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RESEARCH ARTICLE

Locating Geodiversity Hotspots through Grid-Based Spatial Indexing: Lombok Island, Indonesia

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Abstract

Locating geodiversity hotspots across large areas poses a challenge for further geopark development in Indonesia, especially on Lombok Island, which spans 5,435 km². A geodiversity hotspot is an area rich in unique geological features that need to be determined. Therefore, this study's objective is to track and assess the potential of geodiversity on Lombok Island. The methods employed a grid-based spatial indexing method to pinpoint potential geodiversity hotspots in Lombok. The entire island was covered using 238 grids of 5×5 km² for this study. The technique applied these equal weight parameters: relative drainage density (20%), diversity of topographical slope (20%), elevation (20%), diversity of geological formation (20%), and soil characteristics (20%). The identified geodiversity hotspots were validated through ground checking.

The results show significant geodiversity hotspots: Gangga (116°12'13.122"E;8°21'24.154"S), Sikur (116°24'32.015"E;8°29'23.597"S), Bayan (116°32'33.211"E;8°16'22.39"S), Sembalun (116°29'18.063"E;8°23'22.156"S), Sambelia (116°35'40.856"E;8°24'1.371"S), and Gerung-Kuripan (116°8'20.085"E;8°41'46.513"S). These hotspots showcase a range of lithologies from the Oligo-Miocene to the Plio-Pleistocene, along with terrestrial and marine fossils, minerals, geothermal activities associated with the Rinjani Volcano, and diverse soil types that support rich biodiversity. The dense drainage systems in these regions create stunning waterfalls and distinct elevational ecosystems. Tourism is primarily concentrated in well-known sites like Sembalun and Gerung-Kuripan, while lesser-known areas such as Sambelia, Gangga, Sikur, and Bayan remain underexplored. The natural drainage systems in these hotspots play a crucial role in hydrology and contribute to the beautiful landscapes.

This study concludes that Lombok Island has six significant geodiversity hotspots, which hold geological importance for supporting the geoheritage of the Rinjani-Lombok UNESCO Global Geopark. The findings contribute to promoting local development by integrating cultural aspects and ensuring sustainability in line with global sustainable development goals. Additionally, the study provides new insights into the geotourism potential that can support sustainable development within the Rinjani-Lombok UNESCO Global Geopark.

Keywords: Geopark, Geotourism, Sustainable development, Geoconservation, grid-based spatial indexing.

1. Introduction

Geodiversity refers to the variety of geological elements, such as rocks, minerals, and fossils, along with geomorphological features, soil types, and physical processes that shape the landscape of an area (Brilha et al., 2018; Gerstner et al., 2024; Serrano and Ruiz-Flaño, 2007; Tukiainen et al., 2023). This concept includes all non-biological components of Earth's physical environment, spanning different spatial and temporal scales. Regions with high geodiversity often support rich biodiversity, providing diverse soil characteristics and landforms that foster the development of various ecosystems (Natalia et al., 2021; Tukiainen et al., 2023). These regions, known as geodiversity hotspots, offer valuable insights into the Earth's history, the evolution of life, and natural processes (Bétard et al., 2018; Bétard and Peulvast, 2019; Kaur, 2022; Quesada-Valverde and Quesada-Román, 2023). By identifying geodiversity hotspots, valuable information about the Earth's history, the evolution of life, and natural processes can be better understood. This leads to efforts in natural resource conservation, including the conservation of geological resources that are essential for human life over long periods (Wallis et al., 2021).

This conservation effort aligns with the objectives of the UNESCO Global Geopark Initiative, which integrates nature tourism within unique scenic landscapes, enabling local communities to participate in economic development through tourism. One notable example in Indonesia is the UNESCO Global Geopark Rinjani-Lombok, located on Lombok Island in West Nusa Tenggara (**Figure 1**). This geopark encompasses the area of Mount Rinjani and its surroundings, which are renowned for their natural beauty and geological diversity, as well as biodiversity, culture, and the cultural history of the Nusantara (Idrus et al., 2021; Wahyudin et al., 2023). The Rinjani-Lombok Geopark has significantly contributed to conservation, education, and community empowerment and has become an international tourist destination (Kartika and Wibisono, 2020; Wahyudin et al., 2023). These examples clearly illustrate how geodiversity, encompassing a wide range of geological elements, geomorphological features, and related processes, plays a vital role in supporting biodiversity, informing conservation efforts, and promoting geotourism. The Rinjani-Lombok Geopark showcases geological and ecological diversity, providing valuable insights into Earth's history and promoting sustainable community development.

Nevertheless, the identification of geodiversity still requires attention, considering the importance and need for a deeper understanding of scientific information, including geological data studies and their implications for the surrounding ecology (Harbowo, 2023; Natalia et al., 2021). Despite the acknowledged significance of geodiversity, there remains a critical need for more efficient, rapid, and cost-effective methods for identifying geodiversity hotspots. Moreover, a richer scientific understanding of the complex interactions between geological data and environmental impacts is needed. This is crucial because of the potential vulnerability of ecosystems, threat of degradation from global climate change, and continuously growing human activities on the island (Harbowo and Muliawati, 2023; Mahrup et al., 2021). Additionally, challenges related to increasing public awareness and ensuring sustainable tourism management under growing anthropogenic pressures remain unresolved. These efforts aimed to preserve the environmental conditions and geoheritage inherited in this geopark area. These initiatives must involve various stakeholders, including the government, scientists, local communities, and non-governmental organizations (Harbowo, 2023; Kartika and Wibisono, 2020).

