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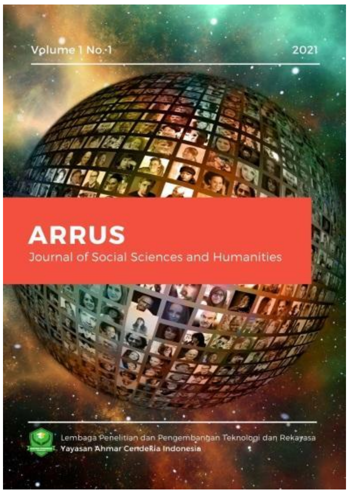

RESEARCH ARTICLE

Rammang-Rammang as a Natural Laboratory for Enhancing Geography Learning in Senior High Schools

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Abstract: Geography education in high schools requires learning resources that link concepts to real-world phenomena. The Rammang-Rammang Karst area holds potential as a natural laboratory due to its diverse geospheric and socio-environmental phenomena. This study aims to analyze Rammang-Rammang's potential as a natural laboratory based on the characteristics of geospheric phenomena, the relevance of the subject matter, and student geographical activities. A qualitative descriptive method with an exploratory approach was employed, utilizing field observations and literature reviews. Analysis involved data reduction, categorization of geospheric components, interpretation, and mapping the connections between specific features and the learning curriculum. The results indicate that the karst formations, Stone Forest, caves, Pute River, Berua Village, agricultural lands, and vegetation are relevant to lithospheric dynamics, geomorphology, hydrology, the biosphere, and human-environment interactions. The area also fosters skills in observation, mapping, spatial interpretation, environmental analysis, and critical thinking. Rammang-Rammang can be developed into an authentic learning space through field studies, problem-based inquiry, and geospatial technology, while adhering to conservation principles.

Keywords: Rammang-Rammang, Karst, Natural Laboratory, Geography Learning, Field Study, Environmental Literacy

1. Introduction

Geography instruction at the high school level should not rely solely on mastering concepts through textbooks and classroom explanations. The nature of geography—which examines the relationships between humans, space, the environment, and the processes shaping the Earth's surface—demands learning experiences closely connected to real-world phenomena (Bos et al., 2022). Concepts regarding the lithosphere, hydrosphere, biosphere, environmental dynamics, land use, human-environment interactions, and even sustainable development become more meaningful when students engage directly with the subjects of their study (Saripudin et al., 2022). In this context, the area surrounding the school and regions with distinctive geographical characteristics can serve as both learning resources and natural laboratories (Y. Wang & Liu, 2024). A natural laboratory is not merely a site for visits, but a learning space that provides geographical phenomena to be observed, measured, compared, analyzed, and interpreted based on geographical concepts and approaches.

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The need for field-based learning becomes increasingly important when geography education is geared towards developing spatial thinking, critical thinking, problem-solving skills, and environmental literacy (Malchykova & Mezentsev, 2022). Students are required not only to know that karst is a landscape formed through the dissolution of carbonate rocks but also to understand how the characteristics of these rocks relate to landforms, hydrological systems, ecosystems, spatial use, and human activities (Zhu et al., 2024). This type of learning provides students with the opportunity to view the interconnections between geosphere phenomena in a holistic manner (Pratama et al., 2026). This type of learning provides students with the opportunity to view the interconnections between geosphere phenomena in a holistic manner.

One area that exhibits these characteristics is Rammang-Rammang in Maros Regency, South Sulawesi. This area is part of the Maros-Pangkep karst landscape, which features geomorphological characteristics such as clusters of karst towers, limestone hills, caves, valleys, rivers, and various landforms shaped by geological and geomorphological processes over a long period (Jaya et al., 2022). Rammang-Rammang is also located within the Maros Pangkep UNESCO Global Geopark, which is known for its distinctive karst landscape (Arsyad et al., 2024; Hasaniyah et al., 2025). UNESCO notes that the Maros-Pangkep region features hundreds of caves with horizontal and vertical characteristics, as well as subsurface hydrological systems associated with the development of karst landscapes (Wekke et al., 2024).

