

Spatial clustering of geosites and tourism objects in Kebumen UNESCO Global Geopark: a kernel density approach

Pandita Hita^{1,3}, *Ni'mah Novi Maulida*^{2,3*}, and *Pramana A. Yunastiawan Eka*^{2,3}, *Putri Dhea Cahya Aprilia*, *Irawan Rio*², *Tambu Mario Savio Evodius*²

¹Study Program of Geological Engineering, Faculty of Engineering and Planning, Institut Teknologi Nasional Yogyakarta, Indonesia

²Study Program of Urban and Regional Planning, Faculty of Engineering and Planning, Institut Teknologi Nasional Yogyakarta, Indonesia

³Pusat Studi Geopark dan Lingkungan Berkelanjutan, Institut Teknologi Nasional Yogyakarta, Indonesia

Abstract. Geotourism serves as a catalyst for sustainable development in geoparks by linking conservation, education, and community-based economic growth. The Kebumen UNESCO Global Geopark in Central Java, Indonesia, possesses exceptional geodiversity and landscape diversity but remains underdeveloped in terms of spatially grounded geotourism planning. This study applies Kernel Density Estimation (KDE) to examine the spatial distribution and clustering of geosites and tourism objects, establishing a geospatial foundation for integrated geotourism development. Data were compiled from scientific publications and online platforms, and processed using GIS-based spatial analysis. The KDE results reveal four distinct spatial clusters, shaped by geological structure and tourism intensity. Among these, three form the core framework of Kebumen's geotourism identity: (1) the Northern Core Cluster, serving as the scientific and educational hub; (2) the Central Transitional Cluster, integrating cultural, artificial, and educational attractions; and (3) the Southern Coastal Cluster, representing the main nature-based and recreational tourism corridor. Supporting clusters in the peripheral plains indicates potential for community-driven and rural tourism initiatives. This spatial structure highlights the complementarity between geological and tourism assets, providing a basis for thematic differentiation, spatial integration, and balanced regional growth.

1 Introduction

Geopark development has increasingly emerged as a strategic instrument for sustainable regional development, combining conservation, education, and economic development through geotourism. In Indonesia, geopark development has been elevated as a national

* Corresponding author: novimaulida@itny.ac.id

priority program, aligning with government initiatives at both central and regional levels [1]. The three pillars of geopark development, including conservation, economy through tourism, and education, create a framework that supports holistic regional development while fostering local engagement and resilience [1]. Within this context, geotourism becomes a crucial driver, as it not only enhances geoheritage value but also integrates it into broader socio-economic systems that empower communities.

Globally, UNESCO Global Geoparks have been recognized as platforms for sustainable development through bottom-up territorial management, with geotourism serving as a significant mechanism to balance conservation with community-based economic benefits [2]. The Kebumen Geopark, situated in Central Java, Indonesia, is one of the UNESCO Global Geoparks (UGGp) designated sites [3]. Rich in natural landscapes, biodiversity, and cultural heritage, the area's geotourism potential remains largely underdeveloped. Unlocking this potential requires spatially informed strategies that can map and strengthen clusters of geotourism sites, ensuring both accessibility and sustainability. By analyzing patterns of spatial concentration, geotourism clusters can be identified as priority zones where conservation, tourism, and education can be most effectively synergized. This process directly supports sustainable development by linking environmental stewardship with socio-economic advancement.

Spatial clustering is a crucial analytical approach for identifying priority zones for geotourism development. Prior studies in the Kebumen Geopark have applied classification methods to define development subregions, showing how the northern, western/southern, and eastern areas offer different potentials and challenges [4]. Such classification lays the foundation for more detailed spatial analyses, including Kernel Density Estimation (KDE), which can capture the intensity and spatial distribution of geotourism resources. Identifying high-density clusters enables planners to focus investments, enhance infrastructure, and design integrated tourism routes that enhance both visitor experiences and local economic opportunities. In this way, spatial clustering contributes directly to regional planning and territorial development. Beyond its technical contributions, spatial analysis plays a crucial role in facilitating participatory and inclusive governance of geoparks. UNESCO guidelines emphasize that geopark management should follow a bottom-up approach, involving local communities in planning and decision-making [2]. Geographic Information Systems (GIS) and spatial clustering methods can support this vision by producing maps and visual tools that translate complex data into accessible information for stakeholders. Such tools not only guide policymakers but also empower communities to understand and shape their territories, thereby reinforcing local ownership of development initiatives.

