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DOCTORAL THESIS

- a b s t r a c t -

**Multidisciplinary modeling of territorial attractiveness for
supporting the development of geoparks. Case Study:
Maramureş Geopark.**

Keywords: spatial analysis; multi-criteria evaluation; GIS; geopark assessment; attractiveness evaluation model; UNESCO Global Geopark; attractiveness; attractiveness index; ecotourism; bibliometric analysis; R; automatically merged database; PRISMA; sustainability

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1. INTRODUCTION

The theme of this research is situated within a contemporary context shaped by global concern for sustainable development and the responsible valorization of natural and cultural heritage. At the international level, UNESCO Global Geoparks function as strategic instruments for conservation, education, and regional development, promoting an integrated model that merges environmental protection and education with active community engagement and the stimulation of sustainable tourism. The rapid expansion of the global geopark network demonstrates the relevance of this concept in relation to contemporary public policies and international sustainability priorities.

In the national context, the research acquires particular significance due to Romania's high potential for geopark development, stemming from its geological, cultural, and landscape diversity. Romania has demonstrated receptiveness to this sustainable development approach, as evidenced by the existence of two UNESCO Global Geoparks and several national geoparks.

Aligned with current international research paradigms, our study opens an innovative direction in the field of geoparks and sustainable tourism by focusing on the development of scientifically grounded models for assessing territorial attractiveness. These models possess practical applicability and methodological transferability, particularly through the lens of sustainable tourism: ecotourism.

The main aim of the thesis consists in developing scientific methods and models from a proactive perspective, oriented toward anticipating territorial planning needs and optimizing decision-making processes. This is achieved through the creation of complex instruments for analysis, simulation, and prediction designed to support the establishment of geoparks and the sustainable and intelligent development of ecotourism (including "smart" indicators and "Building a Smarter World with GIS" (Esri, 2016)).

Given the accelerated pace of geopark establishment over the past decade, modeling has become essential in decision-making and planning processes. Moreover, models support comparability and replicability of analyses, enabling the application of the same methodology across different territories and/or similar contexts. Based on the definition stating that "*Modeling is a fundamental method used in science and engineering, consisting of the schematic reproduction of an object or system in the form of a similar or analogous model, for the purpose of studying the properties and behavior of the original system*" (Dexonline, n.d.), it can be asserted that modeling constitutes an indispensable tool in contemporary applied research.

Achieving the aim outlined above requires defining and addressing a set of specific objectives:

- (1) Synthesizing the evolution and expansion of the research domain;
- (2) Forecasting the volume of scientific publications on geoparks for the period 2025 – 2027;
- (3) Identifying strategic themes as well as gaps within the specialized literature;
- (4) Developing a model for assessing the attractiveness of territories intended to become geoparks, useful for decision-making in the planning process of an aspiring geopark seeking to obtain geopark status (potential UNESCO Global Geopark);
- (5) Identifying appropriate evaluation criteria for the field, namely a set of SMART parameters that can be clearly expressed, quantified, and feasibly achieved (specific, measurable, achievable within time constraints, relevant);
- (6) Assessing the attractiveness of the territory designated as a geopark (potential UNESCO Global Geopark);
- (7) Determining potential areas suitable for ecotourism within the territory designated as a geopark, by identifying the most valuable zones and potential locations for ecotourism objectives and recreational activities (multifactorial ecotourism favorability);
- (8) Automating spatial analysis and GIS-based modeling to highlight the suitability of the geopark-designated territory for ecotourism development.

The logical fulfillment of the previously stated objectives will enable the establishment of a solid theoretical-methodological foundation, indispensable for advancing applied scientific research in the field of geoparks.

In this context, our approach targets the geopark domain from the perspective of territorial attractiveness in both national and international settings, given that the valorization of a territory's tourism heritage depends fundamentally on understanding and objectively evaluating its intrinsic value (Formica, 2000). This endeavour requires, first and foremost, determining the potential for attractiveness. Attractiveness represents the “driving force” behind stimulating tourist interest—the core strength or compelling power of a destination; in other words, “attractiveness is the force of attraction” (Formica & Uysal, 2006; Nyulas, Dezsai, Haidu, et al., 2024). The attraction of tourists is a crucial element in the success of any destination, with tourist attractions constituting the cornerstone of the tourism industry (Lew, 1987). These attractions not only draw visitors but also

play a significant role in shaping the local economy and strengthening community identity (Morachat, 2003).

The Romanian specialized literature is distinguished by a significant number of valuable studies on geoparks, focusing particularly on geotourism and geological heritage, with emphasis on the inventory and evaluation of geosites and their role in conserving natural resources (Csiki-Sava & Andrășanu, 2021; Denuț et al., 2018; Givulescu, 1962; Grigorescu, 2017, 2019, 2020). However, both national and international literature reveal a limited emphasis on the analysis of tourism attractiveness in the context of geoparks, despite the essential role it plays in the valorization of a region's natural and cultural heritage. Moreover, although ecotourism is one of the forms of tourism most closely aligned with the fundamental principles of geoparks – through its sustainable character and responsible use of resources – studies dedicated to this topic remain limited and fragmented (Kamyabi, 2014).

In this regard, the present study addresses a significant gap identified in the specialized literature by adopting an integrated perspective on the concept of attractiveness and by providing an original contribution to strengthening the methodological framework and substantiating ecotourism as a form of sustainable tourism within the specific context of geoparks.