The uniqueness of Rammang-Rammang lies not only in the physical form of its landscape. The area reveals a close relationship between abiotic, biotic, and social elements. The journey to the core area via the Pute River highlights the interconnectedness of the river system, vegetation, settlements, agricultural land, the karst landscape, and the community's economic activities (Mappasomba et al., 2024). On a broader scale, the ecosystems and biodiversity of the Maros-Pangkep area also enhance the region's ecological value. UNESCO has recorded the presence of over 1,400 species of flora and fauna within the geopark, including a number of species endemic to Sulawesi (Fatnassi et al., 2025). This situation provides a rich geographical context for linking the study of natural processes with issues regarding environmental utilization and management.

That potential has actually received attention in geography education research. Ikhsan and Haris (2022), For instance, six locations within the Rammang-Rammang ecotourism area have been identified as suitable for use as geography learning laboratories: the Stone Forest, Kampung Berua, Tunnel Cave, Diamond Cave, Bat Cave, and Angel's Pond. These six sites exhibit geospheric phenomena—spanning geology, geomorphology, hydrology, and biodiversity—that can be linked to secondary school geography education (Hasaniyah et al., 2025). The findings indicate that Rammang-Rammang possesses a strong empirical basis for development as an outdoor learning space.

However, utilizing karst areas as natural laboratories should not stop merely at the identification of features. A more critical issue is how a location's geographical characteristics can be translated into a purposeful learning experience—incorporating observational activities, data collection, and analytical processes—that aligns with the nature of geography education at the high school level (Oliveira & Bonito, 2023). A cave, for instance, does not automatically become a learning resource simply because it possesses geological value (Jones & Washko, 2022). Caves serve as a learning resource when students are guided to observe morphological forms, understand the processes of their formation, identify their relationship with groundwater systems, and subsequently link these observations to karst concepts and environmental dynamics (As'ari et al., 2021). Similarly, the presence of settlements and agricultural land in the vicinity of karst areas can be used to analyze the human-environment relationship, land-use changes, and issues of sustainability.

This perspective is important because environment-based learning often tends to treat field trips merely as recreational activities. A student visit to a tourist site does not necessarily result

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in a deep learning process unless the activity is accompanied by geographical questions, observation instruments, data collection, and interpretation tasks (Zimmerman & Land, 2022). Therefore, the concept of a natural laboratory needs to be situated within a more focused pedagogical framework (Kiviranta et al., 2024; Singleton & Arribas-Bel, 2021). A natural laboratory in geography education should provide students with the opportunity to engage in simple scientific work—ranging from observation, identification, measurement, and data recording to spatial interpretation and the formulation of conclusions based on field evidence (Remmen & Iversen, 2023).

Karst regions offer advantages in this context because their landscape characteristics provide relatively complex subjects for study within interconnected spaces. Karst tower landforms can be used to examine geomorphology and the dissolution processes of carbonate rocks (Li et al., 2025). Caves can be used to understand the formation processes of subsurface landforms and karst hydrological systems. Rivers can serve as subjects for observing hydrological dynamics and the interactions between surface systems and the surrounding environment (Tang et al., 2026). Vegetation and biodiversity can be studied within the context of the biosphere, whereas Kampung Berua and the activities of the surrounding community can be used to understand the relationship between humans and the environment, as well as spatial utilization (Xiang et al., 2025). This complexity makes karst areas relevant not just to a single topic but also suitable as an integrative space for various themes in geography education.

In the context of geography education in Indonesia, this approach aligns with learning needs that position students as active subjects who observe and analyze phenomena. Geography instruction is not ideal if it merely fosters the ability to memorize terms such as karst, doline, stalactite, stalagmite, or underground river (Ruan et al., 2021). Students need to understand the processes and spatial relationships underlying the existence of these phenomena. When students observe the Rammang-Rammang landscape firsthand, previously abstract concepts can be placed within a concrete spatial context (García de la Vega, 2022; Park, 2022). The process also provides students with the opportunity to use maps, imagery, field data, visual documentation, and measurement results as part of the geographical analysis process.

