regional gap. The assessment incorporates expert and visitor perceptions to evaluate Main Values (MV) and Additional Values (AV) across geological, educational, and touristic criteria. Field surveys and questionnaire-based evaluations were conducted with 22 experts and 55 visitors. The results show that Rayo Lake attained a high MV score and a moderate AV score, placing it in quadrant Z33, indicating strong geological significance supported by adequate visitor-related attributes. In contrast, Sosokan Waterfall was positioned in quadrant Z22, reflecting moderate performance in both MV and AV categories, primarily constrained by limited infrastructure and accessibility. These findings confirm that geological attributes alone are insufficient to elevate geosite readiness without parallel development of visitor-oriented facilities. The study's novelty lies in providing the first M-GAM-based comparative assessment for geosites in North Musi Rawas, offering actionable insights for regional planning. Strengthening infrastructure, interpretive media, and accessibility is recommended to optimize geotourism development strategies.

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1. INTRODUCTION

Geotourism has been recognised as an essential pillar of sustainable tourism because it integrates geological diversity, geoheritage, and educational values to enhance the understanding of Earth processes while contributing to local socio-economic development (Dowling & Newsome, 2022). Geotourism provides opportunities for public awareness and education about Earth's processes through geological heritage, connecting environmental recreation and conservation strategies. Over the past two decades, the concept has evolved into an integrative tourism model encompassing abiotic, biotic, and cultural components within the framework of geodiversity (Gray et al., 2021; Mahato & Jana, 2021; Zhao et al., 2023). This expansion strengthens geotourism's role in heritage preservation and community-based development, positioning it as a tool for sustainable regional growth and development.

Effective geoheritage management requires standardised and robust assessment frameworks capable of identifying a site's scientific significance, tourism potential, and conservation needs. Such frameworks are critical for guiding informed decision-making, prioritizing development actions, and ensuring that tourism growth aligns with heritage preservation goals (Brill & Rangel-

Buitrago, 2021; Gordon & Barron, 2022). The Modified Geosite Assessment Model (M-GAM) has gained prominence as one of the most comprehensive methodologies for evaluating geosite potential because of its balanced reliance on expert judgment and visitor perception (Tomić et al., 2014). By integrating these dual perspectives, the M-GAM enables a more holistic and realistic interpretation of site quality and visitor-centred development needs (Reynard & Coratza, 2021; Tomić et al., 2021; Rachmad et al., 2021).

M-GAM distinguishes between a geosite's Main Value (MV), which represents scientific, aesthetic, and protection aspects, and its Additional Value (AV), which encompasses functional, touristic, and infrastructural attributes (Farsani, Coelho, & Costa, 2022; Zouros & Valiakos, 2023). The M-GAM method includes two types of indicators: Main Value (MV) and Additional Value (AV), which consist of scientific, touristic, and protection aspects evaluated by integrating expert and visitor perspectives. This structure allows not only for the scientific ranking of sites but also for identifying targeted improvements required to enhance geotourism readiness.

Recent applications of M-GAM across diverse geological and geographical contexts have demonstrated its methodological robustness and versatility. Studies in Serbia (Tomić et al., 2021), Vietnam (Nguyen & Tran, 2022), and arid desert environments (Al-Amr & Abujayyab, 2023) consistently highlight the usefulness of the M-GAM in identifying key weaknesses, such as limited accessibility, insufficient infrastructure, and inadequate interpretive media, which are factors that commonly constrain geotourism development (Fassoulas & Iliopoulos, 2021; Pereira & Pereira, 2022; Sucahyanto et al., 2024). Although these findings underscore the model's global applicability, its systematic use in Indonesia remains limited, leaving substantial room for methodological advancements in emerging geotourism areas.

Given its capacity to evaluate multidimensional geosite attributes, M-GAM is particularly suitable for regions where geological potential exists but remains underdeveloped because of a lack of structured assessment. International research shows that M-GAM effectively guides strategic planning by identifying development priorities, ranking sites based on readiness, and highlighting the infrastructure investments necessary for tourism enhancement. Its comparative function is particularly valuable in regional planning, enabling policymakers to allocate resources based on quantified potential rather than subjective judgments.