2. CURRENT STATE OF SCIENTIFIC KNOWLEDGE AND RESEARCH DIRECTION

2.1. General scientific context

The original concept of the geopark was developed in Europe in the late 1980s. It refers to a territory that encompasses a particular geological heritage and a strategy for sustainable territorial development. Although several decades have passed since the establishment of the first geoparks, the concept still generates frequent misunderstandings, especially among the increasing number of researchers approaching this topic for the first time: a geopark is a new category of protected area; a geopark is the same as a geological park; a geopark is a legal designation for protecting geological heritage; a geopark refers solely to geology. The answer to all four statements is negative, and it must be emphasized that the role of a geopark is that of a strategic development framework for a territory with significant geological heritage that must be conserved, together with other natural and cultural assets, for the purpose of promoting the sustainable economic development of local communities (Henriques & Brilha, 2017).

The geopark concept currently promoted by UNESCO encompasses not only geological, geomorphological, and biological richness. It forms part of the global objectives for sustainable development, addressing both regions located at the margins of major economic activity and those that are densely populated and prosperous. Tourism stakeholders, guesthouse operators, and local businesses are invited to become partners of the Geopark by signing the UNESCO charter, which ensures environmental protection and responsible business conduct (Quinif et al., 2024).

The geopark was initially conceived as a strategic option for conservation, based on the premise that, through its framework, the protection of heritage would become more effective and would simultaneously generate a significant increase in awareness of its value and importance, both among decision-makers and the general public (Prosser & King, 1999).

Today, UNESCO Global Geoparks (UGGp) are defined as territories composed of unique geographical areas that encompass sites and landscapes of international geological significance (exceptional geological heritage of international importance, rarity, or aesthetic value), which are managed in a holistic manner that integrates protection, education, and sustainable development. Geoparks are developed as part of an integrated concept of conservation, education, and local economic development. Their bottom-up approach combines conservation with sustainable development and involves local communities (*UNESCO Global Geoparks / UNESCO*, n.d.). This model employs a holistic approach to conservation, in which all aspects of natural and cultural heritage are valorized, protected, and promoted under the geopark designation.

A geopark is designated on the basis of three core components: conservation (protection), education, and sustainable territorial development — a concept aligned with the broader trend of integrating science and culture while simultaneously recognizing the importance of preserving the uniqueness of the physical landscape (Azman et al., 2010).

The main characteristics of the geopark have been formulated as follows:

- it must encompass a particular geological heritage, with specific geological, mineralogical, geophysical, geomorphological, paleontological, or geographical characteristics, grouped within geological sites of exceptional scientific quality, rarity, aesthetic appeal, or educational value. Most of these features should form part of the geological heritage, although their relevance may also be archaeological, ecological, historical, or cultural (Zouros, 2004);
- the local authorities of each geopark must agree to its promotion, with the financial support of the European Union, within a strategy for sustainable territorial development aimed at the evolution of the geopark (Zouros, 2004);

- it must have clearly defined boundaries and a surface area sufficient to enable genuine territorial economic development in support of sustainable economic growth (Zouros, 2004);
- the sites within a geopark must be interconnected in a network and benefit from protection and management measures, meaning that they must be managed by a clearly defined structure organized in accordance with the national legislation of each country and capable of implementing policies for protection, valorization, and sustainable development within its territory (Zouros, 2004);
- geoparks and geological heritage serve as promoters of sustainable development (Brilha, 2020);
- integrating conservation objectives into tourism activities generates, in addition to the protection of unique features of the geological heritage, scientific research, extended ecological education, and the enhancement of local economic development based on tourism (Azman et al., 2010);
- the promotion of heritage sites through geoparks is achieved through educational and conservation efforts aimed at increasing knowledge and appreciation of geological, cultural, and biological heritage (Azman et al., 2010);
- the participation of the local community in the decision-making process related to geopark and geotourism development improves people’s quality of life and strengthens their appreciation of geological and cultural heritage (Azman et al., 2010);
- geological heritage sites within a geopark function as an authentic “outdoor classroom,” offering both children and adults—locals and visitors alike—the opportunity to learn directly, in a real-world context, about the history, nature, and culture of a region. In addition to educational and experiential learning opportunities, heritage sites hold additional potential for raising public awareness (Azman et al., 2010);
- the abiotic–biotic–cultural connection approach (the ABC concept), integrating Abiotic (geology), Biotic (nature), and Cultural (traditions, history) elements in territorial development (Pásková et al., 2021);
- they represent territories in which humanity lives in harmony with nature (Henriques & Brilha, 2017);
- through the practice of sustainable tourism, geoparks play a significant role in implementing the 2030 Agenda for Sustainable Development, integrating sustainable tourism as a tool for the valorization of natural and cultural heritage. This dimension aligns with Goal 8.9, promoting tourism that creates jobs and supports local culture, and with Goal 12.b,

concerning the development of tools for monitoring the impacts of tourism on sustainable development (*Sustainable Tourism / Department of Economic and Social Affairs*, n.d.).