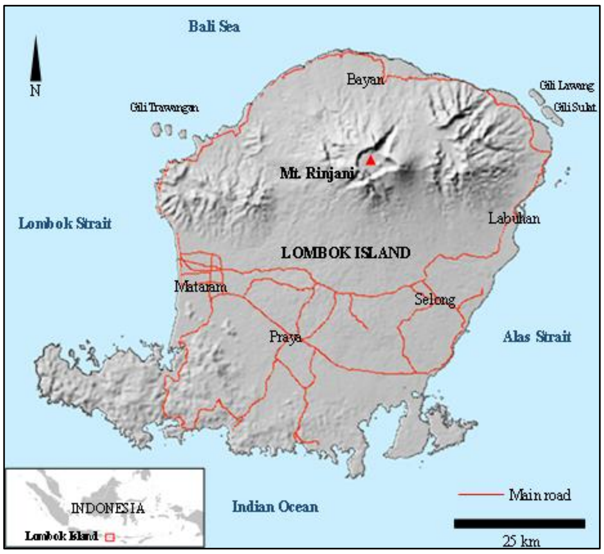

Fig 1. Representative map of Lombok Island, Indonesia.

Therefore, in this study, we aim to track and determine the potential of geodiversity on Lombok Island as a form of rapid identification to anticipate potential environmental disturbances while simultaneously exploring opportunities for community-based geotourism development. Identifying geodiversity typically requires significant time and operational costs; thus, we have designed an effective preliminary method using a grid-based spatial indexing approach that can later be validated through detailed field surveys. This method has been successfully applied in regional geodiversity assessments in various countries (Ahmadi et al., 2022; Atkinson and De Clercq, 2022; Toivanen et al., 2024). We emphasize that recognizing and managing geodiversity should not merely aim to preserve landscapes in a static state, but must also create tangible socio-economic benefits for local communities. In this context, the findings of this study are expected to provide valuable guidance for geopark managers and stakeholders, supporting the alignment of the UNESCO Global Geopark objectives with community empowerment strategies to achieve sustainable (Ferreira and Valdati, 2023; Hutabarat, 2023).

2. Methods

This study employed a grid-based spatial indexing method to pinpoint potential geodiversity hotspots in Lombok. Grids of 5 × 5 km^2 covered the entire island. The technique applied five main parameters (with equal weights): relative drainage density (25%), diversity of topographical slope (25%), elevation (25%), diversity of geological formation (25%), and soil characteristics (25%). This spatial analysis referenced available spatial data, including a digitized geological map from the Indonesia Geological Agency (1:250.000), a digitized FAO-UNESCO soil map of Southeast Asia (*fao.org*), and a digital elevation model along with related spatial features from Indonesia's geoportal database (*tanahair.indonesia.go.id*), resolution: 0.27 arc-second. This method was applied based on previous research on more significant regions (Ahmadi et al., 2021; Atkinson and De Clercq, 2022; da Silva et al., 2019; de Paula Silva et al., 2015; Wolniewicz, 2023).

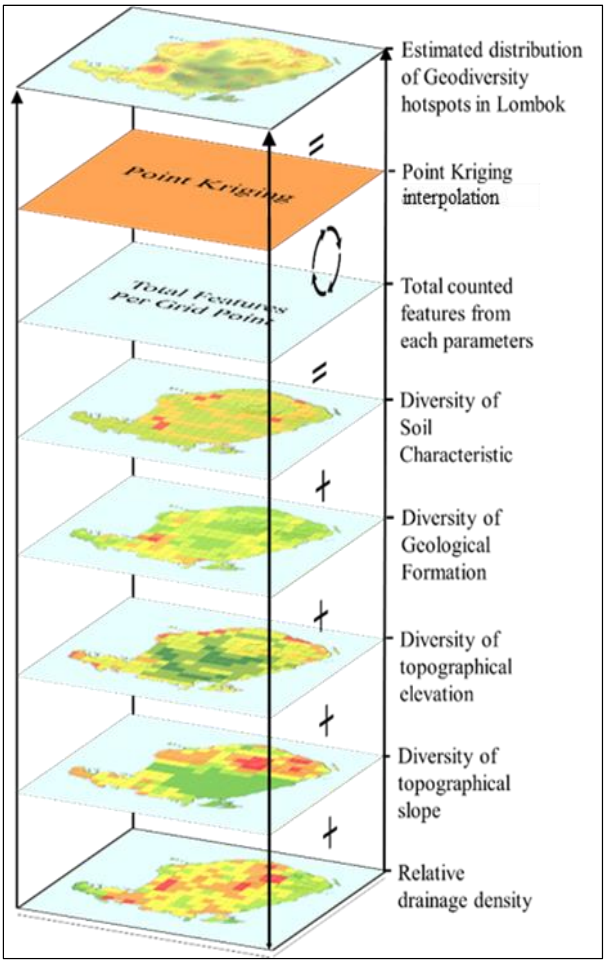

Fig 2. Scheme of grid-spatial indexing of this study.

Spatial data processing utilizes a geospatial processing program to calculate the number of different features for each parameter within the designated grid areas. A higher number of features within a grid indicates greater diversity in that specified area. Given Lombok Island's area of approximately 5,435 km^2, a 5 × 5 km^2 grid was considered relevant for the initial identification. To identify geodiversity hotspots, we assigned a point value to the number of features counted in each parameter within each grid, placing this value at the center of the grid (Figure 2). These values were summed to provide a cumulative count of the geological features as an index value (Carrión-Mero et al., 2022; Kaur, 2022). The resulting values were interpolated using the kriging method (Bétard and Peulvast, 2019; Oliver and Webster, 1990).

The identified geodiversity hotspots were then validated by ground checking, which was conducted in June 2024. Field validation involved visiting selected grid locations representing both high and moderate index values across various parts of Lombok. At each identified geodiversity hotspot site, direct geological observations were GPS tagged, recorded, and documented to validate the previous spatial recognition. The collected field data were then compared with the predicted geodiversity values from the spatial model to assess coordinate reliability.

