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GEOTRAILS: BLENDING GEOTOURISM AND GEOLOGICAL DISCOVERY AT THE BAYAH DOME GEOPARK, INDONESIA

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Abstract: Lebak Regency in Indonesia is endowed with abundant geotourism potential spread across several regions, including beaches, waterfalls, hot springs, caves, and panoramic landscapes. The Bayah Dome Geopark is distinguished by its remarkable geological importance and significant potential for geotourism development. However, the development of its geotourism resources, particularly within the Bayah Dome Geopark, remains underdeveloped due to lack of infrastructure, integration of geo-sites and accessibility problems. These barriers affect tourism viability for local economies and restrict their socio-economic benefits. Addressing these issues, this study examines strategies to improve accessibility and geotourism trail development in the Bayah Dome Geopark, encompassing 15 sub-districts. The research employed a combination of primary and secondary data collection, including literature reviews, field observations, interviews with stakeholders, and geosite mapping. Secondary data was obtained by a comprehensive literature examination of geological reports, tourism studies, and regional development plans. Furthermore, geospatial analysis, encompassing geosite mapping and cluster analysis, was performed to enhance spatial planning and resource distribution. Cluster analysis was utilized to group geosites and tourist attractions based on geological, biological, and cultural diversity, enabling the creation of thematic geotrails. These trails were designed to optimize visitor experiences while minimizing environmental impact, considering accessibility, travel distances, and supporting infrastructure.The findings reveal that the Bayah Dome Geopark has 74 geotourism attractions, categorized into 60 geological, 5 biological, and 12 cultural sites. These were clustered into six major themes and corresponding sub-themes, such as Coastal Scenic Scape and Goldmine Heritage, which offer diverse tourism experiences. The development of geotrails as "natural geological laboratories" not only fosters educational opportunities but also promotes environmental conservation and cultural preservation. The implications of this study are significant for geotourism development globally. The thematic geotrail framework offers a replicable model for other geoparks, demonstrating how clustering and mapping can transform scattered geosites into cohesive and engaging tourism networks.

Keywords: accessibility, geotrail, geotourism, geosites, thematic trails, Geopark Bayah Dome

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INTRODUCTION

According to the United Nations (UNESCO), a Geopark is an area with clearly defined boundaries and a surface area large enough for local economic development. Geoparks comprise a number of sites of geological diversity of special scientific interest, rarity and beauty known as geological heritage (Duangkrayom et al., 2022; Zangmo Tefogoum et al., 2022). Geoparks relate not only to geological diversity but also to archaeological, ecological, historical or cultural values . Based on Presidential Regulation No. 9 of 2019 concerning the Development of Geopark, Geopark is a single or combined geographic area, which has Geological Heritage Sites (Geosite) and valuable landscapes, related to aspects of Geoheritage, Geological Diversity, Biodiversity, and Cultural Diversity and managed for the purposes of conservation, education, and sustainable economic development of the community with the active involvement of the community and local government (Chen et al., 2022; Newsome & Ladd, 2022). Therefore, it can be used to foster people's understanding and concern for the Earth and the surrounding environment. Currently, the development of geoparks in Indonesia has been quite massive in recent years (Ginting et al., 2021; Rosyidie et al., 2018; Zaenal et al., 2016), especially related to geotourism, which is also increasingly popular among tourists today (Antić et al., 2022).

Geotourism has arisen as a sustainable tourism strategy that harmonizes environmental conservation with socio-economic advantages (Williams et al., 2024). It emphasizes the judicious utilization of natural resources, advancing the

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dual objectives of education and conservation (Dowling, 2023). International studies underscore the need of incorporating accessibility and conservation within geotourism frameworks, especially in topographically demanding regions such as rural Geoparks (Berred et al., 2022; Morante-Carballo et al., 2023). Geotourism development is a prominent topic not only in Indonesia but also in many global locations (Chen et al., 2022).

The endorsement of Geopark development by UNESCO has motivated each nation to safeguard its Geopark initiatives (Guimarães et al., 2018; Németh & Gravis, 2022), as these efforts not only focus on environmental preservation but also on education and the socio-economic enhancement of the populace (Pásková & Zelenka, 2018; Suzuki & Takagi, 2018). At now, geotourism has emerged as an alternative tourism management approach centred on the secure and sustainable utilisation of natural resources, which is widely recognised in Indonesia. This is inextricably linked to Indonesia's abundant geological history, characterised by a distinctive and intricate geological and geomorphological structure.

The advancement of geotourism within sustainable tourism has emerged as a novel impetus for conservation initiatives while enhancing the well-being of local populations. Geotourism is a viable solution to the genuine contradiction between environmental and cultural preservation and economic development (Williams et al., 2024). Abou Arrage & Chamra (2022) indicated that geotourism has expanded markedly across all continents in the last two decades, generating a substantial demand for innovative and systematic methodologies to identify sites of geological significance and establish a comprehensive management framework. Current geotourism research predominantly emphasise on improving accessibility or safeguarding environmental conservation (Bollati et al., 2024). Few have successfully integrated these two components into a unified framework that harmonises visitor accessibility with ecological conservation, especially in rural and topographically complex areas such as the Bayah Dome Geopark.

Accessibility in geotourism development is a crucial determinant of success. Many geosite areas lack sufficient access, hindering visitor attendance (Berred et al., 2022; Ketut Ari Pegatariana et al., 2024; Quesada-Valverde & Quesada-Román, 2023). However, it is imperative to exercise caution while constructing road access to the geosite to avoid harming the current ecology (Stolz & Megerle, 2022; Williams et al., 2025). Geotrails constitute a segment of the transportation network facilitating access between geosites. Visitors are typically driven to explore geotrails for five primary reasons: to seek entertainment, to acquire knowledge and discover new information, to engage in local activities, and to enjoy themselves (Ang et al., 2024; Stolz & Megerle, 2022). Geotrails have emerged as a contemporary trend in the 21st century, interlinking a sequence of geosites, natural, mining, and cultural attributes, so effectively connecting geo-themes on a broad scale (Bollati et al., 2024). Consequently, they can substantially augment and elevate the attractiveness of a region to the visiting populace (Lewis, 2020).

Geotrails provide various functions and advantages, including enhancing visitor experiences and safeguarding geosites from excessive utilization. The subsequent functions underscore their importance in geotourism: First, Geotrails function as "outdoor classrooms" or "natural geological laboratories," imparting knowledge to visitors regarding Earth's history, geological processes, and cultural legacy. Interpretative signs, guided tours, and digital platforms can augment the educational component by offering context on the sites and their importance (Dowling, 2023). Educational geotrails significantly enhance geoscience literacy, enabling tourists to value geological features and their environmental significance (Grobbelaar et al., 2019). Second, a primary role of geotrails is to reduce the ecological footprint of tourism. Geotrails restrict direct engagement with delicate geological formations, vegetation, and wildlife by directing visitors along specified routes. This mitigates prevalent problems such as soil erosion, littering, vandalism, and over-tourism. Effectively administered geotrails safeguard the natural integrity of geosites while permitting regulated access (Gordon et al., 2021). Third, geotrails facilitate access to isolated or dispersed geosites by connecting them via navigable pathways. These routes are frequently planned for several means of transportation, including walking, cycling, driving, or horseback riding (Bollati et al., 2024).

In regions with difficult topography, geotrails offer a systematic and safer method for tourists to navigate otherwise unreachable locations (Lewis, 2020). Forth, by aggregating and linking geosites into thematic trails, geotrails enhance the overall appeal of a location. Themes like “Coastal Scenic Scapes,” “Volcanic Landscapes,” and “Cultural Heritage Routes” generate compelling tales that attract tourists and promote extended visits. These themes enhance the tourism experience, rendering locations such as the Bayah Dome Geopark more competitive in the global tourism industry (Ginting et al., 2021).