Astfel, geoparcurile pot fi considerate instrumente-cheie pentru promovarea dezvoltării durabile, întrucât îmbină conservarea patrimoniului geologic și cultural (Zouros, 2004) cu participarea comunităților locale și valorificarea educațională și turistică a resurselor (Azman et al., 2010). Prin integrarea conexiunilor abiotice–biotice–culturale (Pásková et al., 2021) și prin aplicarea unor strategii teritoriale durabile acestea pot fi considerate una dintre multiplele căi de atingere a sustenabilității globale, contribuind la implementarea Agendei 2030, în special prin obiectivele privind turismul durabil și monitorizarea impacturilor asupra dezvoltării (*Sustainable Tourism / Department of Economic and Social Affairs*, n.d.).

2.2. Conceptual structure of the research

The conceptual structure of the research was obtained following the generation of a strategic map in the R program, using the Biblioshiny application, which enabled the identification of dominant themes within the field. The result consists of a clear and intuitive visualization of the positioning of themes according to their level of development and relevance, facilitating the identification of motor themes, basic themes, emerging or marginal themes, and supporting strategic decision-making for the orientation of future projects.

The strategic map (also referred to as the thematic map) (Soesanto et al., 2023) presents the conceptual structure of studies conducted between 1999 and 2025, comprising four quadrants, each representing a theme and using two axes. Thus, the X-axis—representing development density—indicates the importance or centrality of the study theme, while the Y-axis represents the degree of relevance, namely the density that measures the progress of the theme (Cobo et al., 2011).

Our analysis was conducted on the basis of the abstracts of the studies consulted, using the Louvain clustering algorithm (J. Zhang et al., 2021), through which the themes were divided into four categories (quadrants): motor themes, basic themes, niche themes, and emerging or declining themes (Figure 1).

Motor themes, positioned in the upper-right quadrant, are characterized by high centrality and high density and represent highly relevant and well-developed subjects. They form the conceptual core of geopark research and generate major, innovative scientific directions.

In **Group A**, the main themes relate to the global network of geoparks (UNESCO Global Geopark). Their significance is reflected in studies on the geodiversity of geoparks, including *geoheritage* and *geological features*, along with their assessment, conservation, and promotion (Ha

et al., 2022; Iranzo-García et al., 2023; Ruban, 2017; Sheibani & Zamanian, 2023; Shitole et al., 2023). These are complemented by *sustainable development*, recognized as one of the principal roles of geoparks (Ballesteros et al., 2023; Jia et al., 2022; Khalaf & El-Kheir, 2022; Magliacani & Francesconi, 2022; Mehdioui et al., 2022), with recent literature increasingly emphasizing the connection between geoparks and the United Nations Sustainable Development Goals (SDGs) (Bollati et al., 2024; de Araújo Pereira, 2022; Khasanah et al., 2023). Another defining element of this group is the heritage associated with geoparks, represented in analyses through concepts such as *heritage sites*, *natural heritage*, *cultural heritage*, and *world heritage* (Akbulut et al., 2023; Bollati et al., 2023; Gray, 2023; Guerini et al., 2023; He et al., 2024; Parkes et al., 2021), as well as the *geopark network*. The functioning of geoparks within the GGN facilitates collaboration and the exchange of good practices among geoparks, and its important role in the multilateral development of geoparks is frequently highlighted in the specialized literature (Custódio et al., 2024; Tavares et al., 2020).

The second group is illustrated by **Cluster B**, whose themes are characterized by strong internal interconnectedness, demonstrated by high density, even though their size and overall relevance are lower compared to those in Cluster A. The central theme of this group is the role of *local communities* within geoparks (Permanadewi et al., 2024; J. Wang & Zouros, 2021), directly linked to the other subthemes. These include *tourism* (Gałaś et al., 2022), the *tourist* (Luan & Wang, 2023), as well as destination-oriented dimensions related to *tourism development* through communication tools and events designed to enhance visibility and awareness (Muhtar et al., 2024). Likewise, *sustainable tourism*—particularly geotourism—plays a major role, supporting both the conservation and valorization of *tourism destinations*, *tourist attractions*, and *tourism activities* (Hutagalung et al., 2024; Tang & Liang, 2023), along with *cultural diversity*. The analysis also highlights that all these themes converge toward the active involvement of communities in *geopark development*, thereby contributing to *regional development* (Gutak et al., 2023; Nakarmi et al., 2023; Nuh et al., 2024). Within this group, *data analysis* plays an essential role in the research methodology, being emphasized as a central component of the investigative process.

Therefore, the two groups – A and B – constitute the core that drives current research directions.

Basic themes are fundamental and cross-cutting topics, characterized by high centrality and low density. They are indispensable in the field of geoparks, as they represent the most frequently used subthemes, forming central axes of recurrent, theoretically and methodologically consolidated research.

Cluster C spans all quadrants, indicating that it is both fundamental and of primary importance, reflecting the relevance of its themes across multiple research contexts. Its overlap with niche, emerging, or declining themes demonstrates that these directions remain open to further exploration. The studies included in this cluster highlight the importance of *national geoparks* as areas dedicated to the conservation of geological heritage (Cunningham, 2021; Y. Wang et al., 2023). They examine *geological resources*, *geological relics*, and *geological structures* (Lü et al., 2019; J. Wang et al., 2022; Zhen & Gao, 2017), along with their *spatial distribution*—an essential element for understanding the location of resources and for planning geotourism activities. Geological features are analyzed from both scientific and educational perspectives, as well as from the standpoint of tourism valorization, constituting primary *tourist resources*, given that tourism activities in geoparks largely revolve around these elements (González Barahona et al., 2021). The *scientific research* within this cluster confirms the role of these subjects in deepening the understanding of geological resources and phenomena, emphasizing their scientific value, primarily reflected through empirical and applied studies (Brilha, 2016; Dowling, 2011). Another major theme is *geotourism*, which contributes to shaping regions toward sustainable development and promotes *scientific education*, highlighting the role of geoparks in providing educational opportunities (Brilha, 2016; Dowling, 2011).