3. Results and Discussion

Our study shows that with a 5 x 5 km² grid, the entire Lombok region can be covered by 238 grids. Each grid represents the area covered in the study (**Figure 3** and **Figure 4**). This grid size is generally more suitable compared to other area units. Grids that are too small are not sufficiently representative to describe regional areas like Lombok Island. Conversely, grids that are too large may overlook some remarkable features that need to be examined. The estimated of geodiversity hotspot from this study are represent in **Figure 5** and described in **Table 1.**

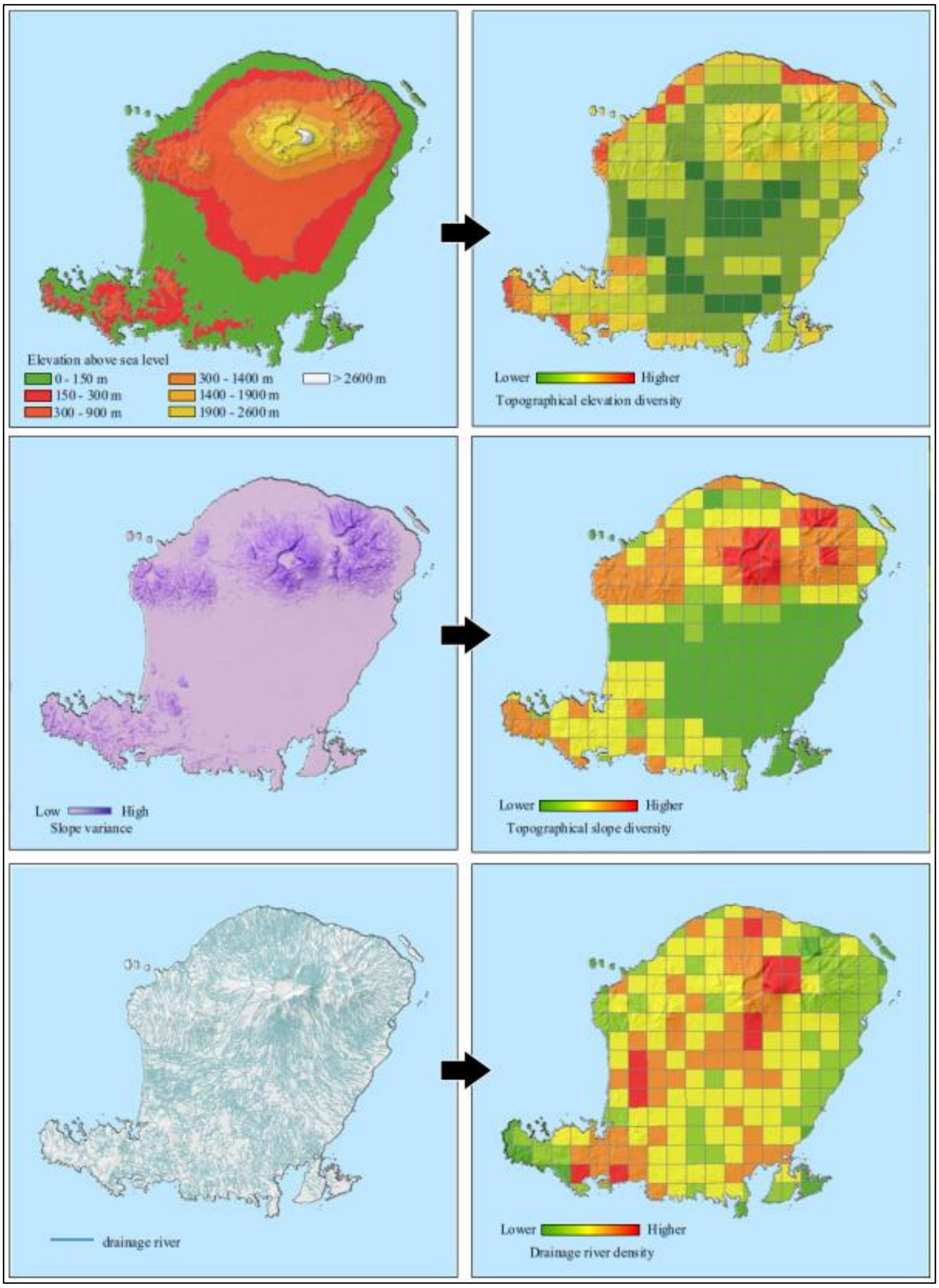

Fig 3. Features counting on every grid of topographical elevation, slope and drainage density parameters