The significance of Rammang-Rammang as a natural laboratory is also linked to the status of the Maros-Pangkep area as a UNESCO Global Geopark. This status underscores that the area possesses geological heritage value that is significant not only for the beauty of its landscape but also in terms of education, conservation, and community development (J. Wang & Zouros, 2021). UNESCO designates Rammang-Rammang as an area where Earth's heritage can be explored through its karst landscape, ecosystems, community life, and local traditions (Martínez-Martín et al., 2023). In a recent development, the Maros-Pangkep karst landscape has also been included in the UNESCO World Heritage Tentative List, with values encompassing cultural, geological, and biodiversity aspects (Martínez-Martín et al., 2024). This position further strengthens the academic rationale for developing this area as a geography learning resource focused on environmental understanding and sustainability.

However, there is a gap between the area's high geographical value and its utilization as a structured learning laboratory. While previous research has identified several sites relevant to geography education, a more comprehensive assessment of the area's potential remains to be developed—specifically by linking the characteristics of each site to high school geography learning competencies, potential student learning activities, and the types of geographical skills that can be cultivated (Hu & Chen, 2026; Hursen & Beyoğlu, 2025; Sonrum & Worapun, 2023). Studies of this kind are important to ensure that the use of Rammang-Rammang does not stop at the concept of a field trip, but evolves into inquiry-based learning that yields geographical data and interpretations (Nicholson et al., 2023).

Given this context, this study aims to analyze the potential of the Rammang-Rammang karst area as a natural laboratory for high school geography education. The analysis focuses on identifying geospheric phenomena, the characteristics of geographical features, their relevance to the curriculum, and opportunities for utilizing the site for geographical observation and inquiry. The findings are expected to provide a conceptual foundation for geography teachers to design environment-based lessons that are not only visually engaging but also possess academic, contextual, and ecological value.

By positioning Rammang-Rammang as a natural laboratory, geography instruction can shift from a predominantly text-based approach to a phenomenon-based learning experience. Students do not merely study karst as an abstract concept; instead, they engage directly with the karst landscape as a subject of simple inquiry. They can observe, ask questions, gather evidence, interpret spatial contexts, analyze relationships between phenomena, and draw conclusions based on real-world conditions. This approach integrates the environment into the learning process while reinforcing geography's role as a discipline that bridges the understanding of natural processes, spatial dynamics, human activity, and environmental sustainability.

2. Research Method and Materials

2.1. *Jenis Penelitian*

This study employs a qualitative descriptive method with an exploratory approach to identify and analyze the geographical characteristics of the Rammang-Rammang Karst Area and its relevance as a natural laboratory for high school geography education. The study focuses on geospheric phenomena encompassing geology, geomorphology, hydrology, the biosphere, and human-environment interactions. Each geographical feature is examined based on its physical and social characteristics and subsequently linked to the geography curriculum content, activities, and skills that students can develop. The research views Rammang-Rammang not merely as a field trip destination but as a learning space offering objects for observation, geographical data, and environmental issues for contextual analysis. The study was conducted in the Rammang-Rammang Karst Area, Maros Regency, South Sulawesi, which is part of the Maros Pangkep UNESCO Global Geopark.

2.2. *Sumber Data*

The research data comprises both primary and secondary data. Primary data were obtained through field observations of geographical features in the Rammang-Rammang Karst Area—including karst landforms, the Pute River, the Stone Forest, karst caves, Berua Village, agricultural land, vegetation, land use, and community activities—documented via photographs and records of feature characteristics. Each feature was analyzed based on geospheric phenomena, high school geography concepts, and potential field-based learning activities. Secondary data were gathered through a literature review of scientific articles, books, area management documents, official UNESCO Global Geopark information, and high school geography curriculum and learning outcome documents; these data served to reinforce the interpretation of karst characteristics, ecological value, conservation aspects, and the area's relevance as a natural laboratory for geography education.