Overall, these subthemes underpin and support the development of motor themes, forming an essential framework for advancing research in the field of geoparks.

In the lower-left quadrant are the *emerging or declining themes*, characterized by low centrality and low density, reflecting either insufficiently developed subjects or areas that gradually lose relevance over time.

Cluster D is centered on the *economic development* of geopark territories, with *local residents* as the main actors, playing an essential role in promoting sustainable local economic development (Carvalho et al., 2021; Deng & Zou, 2021). This group also integrates fundamental themes within the broader context of *natural resources* and the *natural environment*. The *geopark concept* (Bauer, 2008; Briggs et al., 2023; Fepuleai et al., 2021) was a widely debated subject during the period 1999–2009, yet it has continued to be revisited in recent studies, often associated with the subtheme of *geopark status* (Muslim et al., 2022). Although this cluster exhibits low centrality, it encompasses relevant themes that warrant further exploration.

Moreover, **Group E**, characterized by lower centrality and smaller size, is positioned in the emerging area and comprises a limited number of scientific articles. It includes a set of case studies based on the use of geographic information systems, such as *information systems*, *geographic information*, *remote sensing*, *satellite images*, *GIS systems*, and *digital elevation* (DEM). Research

has demonstrated the applicability of GIS in producing cartograms for visualizing the spatial distribution of sites, as well as the role of remote sensing in assessing and quantifying geodiversity through multispectral and hyperspectral imagery, digital elevation models, and various indicators derived from satellite data (such as RSEI-2 and NPP) (Blersch et al., 2023; Gray, 2024; Jiang et al., 2023; Pham et al., 2024; J. Wang et al., 2022). This group of studies reflects a methodological orientation distinct from the other subthemes, although it contains a relatively small number of articles.

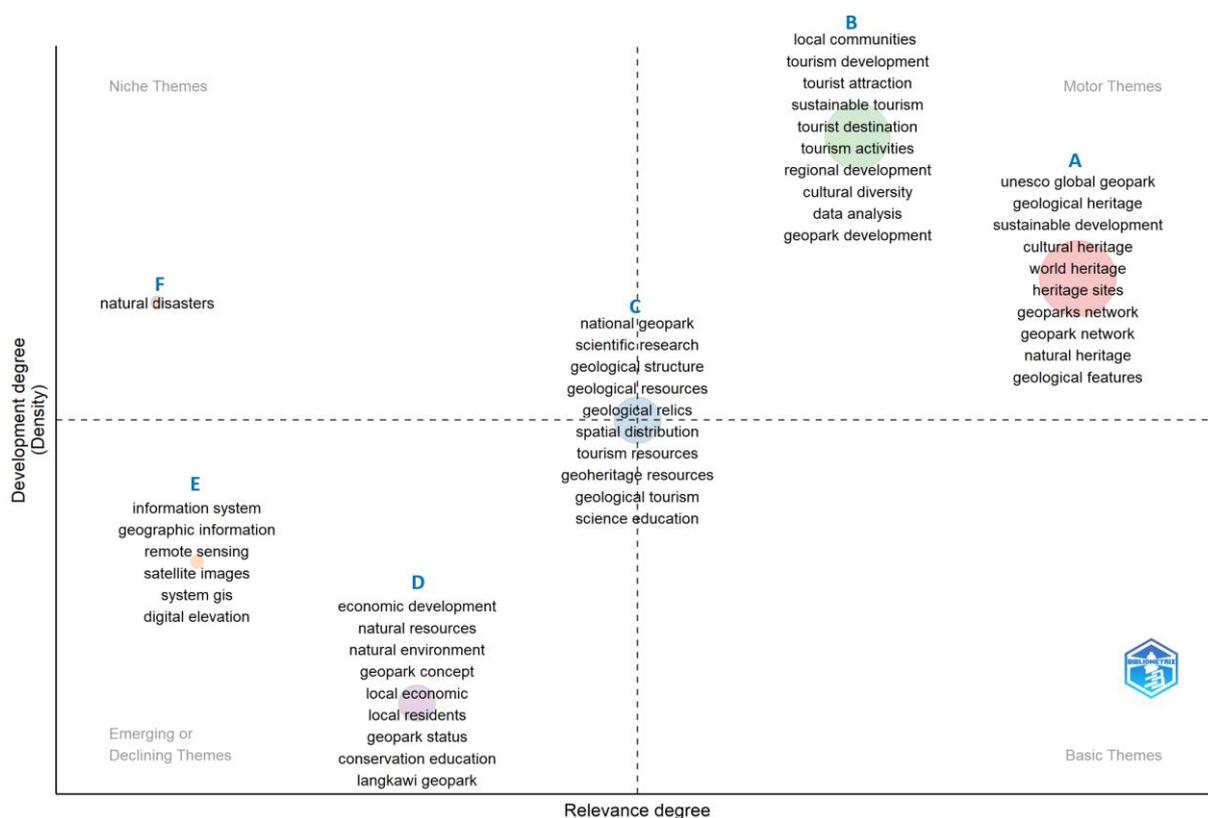


Figure 1. Strategic conceptual structure of research on the topic of geoparks (own elaboration using the Biblioshiny application, R program.) (Nyulas et al., 2025)

Note: the size of the bubble indicates the number of documents with terms correlated within groups A, B, C, D, E, and F.