The last, Geotrails facilitate local economic development by incorporating adjacent communities into tourism initiatives. In addition to the geosites, tourists may engage with local crafts, traditional foods, or cultural performances, so bolstering local enterprises and enhancing community pride (Doucek & Zelenka, 2018; Gray, 2019). This engagement guarantees the equitable distribution of tourism gains, hence enhancing the region's social sustainability (Antić et al., 2022).

Geotrails can be readily established along existing routes utilised by 4WD vehicles, cars, bicycles, pedestrians, and equestrians, which are conveniently linked to lodging and attractions while avoiding conflicts with land management and access concerns (Herrera-Franco et al., 2022). Moreover, the necessity of establishing routes between geosites may limit direct visitor access, consequently mitigating possible damage inflicted by visitors (Herrera-Franco et al., 2022; Williams et al., 2025). Human activities, such as tourism, can exert environmental, socio-cultural, and economic effects. A crucial element of geosite conservation is the management of both the site and its visitors (Gordon et al., 2021).

Geological sites are compromised due to excessive visitation, vandalism, graffiti, littering, pollution, sewage issues, and negligent visitors. Besides safeguarding geosites, geotrails can serve as appealing tourist attractions for visitors (Williams & McHenry, 2021). The concept of geotrails is acknowledged in geotourism, although their capacity to function as educational platforms and stimulate local economic development is inadequately explored in current research. Limited research has shown how geotrails can concurrently educate visitors and support local communities. To realize their potential, geotrails must integrate specific attributes that conform to geotourism principles such as integration with

established infrastructure, interpretation and signage, sustainability initiatives and scalability and replicability (Abou Arrage & Chamra, 2022; Morante-Carballo et al., 2023). However, the development of geotrails presents problems.

These encompass: topographical constraints, reconciling accessibility with conservation, and community involvement (Herrera-Franco et al., 2022; Williams & McHenry, 2021).

Lebak Regency is presently promoting the advancement of geotourism within the Bayah Dome Geopark, featuring approximately 156 tourist attractions. Lebak Regency, predominantly rural, faces difficulty in establishing a sufficient transit system. Rural regions characterised by mountainous terrain encounter significant challenges in delivering transit services and infrastructure. In contrast, tourism that has enough amenities and infrastructure can effectively attract visitors. Moreover, the presence of accessibility, supportive services, and infrastructure can foster sustainability and enhance competitiveness in tourism within a region. Consequently, research on the advancement of tourism accessibility is crucial for promoting the development of geosite support facilities and infrastructure. This research combines geotrail construction with an extensive evaluation of accessibility and infrastructure. It delineates transportation networks, geosites, and hubs while accounting for environmental constraints. The study proposes thematic geotrails that link geosites through sustainable paths, so reconciling accessibility with conservation and providing a reproducible model for additional geoparks. The main objective of this study is to improve tourism accessibility in the Bayah Dome Geopark by creating thematic geotrails that link geosites via sustainable routes. This study examines current infrastructure and transportation systems, identifies geosites and tourism centers, and considers environmental limitations. The study aims to establish a geotrail framework that integrates accessibility enhancements with conservation principles, thereby fostering geotourism development and providing a repeatable model for additional geoparks globally.

METHODS

This study employs descriptive research methodologies. The methodologies employed for primary and secondary data collecting included literature review, observation, interviews, and mapping. This study involved direct observations of the current conditions, including tourist destinations, road networks within the Bayah Dome Geopark Area, and access routes to geotourism. Furthermore, data collection through interviews targeted various authorised entities to obtain the requisite information, including the Lebak Regency Culture and Tourism Office, Lebak Regency Transportation Office, Lebak Regency Public Works and Spatial Planning Office, POKDARWIS (local tourism organisation), and the local community within the study area.

The acquired data will subsequently undergo examination through mapping of the locations of Geotourism attractions and their accompanying facilities. The findings from observations conducted on tourist sites will serve as the foundation for establishing priority tourism within the Bayah Dome Geopark. This study additionally superimposes maps (geosite, tourist attraction, and road network) to ascertain the configuration of geotourism routes. The geotourism attractions in Bayah Dome Geopark encompass not only geological features but also ecological and cultural elements that enhance geotourism activities. Geotourism attractions are distributed across 15 sub-districts within the Bayah Dome Geopark region. In total, the Bayah Dome Geopark encompasses 74 geosites, categorised into 60 geological, 5 biological, and 12 cultural attractions.

The research utilises cluster analysis to categorise 74 geosites and tourist attractions into six principal themes and sub-themes. This method facilitates the recognition of synergies between geosites, cultural landmarks, and ancillary infrastructure, thereby establishing a full geotrail network (Figure 1). This theme organisation will augment tourist experiences, mitigate overcrowding, and promote management efficiency (Herrero et al., 2017; Williams et al., 2025).

The concept can be implemented in other geoparks to offer a systematic framework for combining various attractions into cohesive, purpose-driven tourist experiences. The geotrail route assessment includes an analysis of transportation entry and exit points (HUB) to geotourism areas, evaluation of the current road network and future development plans for geotourism routes, distribution of geosites/geotourism as primary locations, identification of Sub HUBs as resting points based on travel distance and time, and clustering based on thematic identification of geotourism groups. This analysis includes a map overlay that displays the geosite location with the existing road access map. The study presents an innovative method for visualising and planning geotrail accessibility by superimposing maps of geosites, road networks, and transit hubs. This approach guarantees that geotrails are both ecologically sustainable and physically accessible, especially in rural and topographically difficult regions.

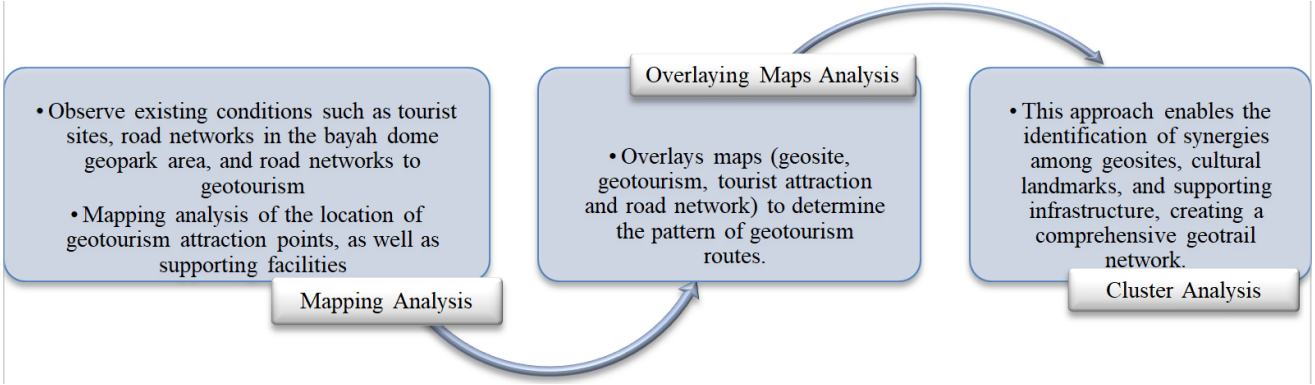

Figure 1. Stage of Analysis

To facilitate the recommendation of the appropriate geotourism route in this region. This integrated mapping approach significantly contributes to geotourism research by addressing deficiencies in accessibility planning identified in prior studies. The Santa Elena research, for example examining geosites and routes (e.g., GtRAM) and assessing local reception capacity, with an emphasis on integration with socio-economic activities (Herrera-Franco et al., 2022). The Williams and McHenry (2021) research investigates the application of Least-Cost Path (LCP) analysis for optimizing geotrails in a post-mining environment. It integrates GIS modeling, Analytic Hierarchy Process (AHP), and field validation to develop geotrails that correspond to user requirements, environmental limitations, and geotourism best practices. Current geotourism research has not extensively utilised advanced approaches, such as cluster analysis, to categorise geosites into accessible and interesting thematic itineraries. This constrains the capacity to create geotrails that accommodate varied visitor interests while ensuring efficient site administration.This study, however, innovates by applying cluster analysis to develop thematic trails in rural geoparks and highlights the importance of community involvement and sustainable infrastructure development.