2.3. *Teknik Analisis Data*

The data were analyzed using a qualitative descriptive approach involving data reduction, categorization, interpretation, and conclusion drawing. Data obtained from observations and literature reviews were classified according to geosphere components: the lithosphere, hydrosphere, biosphere, and anthroposphere. Subsequently, each object was analyzed based on its geographical potential, relevance to the high school Geography curriculum, and potential student learning activities. The analysis encompassed features such as karst landscapes, the Pute River, caves, and vegetation, as well as Kampung Berua and local community activities, examined through the lenses of geomorphology, hydrology, the biosphere, human-environment interaction, and sustainability.

The analysis results were organized into a "natural laboratory potential" matrix detailing geographical objects, geosphere phenomena, learning topics, field activities, and the

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geographical skills that could be developed. Interpretation involved comparing observational findings with scientific literature, official area documentation, and educational materials. Data validity was reinforced through source triangulation to ensure that the assessment of Rammang-Rammang's potential was grounded in the geographical characteristics and pedagogical value of each object. The overall analysis serves as the basis for formulating Rammang-Rammang's potential as a natural laboratory for high school Geography education.

3. Results and Discussion

3.1. Results

3.1.1. Geographical Characteristics of the Rammang-Rammang Karst Area

Observations indicate that the Rammang-Rammang Karst Area possesses a diverse range of geographical features—including karst hill clusters, limestone cliffs, caves, rivers, valleys, vegetation, agricultural land, and settlements within a unified spatial setting—that can serve as subjects for direct observation in geography education. The karst landscape serves as a primary feature for understanding the relationships between rock types, dissolution processes, geomorphology, and landform development, while the Pute River and its valley environment offer opportunities to examine drainage patterns, riparian vegetation, and the connections between surface water systems and karst rock fractures and cavities. Beyond physical aspects, activities such as agriculture, settlement, water-based transport, and economic endeavors provide a context for studying spatial utilization and human-environment interactions. This diversity facilitates a tangible learning experience through activities involving feature identification, data collection, analysis of interrelationships among geosphere components, and an understanding of karst area conservation and sustainability.

3.1.2. Potential of Geographical Features as Natural Laboratories

Identification results indicate that a number of sites in Rammang-Rammang possess significant educational value, as they offer a direct view of geospheric phenomena. These sites not only offer visual appeal but also provide a context for conducting observations, simple measurements, spatial interpretation, and the analysis of relationships between geographical features.

Table 1. The Potential of the Rammang-Rammang Karst Area as a Natural Laboratory for Geography Education

object	Observable phenomena	High School Geography Curriculum Materials	Learning Activities
Cluster of karst hills/towers	Landforms, carbonate rocks, relief	Lithosphere and geomorphology	Landform identification and interpretation of geomorphological processes
Stone Forest	Karst morphology and dissolution processes	Lithospheric dynamics	Observation of karst forms and documentation of phenomena
Karst cave	Subsurface cavities, cave formations, dissolution processes	Lithosphere and hydrology	Identification of cave characteristics and their relationship to dissolution processes
Pute River	Surface runoff and fluvial environments	Hydrosphere	Observation of river characteristics and their relationship to the environment
Berua Village	Settlements, land use, human-environment interactions	Anthroposphere and the environment	Analysis of settlement patterns and spatial utilization
Agricultural land	Land utilization and economic activities	Anthroposphere	Identification of land use and environmental suitability analysis

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Karst vegetation	Vegetation diversity and adaptation	Biosphere	Identification of vegetation and its relationship to environmental conditions
Overall karst landscape	Interactions among the lithosphere, hydrosphere, biosphere, and anthroposphere	Integrated geography	Analysis of the interrelationships between geospheric phenomena

Source: Observations from 2026

The table demonstrates that a single area can offer a variety of interconnected learning subjects. Karst hills, for instance, serve as sites for studying geomorphological processes, while the river situated amidst these landforms provides a context for understanding hydrological dynamics. By examining both features together, students move beyond studying the lithosphere and hydrosphere in isolation, enabling them to analyze the interrelationship between the two within a unified environmental system.

The Stone Forest and karst caves offer significant educational value regarding geomorphology. The Stone Forest allows for the identification of landforms, rock characteristics, and karst relief through activities such as profile sketching, coordinate mapping, and the interpretation of karst formation processes. Meanwhile, karst caves provide an opportunity to understand carbonate rock dissolution and the connections between surface water and underground hydrological systems. Both sites facilitate the integration of conceptual understanding with geographical skills through field observation and interpretation.