For the Kebumen Geopark, identifying clusters through kernel density analysis provides a scientific basis for balancing regional development with conservation, thereby ensuring that the most vulnerable sites are protected. The integration of spatial clustering into geotourism planning and development also addresses a broader gap in geopark research and practice. As highlighted in a global bibliometric review, much of the current scholarship on geoparks still leans toward inventory-focused and quantitative assessments, with relatively less emphasis on applied strategies for sustainable development [5], [6]. By applying kernel density approaches to the Kebumen Geopark,

this research bridges that gap by offering methodological insights that combine scientific rigor with practical planning implications.

2 Methods

2.1 Research Area

The Kebumen UNESCO Global Geopark (UGGp) is situated in Kebumen Regency, Central Java, Indonesia. The geopark's development began in 2004, when the South Gombang Karst Landscape was designated a sustainable development area, followed by the designation of the Karangsembung Geological Nature Reserve in 2006. It was later formalized as the Karangsembung–Karangbolong National Geopark in 2018, and subsequently expanded and renamed Kebumen Geopark through Regent Regulation No. 25/2023, now covering 1,138.70 km² of land and 21.98 km² of sea across 22 districts and 374 villages (Figure 1).

Administratively, Kebumen Regency covers approximately 1,281 km² and comprises 26 districts, 449 villages, and 11 urban wards, with a population of approximately 1.2 million. On April 17, 2025, Kebumen Geopark was recognized as a UNESCO Global Geopark, affirming its global significance as a site where geological, biological, and cultural values converge to support sustainable regional development.

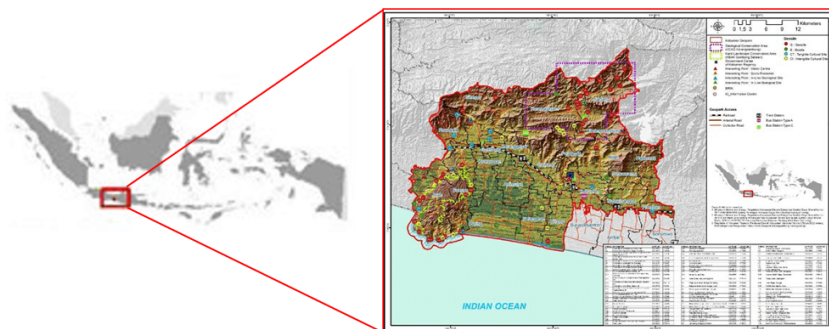


Fig. 1. Map of Kebumen Geopark (Source: <https://geoparkkebumen.id/>)

2.2 Research Data and Analysis

The data processing and analysis in this study were designed to systematically examine the spatial structure of geosites and tourism objects within the Kebumen UNESCO Global Geopark. The methodological framework integrates quantitative spatial analysis and geostatistical interpretation using ArcGIS and QGIS environments. The process was divided into two main stages, data preparation and spatial analysis, resulting in three analytical outputs: (1) spatial profiling, (2) Kernel Density Estimation (KDE) analysis, and (3) geotourism concentration mapping (Figure 2).

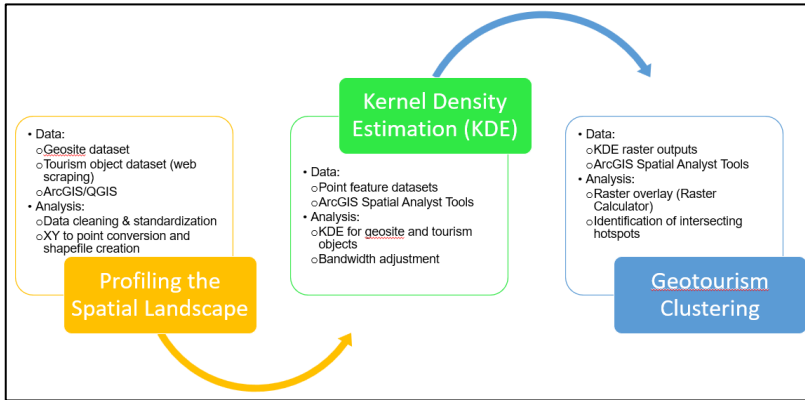


Fig. 2. Data processing and spatial analysis workflow

3 Results

3.1 Profiling the Spatial Landscape: An Overview of Geosites and Tourism Objects

The assessment of 41 geosites across Kebumen UNESCO Global Geopark reveals a diverse range of geological features with varying scientific, educational, tourism, and conservation values [7]. The final composite scores (averaged from Scientific Value, Educational Value, Tourism Value, and Degradation Risk) range from 235.25 to 321.50, reflecting the heterogeneity in geological significance and tourism potential across the region (Figure 3).