Within the quadrant of *niche themes*, characterized by low centrality and high density, lie the specialized topics. These represent a relevant and well-defined research direction, yet one that remains secondary in relation to the overarching objectives of geoparks. **Cluster F** includes the subtheme of *natural disasters*, such as earthquakes, flash floods, and drought episodes—phenomena associated with complex geological and climatic processes that require continuous hazard monitoring (Al-Halbouni et al., 2022; Ar-rouf & Masitoh, 2023). These constitute mature niche domains that are not widely connected to other themes and remain relatively isolated within the research field. They reflect potential thematic directions for geoparks that may be explored on a

broader scale (involving more geoparks) and in greater depth (through an increased number of studies).

Within the quadrant of niche themes, the strategic map highlights potential future research directions, particularly those that have been less explored to date. These focus on the global issue of natural disasters (earthquakes, landslides, and volcanic eruptions) and their connection with the SDGs. Although these themes currently exhibit a low level of centrality (see Figure 1), they present considerable potential for scholarly interest, being associated with emerging or declining subjects. In particular, GIS-based subthemes (mapping, spatial analysis, satellite remote sensing) are used for analyzing, representing, and promoting geological resources, as well as for assessing typologies and spatial information specific to the studied areas.

In the scientific literature on geoparks, the theme of attractiveness occupies an important position, yet remains peripheral in relation to the broader research domain, representing approximately 8% of all studies analyzed in the automatically integrated bibliometric database (Nyulas, Dezsi, Niță, et al., 2024). Although attractiveness is an essential factor for the functioning and development of a destination—and therefore for geoparks—a conceptual analysis of this topic from a functional perspective reveals a relatively low level of scientific interest compared to other research areas, such as geodiversity, geoconservation, or the role of the local community.

The conceptual structure of studies on attractiveness is represented through the four quadrants: *motor themes*, *basic themes*, *emerging and declining themes*, and *niche themes*, as illustrated in Figure 2 (see the sections of the conceptual structure map). The map highlights the thematic distribution of subjects across several distinct groups (A–E), considerably smaller in size compared to those identified at the global level in the geoparks domain (Figure 1). This discrepancy can be explained by the fragmented approach in the specialized literature, meaning that the resulting groups are weakly connected to one another, which indicates a divergence in authors' perspectives regarding the integration of studies addressing attractiveness (for example, geological attractiveness, cultural attractiveness, tourism attractiveness), as well as the influence of the comparatively smaller number of articles focused on geopark attractiveness.

Motor themes, as the central driving force in the analysis of geopark attractiveness, are reflected in two main directions: the development of tourism and the integration of local communities, and the strengthening of geopark development processes and geotourism.

On the one hand, **group A**, characterized by higher density, includes subthemes such as *tourist attractions*, *tourism development*, and the *local community*. These constitute the foundational elements that ensure the functionality and sustainability of geoparks (Eraku et al., 2023; Utama et al., 2023; Wulung et al., 2021). Group A brings together subthemes that support the idea that

geoparks become attractive spaces for both visitors and local communities, generating socio-economic benefits and strengthening the cultural identity of regions.