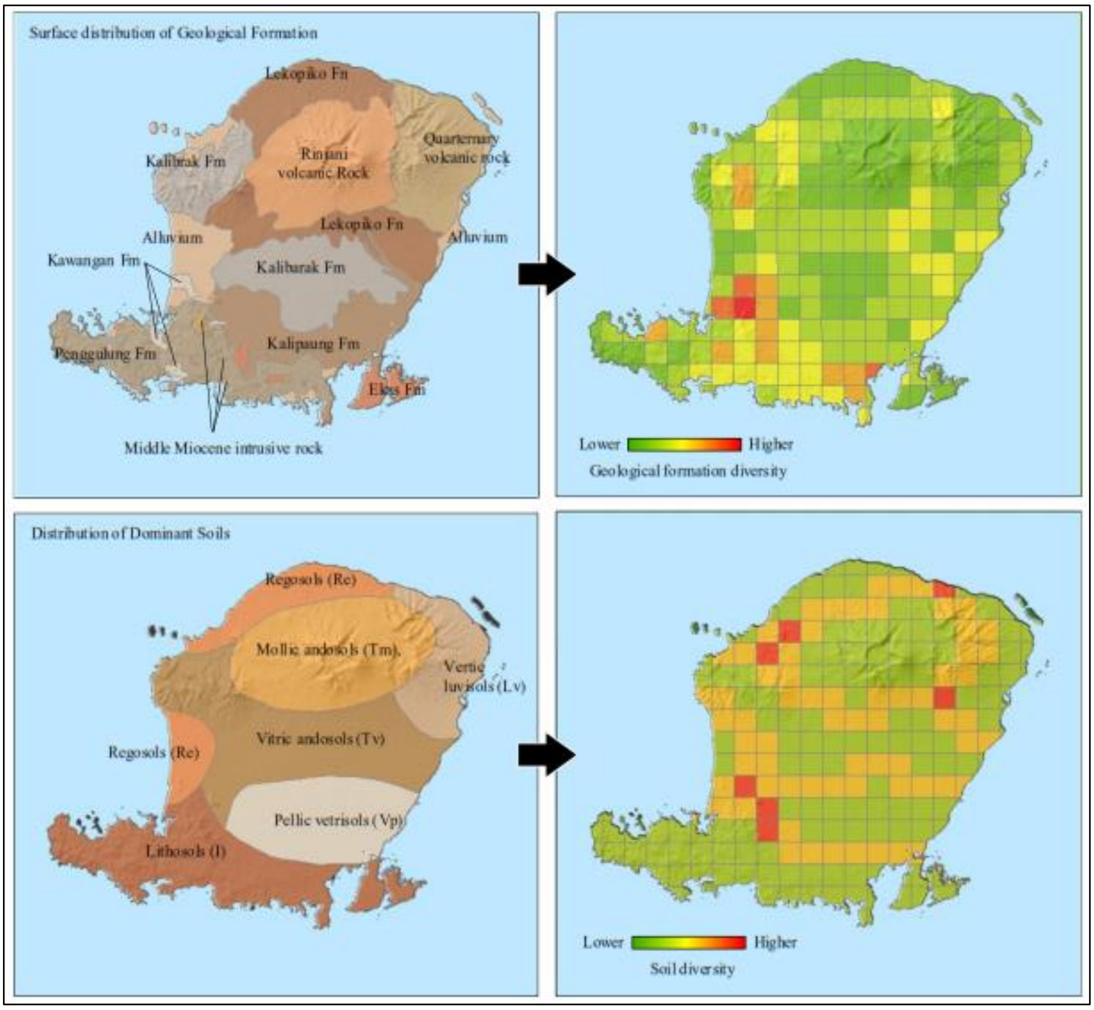

Fig 4. Features counting on every grid of geological formation and dominant soils parameters

The basemap in the form of a digital elevation model can aid in classifying topographic elevation, slope, and identifying drainage patterns on Lombok Island. These three parameters significantly represent the distribution of geomorphology on Lombok Island. Through these parameters, several locations on the island with stunning landscapes within a 5 x 5 km^2 area can be clearly observed. From this perspective, the natural beauty of these areas can be appreciated comprehensively, offering an attractive view to behold (**Figure 6**).

From its geological characteristics, this study focuses on the distribution of geological formations exposed in the area. Currently, Lombok Island is known to consist of various geological formations (Fm), including the Oligo-Miocene Pengulung Fm, Oligo-Miocene Kawangan Fm, Middle Miocene intrusive rock, Late Miocene Ekas Fm, Early Pliocene Kalipaung Fm, Plio-Pleistocene Kalibarak Fm, Late Pleistocene Lekopiko Fm, Quarternary Volcanic Rock complex, and Early Holocene Rinjani Volcanic Rock. Some formations contain fossils that trace the history of life that coincided with the early formation of Lombok Island (Mangga et al., 1994), such as plant fossils in the Late Miocene Ekas Fm, Early Pleistocene Kalipaung Fm, and Late Pleistocene Lekopiko Fm. In this study, it is identified that within a 5 x 5 km area, few locations on Lombok Island exhibit more diverse geological formations.

Our study results indicate that certain areas in the Rinjani Complex exhibit higher drainage density, indicating valleys that serve as river channels. This aligns with the slope variations found in these areas, particularly on the western side of Mount Rinjani. Based on its topographical elevation, the northern side of the island represents diverse topography, including views of the high peaks of Mount Rinjani and coastal scenery in the same vicinity. Similar features are also found on the southwest side of Lombok Island, characterized by steep hillsides facing directly towards the Lombok Strait and Indian Ocean. The classification of topographical elevation in this study refers to altitudinal vegetation zoning on tropical islands in Southeast Asia. This classification helps in understanding the relationship with identified geodiversity hotspots, marked by the natural vegetation characteristics that thrive in these areas.

Spatial grid analysis results indicate one significant location with a variety of formations, located south of Mataram city. This area exposes at least 4 geological formations including the Oligo-Miocene Kawangan Fm and Penggulung Fm, Plio-Pleistocene Kalibarak Fm, and Middle Miocene Intrusive Rock. This area is highly visible and recommended for a day trip to visit key geological history sites on Lombok Island. The diverse geological formations in Lombok Island are predominantly found on the southern side, especially the island's oldest rocks.

In contrast, the northern part is dominated by Quarternary volcanic rock, including the Rinjani Volcanic Complex, which is identified as still active to this day. The geological conditions on Lombok Island contribute to the diversity of soil characteristics that have formed. There are at least 6 soil characteristics that can be found, including eutric regosols (Re), mollic andosols (Tm), vertic luvisols (Lv), pellic vertisols (Vp), lithosols (I), and vitric andosols (Tv). Each soil characteristic is heavily influenced by its parent rock, which is controlled by the lithological characteristics of the existing geological formations. These soil characteristics also influence the vegetation conditions that grow above them. Therefore, the diverse geological conditions impact the diversity of vegetation that thrives on Lombok Island, consequently affecting the biodiversity levels. It is clear that geodiversity directly impacts the biodiversity of an area (Harbowo and Zahra, 2021; Tukiainen et al., 2023).

Based on the grid-spatial analysis conducted in this study, at least six geodiversity hotspots have been identified for prioritization in future steps. These include the areas of Gerung-Kuripan (center point: 116°8'20.085"E; 8°41'46.513"S, radius: 13.7 km), Gangga (center point: 116°12'13.122"E; 8°21'24.154"S, radius: 13.5 km), Bayan (center point: 116°32'33.211"E; 8°16'22.39"S, radius: 13.1 km) Sembalun (center point: 116°29'18.063"E; 8°23'22.156"S, radius: 9.7 km), Sambelia (center point: 116°35'40.856"E; 8°24'1.371"S, radius: 8.9 km), and Sikur (center point: 116°24'32.015"E; 8°29'23.597"S, radius: 8.5 km), for detail see **Figure 5** and **Table 1**. Each of these spots possesses distinct characteristics and holds significance in representing the geological conditions of Lombok Island. Within each hotspot, several representative sites showcase the diversity of geodiversity. Some of these sites are recognized tourist destinations such as Segaraanakan Lake in Rinjani Caldera, Propok Savannah, Kertagangga Waterfall, Sambelia Beach, Goalandak Beach, and others (**Figure 6**). These locations serve as a promising starting point for engaging local communities in nature-based tourism conservation efforts. However, achieving this vision requires a sound interpretation of the geological history that effectively communicates the message of nature conservation on Lombok Island. Thus, further actions are needed to realize this aspiration.