The analysis identifies several high-value geosites, particularly in the northern zone (Karangsambung area), that stand out for their exceptional geological integrity and educational potential; in the southern zone (Karangbolong–Ayah), these areas represent both high scientific importance and strong tourism appeal. Geographically, many globally significant sites are concentrated in the Karangsambung region, confirming its historical role as the geological heart of Kebumen. Meanwhile, national-level and local-level geosites are more evenly distributed across both northern and southern zones.

Meanwhile, a total of 74 tourism objects were identified across the regency and classified into three main categories (Figure 3): natural, artificial/recreational, and cultural-historical attractions. Nature-based tourism sites make up approximately 70% of all attractions. These sites are primarily concentrated along the southern coastal corridor, particularly within the Ayah, Buayan, Puring, and Mirit Districts, which collectively form the regency's central tourism belt. Artificial and recreational tourism attractions account for about 15–20% of the total. Such sites are mainly located in Pejagoan, Kebumen City, and Alian, areas characterized by higher accessibility and proximity to urban centers. Cultural and historical attractions account for approximately 10% of all sites. These cultural landmarks are concentrated in Gombong and Kebumen City, serving as focal points for heritage-based tourism and the preservation of local cultural identity.

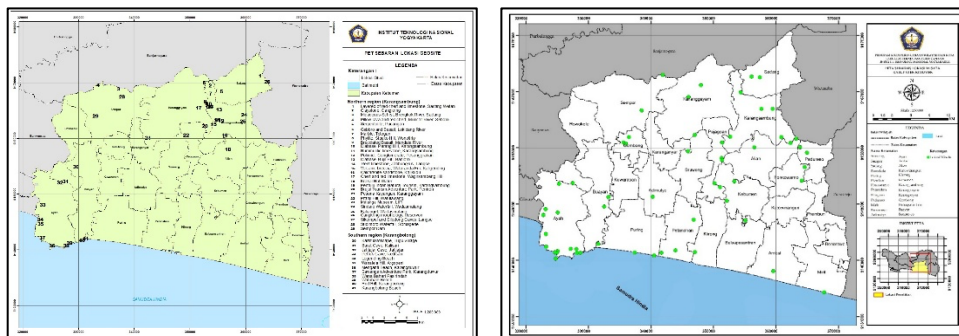


Fig. 3. Distribution of geosite (left) and tourism objects (right) in Kebumen regency

Spatially, the distribution of tourism objects exhibits a distinct south–north pattern that closely aligns with Kebumen’s physical geography and accessibility. The southern coastal corridor aligns with the coastal geomorphology, major transport routes, and high-visibility attractions, illustrating the region’s geological and scenic richness. In contrast, the northern upland area around Karangsambung and Karanggayam features a concentration of educational and geological tourism, anchored in geological, riverine, and hilly landscapes associated with the Kebumen UGGp, linked to key geosites of the geopark, and functioning as outdoor laboratories that integrate scientific, educational, and recreational values. Additional localized concentrations are observed in Sempor, Pejagoan, and Kebumen City, where tourism assets are more diverse, combining recreational, cultural, and urban attractions, supported by improved infrastructure and accessibility.

3.2 Mapping Tourism Hotspots: Kernel Density Analysis

The Kernel Density Estimation (KDE) analysis map illustrates the spatial distribution and concentration of geosites within the Kebumen UNESCO Global Geopark (Figure 4). The resulting pattern reveals a distinct clustering in the northern region, particularly across the Karangsambung–Karanggayam–Sadang area. These areas also coincide with the core of the *True Mother Earth Geotrail*, which integrates geological, biological, and cultural elements into a cohesive geotourism corridor that emphasizes educational interpretation of ancient tectonic processes [8]. In the southern part of Kebumen, where karst and coastal geomorphology dominate, geosites appear more dispersed but retain substantial geomorphological and geotourism value, as highlighted in early surveys of the Karangbolong sector [9]. These areas include cave and coastal formations representing the karstic continuation of the northern subduction-derived terrain.