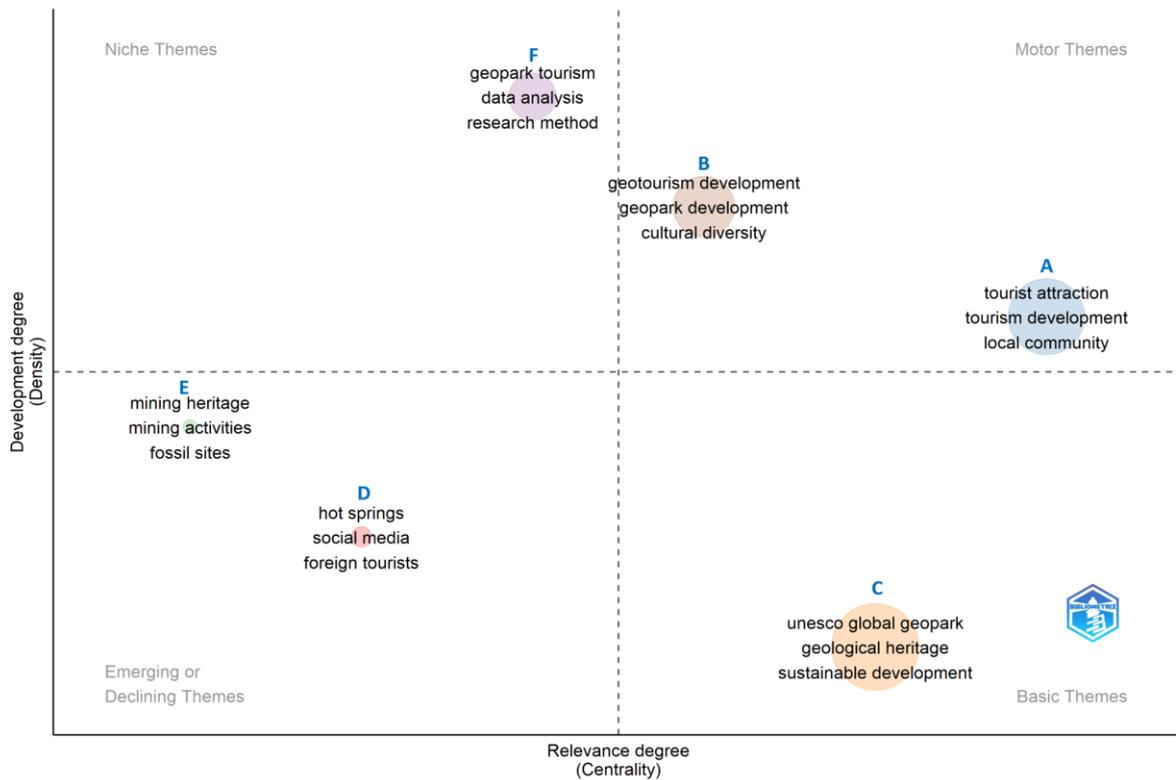


Figure 2. Strategic conceptual structure of research on the topic of geopark attractiveness (own elaboration using the Biblioshiny application, R program) (Nyulas, Dezsi, Haidu, et al., 2024)
 Note: the size of the bubble indicates the number of documents with terms correlated within groups A, B, C, D, E, and F.

On the other hand, **group B** integrates subthemes such as *geopark development*, *geotourism development*, and *cultural diversity*, all of which hold high relevance in the specialized literature (Khalaf, 2022; Manco-Jaraba et al., 2023; Sheibani & Zamanian, 2023; Solé-Benet et al., 2024; Wulung et al., 2023). These subthemes reflect the ways in which geoparks can evolve into engines of sustainable development by promoting geotourism as an integrated form of responsible tourism, by valorizing natural heritage, and by highlighting cultural diversity.

The *basic themes* are included in **group C** and, in the context of attractiveness, are structured around three interdependent concepts: *UNESCO Global Geopark*, *geological heritage*, and *sustainable development* (Kim et al., 2023). These are interconnected in the sense that UNESCO geopark status entails international recognition of the value and uniqueness of geological heritage, and once protected and valorized, this heritage becomes the foundation of strategies oriented toward sustainable development, in which resource conservation is combined with educational, tourism, and socio-economic benefits. The subthemes in this group are highly developed, recurrent, and

theoretically and methodologically consolidated, representing the three core themes that define the essence of geoparks.

The *emerging and declining themes* associated with **group D** include subthemes such as *hot springs*, *social media*, and *foreign tourists*. These exhibit higher density than cluster E and have been examined only occasionally in the specialized literature. From a tourism perspective, they are important for attracting visitors: the promotion and presentation of geosites on social media platforms, the use of media to attract foreign tourists, as well as the effectiveness and influence of mass media in shaping revisit intentions (Dezilia & Harnani, 2023; Erfurt-Cooper, 2017; Harahap et al., 2021; E. Y. Zhang & Cui, 2022).

Also located within this quadrant is **group E**, which primarily focuses on *mining heritage*. Closed mines, considered attractions of geological and cultural value, warrant deeper exploration from both scientific and tourism perspectives. *Mining activities* likewise hold specific relevance for geoparks; although often viewed solely through the lens of their negative environmental impact, they represent a significant part of the cultural and historical heritage of communities in mining regions (Rohaendi & Herlinawati, 2024; Tang & Liang, 2023). In addition, the presence of fossil sites — which possess scientific and educational value and function as geotourism attractions — supports the local economy through responsible tourism with economic potential, attracting visitors interested in paleontology and natural history (Sinnyovsky, 2023).

Within the quadrant of niche themes, the strategic map highlights in **group F** several potential future research directions. These focus particularly on tourism within geoparks (*geopark tourism*), geotourism, and other associated forms of tourism. Alongside these, ecotourism and tourism centered on volcanic landforms have been identified as having low frequency in the specialized literature (Nyulas, Dezsi, Niță, et al., 2024, p. 16). Although these subjects have been addressed in previous research, they remain peripheral compared to geotourism, which constitutes the primary direction. In parallel, another relevant domain within this group is the methodology of geopark research, especially *data analysis* and *research methods*, as emphasized in recent studies (Al Mohaya & Elassal, 2023; Nyulas, Dezsi, Haidu, et al., 2024; Zahrani & Mubarak, 2022).

On the one hand, the conceptual structure map of the research highlights as future study directions the development of tourism forms specific to geoparks (such as ecotourism or tourism centered on the attractive elements of volcanic landforms), and on the other hand, the deepening of methodological tools through the use of data analysis, advanced research methods, and modeling, which have constituted the methodological foundation of the present study.

Nevertheless, the sector of emerging or declining themes may also present interest for researchers, particularly those subthemes with the lowest density, such as mining heritage and mining activities, as well as fossil sites.