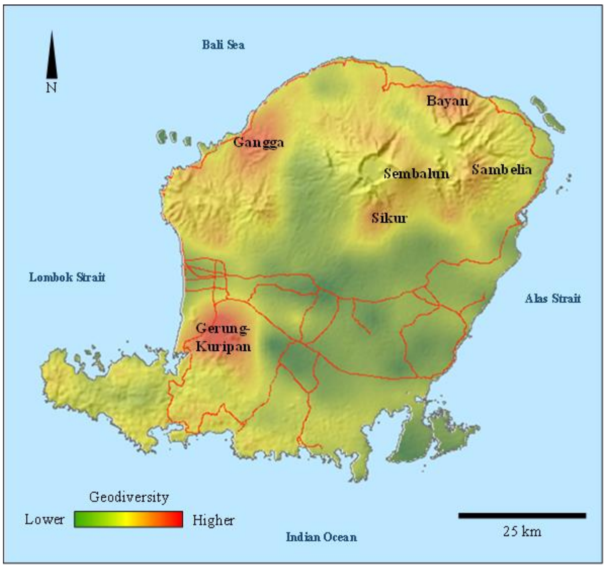

Fig 5. Estimated geodiversity hotspots in Lombok Island, Indonesia from this study.

Table 1: Detail of identified geodiversity hotspots in Lombok Island, Indonesia from this study.

Geodiversity Hotspot area	Gerung -Kuripan	Gangga	Bayan	Sembalun	Sambelia	Sikur
Center point coordinate	116°8'20.085"E 8°41'46.513"S	116°12'13.122"E 8°21'24.154"S	116°32'33.211"E 8°16'22.39"S	116°29'18.063"E 8°23'22.156"S	116°35'40.856"E 8°24'1.371"S	116°24'32.015"E 8°29'23.597"S
Radius area	13.7 km	13.5 km	13.1 km	9.7 km	8.9 km	8.5 km
Geological Formation	Kawangan Fm Kalipaung Fm Penggulung Fm Ekas Fm Intrusive Rock	Penggulung Fm Kalibarak Fm Alluvium	Lekopiko Fm Rinjani Volc. Quaternary Volc.	Rinjani Volc. Quaternary Volc	Quaternary Volc Alluvium	Lekopiko Fm Rinjani Volc.
Soil Characteristic	Regosols Lithosols Vitric andosols	Regosols Vitric andosols	Regosols Mollic andosols	Mollic andosols	Mollic andosols Vetric luvisols	Mollic andosols Vitric andosols
Geomorphology	Coastal Lowlands Lower hills	Coastal Lowlands Hills	Coastal Lowlands Hills Submontane	Hills Montane Subalpine	Hills Montane	Hills Montane
River drainage density	Medium	Medium	Dense	Very dense	Low	Very dense
Prospected Geosite	Penangissembor Bonggarang Goalandak Bunbeleng	Kertagangga Sire Beach Gili Trawangan	Sendalem Mangkusakti Lendangdanger	Sembalun Propok Savannah Segaraanakan	Sambelia. Lawang-Sulat Is. Kondo-Bubu Is.	Danaubiru, Batuliang Tetebatu
Geological Uniqueness	The oldest outcropped sedimentary rocks (Oligocene) in Lombok represents the geological history timeline from marine to transitional paleoenvironments associated with paleovolcanic deposits.	The geomorphological rifts, formed by Pliocene paleovolcanism, exposed through river flows and waterfalls associated with alluvium and Quaternary reef islands, forming an attractive coastal landscape.	Lithological records of the explosives eruption of Quaternary volcanoes, alongside the presence of the Paleo Prigi caldera remains, with the Lendangdanger savanna covering on these landscapes.	A fertile plain, remnant of the older Rinjani Caldera, shaped by vulcano-tectonic processes at over 2000 mASL, the geothermal manifestations enriching the wetland nutrients.	The eastern coastal of Lombok offers a remarkable sunrise view. Hot springs can be found upstream, just off the shore, there is a cluster of small islands withpreserved mangrove ecosystems.	Located to the south of the Rinjani Complex, the area features a series of breathtaking waterfalls and a beautiful blue lake cradled among ridges & valleys. Fossilized plant remains can be found in the Lekopiko Fm.

The sensitivity of geodiversity hotspot identification was analyzed by considering the balanced weighting of the key parameters influencing the geodiversity index values. Each parameter was systematically adjusted by ±10% to observe changes in the spatial distribution of the high-index grids. The analysis revealed that the geodiversity index was most susceptible to variations in geological formation diversity and slope variation, whereas elevation and soil characteristics exhibited relatively lower sensitivity. Geological formation diversity and topographic slope variation are key factors shaping the unique natural landscape and enhancing its potential for tourism appeal.

Spatial data resolution was also an important consideration; using 5 × 5 km^2 grids over an area exceeding 5,000 km^2 allowed for the compensation of detail contrasts among different maps, particularly during the interpolation process of the Kriging method. Therefore, field validation through ground-checking activities must support spatial analysis results to compare the spatially identified geodiversity potential with the actual conditions on the ground (Compiled documentation expressed in Figure 6). This study provides a more fine and attentive interpretation of geodiversity hotspot distribution while emphasizing the need for ongoing refinement as higher-resolution or more localized data become available for future geodiversity research.