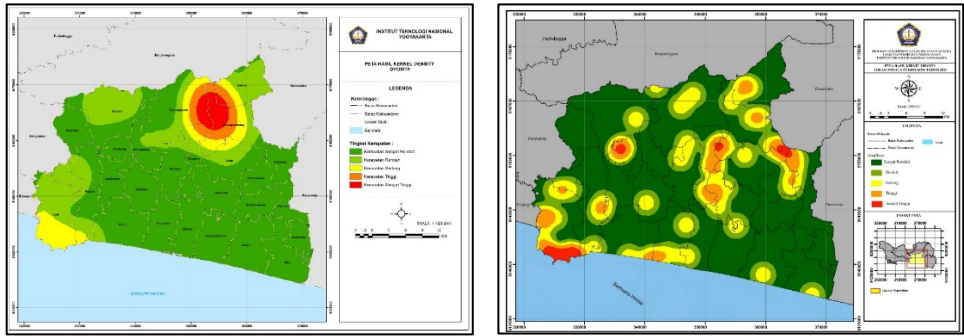


Fig. 4. KDE analysis of geosite (left) and tourism objects (right) in Kebumen regency

The KDE analysis of tourism objects reveals a multicentric spatial pattern that reflects both the physical geography and accessibility network of Kebumen Regency (Figure 4). The southern coastal belt, particularly in Ayah District, is the most tourism-intensive area. This corridor, which also includes the Buayan, Puring, and Petanahan Districts, encompasses the regency's flagship coastal and karst destinations, which collectively serve as the backbone of Kebumen's nature-based and recreational tourism, partly due to their high visitor satisfaction, diverse attractions, and infrastructure readiness.

Moving northward, secondary concentrations emerge across districts of Gombang, Pejagoan, Kebumen, Alian, Padureso, and Poncowarno, where the tourism landscape transitions from predominantly natural attractions to cultural and artificial tourism. In the northern upland zone, particularly within Karangsembung and Sadang Districts, moderate to high tourism densities are observed, driven by their proximity to major geosites. Through this integration, regional competitiveness can be strengthened, local attractions can evolve more sustainably, and geotourism can serve as a unifying platform linking nature, culture, and community-based innovation within the Kebumen UNESCO Global Geopark.

The results of the KDE analysis for geosites and tourism objects within the Kebumen UNESCO Global Geopark reveal distinct spatial structures, reflecting the different functional and geomorphological characteristics of each dataset. While the geosite KDE displays a highly concentrated and scientifically oriented pattern, the tourism object KDE shows a more dispersed, accessibility-driven distribution across multiple centers and diverse attractions.

3.3 Geotourism Clusters: Integrating Geosite and Tourism Object Densities

The overlay of Kernel Density Estimation (KDE) results for geosites and tourism objects reveals a clear spatial pattern in geotourism activity across the Kebumen UNESCO Global Geopark (Figure 5). Based on the map, the interpretation was carried out by also considering the existing geotrail model and the accessibility of the area [8]. The interpretation results indicate three core clusters and one supporting cluster, each reflecting distinct functional and thematic roles (Table 1 and Figure 6).

The Northern Core Cluster, encompassing the Karangsembung–Karanggayam–Sadang–Sempor area, represents the scientific and educational nucleus of the geopark. The Southern Coastal Cluster, spanning the districts of Ayah, Buayan, Puring, Kuwarasan, Adimulyo, and Petanahan, constitutes the regency’s main nature-based tourism corridor, exemplifying the fusion of geological and recreational appeal. The Central Transitional Cluster, which includes Rowokele, Gombong, Karanganyar, Sruweng, Pejagoan, Alian, Kebumen City, Kutowinangun, Prembun, Poncowarno, and Padureso, serves as a connective belt between the scientific north and the recreational south. This zone integrates cultural landmarks, educational sites, artificial attractions, and urban amenities, representing the spatial diversification of tourism functions. Peripheral districts and low-density plains, such as Klirong, Buluspesantren, Ambal, Mirit, and Bonorowo, hold potential for rural and educational geotourism, aligning with community-driven geotourism approaches. Although the area remains agriculturally dominant, it could be incorporated into thematic or village-based tourism networks to promote locally grounded, sustainable tourism growth.