On the other hand, expressing the attractiveness of geoparks represents a genuine need in the current context, marked by their accelerated development and by the existence, according to spatial distribution results, of significant potential at the global level. The expansion of the geopark network directly influences the volume of scientific research, with a demonstrated positive correlation between the two variables (0.68) (Nyulas, Dezsi, Haidu, et al., 2024).

Producing a forecast of the volume of academic publications for the next three years constitutes strategically fundamental information in the context of contemporary scientific research, particularly for researchers, research groups, university centers, or institutes seeking to maximize their academic impact.

Figure 3 reveals, on the one hand, that the forecast estimated up to the year 2027 indicates the production of 2,192 scientific studies (2025–2027), and, on the other hand, that researchers' decisions can provide valuable insights for choosing between subjects that offer stability (motor and basic themes) and those that have been less explored to date (grouped under the section “themes to be researched”). Thus, this figure synthesizes the themes that generate and drive scientific development in the field of geoparks, offering a comparative representation between established research axes and emerging ones. The themes in the first column (depicted in green) reflect research directions considered motor and basic themes in geopark studies – those that drive scientific development – and are conceptually and methodologically consolidated, with recurrent frequency in the specialized literature. Moreover, the second column (marked in pink) brings together the themes extracted from the analysis of publications focused on geopark attractiveness.

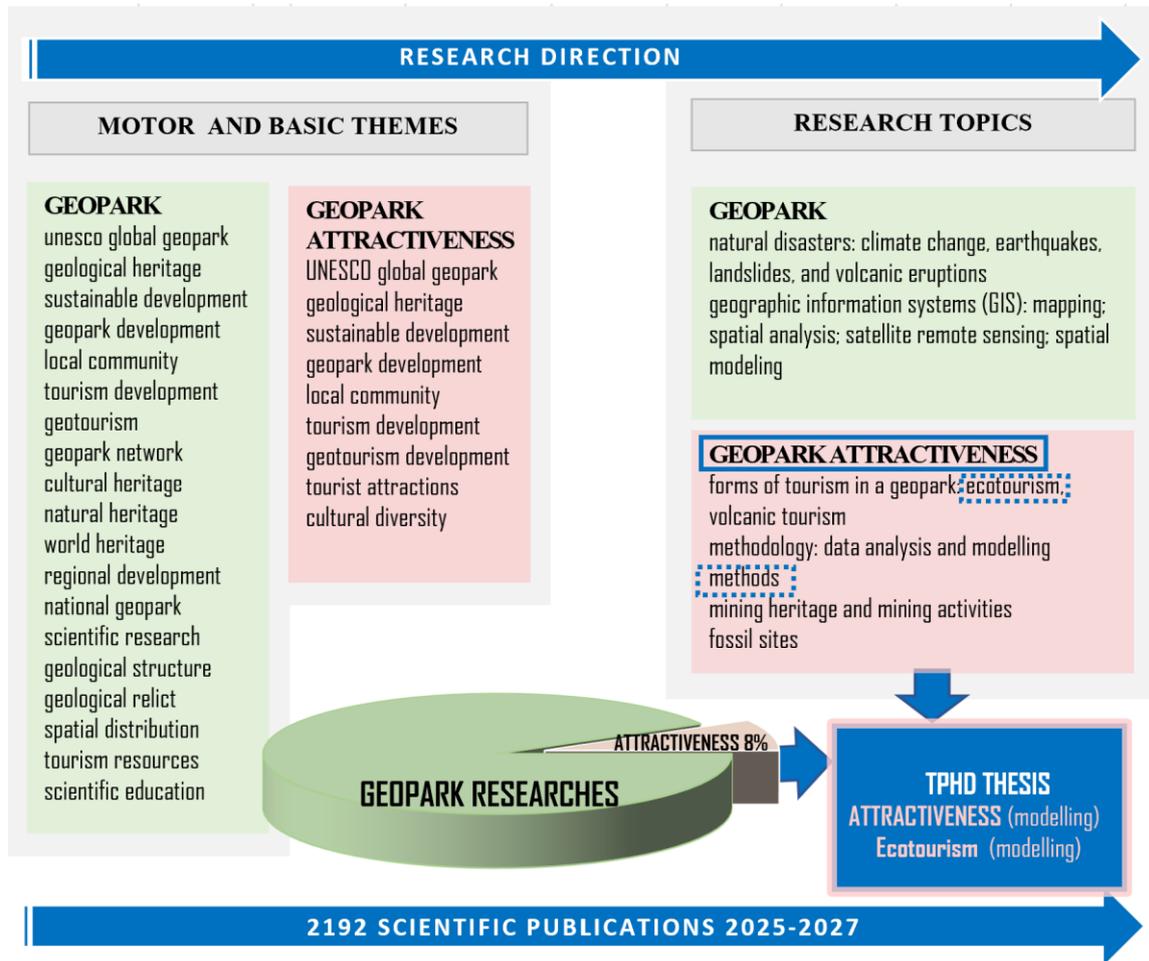


Figure 3. Research Direction of the Thesis within the Strategic Conceptual Structure of Geoparks Analyzed through the Lens of Attractiveness

Therefore, the present research aims to contribute to reducing these epistemic gaps (“fill the gap”) by prioritizing the segment of geopark attractiveness. In particular, the study focuses on emerging subthemes – ecotourism – as well as on modeling, specifically the development of an attractiveness assessment model for territories intended to become geoparks.