Furthermore, research consistently demonstrates that M-GAM uncovers deficiencies that are critical for improving geosite competitiveness, including the quality of visitor facilities, interpretive materials, and overall destination management. These insights are vital for regions such as Indonesia, where geoheritage is abundant but often not supported by adequate tourism infrastructure. The absence of comprehensive assessment tools has slowed the development of geotourism initiatives, indicating the need for studies applying M-GAM in the Indonesian context.

Musi Rawas Utara contains volcanic and fluvial landforms, including Danau Rayo and Sosokan Waterfall with geoheritage significance. These two geosites show geological potential but lack holistic evaluation using standardised assessment methods. Studies have mainly focused on geological descriptions without integrating visitor perceptions and infrastructure assessments, limiting evidence for regional planning and geotourism development.

The absence of M-GAM-based evaluations for these geosites limits stakeholders' understanding of their comparative strengths, weaknesses, and readiness levels. As tourism development accelerates across Indonesia, regions such as Musi Rawas Utara require data-driven approaches to ensure that geoheritage resources are utilised effectively and responsibly. Addressing this gap is essential for establishing strategic development pathways aligned with geoconservation principles and community empowerment.

This study applies the M-GAM method to evaluate the geotourism potential of Danau Rayo and Sosokan Waterfall by assessing their Main and Additional Values, identifying strengths and weaknesses across 27 indicators, and formulating recommendations for sustainable development. As the first M-GAM application in Musi Rawas Utara, this study provides insights into Indonesia's geotourism while supporting regional planning. The study covers geological assessment, expert and visitor evaluations, and geosite classification using the M-GAM matrix, with findings that guide authorities in improving infrastructure, site management, and geotourism strategies.

2. METHOD

2.1. Materials

This study used geological field observations, surveys, and secondary data to evaluate the geotourism potential of two geosites in Musi Rawas Utara Regency: Danau Rayo and the Sosokan Waterfall. Rayo Lake lies in the volcanic terrain of the Kasai and Papan Betupang Formations, whereas Sosokan Waterfall shows volcanic deposits and fluvial sediments reflecting regional geomorphology. These features were assessed using the Modified Geosite Assessment Model (M-GAM).

The primary materials included field documentation, observational records of site morphology and visitor facilities, and photographic evidence. Secondary materials included geological maps, regional geomorphological studies, and methodological literature pertaining to geosite assessment. The evaluation utilised a standard set of 27 M-GAM indicators, classified into Main Values (MV) and Additional Values (AV).

Table 1. Main Value (MV) Indicators

Indicator/Sub Indicator (SI)	Information
Scientific/educational value (VSE)	Main Value (MV)
Scarcity ($SIMV_1$)	Number of other/nearby identical sites
Representation ($SIMV_2$)	Didactic characteristics and exemplary due to its own value and general configuration
Geoscientific knowledge ($SIMV_3$)	Number of papers written in recognized journals, theses, presentations, and other publications
Interpretation level ($SIMV_4$)	Interpretation of geological processes
Aesthetic value (VSA)	
Viewpoints ($SIMV_5$)	Points that can expose the beauty of the site from a distance
Surface ($SIMV_6$)	Site surface area
Scenery and natural condition around ($SIMV_7$)	The quality of panoramic views, the presence of water and vegetation, the absence of human-made damage, around urban areas, etc
Site/object compatibility with the surroundingenvironment ($SIMV_8$)	Contrast with nature, color contrast, shape appearance, etc
Protection value (VPr)	
Current State ($SIMV_9$)	The situationgeosite At the moment
Protection level ($SIMV_{10}$)	Protection by local, national, international etc
Vulnerability ($SIMV1_{11}$)	Potential damage geosite
Limited number of visitor ($SIMV_{12}$)	Enter geosite at the same time according to area, vulnerability and status geosite available
Functional Value (VFn)	Added Value (AV)
Accessibility ($SIAV_{13}$)	Likelihood or opportunity towards geosite
Additional natural value ($SIAV_{14}$)	Total additional natural values within a 5 km radius (inclgeosite)
Anthropogenic value ($SIAV_{15}$)	Total additional anthropogenic values within a 5 km radius
Proximity tothe city center ($SIAV_{16}$)	Proximity to city center
Proximity to major/important roads ($SIAV_{17}$)	Close to important road network within 20 km radius
Has additional functional value ($SIAV_{18}$)	Parking lots, gas stations, workshops, etc

Source: Božić & Tomić (2021)

The main Value indicators in Table 1 represent geosites' scientific, aesthetic, educational, and conservation attributes. The M-GAM framework includes additional value indicators for infrastructure, services, and management effectiveness (Table 2) beyond intrinsic quality.