The Pute River extends the scope of learning to hydrology and human-environment interactions by allowing for the observation of river characteristics, riparian vegetation, water usage, and the river's relationship with the surrounding landscape. Kampung Berua complements the study by highlighting social phenomena, such as settlement patterns, land use, economic activities, accessibility, and community adaptation to the karst environment. The interconnections among these four sites demonstrate that Rammang-Rammang serves as a natural laboratory, integrating the study of geomorphology, hydrology, spatial use, and human-environment interactions.

3.1.3. The Relevance of Rammang-Rammang to High School Geography Education

Mapping results indicate that Rammang-Rammang is relevant to various high school geography topics, including the dynamics of the lithosphere and hydrosphere, the biosphere, the environment, human-environment interactions, and the sustainable use of natural resources. The diversity of these phenomena also fosters the development of students' geographical skills, such as observation, data recording, map interpretation, coordinate acquisition, landform identification, land-use analysis, visual documentation, and report writing. Integrating simple geospatial technology can enhance these activities by linking field data with digital maps.

Given these characteristics, Rammang-Rammang serves as an ideal natural laboratory for geography education, offering tangible subjects of study, a diverse range of phenomena within a single area, and relevant environmental issues for analysis. The region also provides a local context that enables students to connect geographical concepts with actual environmental conditions through experiential learning, inquiry-based approaches, and environmental literacy.

3.2. Discussion

Research findings indicate that Rammang-Rammang's primary strength as a natural laboratory lies in the diversity of geographical phenomena observable within a single spatial unit. The area not only features karst landscapes but also demonstrates the interconnections between landforms, hydrological systems, vegetation, land use, settlements, and community activities (Mappasomba et al., 2024). This characteristic aligns with the essence of geography, which examines spatial relationships and interactions among environmental components. In the learning process, the presence of various geosphere components within a single area can

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help students gain a more concrete understanding of the interconnections between the lithosphere, hydrosphere, biosphere, and anthroposphere (Laiskhanov et al., 2026). These findings reinforce the research by Ikhsan and Haris, which identified the Stone Forest, Kampung Berua, Berlian Cave, Kelelawar Cave, Terowongan Cave, and Telaga Bidadari as sites relevant to geography education (Popovič, 2024). However, in this study, Rammang-Rammang is viewed from a broader perspective—not merely as a collection of visitation points, but as an integrated natural laboratory system that can be designed based on learning objectives and activities.

The educational value of karst areas is increasingly evident through their geomorphological and hydrological characteristics. The Stone Forest serves as a site for identifying karst landforms, rock characteristics, relief, and the dissolution processes that shape the landscape. Karst caves offer an opportunity to understand subsurface geomorphological processes, the development of cavities, and the interaction between water and carbonate rock (Jaya et al., 2022). Meanwhile, the Pute River can serve to link the study of the lithosphere and hydrosphere through observations of flow direction, riverbank conditions, surrounding vegetation, and the community's utilization of the river (Jaya et al., 2022). The characteristics of the Maros-Pangkep Karst—featuring tower karst landscapes, caves, dolines, and subsurface hydrological systems—provide a tangible context for understanding the interconnections between geological, geomorphological, and hydrological processes (Ikhsan & Haris, 2022). Thus, learning can shift from merely recognizing karst terminology toward more analytical questions regarding formation processes, the role of water, the relationship between organisms and the environment, and the utilization and conservation of the area.

Rammang-Rammang also holds great potential for developing students' geographical skills, as field activities can be directed toward the abilities to read spatial environments, determine locations, recognize patterns, analyze relationships, and present spatial information (Elhashash et al., 2022). Digital maps and simple geospatial technology can be used to determine object positions, record coordinates, measure distances, and link observation points to landscape features (Madimarova et al., 2024). The activity can be developed into problem-based fieldwork—for instance, by asking students to analyze the relationship between karst landforms and land-use patterns in Kampung Berua. Students can conduct observations, document findings, and record environmental conditions, then compare the field data with maps to formulate an interpretation (Sestras et al., 2023). The process provides an authentic learning experience because students do not merely receive data from the teacher but are directly involved in acquiring, selecting, and interpreting data to answer geographical questions.