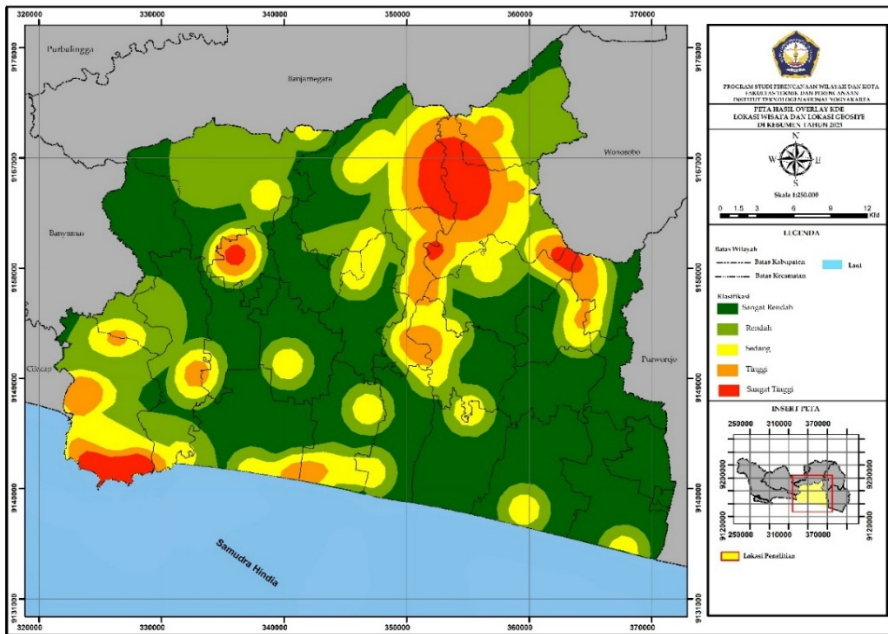


Fig. 5. Spatial cluster of geotourism through KDE analysis

Table 1. Geotourism Cluster Potential in Kebumen UNESCO Global Geopark

Cluster Zone	Dominant Characteristics	Interpretation
1. Northern Core Cluster - Karangsembung–Karanggayam–Sadang–Sempor	Scientific and educational core; dense concentration of geosites.	Serves as the geological and scientific nucleus of Kebumen Geopark, supporting research, education, and conservation-based geotourism.
2. Central Transitional - Rowokele, Gombong,	Mixed natural, cultural, and artificial attractions linked	Acts as a functional transition belt connecting the northern

Cluster Zone	Dominant Characteristics	Interpretation
Karanganyar, Sruweng, Pejagoan, Alian, Kebumen City, Kutowinangun, Prembun, Poncowarno, dan Padureso	by major transportation corridors; moderate geosite density with substantial tourism diversity.	scientific core with the southern recreational zones; it serves as a hub for heritage, education, and urban leisure tourism.
3. Southern Coastal Cluster - Ayah, Buayan, Puring, Kuwarasan, Adimulyo, and Petanahan	Coastal–karst landscape with beaches, cliffs, and caves; a dominant nature-based tourism zone.	Represents the recreational and nature-based tourism hub, integrating karst, coastal, and cultural landscapes.
4. Peripheral Low-Density Zones - Klirong, Buluspesantren, Ambal, Mirit, and Bonorowo	Scattered sites, mainly agricultural and settlement landscapes.	Areas with low geotourism intensity but possible inclusion in thematic tourism networks.