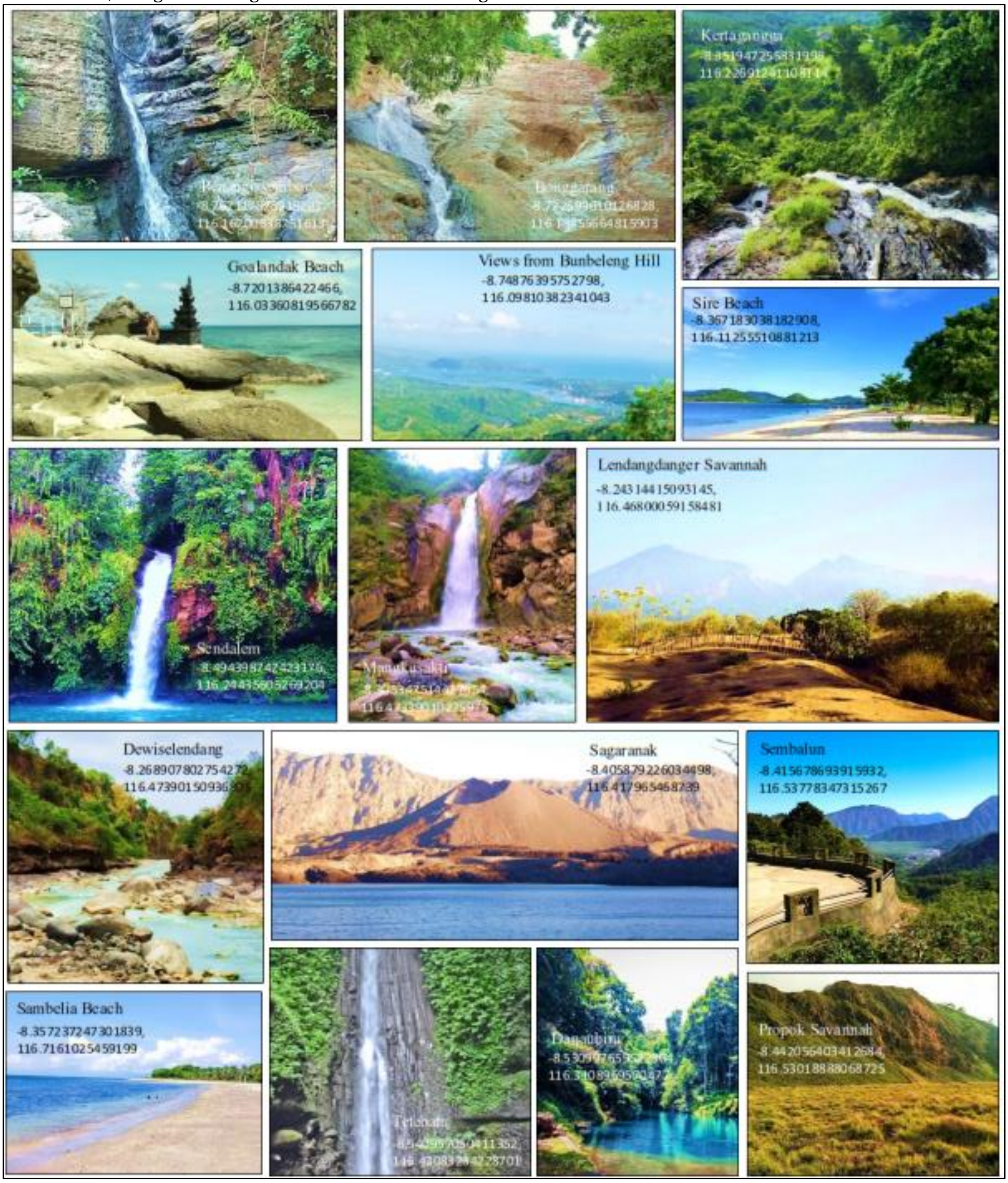

Fig 6. Documentation of noticeable geological site, represent the geological history of Lombok Island.

The grid-based spatial analysis employed in this study has proven to be an effective method for the preliminary recognition of geodiversity within a region, as it is generally capable of spatially identifying potential points. The geodiversity hotspots identified through this grid-based analysis can subsequently be followed up with more detailed investigations through geosite assessments to detailed geological studies, as demonstrated in previous studies (Ansori et al., 2021; Sahara and Setiawan, 2022; Yusuf et al., 2023).

In this study, we limited the use of this method to five parameters: relative drainage density (20%), diversity of topographical slope (20%), elevation (20%), diversity of geological formation (20%), and soil characteristics (20%). Other parameters, such as more detailed aspects of soil formation, landforms, hazards, stratigraphy, and geological structures, can be included as data becomes available. This will ensure balanced spatial weighting, which will become possible as research in this field progresses. This method can also be further developed by applying the Analytical Hierarchy Process (AHP), which involves a more extensive process.

Studies indicate that Lombok Island features various geological formations ranging from Oligo-Miocene to Quaternary volcanics. This geological diversity not only shapes the island's physical landscape but also creates diverse soil conditions (such as eutric regosols, andosols, luvisols, vetrisols, and lithosols) that influence vegetation growth and ecosystem balance. These different geological characteristics provide unique habitats for various flora and fauna. Certain geological formations may be more favorable for specific types of vegetation owing to the soil conditions, water availability, and elevation (Serrano and Ruiz-Flaño, 2007; Tukiainen et al., 2023; Wallis et al., 2021). These vegetation communities support distinct wildlife, contributing significantly to Lombok Island's biodiversity. This diversity has shaped human life and cultures, which have historically adapted to these natural conditions, defining the communities on Lombok Island. The island's natural beauty and geological features have become major attractions for both local and international tourism. Education about geological resources, biodiversity, and culture plays a crucial role in raising public awareness about the importance of conserving natural resources sustainably. Awareness of environmental degradation risks also encourages community engagement in future conservation efforts.

This study recommends that Geopark Management actively establish formal communication with the government as policymakers to prioritize the formal protection of geodiversity hotspots through legal designation and integration into regional spatial planning. This effort should also involve local communities in preserving tourism potential while fostering a sustainable green economy. Specific actions that can be taken include the development of community-based geoconservation programs, the enhancement of visitor facilities in less-developed areas such as Sambelia and Gangga, and the promotion of educational initiatives that emphasize the interconnection between geological heritage, local culture, and environmental conservation efforts.