Table 2. Matrix Description Modified Geosite Assessment Model (M-GAM)

Is	Main Value (MV)	Added Value (AV)
Z11	Low	Low
Z12	Low	Medium
Z13	Low	High
Z21	Medium	Low
Z22	Medium	Medium
Z23	Medium	High
Z31	High	Low
Z32	High	Medium
Z33	High	High

Source: Božić & Tomić (2021)

The Additional Value (AV) indicators in Table 2 complement the functional aspects of geosites. While MV focuses on geological and educational significance, AV examines tourism feasibility based on accessibility, facilities, services, and maintenance. Together, the MV and AV enable the comprehensive classification of geosites within the M-GAM framework.

2.2. Sample Preparation

The assessment incorporated both expert and visitor perspectives, following the established M-GAM procedures. The visitor assessment involved 55 respondents selected using convenience sampling, representing a range of educational and experiential backgrounds relevant to tourism. The expert evaluation consisted of 22 specialists in geology, geography, conservation, and tourism, whose input was essential for determining the scientific and functional attributes.

Survey instruments were validated prior to deployment to ensure conceptual clarity and reliability of the data collected. All items were rated using a 0.00–1.00 Likert scale, enabling a quantitative comparison across the 27 indicators. Responses were subsequently coded and aggregated into the MV and AV categories in preparation for computational analysis.

2.3. Experimental Set-up

This study employed the Modified Geosite Assessment Model (M-GAM) as the analytical framework. The M-GAM method includes two types of indicators: Main Value (MV) and Additional Value (AV), which consist of scientific, touristic, and protection aspects evaluated by integrating expert and visitor perspectives. This dual-perspective approach offers a balanced interpretation of geosite value, ensuring that assessments reflect both intrinsic geoheritage qualities and user-centred functional attributes of geosites.

Indicator scores were processed using the M-GAM formula for Im, involving the computation of mean values from expert and visitor assessments, followed by aggregation into MV and AV. The final scores are traditionally plotted in the M-GAM matrix to classify site readiness.

2.4. Parameters

The parameters assessed in this study correspond to the 27 M-GAM indicators, wherein the MV parameters evaluate scientific significance, aesthetic qualities, educational importance, and conservation status, serving to determine the intrinsic geological quality and the capacity of each site to function as a scientific and educational resource. In parallel, AV parameters measure tourism-supporting attributes such as accessibility, interpretive materials, infrastructure, safety, and promotional factors, thereby reflecting the geosite's readiness to support tourism activities and its potential contribution to regional tourism. Scores for each parameter were obtained from expert and visitor responses and subsequently aggregated into composite MV and AV values, which formed the basis for qualitative interpretation.

2.5. Statistical Analysis

Descriptive statistical techniques were employed to summarise the mean values, evaluate response distributions, and compare expert and visitor assessments. Given the evaluative nature of the M-GAM framework, no inferential statistical tests were performed. Analytical emphasis was placed on the consistency of the scoring patterns and the alignment between the intrinsic and functional site attributes.

3. RESULTS AND DISCUSSION

3.1. Geological Aspect

3.1.1. Rayo Lake

Rayo Lake is situated within the Kasai Formation (Qtk), which consists predominantly of tuffaceous deposits. This formation is of Plio–Pleistocene age and is associated with volcanic facies resulting from explosive volcanism. The tuff deposits exhibit varying grain sizes, from fine ash to lapilli tuff, and are characterised by light-coloured and poorly consolidated pyroclastic material. The geomorphological setting suggests that Lake Rayo represents a volcanic crater lake formed by volcanic-tectonic activity during the late Quaternary. These lakes are significant as hydrogeological reservoirs and as attractive geotourism sites due to their scenic qualities and rarity in South Sumatra (Karuniastuti et al., 2021; Pica et al., 2022; Santangelo et al., 2023).

Figure 1. Geosite Rayo lake

3.1.2. Sosokan Waterfall

The Sosokan Waterfall is situated within the Papan Betupang Formation (Tomp), which spans the Early Oligocene to the Late Miocene. This formation is primarily composed of volcanic products, including andesitic lava flows, pyroclastic rocks, and reworked volcaniclastic deposits, resulting from a series of volcanic eruptions during its deposition. The waterfall is formed where resistant andesitic volcanic layers are exposed and incised by fluvial processes, resulting in vertical drops and cascades of water. This lithological control, combined with ongoing erosion, creates the spectacular geomorphology observed at the Sosokan today. The volcanic heritage of this formation underscores the region's extensive history of arc volcanism, which has significantly contributed to the landscape evolution in South Sumatra.