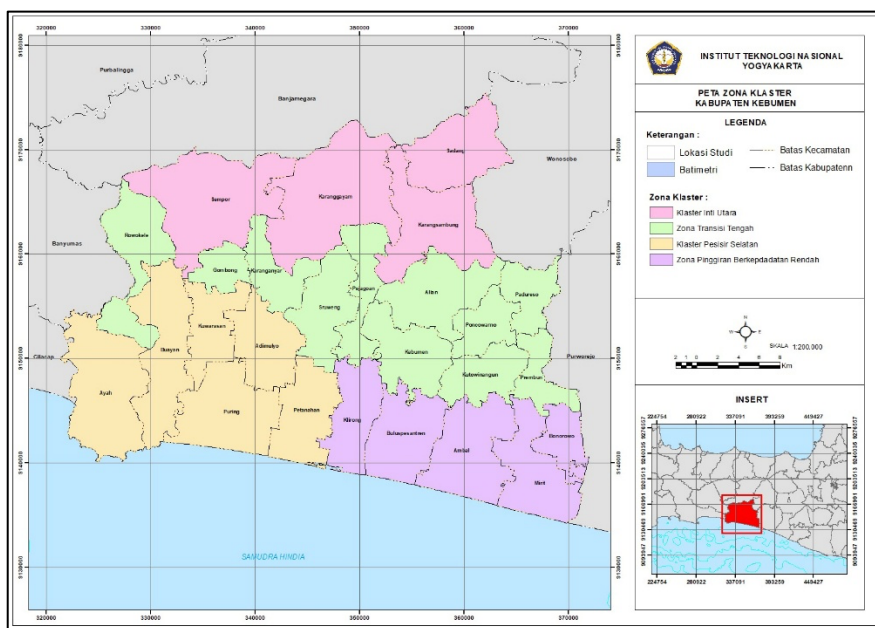


Fig. 6. Geotourism cluster in Kebumen Geopark: Northern Core Cluster (Pink); Central Transitional Cluster (Green); Southern Coastal Cluster (Orange); and Peripheral Low Density Zones (Purple).

4 Conclusion

The Northern Core Cluster exhibits the scientific and educational nucleus of the geopark. This area encompasses the Karangasambung geological complex, internationally recognized for its diverse rock assemblages and long-standing role as a natural laboratory for research and learning. The Southern Coastal Cluster forms the principal nature-based tourism corridor, creating Kebumen’s most vibrant tourism landscape. Meanwhile, the Central Transitional Cluster functions as an intermediary belt connecting the northern

scientific zone and the southern recreational corridor, integrating cultural landmarks, artificial attractions, and urban leisure destinations.

Collectively, this spatial configuration demonstrates how geosites and tourism objects form a multi-nodal geotourism system that integrates scientific, recreational, and cultural dimensions. The three main clusters represent the core identity of Kebumen Geopark: scientific in the north, recreational in the south, and integrative in the center. The remaining areas serve as supportive zones that enhance inclusivity and local participation. This structure reinforces Kebumen's identity as a geopark-based tourism landscape, balancing conservation, education, and regional competitiveness within a coherent spatial framework.

References

1. F. Lestari and I. Indrayati, Pengembangan kelembagaan dan pembiayaan geopark di Indonesia: Tantangan dan Strategi, *J. Reg. Rural Dev. Plan.* **6**(2), 102–122 (2022). doi: 10.29244/jp2wd.2022.6.2.102-122.
2. E. M. Rosado-González, J. M. M. Lourenço, J. L. Palacio-Prieto, and A. A. Sá, Collaborative mapping on sustainable development goals in Latin America UNESCO global geoparks: A methodological discussion. *Int. J. Geoheritage Park.* **11**(2), 203–220 (2023). doi: 10.1016/j.ijgeop.2023.02.002
3. A. A. Siregar, Analisis konsep pembangunan berkelanjutan dalam aspek geowisata pada geopark Kebumen. *J. Semarak Kabumian*, **2**(1), 9–17 (2024)
4. F. F. Affandi, D. A. Styawan, and S. Suharto, Pengembangan kawasan geopark kebumen berbasis karakteristik topografi dan potensi ekonomi lokal. *J. Semarak*, **1**(2), 46–56 (2023)
5. M. E. Pérez-Romero, J. Álvarez-García, M. B. Flores-Romero, and D. Jiménez-Islas, UNESCO Global Geoparks 22 Years after Their Creation: Analysis of Scientific Production. *Land.* **12**(3), (2023). doi: 10.3390/land12030671
6. V. Gupta, S. Anand, D. Wei, G. Wang, and S. C. Tripathi, Exploring applied sustainable strategies through geoheritage and geotourism: A systematic literature review. *Int. J. Geoheritage Park.* **12**(4), 660–677 (2024). doi:10.1016/j.ijgeop.2024.11.009
7. C. Ansori, N. I. Setiawan, I. W. Warmada, and H. Yogaswara, Identification of geodiversity and evaluation of geosites to determine geopark themes of the Karangsembung-Karangbolong National Geopark, Kebumen, Indonesia. *Int. J. Geoheritage Park.* **10**(1), 1–15 (2022). doi: 10.1016/j.ijgeop.2022.01.001.
8. C. Ansori, A. Kusworo, N. Mareta, D. Hastria, and I. N. Y. Putro, The True Mother Earth Geotrail, in Kebumen Geopark. *IOP Conf. Ser. Earth Environ. Sci.* **1424**(1), (2024). doi: 10.1088/1755-1315/1424/1/012011.
9. C. Ansori, Geosite identification in Karangbolong High to support the development of Karangsembung-Karangbolong Geopark candidate, Central Java. *IOP Conf. Ser. Earth Environ. Sci.* **118**(1), (2018). doi: 10.1088/1755-1315/118/1/012014.