RESULTS AND DISCUSSION

Lebak Regency is a region in Indonesia rich in natural beauty and cultural diversity that supports the tourism sector, however its development remains suboptimal. The development of geoparks as new and protected tourist destinations must be accompanied by enhancements in accessibility to promote sustainability and ensure competitiveness in tourism for the future. The Bayah Dome Geopark size in Lebak Regency encompasses 15 sub-districts, spanning a total size of 197,853 hectares. The demarcation of the region, encompassing over fifty percent of the total sub-districts in Lebak Regency, is established based on the presence of Geoheritage, Geodiversity, Biodiversity, and Cultural Diversity of significant value, which are managed for conservation, educational, and sustainable community economic development purposes.

A. Analysis of Attraction and Geotourism Support Facilities

Tourist attractions may be categorised as either natural or artificial. Natural attractions include beaches, waterfalls, mountains, caves, and similar features. Man-made attractions including museums, parks, ponds, and similar sites. Lebak Regency is a region with numerous tourist attractions. According to the Lebak Regency Culture and Tourism Office, there are 124 tourist sites; however, only 23 are incorporated in the Lebak Regency Regional Spatial Plan within the Bayah Dome Geopark Area (Figure 2). Notwithstanding the region's geological wealth, chances for geotourism development have been neglected, resulting in its geoheritage remaining mostly unexploited for tourism. The Bayah Dome Geopark Area features not only natural attractions distributed among its sub-districts but also encompasses cultural, religious, and manmade tourism opportunities. The presence of the Baduy Tribe Tourism Village in Leuwidamar District, Lebak Regency exemplifies existing cultural tourism. Furthermore, Malingping District features religious tourism. The georoute or geotrail, which integrates natural and cultural assets, is purposefully crafted for geotourism and geoeducation, with the objective of promoting geoconservation in rural regions (Carrillo-Hernández et al., 2024). Nonetheless, its complete geotourism potential remains unexploited. The quantity of tours in the Bayah Dome Geopark necessitates the development of this location, particularly for accessibility, including road condition and transit options.

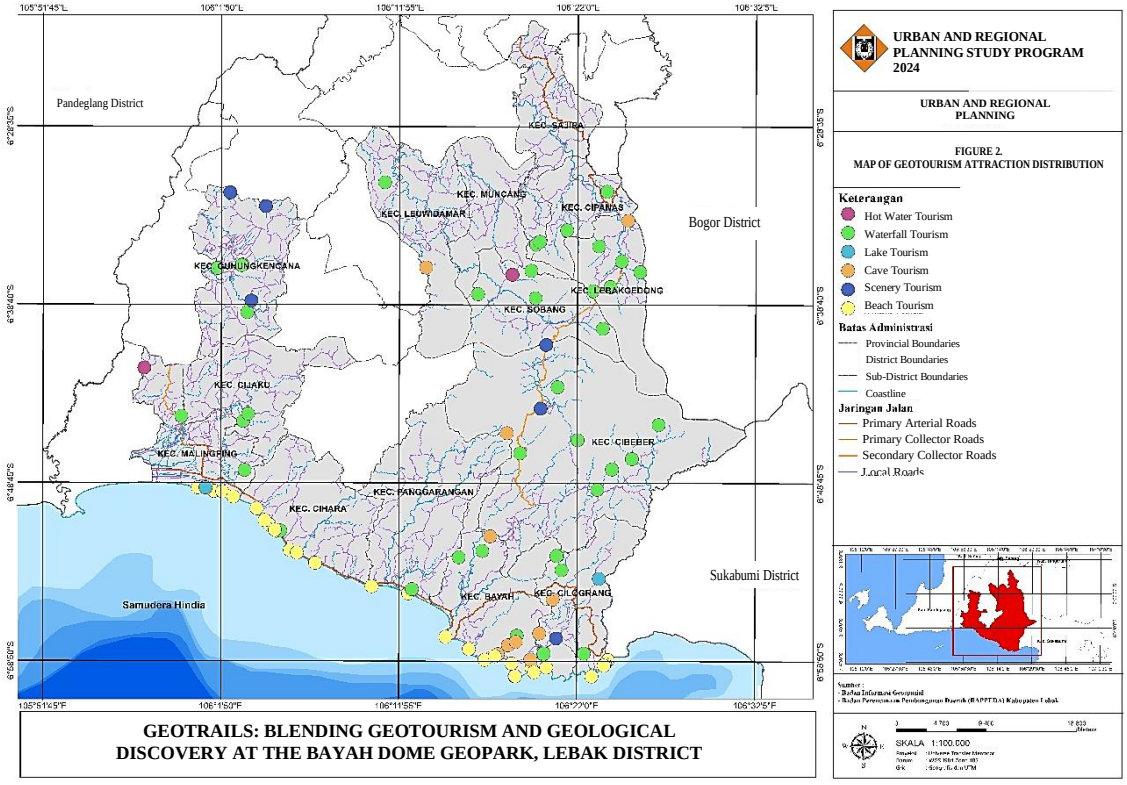

Figure 2. Map of geotourism attraction distribution (Source: Authors analysis, 2024)

Sawarna Beach, a renowned tourist destination in Lebak Regency, offers a coastal vista directly overlooking the Indian Ocean. Sawarna Beach is renowned for its white sand, towering surf, and many beaches featuring expansive coral formations. Sawarna Beach in the south features sufficiently large waves suitable for leisure activities, including surfing (Figure 3). Besides beaches, Bayah Dome Geopark offers mountain and scenery trips. The Negeri di Atas Awan tour, situated near Gunung Luhur, is a renowned mountain excursion within the Bayah Dome Geopark. The Negeri di Atas Awan trip is characterised by expansive natural vistas adorned with abundant white clouds. The Bayah Dome Geopark features waterfalls such as Curug Kadu Punah, Curug Munding, Curug Rame, among others. There are waterfalls, specifically the Citando hot springs, which emerge from behind the rocks around the spring, and the Tirta Lebak Buana hot spring situated in the Cipanas District. Lebak Regency features cave tourism, including Langir Cave, Seribu Candi Cave, and Lalay Cave, and others.

Figure 3. Geotourism Potential in Bayah Dome, Lebak Regency: a. Sawarna Beach features white sand and rather gentle waves b. Karang Taraje Sawarna Beach features sedimentary layers from ancient volcanic eruptions and coral formations resembling stairs c. The vista from Cikujang Peak encompasses Mount Anak Krakatau, which emerged in 1927, 43 years subsequent to the eruption of Mount Krakatau. d. Citorek Peak is situated in the mountainous region of Mount Luhur, offering breathtaking vistas of the sea of clouds (Source: Authors analysis; Lebak 2024)

Table 1 shows the number of visits, the Bayah *Dome Geopark* only has domestic tourists and there are no foreign tourists. In the Bayah *Dome Geopark* in 2023 there were 172,546 tourists who came to visit the existing tours. It can be seen from the table that several geosites has lesser, or no tourist since there is lack of access such as Sangiang Cave and Seupang Beach Tourism. Based on the data above, the majority of tourist visits are at the beach because of its easy access. Meanwhile, several points for caves and waterfalls still do not have good access. Apart from that, this data also shows that the majority of visitors are only local tourists.