Figure 2. Geosite Sosokan Waterfall

3.2. Assessment Result Using the M-GAM Method

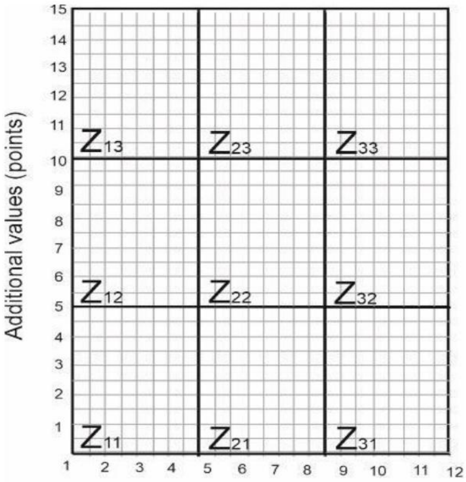

Figure 3. M-GAM Matrix of Geotourism Assessment Results

The geotourism assessment of Danau Rayo and Sosokan Waterfall was conducted using the Modified Geosite Assessment Model (M-GAM). The calculated scores for the Main Values (MV) and Additional Values (AV) are presented in Table 4 and subsequently plotted on the M-GAM matrix, which classifies geosite development priorities across nine fields (Z11–Z33).

The results indicated different matrix classifications for the two sites. Danau Rayo is located in the Z33 field, indicating high MV and AV. This status demonstrates that Danau Rayo possesses strong geological and aesthetic significance as a volcanic crater lake of the Kasai Formation (Qtk) and benefits from better accessibility and supporting tourism infrastructure. Nonetheless, promotional efforts, interpretive facilities, and structured visitor programs remain limited and should be strengthened to enhance educational engagement and sustainability.

In contrast, Sosokan Waterfall is categorized in the Z22 field, where both MV and AV are moderate. Although the waterfall possesses valuable geomorphological characteristics shaped by incision into the volcanic succession of the Papan Betupang Formation (Tomp), its tourism-related attributes particularly infrastructure, access quality in specific segments, and promotional visibility remain underdeveloped. These shortcomings hinder the visitor experience and restrict the geosite's ability to realise its full geotourism potential.

Table 4. Matrix Description Modified Geosite Assessment Model (M-GAM)

No-Geosite	Main Value	(VSE+VSA+VPr)		∑
	EVERYTHING	EVERYTHING	VPr	
GS1- Rayo Lake	4.11	4.36	4.23	12.7
GS2 - Sosokan Waterfall	4.16	4.1	3.44	11.7

No-Geosite	Addtional Value	(VSE+VSA+VPr)	∑
	VFn	Vtr	
GS1- Rayo Lake	4.16	4.27	8.43
GS2 - Sosokan Waterfall	3.78	2.72	6.5

4. CONCLUSIONS

This study applied the Modified Geosite Assessment Model (M-GAM) to evaluate the geotourism potential of two geosites in Musi Rawas Utara Regency—Danau Rayo and Sosokan Waterfall. The results demonstrate that Danau Rayo possesses strong intrinsic geological, educational, and aesthetic values, complemented by moderate functional readiness, placing it in the category Z33. This indicates a high potential for geotourism development, with the targeted enhancement of interpretive and educational components. In contrast, the Sosokan Waterfall, positioned in category Z22, exhibits significant geological importance but remains constrained by limited accessibility, inadequate infrastructure, and minimal visitor support facilities.

Overall, the findings underscore that intrinsic geological value alone is insufficient to elevate geosite readiness without corresponding improvements in the functional attributes. To achieve sustainable geotourism growth, development strategies must be tailored to each site's specific conditions, prioritising interpretive strengthening at Danau Rayo and foundational infrastructure investment at Sosokan Waterfall. These insights provide an evidence-based framework for guiding regional planning, geoconservation efforts, and future geotourism initiatives. Further research integrating spatial analysis, community engagement, and long-term monitoring can enhance the robustness of geosite management strategies in the region.

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