Beyond spatial skills, the conditions at Rammang-Rammang offer opportunities to foster critical thinking and environmental literacy. The area's geological and biodiversity values are not merely objects of admiration; they can be examined through the lenses of land use, tourism, conservation, and sustainability (Morante-Carballo et al., 2023). Information regarding the diversity of flora and fauna in the Maros-Pangkep area can serve as a basis for students to discuss the relationship between economic activities and conservation needs (Németh et al., 2021). Kampung Berua also provides a tangible context for understanding the interrelationships between landforms, spatial availability, agriculture, settlements, and community activities. Within this context, students can analyze how the community adapts to the environment while also identifying potential pressures resulting from human activities (Tukiainen et al., 2025). Ultimately, local environment-based learning can help students understand that conservation is not merely a concept but is directly linked to the sustainability of ecological functions and community life.

Utilizing Rammang-Rammang as a natural laboratory requires a systematic instructional design to ensure that field activities do not devolve into mere educational tourism. Teachers need to define learning competencies, objects of observation, data collection instruments, inquiry questions, and the products students are expected to produce (Jaya et al., 2022). The pre-visit stage can be used to build foundational knowledge about karst and formulate

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research questions; the field stage is used for conducting observations and data collection; while the post-visit stage focuses on data processing, interpretation, and the preparation of outputs (Yelastri et al., 2023). Learning outputs may take the form of simple thematic maps, field reports, story maps, infographics, or environmental management recommendations. These designs can be implemented through field studies, inquiry-based learning, problem-based learning, or project-based learning, thereby ensuring continuity between fieldwork and classroom instruction.

Overall, Rammang-Rammang's potential as a natural laboratory is defined not only by the uniqueness of its karst landscape but also by its capacity to provide a learning experience that integrates knowledge, geographical skills, and environmental awareness. The area offers tangible subjects for studying geomorphology, hydrology, the biosphere, land use, and human-environment interactions within a single geographical entity (Wekke et al., 2024). Its status as part of the Maros Pangkep UNESCO Global Geopark further enhances its educational value, as aspects of geological heritage, biodiversity, and local community life can be studied in an integrated manner (Selfiardy et al., 2025). Therefore, Rammang-Rammang can be positioned not merely as a natural tourism destination, but as an authentic space for geographical learning (Ikhsan & Haris, 2022). Therefore, Rammang-Rammang can be positioned not merely as a natural tourism destination, but as an authentic space for geographical learning.

4. Conclusion

The Rammang-Rammang karst area holds significant potential for development as a natural laboratory for high school geography education, as it presents a diverse array of geographical phenomena within a unified spatial setting including karst landscapes, limestone hills, caves, the Pute River, vegetation, agricultural lands, settlements, and community activities. These elements allow for the integration of concepts regarding the lithosphere, hydrosphere, biosphere, and anthroposphere, as well as human-environment interactions. Mapping results indicate that each feature serves a complementary educational function: karst clusters and the "Stone Forest" facilitate the study of geomorphology and lithospheric dynamics; caves offer insight into dissolution processes and the connection between surface and subsurface systems; the Pute River enables the study of hydrological dynamics; and Kampung Berua, agricultural areas, and community activities provide opportunities to examine land use, human-environment interactions, and regional sustainability. The primary value of Rammang-Rammang lies not only in its unique landscape but also in its capacity to provide a space where students can conduct observations, gather data, perform spatial interpretations, and investigate geographical phenomena, thereby fostering skills in mapping, landform identification, spatial analysis, critical thinking, and environmental literacy. Furthermore, the integration of geological heritage, biodiversity, hydrological systems, and community life positions Rammang-Rammang as a contextual learning resource that supports interdisciplinary study and reinforces the nature of geography education which treats space and the environment as fundamental sources of knowledge.

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