Table 1. Number of Bayah Dome Geopark Tourists (Source: Culture and Tourism Office of Lebak Regency, 2023)

No.	Origin of Travelers	Destinations	Total	No.	Origin of Travelers	Destinations	Total
1	Local Tourist	Bagedur Beach	4,189	**11**	Local Tourist	Karang Bokor Beach	8,667
2	Local Tourist	Cibobos	1,777	**12**	Local Tourist	Karang Nawing	5,782
3	Local Tourist	Cipicung waterfall	593	**13**	Local Tourist	Cikujang Nature Panorama	525
4	Local Tourist	Ciporolak waterfall	450	**14**	Local Tourist	Cibareno Beach	7,198
5	Local Tourist	Munding waterfall	486	**15**	Local Tourist	Legon Pari Beach	10,919
6	Local Tourist	Sata waterfall	264	**16**	Local Tourist	Pulomanuk Beach	10,419
7	Local Tourist	Lake Talanca Beach	5,847	**17**	Local Tourist	Sawarna Beach	103,778
8	Local Tourist	Lalay Cave	15	**18**	Local Tourist	Seupang Beach	-
9	Local Tourist	Sangiang Cave	-	**19**	Local Tourist	Tirta Lebak Buana Hotspring	6,428
10	Local Tourist	Mount Luhur Citorek	5,208				
Total Tourist Visit 172,546							

B. Cluster and Path Analysis

Cluster analysis aims to group geoheritage objects and tourist objects that are agglomerated and become a consideration in determining tourist routes in one area so that it is easier to see the correlation from one object to another, where each object can be related to each other. This *clustering* can maximize the variation between clusters. Cluster analysis has been underutilized in geotourism research, with most studies emphasizing descriptive approaches to site identification. For example, Suzuki & Takagi (2018) focused on geosite evaluation but did not explore clustering methodologies to optimize visitor access and site management. This study's application of cluster analysis to group geosites into accessible and thematically cohesive routes represents a novel contribution, enabling better management of visitor flows and enhanced interpretive opportunities. *Clustering* in geosites and tourist attractions in the Bayah *Dome Geopark* Area can be seen in Figure 4.

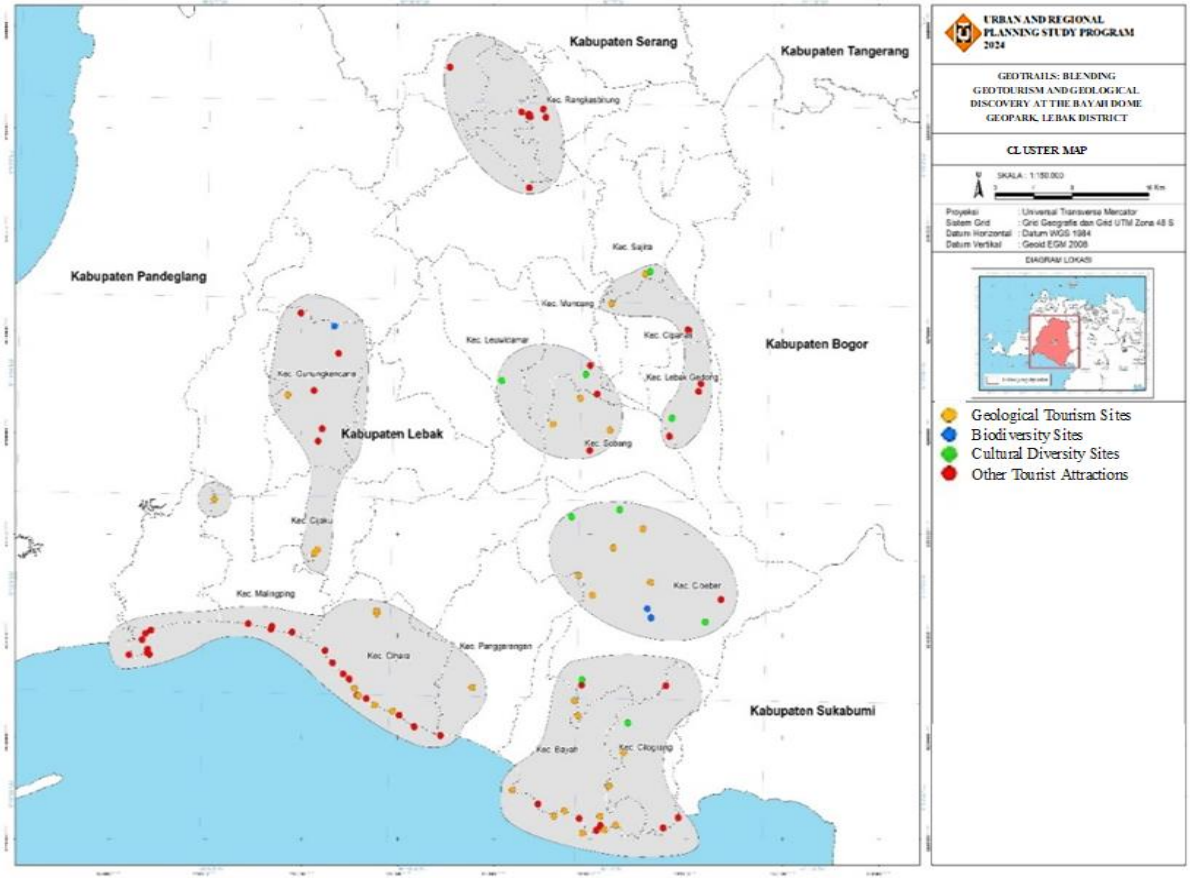

Figure 4. Cluster map (Source: Authors analysis, 2024)

During the clustering process, the initial category of geosite is determined, including geological, biological, cultural, and other tourism attractions in the region. The last phase involves establishing categories based on geographic closeness and accessibility. The analysis of tourism georoutes is conducted based on roadways that possess existing potential for development, facilitated by road classification and transportation infrastructure.

Table 2. Potential Roadways for Geotrail Access (Source: Authors Analysis, 2024)

	Status	Function	Length (km)	Description
1	National Road	Primary Collector 1	103,64	The connecting road between activity centers on the southern shore of Lebak serves as the sole access route, hence has the potential to function as a tourist pathway, particularly in this region abundant with tourist attractions and geosites. In the north, this national road serves as a vital access route to the Cipanas area, which boasts numerous attractions and geosites, so establishing its potential as a principal geotourism route.
2	Provincial Road	Primary Collector 2	156,39	The road linking to the southern region of Lebak is in relatively good condition and is frequently utilized by public transportation, including buses and local transit, to access the terminal in southern Lebak, indicating its clear potential as a tourist route.
3	District Road	Local Primary	157,83	This regency road serves as an access link between the Rangkas Bitung urban area and the southern region of Malimping. This route is typically utilized by public transit to the Malimping terminal and provides access to the Cihara-Bayah-Cilograng National Road. Its efficacy is notable due to the conditions and trip duration, indicating its potential as a tourism route. Furthermore, this road links the western and eastern regions of Lebak and serves as the primary route to Badui Village.
		Local Secondary	98,94	
4	Neighbourhood Road	Local Secondary	7,25	Local roads or village roads facilitate access to potential geotourism areas, with the expectation that these roads will enhance the accessibility of geotourism development.
			524,04	

This georoute examines the correlation between transportation infrastructure and tourist attractions distributed throughout the Bayah Dome Geopark Area. The accessibility of geosites is the primary criterion for selecting routes, taking into account the state of existing highways. There are four prospective routes and one designated development plan route available for geotourism. This prospective trajectory is illustrated in Figure 5 and Table 2 below.