Stakeholders, including local governments, tourism operators, educational institutions, and conservation organizations, must collaborate to formulate a comprehensive management plan that balances tourism development with conservation needs. Regular forums, annual networking gatherings, and discussion panels during international conferences represent effective practices for maintaining continuous communication among stakeholders. By leveraging the Pentahelix collaboration model, the UNESCO Global Geopark Rinjani-Lombok area can serve as a dynamic, collaborative platform to ensure the achievement of sustainable development goals on Lombok Island. Through these measures, Lombok can secure the long-term sustainability of its geoheritage assets while simultaneously enhancing socioeconomic benefits for local communities in the future.

4. Conclusion

In conclusion, this study demonstrated that Lombok Island hosts six significant geodiversity hotspots vital for supporting the geoheritage of the Rinjani-Lombok UNESCO Global Geopark. These include Gerung-Kuripan (center point: 116°8'20.085 "E; 8°41'46.513 "S, radius: 13.7 km), Gangga (116°12'13.122"E; 8°21'24.154"S, radius: 13.5 km), Bayan (116°32'33.211 "E; 8°16'22.39 "S, radius: 13.1 km), Sembalun (116°29'18.063 "E; 8°23'22.156 "S, radius: 9.7 km), Sambelia (116°35'40.856 "E; 8°24'1.371 "S, radius: 8.9 km), and Sikur (116°24'32.015"E; 8°29'23.597"S, radius: 8.5 km). Lombok Island's geological diversity study revealed at least 12 distinct lithological types, ranging from Oligo-Miocene to Plio-Pleistocene formations. These are particularly concentrated in the southeast of Rinjani Volcano and are complemented by diverse soil types, such as eutric regosols, vitric andosols, and lithosols, which sustain the island's ecological richness. Natural drainage systems shape the hydrological complex and contribute to scenic waterfalls, whereas elevational diversity supports unique ecosystems.

Although locations like Sembalun and Gerung-Kuripan are well-established tourist destinations, lesser-known areas such as Sambelia, Gangga, Sikur, and Bayan offer considerable untapped potential for geotourism development integrated with local cultural values. The grid-based spatial indexing method, validated through field checking, has proven to be effective in identifying priority zones. Conservation has become increasingly crucial amid ongoing economic growth, necessitating a balance between development and environmental stewardship. This study informs sustainable land-use planning and geotourism strategies and underscores the importance of geological conservation in achieving global sustainable development goals.

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References

Ahmadi, M., Derafshi, K., Mokhtari, D., Khodadadi, M., Najafi, E., 2022. Geodiversity Assessments and Geoconservation in the Northwest of Zagros