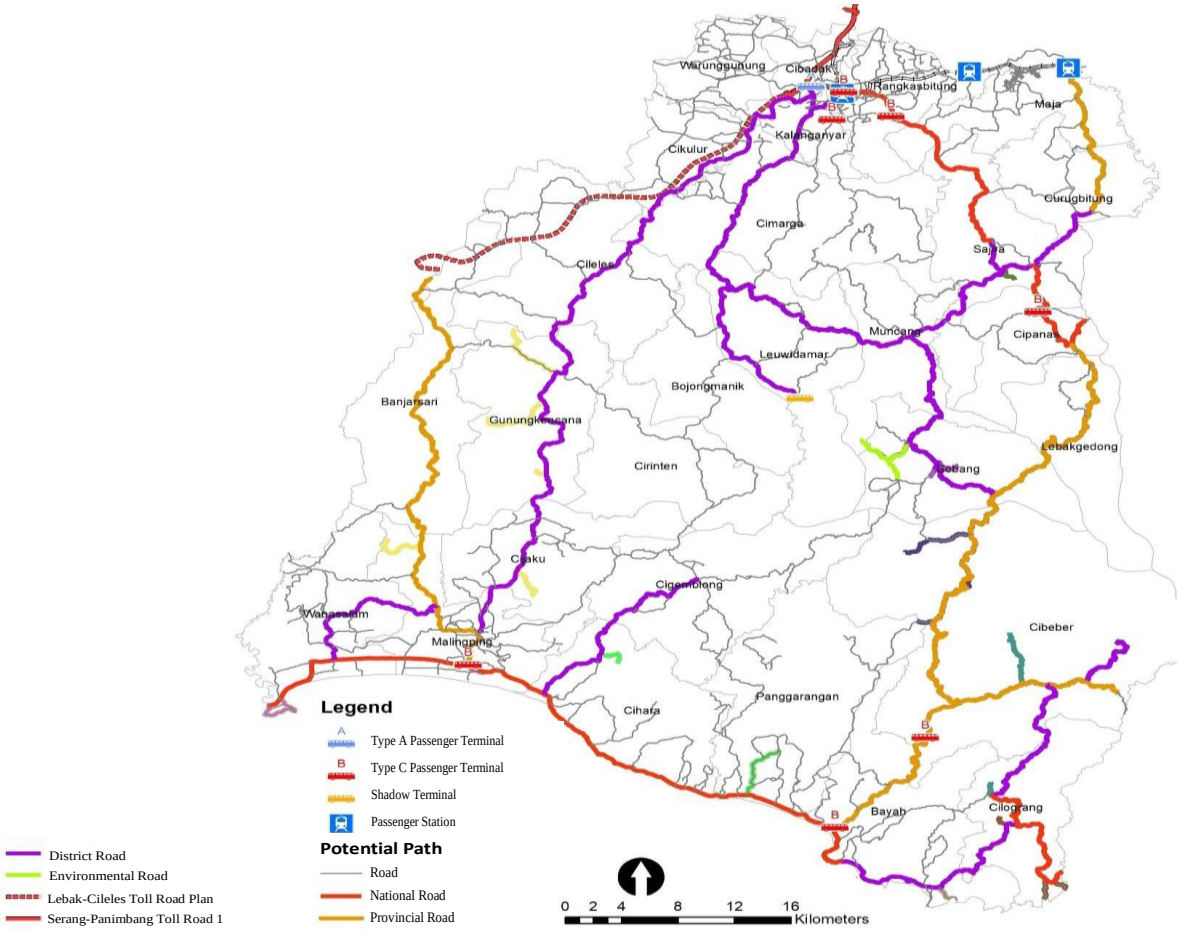

Figure 5. Road classification map (Source: Authors analysis, 2024)

In establishing this geotrail, it is essential to map the road network for accessibility, while also considering the location of the terminal that could serve as a HUB, along with other potential sub-hubs that may function as temporary stopping points for visitors to rest and obtain information about the geosite, as well as access and amenities related to their destination. Four roadways originate from Rangkasbitung City, which serves a HUB function, while both HUB and sub HUB are represented by terminals and stations, encompassing a toll road network that facilitates connectivity for tourists (Table 3). Subsequently, the HUB and Sub HUB will be outfitted with informational displays and transportation options for accessing geotourism. This georoute should ideally integrate all attractions, including geosites (geology, biology, culture, and social economy) and tourism sites, into a cohesive tourist path or route. This generates a multiplier effect from the construction of the Bayah Dome Geopark, including geoproducts, geotour guides, homestays, and more.

Table 3. Transportation Facilities to Connect Tourist Lines (Source: Authors Analysis, 2024)

Type	Hub/Sub Hub	Description
Maja Station	HUB	Maja Station that connects the regional road Jalan Maja-Koleang
Rangkasbitung Station and Mandala Terminal	HUB	Rangkasbitung Toll Gate, Rangkasbitung Station and Terminal, and Regional Road (Jalan Maja Raya)
Cileles Toll Road Plan	HUB	Cileles toll gate which is directly connected to the regional road Kaduangung-Cileles Road
Bayah Dome Geopark Information Center	HUB	Information center about Bayah Dome geopark as well as geotourism center in Lebak.
Citeras Station	Sub HUB	Connected to Maja and Rangkasbitung Stations, and connected to Cikande Rangkasbitung Highway on the border with Serang Regency.
Malingping Terminal	Sub HUB	Connecting Road Ps. Malingping and Jalan Simpang - Bayah
Bayah Terminal	Sub HUB	Connecting between Jalan Simpang - Bayah and Jalan Raya Bayah - Cikotok
Cikotok Terminal	Sub HUB	Connectors starting from the northern part, namely Terminal Rangkasbitung and the southern part, namely Terminal Bayah.
Cipanas Terminal	Sub HUB	Connected to Rangkasbitung Terminal
Ciboleger Terminal	Sub HUB	Connected to Rangkasbitung Terminal and Station, as well as Rangkasbitung Toll Gate
Rest area	Sub Hub	Locations that can be stops and rests and gathering points of geotourism

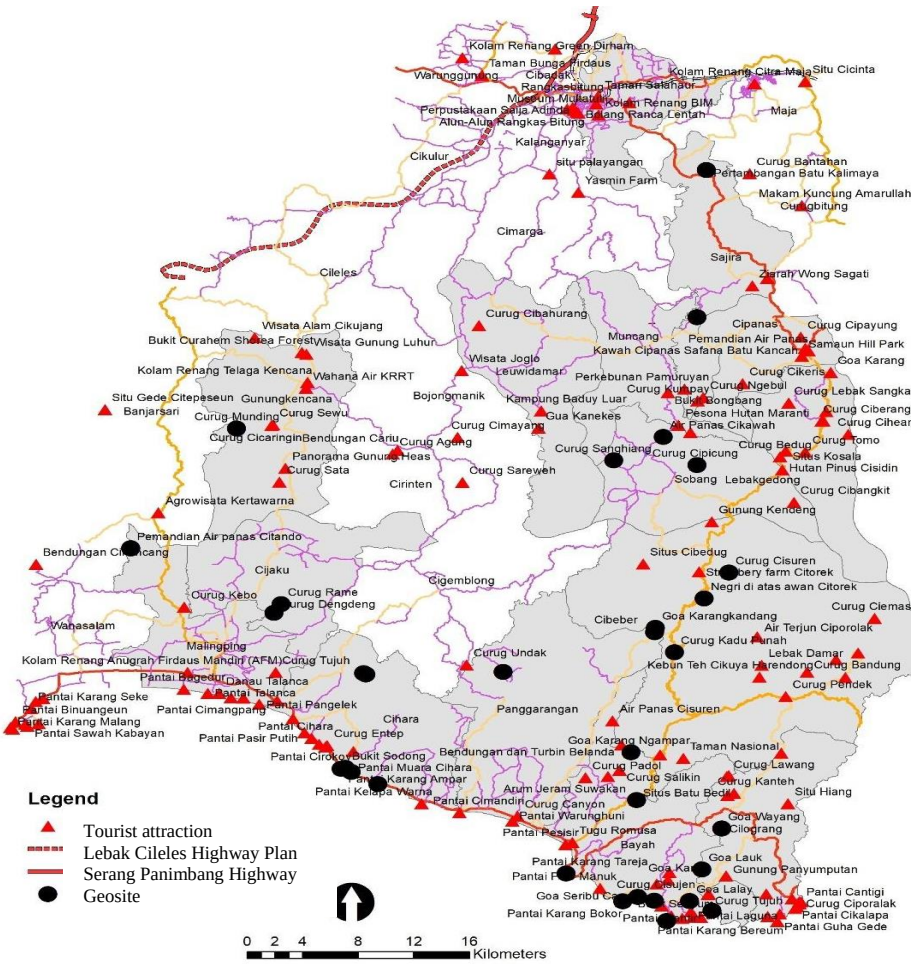

Figure 6. Map of geosites distribution and tourism objects in Geopark Bayah Dome, Lebak Regency (Source: Authors analysis, 2024)

Numerous geotourism studies concentrate on established or urban geoparks, neglecting the distinct issues faced by rural regions, including inadequate infrastructure, challenging topography, and insufficient public transportation networks. This study concentrates on the Bayah Dome Geopark, an area characterised by its agricultural nature and mountainous terrain. By evaluating current road networks, suggesting HUBs and sub-HUBs, and integrating local mobility options, it offers a scalable framework for addressing rural geotourism concerns. The distribution of sites and tourist attractions illustrated in Figure 6 indicates a concentration within a single area, which enhances its thematic appeal to visitors. The distribution presented will serve as important input for the subsequent grouping of areas to be discussed in Table 4.

Table 4. Geotourism trail themes and sub themes (Source: Authors analysis, 2024)

No.	Theme/Sub Theme	Geotourism Trail
A	**Coastal Scenic Scape**	
A.1	**Cihara Coral Bed** This sub-theme tells the story of the formation of millions of years of rock resulting from the melting of rocks on the beach and coral piles. The results of this formation create distinctive and unique shapes that can be used as a natural geological "laboratory".	▪ Information Center of Bayah Dome Geopark Center **(Infrastructure Site);** Bukit Curahem Shorea Forest **(Biological Site);** Malingping Ceu Bai Fish Baso **(Socio-Economic Site);** Malingping Terminal **(Infrastructure Site);** Bagedur Beach **(Nature Site);** Lake Mangrove Forest & Talanca Beach **(Biological Site);** Karang Nawing Beach **(Nature Site);** Karangmeja Beach **(Geological Site);** Karangampar Beach **(Nature Site);** Sodong Hill **(Geological Site);** Karang Songsong **(Geological Site);** Karangkamulyan Lignite **(Geological Site);** Kelapa Warna Beach (**Nature Site);** Cimandiri Beach **(Nature Site);** Bayah Terminal **(Infrastructure Site)**
A.2	**Tracing Ancient Delta Deposits** This sub-theme tells the story of the formation of rocks for millions of years as a result of melting rocks on the beach and piles of corals forming caves. The results of this formation create distinctive and unique shapes that can be used as a natural geological "laboratory".	▪ Bayah Terminal **(Infrastructure Site);** Karang Taraje Delta Deposits **(Geological Site);** Pulo Manuk Beach **(Nature Site);** Karang Bokor **(Geological Site)** ▪ Langir Cave Complex **(Geological Site);** *Geopark Product* Salequ Postharvest Ward **(Socio-Economic Site);** Ciantir Beach **(Nature Site);** Tanjung Layar **(Geological Site);** Legon Pari Beach (**Nature Site);** Turbidite deposits of Karang Taraje Sawarna **(Geological Site);** Seupang Beach (**Geological Site);** ▪ Tourism Information Center Sawarna **(Infrastructure Site)**
A.3	**Cilograng Karst Panorama** This sub-theme gives an overview of the formation of deltas and cliffs from the waves. The sensation of a typical cliffed beach atmosphere.	▪ Tourism Information Center Sawarna **(Infrastructure Site);** Lalay Cave **(Geological Site);** Lauk Cave **(Geological Site);** Cilograng MSME Gallery **(Socio-Economic Site);** Wayang Cave **(Geological Site);** Citarate Beach **(Nature Site);** ▪ Cibareno Beach **(Nature Site);** Cilograng Gunungbatu Gallery and Gazebo **(Infrastructure Site)**