Mountain Range, Iran: Grid and Fuzzy Method Analysis. Geoheritage 14, 132. https://doi.org/10.1007/s12371-022-00769-7
Ahmadi, M., Mokhtari, D., Khodadadi, M., Shahabi, H., 2021. Geodiversity evaluation and geoconservation using grid analysis: case study, north of Ilam Province. Appl. Geomatics 13, 537–553. https://doi.org/10.1007/s12518-021-00377-0
Ansori, C., Warmada, I.W., Setiawan, N.I., Yogaswara, H., 2021. Geomorphosite Assessment at North Karangsambung -Karangbolong Geopark Kebumen, as Tools of Geotourism Development. J. Geosci. Eng. Environ. Technol. 6, 164–171. https://doi.org/10.25299/jgeet.2021.6.3.6753
Atkinson, J.T., De Clercq, W.P., 2022. Unravelling Regional Geodiversity: A Grid-Mapping Approach to Quantify Geodiversity in the uThukela District, KwaZulu-Natal, in: Remote Sensing of African Mountains. Springer International Publishing, Cham, pp. 19–50. https://doi.org/10.1007/978-3-031-04855-5_2
Bétard, F., Peulvast, J.-P., 2019. Geodiversity Hotspots: Concept, Method and Cartographic Application for Geoconservation Purposes at a Regional Scale. Environ. Manage. 63, 822–834. https://doi.org/10.1007/s00267-019-01168-5
Bétard, F., Peulvast, J.-P., Magalhães, A. de O., Carvalho Neta, M. de L., de Freitas, F.I., 2018. Araripe Basin: A Major Geodiversity Hotspot in Brazil. Geoheritage 10, 543–558. https://doi.org/10.1007/s12371-017-0232-5
Brilha, J., Gray, M., Pereira, D.I., Pereira, P., 2018. Geodiversity: An integrative review as a contribution to the sustainable management of the whole of nature. Environ. Sci. Policy 86, 19–28. https://doi.org/10.1016/j.envsci.2018.05.001
Carrión-Mero, P., Dueñas-Tovar, J., Jaya-Montalvo, M., Berrezueta, E., Jiménez-Orellana, N., 2022. Geodiversity assessment to regional scale: Ecuador as a case study. Environ. Sci. Policy 136, 167–186. https://doi.org/10.1016/j.envsci.2022.06.009
da Silva, M.L.N., do Nascimento, M.A.L., Mansur, K.L., 2019. Quantitative Assessments of Geodiversity in the Area of the Seridó Geopark Project, Northeast Brazil: Grid and Centroid Analysis. Geoheritage 11, 1177–1186. https://doi.org/10.1007/s12371-019-00368-z
de Paula Silva, J., Rodrigues, C., Pereira, D.I., 2015. Mapping and Analysis of Geodiversity Indices in the Xingu River Basin, Amazonia, Brazil. Geoheritage 7, 337–350. https://doi.org/10.1007/s12371-014-0134-8
Ferreira, D.R., Valdati, J., 2023. Geoparks and Sustainable Development: Systematic Review. Geoheritage 15, 6. https://doi.org/10.1007/s12371-022-00775-9
Gerstner, B.E., Blair, M.E., Bills, P., Cruz-Rodriguez, C.A., Zarnetske, P.L., 2024. The influence of scale-dependent geodiversity on species distribution models in a biodiversity hotspot. Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 382. https://doi.org/10.1098/rsta.2023.0057
Harbowo, D.G., 2023. An assessment of the scientific value of Krakatoa, Indonesia from a geoheritage perspective. J. Appl. Geosci. Eng. 2, 11–25.
Harbowo, D.G., Muliawati, T., 2023. A decade drought monitoring through enhanced and standardized vegetation index in isolated karst environment: Nusa Penida Island, Bali, Indonesia. IOP Conf. Ser. Earth Environ. Sci. 1287, 012033. https://doi.org/10.1088/1755-1315/1287/1/012033
Harbowo, D.G., Zahra, S., 2021. Microscopy Observation of Samosir Formation Paleosoil, Tuktuk Sidaong, North Sumatera, Indonesia. J. Geosci. Eng. Environ. Technol. 6, 9–15. https://doi.org/10.25299/jgeet.2021.6.1.5217
Hutabarat, L.F., 2023. Pengembangan Geopark Nasional Indonesia menuju UNESCO Global Geopark sebagai Diplomasi Geotourism Indonesia. J. Ilm. Hub. Int. 19, 94–106. https://doi.org/10.26593/jihi.v19i1.6000.94-106
Idrus, A., Ubaidillah, A.S., Warmada, I.W., Maula, S., 2021. Geology, Rock Geochemistry and Ore Fluid Characteristics of the Brambang Copper-Gold Porphyry Prospect, Lombok Island, Indonesia. J. Geosci. Eng. Environ. Technol. 6, 67–73. https://doi.org/10.25299/jgeet.2021.6.1.6145
Kartika, A.P., Wibisono, B.H., 2020. Management Effectiveness of Rinjani-Lombok Geopark on Geotourism Track. Built Environ. Stud. 1, 1–8. https://doi.org/10.22146/best.v1i1.282
Kaur, G., 2022. Geodiversity, Geoheritage and Geoconservation: A Global Perspective. J. Geol. Soc. India 98, 1221–1228. https://doi.org/10.1007/s12594-022-2156-1
Mahrup, Ma'shum, M., Fahrudin, 2021. Climate change in The Lesser Sunda Islands: The harsh region in the maritim continent of Indonesia. IOP Conf. Ser. Earth Environ. Sci. 824, 012115. https://doi.org/10.1088/1755-1315/824/1/012115
Mangga, S.A., Atmawinata, S., Hermanto, B., Amin, T.C., 1994. Geologi Lembar Lombok, Nusatenggara, Lembar 1807. Pus. Penelit. dan Pengemb. Geol. Indones.
Natalia, H.C., Harbowo, D.G., Ikhram, R., 2021. Potensi Geodiversity di Sekitar Kawasan Anak Krakatau-Way Kambas, Provinsi Lampung, Sebagai Kandidat Geopark Indonesia. J. Sci. Appl. Technol. 5, 47–57.
OLIVER, M.A., WEBSTER, R., 1990. Kriging: a method of interpolation for geographical information systems. Int. J. Geogr. Inf. Syst. 4, 313–332. https://doi.org/10.1080/02693799008941549
Quesada-Valverde, M.E., Quesada-Román, A., 2023. Worldwide Trends in Methods and Resources Promoting Geoconservation, Geotourism, and Geoheritage. Geosciences 13, 39. https://doi.org/10.3390/geosciences13020039
Sahara, R., Setiawan, B., 2022. Assessment of Geosite and Geomorphosite at South Solok Aspiring Geopark Area. J. Geosci. Eng. Environ. Technol. 7, 110–116. https://doi.org/10.25299/jgeet.2022.7.3.9520
Serrano, E., Ruiz-Flaño, P., 2007. Geodiversity : a theoretical and applied concept. Geogr. Helv. 62, 140–147. https://doi.org/10.5194/gh-62-140-2007
Toivanen, M., Maliniemi, T., Hjort, J., Salminen, H., Ala-Hulkko, T., Kemppinen, J., Karjalainen, O., Poturalska, A., Kiilunen, P., Snåre, H., Leppiniemi, O., Makopoulou, E., Alahuhta, J., Tukiainen, H., 2024. Geodiversity data for Europe. Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 382. https://doi.org/10.1098/rsta.2023.0173
Tukiainen, H., Toivanen, M., Maliniemi, T., 2023. Geodiversity and Biodiversity. Geol. Soc. London, Spec. Publ. 530, 31–47. https://doi.org/10.1144/SP530-2022-107
Wahyudin, Y.A., Munir, A.M., Rizki, K., 2023. Effectiveness of the UNESCO Global Geoparks Regime on Local Community Development in the Rinjani-Lombok UNESCO Global Geopark Area. pp. 251–263.

https://doi.org/10.2991/978-94-6463-362-7_19
Wallis, C.I.B., Tiede, Y.C., Beck, E., Böhning-Gaese, K., Brandl, R., Donoso, D.A., Espinosa, C.I., Fries, A., Homeier, J., Inclan, D., Leuschner, C., Maraun, M., Mikolajewski, K., Neuschulz, E.L., Scheu, S., Schleuning, M., Suárez, J.P., Tinoco, B.A., Farwig, N., Bendix, J., 2021. Biodiversity and ecosystem functions depend on environmental conditions and resources rather than the geodiversity of a tropical biodiversity hotspot. Sci. Rep. 11, 24530. https://doi.org/10.1038/s41598-021-03488-1
Wolniewicz, P., 2023. Quantifying Geodiversity at the Continental Scale: Limitations and Prospects. Resources 12, 59. https://doi.org/10.3390/resources12050059
Yusuf, N.J., Arifin, Y.I., Hutagalung, R., Manyoe, I.N., 2023. Study of Boalemo Red Limestone for Geotourism Development based on Lithological, Geochemical Analysis and Geological Heritage Assessment. J. Geosci. Eng. Environ. Technol. 8, 212–220. https://doi.org/10.25299/jgeet.2023.8.3.12075