B	**Science of Bayah Dome**	
B.1	**The Journey of Prabu Wong Sagati** The sub-theme that describes the upstream of the series of Bayah Dome formation by looking at the hills and beautiful hot springs.	▪ Bayah Dome *Geopark* Information Center or Maja Station **(Infrastructure Site)** ▪ Cadas Kudatuan (**Geological Site);** Wong Sagati Cemetery **(Cultural Site);** Samaun Hills Park **(Nature Site);** Tirta Lebak Buana **(Nature Site);** Cibolang Slope **(Socio-Economic Site);** Ciberang River Rafting **(Nature Site);** Kosala Site **(Cultural Site);** Kendeng Mountain Rest Area **(Infrastructure Site)**
B.2	**A journey through the land above the clouds** The main sub-theme of the Bayah Dome Geopark is because this sub-theme will provide an overview or story of the formation of the Bayah Dome which is the source of the story of this sub-theme.	▪ Kendeng Mountain Rest Area (**Infrastructure Site);** Kasepuhan Citorek **(Cultural Site);**Seren Taun Kasepuhan Citorek **(Intangible Site);** ▪ Cibedug Site (**Cultural Site);** Rest Area Citorek Tengah **(Infrastructure Site);** ▪ Curug Cisuren **(Geological Site);** Si Nyonya Goldfish **(Socio-Economic Site);** ▪ Awipis Cave Karang Kandang **(Geological Site);** ▪ Gunung Luhur **(Geological Site)**
B.3	**Uncovering Rocks from the Earth's Crust** This sub themes explained the geological evolution of this region has resulted in unique rock outcrops, some of which date back millions of years.	▪ Malingping Terminal **(Infrastructure Site);** Lake Mangrive Forest and Talanca Beach **(Biological Site);** Aci Kawung **(Socio-Economic Site);** Cihara Metamorphic Rocks **(Geological Site);** Cihara Granodiorite (**Geological Site);** Table Coral Beach (**Geological Site);** Karangampar Beach (**Nature Site);** ▪ Sodong Hill (**Geological Site)**
B.4	**Bayah Dome's "Central Belt" rural ambience** Sub-theme that describes the upstream of the series of Bayah Dome formation by looking at the formed waterfalls, hills, rocky rivers and beautiful sites.	▪ Bayah Dome *Geopark* Information Center **(Infrastructure Site);** Sempur Wood Fossils **(Geological Site);** Ranca Hideung Park (**Nature Site);** Meranti Customary Forest (**Biological Site);** Curug Cikawah (**Geological Site);** Hariang Gula Aren (**Socio-Economic Site);** Sanghiang Cave (**Geological Site);** Curug Cipicung (**Geological Site);** Kendeng Mountain Rest Area **(Infrastructure Site)**
C	***Goldmine Heritage***	
C.1	Traces of Indonesia's First Gold Mine A sub-theme that memorializes the oldest gold mine, the legacy of a private Dutch company, NV Mijnbouw Maatschappy Zuid Bantam, in 1839. Here this sub-theme if going to provide an experience back to the heyday of gold and other mineral materials	▪ Bayah Terminal **(Infrastructure Site);** Tugu Romusha **(Cultural Site);** Batu Bedil Site (**Geological Site);** Bantar Gadung Old Volcano Deposits **(Geological Site);** Cikotok Terminal (**Infrastructure Site);** ▪ Km 0 Antam Cikotok Gold Mine (**Cultural Site);** ▪ Cikotok Vein Access Crane/Hole (**Cultural Site);** ▪ Cirotan Mineralization Complex (**Geological Site);** ▪ Gunung Luhur (**Geological Site)**
D	**Eco-Culture of Indigenous People**	
D.1	**Baduy Cultural Saba** This sub-theme provides an experience of interacting with the life of the indigenous tribe of Lebak, namely Baduy, where this experience explores settlements with distinctive buildings, lifestyles and local wisdom that are still practiced today.	▪ Mandala Terminal/Rangkasbitung Station **(Infrastructure Site);** Aweh Terminal **(Infrastructure Site);** Cikapek Agrotourism (**Nature Site);** Baduy Traditional Village (**Cultural Site);** Baduy weaving (**Intangible Site);** ▪ Outer Baduy Forest (**Biological Site);** ▪ Eduwisata Kampung Landeuh (**Nature Site**); ▪ Multatuli Museum (**Cultural Site);** ▪ Bayah Dome Geopark Information Center (**Infrastructure Site)**
D.2	**"Kasepuhan" Forest Buffer Legacy** This sub-theme provides an experience to know the life of the Kasepuhan that still exist in Lebak, how to apply local wisdom that is unique to each Kasepuhan and an experience to learn about the community.	▪ Mandala Terminal/Rangkasbitung Station (**Infrastructure Site);** Kasepuhan Karang (**Cultural Site);** Meranti Customary Forest (**Biological Site);** Hariang Gula Aren (**Socio-Economic Site);** Kasepuhan Pasir Eurih (**Cultural Site);** Kasepuhan Citorek (**Cultural Site);** Si Nyonya Goldfish (**Socio-Economic Site);** Kasepuhan Cisungsang (**Cultural Site**); Cikuya Tea Garden (**Biological Site);** TNGHS (Lebak Damar) **(Biological Site);** Bayah Dome Geopark Information Center **(Infrastructure Site);**
E	***Urban Heritage* Rangkasbitung**	
E.1	**Rangkasbitung History Trail Room** Sub-themes that bring visitors back to the dimension of the colonial era, colonial building heritage, history of Multatuli and knowledge of the Bayah Dome Geopark.	▪ Mandala Terminal/Rangkasbitung Station **(Infastructure Site);** Former Oil Mill (**Cultural Site);** Water Torn Rangkasbitung (**Cultural Site);** Balong Ranca Lentah/Food Court of Rangkasbitung Square (**Socio-Economic Site);** Former Multatuli House **(Cultural Site);** Former Rangkasbitung Kewedanan House **(Cultural Site);** ▪ Multatuli Museum (**Cultural Site);** Rangkasbitung Square (**Infrastructure Site);** ▪ Imah Batik Sahate **(Socio-Economic Site);** ▪ Bayah Dome Geopark Information Center (**Infrastructure Site)**
E.2	**The beauty of religious tolerance in Rangkasbitung** This sub themes shows the story of home to various communities, including Sundanese, Javanese, and Baduy indigenous groups, who practice different faiths such as Islam, Christianity, Hinduism, Buddhism, and indigenous beliefs.	▪ Mandala Terminal/Rangkasbitung Station **(Infrastructure Site);** Ananda Avalokitesvara Monastery (**Cultural Site);** Rangkasbitung Chinatown (**Cultural Site);** Pasundan Church (**Cultural Site);** Immaculate Conception Catholic Church (**Cultural Site);** Balong Ranca Lentah/Food Court of Rangkasbitung Square (**Socio-Economic Site);** Al Araf Grand Mosque **(Cultural Site);** Tomb of Adipati Karta Natanagara (**Cultural Site);** Rangkasbitung Square (**Infrastructure Site);** Imah Batik Sahate (**Socio-Economic Site);** Cave of Mary Bukit Kanada (**Cultural Site**); ▪ Bayah Dome *Geopark* Information Center (**Infrastructure Site)**
E.3	**Menitis Culture Rangkasbitung** The sub themes pictures blending of indigenous traditions, historical influences, and local wisdom creates a unique cultural landscape that coexists harmoniously with nature. The beauty of culture in the Bayah Dome Geopark is reflected in its local communi-ties, traditional arts, rituals, and harmonious way of life.	▪ Mandala Terminal/Rangkasbitung Station **(Infrastructure Site);** ▪ Guriang Theater **(Cultural Site);** ▪ Sanggar Putra Panglipur (Penca drum making) (**Cultural Site);** ▪ Sanggar Lebak Membara (**Cultural Site);** ▪ Imah Batik Sahate (**Socio-Economic Site);** ▪ Multatuli Museum (**Cultural Site);** ▪ Balong Ranca Lentah/Food Court of Rangkasbitung Square (**Socio-Economic Site)**

F	Exploration The Beauty of Lebak	
F.1	**Exploring the Halimun Salak Mountains** The sub-theme that provides another picture of Lebak is seen from the beauty and coolness of nature at 700 above sea level. Another experience was enjoying Camellia Sinesis tea, one of the most expensive and high quality teas.	▪ Mandala Terminal/Rangkasbitung Station **(Infastructure Site);** Tirta Lebak Buana **(Nature Site);** Cibolang Slope (**Socio-Economic Site);** Kendeng Mountain Rest Area **(Infrastructure Site);** Kasepuhan Citorek **(Cultural Site);** Gunung Luhur (**Geological Site);** Cirotan Mineralization Complex (**Geological Site);** ▪ Cikuya Tea Garden (**Biological Site);** TNGHS - Lebak Damar (**Biological Site);** ▪ Curug Ciporolak (**Geological Site);** Kasepuhan Cisungsang (**Cultural Site);** ▪ Bayah Dome Geopark Information Center (**Infrastructure Site)**
F.2	**Discovering the Beauty of Waterfalls** Sub-theme that describes the upstream of the series of Bayah Dome formation by looking at the formed waterfalls, hills and beautiful sites.	▪ Bayah Dome *Geopark* Information Center (**Infrasctructure Site);** Bukit Curahem Shorea Forest (Biological Site); Curug Munding (**Geological Site);** Curug Rame (**Geological Site**); Curug Dengdeng (**Geological Site);** Malingping Ceu Bai Fish Baso **(Socio-Economic Site);** Malingping Terminal (**Infrastructure Site);** ▪ Citando Hot Springs (**Geological Site**)

C. Development of Geotrail Formulation

In developing a geotrail that also promotes geotourism, numerous aspects are taken into account:

One access road may serve as one or multiple geotourism routes characterised by a predominant feature.

1. Previously formed depending on market conditions and prior agreements
2. The designation of sub-themes will use local wisdom and the distinctive conditions of Lebak.

The guidelines for the establishment of this geotourism route comprised of:

1. Employ the Bayah Dome Geopark Information Centre as a central hub and knowledge repository for the Bayah Dome Geopark and the available geotourism routes.

2. Employ the terminals and stations of Rangkasbitung and Maja as hubs, as they serve as gathering points for tourists from diverse regions utilising this mode of transportation; hence, this transportation infrastructure must be organised to facilitate geotourism.

3. To facilitate access to the Bayah Dome Geopark via toll roads, collaboration with toll road operators is essential for promoting the Bayah Dome Geopark area.

4. Employ and establish terminals in additional locations of the Bayah Dome Geopark as Sub HUBs to serve as geotourism information centres.

5. Leveraging the site of the existing and forthcoming rest area as a Sub HUB, appropriate facilities and infrastructure are being developed to serve as a geotourism information centre.

This research introduces a systematic framework for geotrail development that integrates accessibility, thematic route design, and community involvement. The research provides geotrail routes that optimise tourist access by mapping transit hubs, existing road networks, and geosite sites, while ensuring ecological and cultural sustainability. This holistic approach distinguishes itself from prior studies, which frequently prioritises either conservation or visitor access, seldom integrating both cohesively into geotrail planning. In light of the aforementioned concerns, six principal themes and other sub-themes have been categorized, anticipated to engage visitors in accordance with their individual preferences. The subject of the geotrail is illustrated in the table below. The categorisation of geotrails into principal themes (e.g., Coastal Scenic Scape, Science of Bayah Dome, Goldmine Heritage) and subordinate themes (e.g., Tracing Ancient Delta Deposits, Baduy Cultural Saba) exemplifies a novel approach to accommodate varied visitor preferences. This theme organisation not only improves tourist engagement but also establishes a narrative-driven geotourism experience, a facet that has been little examined in previous research. It underscores the significance of narrative in linking tourists to the geological and cultural legacy of the area.

The principle of developing this geotourism path seeks to develop the pillars of conservation, appreciation and education of geological heritage, so that as emphasized by Garcia et al. (2022) this geotourism route needs to be managed properly in order to help realize conservation and preservation. This path will offer educational experiences through interpretive storytelling and thematic structuring. It also emphasizes the integration of local communities, such as the Baduy Tribe and Kasepuhan Villages, into geotourism planning, ensuring that the trails support cultural preservation and generate economic opportunities. This study shows that accessibility is highlighted as a critical factor for geotourism success. By identifying potential routes and integrating transportation hubs (e.g., stations, terminals, and rest areas) with geosites, the study proposes a model for improving geotourism access while minimizing ecological impacts. This dual focus on development and conservation offers a balanced perspective that advances theoretical discussions on sustainable tourism infrastructure (Carrillo-Hernández et al., 2024). The focus on rural geotourism offers a fresh perspective that has been relatively underrepresented in existing literature. The land use significantly affects the established geotourism route, necessitating the anticipation and management of risks, such as land conversion driven by economic opportunities along the geotrail, which eventually jeopardises environmental sustainability in the surrounding area. Consequently, this can be mitigated or regulated by managing the development along the geotrail route. These contributions enhance our comprehension of geotourism theory and provide practical solutions for establishing sustainable and inclusive geotrail networks.

This study's thematic organisation of geotrails corresponds with the global focus on improving tourist experiences via narrative-driven tourism. Prior research by Carrillo-Hernández et al. (2024) has emphasised the significance of thematic geotrails in fostering meaningful and educational visitor experiences. This study enhances the concept by amalgamating cultural and ecological diversity with geological characteristics, resulting in multidimensional geotrails that accommodate varied interests. The greater interconnectedness is less apparent in studies that concentrate exclusively on geological aspects (Dowling, 2023). Eventhough, Stolz & Megerle (2022) highlighted the difficulties of enhancing accessibility while maintaining ecological sustainability. This study reflects these concerns and offers practical answers by utilising existing road networks

and carefully positioning transportation hubs to minimise environmental disruption. This research distinguishes itself by integrating transportation and infrastructure planning into geotourism development, unlike studies that largely concentrate on site conservation (Morante-Carballo et al., 2023). The study's comprehensive methodology for geotrail planning functions as a replicable framework for geoparks globally. This research provides practical solutions for geoparks to improve their worldwide attractiveness and competitiveness in the tourism sector by illustrating methods for clustering varied geosites and creating thematic trails. The results are especially pertinent for geoparks in developing areas, where resource limitations and ecological sensitivities sometimes present considerable obstacles. This study demonstrates the equilibrium attained between accessibility and conservation, underscoring geotourism's capacity to advance sustainable development goals (SDGs) (Frey, 2021).

The findings enhance conversations on how tourism may promote conservation and education while minimising environmental damage and enhancing infrastructure, without jeopardising ecological integrity. This work establishes a standard for innovative geotourism planning through the integration of thematic geotrails, cluster and path analysis, community involvement. It solves current research deficiencies by offering a reproducible and sustainable concept for geoparks worldwide. The results indicate that geotourism can successfully harmonise conservation, education, and economic development, providing significant insights for policymakers, geotourism managers, and conservationists aiming to enhance the role of geoparks in promoting sustainable tourism.

CONCLUSIONS

The results of the Bayah Dome Geopark study provide substantial insights that extend beyond local and regional contexts, serving as a paradigm for geotourism development in geoparks globally. The amalgamation of infrastructure mapping, accessibility planning, and environmental conservation establishes a benchmark for sustainable geotourism development. Numerous geoparks encounter difficulties in preserving ecological integrity while enhancing accessibility. The Bayah Dome Geopark exemplifies the resolution of these difficulties by the strategic utilisation of existing road networks and traffic hubs, while concurrently minimising ecological disturbances. This strategy can be particularly advantageous for geoparks situated in isolated or rural areas with analogous topographical and biological limitations.

Thematic grouping facilitates geotrail construction and improves marketing and branding prospects. By establishing unique themes and tales, geoparks may appeal to various tourist demographics and foster unforgettable experiences. This branding strategy can assist geoparks globally in distinguishing themselves within a progressively competitive tourism sector.

The study offers a data-driven paradigm for establishing geotourism infrastructure, emphasising the significance of accessibility, geosite clustering, and transportation network integration. This approach enables policymakers to prioritise infrastructure expenditures, establish thematic tourism zones, and formulate policies to augment the competitiveness of geotourism in particular regions. The results correspond with national and regional sustainable development objectives, providing practical recommendations that can guide policy frameworks for geopark management and tourism growth.

This study on Geotrails in the Bayah Dome Geopark provides a comprehensive framework for geotourism development, accessibility enhancements, and geoconservation. However, there are several limitations that must be recognized. The research identifies infrastructure requirements, transit centers, and road networks; however, it does not quantitatively evaluate accessibility constraints, road conditions, or travel time. Deeper insights into the optimization of infrastructure improvements and visitor movement could be obtained through a more exhaustive transportation impact analysis. A comprehensive transportation impact analysis should evaluate the travel time between geosites, transit options, and road conditions. This could entail the implementation of alternative transportation solutions, such as eco-friendly shuttle services or cycle trails, as well as traffic flow modeling and accessibility heatmaps.

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