3. METHODOLOGY

3.1. Data collection method using PRISMA 2020

To ensure the methodological rigor of the bibliographic analysis and the transparency of the source selection process, a methodological guideline offering clear criteria for identifying, evaluating, and including relevant studies was employed. In this regard, the PRISMA 2020 guideline (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (*PRISMA 2020 Statement*, n.d.) was used, in accordance with recent recommendations (Page et al., 2021), which remain very

rarely applied in the field of geoparks (as of 08.09.2025, only two articles are indexed in the WoS and Scopus platforms: Hermawan et al., 2025; Nyulas et al., 2025). PRISMA 2020 provides a clear and rigorous framework for reporting the stages of a systematic review, being recognized for its effectiveness in structuring the processes of searching, selecting, analyzing, and synthesizing academic literature.

PRISMA 2020 represents the updated version of the international guideline for reporting systematic reviews and meta-analyses, reflecting the most recent methodological developments in scientific research. This version provides a more detailed and flexible framework for transparently documenting the study selection process, evaluating the quality of sources, and synthesizing results. PRISMA 2020 includes an extended 27-item checklist and an improved flow diagram, both of which enable researchers to clearly report the steps followed and the criteria applied. Its use contributes to increasing confidence in the conclusions drawn and is increasingly applied in bibliometric studies and in the systematic review of specialized literature.

The methodology employed in this research integrated the R program, including its user-friendly application designed for non-programmers (Biblioshiny), while also adhering to PRISMA 2020 standards for ensuring data quality. The primary software used was R, version 4.3.3, together with the Bibliometrix package, for the analysis, synthesis, and graphical representation of results. Additionally, Microsoft Excel 365 was used for data processing, and ArcGIS Pro, version 3.4.0, for mapping the spatial distribution of the analyzed documents.

The selection of databases was carried out based on relevance, credibility, and the availability of scientific data. The selection criteria included: relevance (alignment with the research topic), credibility (publication in recognized scientific journals), impact (number of citations or influence within the field), interdisciplinarity (coverage of related domains), currency (recency of information), diversity (inclusion of global perspectives), and data availability (access to data sets). On this basis, the identification of literature was conducted by consulting ten international databases: Web of Science, Scopus, PubMed, Dimensions, Nature Journals, SpringerLink, Taylor & Francis, Wiley Journals, IEEE Xplore, and CABI.

3.2. Automated integrated method for combining and deduplicating bibliographic records in R

This method was developed to facilitate the first stage of the PRISMA 2020 workflow, immediately after aggregating result sets from various platforms, namely the stage of duplicate removal — an operation for which PRISMA 2020 does not provide an explicit procedure. The main

operation of combining databases and removing duplicates can be carried out in two ways: either through an initial integration of the databases followed by deduplication, or through simultaneous combination and deduplication. These procedures can be performed in R using the Bibliometrix package (*Bibliometrix - Home*, n.d.), with the support of reference manager applications (EndNote, Zotero, Mendeley, or JabRef), as well as in Microsoft Excel. In the present study, we applied combination and deduplication in a single step, using the automatic merging functions available in R. The Bibliometrix package is a free tool for R dedicated to bibliometric analysis.

The method was developed in RStudio using the Bibliometrix package and was refined through successive testing and validation. It was designed to be accessible to both beginners and experienced users, having been applied by two novice researchers and validated by an expert R researcher. Unlike previous studies, in which combination and deduplication were performed separately and typically for only two databases, our method simultaneously integrates metadata from multiple platforms and automatically removes duplicates in a single step. Deduplication based on DOI reduces the risk of redundancy; however, for documents without a DOI, additional verification is required.

The distinction from the methodology found in the specialized literature lies in the fact that merging and deduplication are performed in a single step and through the simultaneous use of multiple databases; previous approaches treated these stages separately, typically for only two sources, with deduplication based on DOI or title (Caputo & Kargina, 2022; Echchakoui, 2020). Deduplication based on DOI (DI) reduces redundancy; however, for records without a DOI, additional verification is required. Another difference concerns the technical environment: in this study, merging and deduplication are carried out entirely in R, unlike solutions implemented in Microsoft Excel, where integration was performed manually and deduplication was conducted using VBA code (Echchakoui, 2020) or the Remove Duplicates function (Caputo & Kargina, 2022). The deduplication rule of the developed methodology follows a clear hierarchy: first, DOI (DI), and in its absence, matching is performed based on the normalized title combined with the publication year (PY).

3.3. Spearman correlation method

On the one hand, the number of geoparks is increasing from year to year, and on the other hand, the volume of scientific publications in the field of geoparks shows a significant growth in academic output.

Against the backdrop of the annual increase in the number of geoparks, we investigated the relationship between their dynamics and the scientific output in the field, comparing for each year the number of newly established geoparks with the number of published studies. The guiding question is: *"What is the impact of geopark creation on research?"*. To capture a potential relationship, we employed the Spearman correlation coefficient (ρ), calculated in the R program.

The Spearman correlation measures the strength and direction of the monotonic relationship between the two variables: in this case, between research publications (variable 1) and geoparks (variable 2).

The result obtained between the production of documents over time and the number of UNESCO geoparks created reveals a value of 0.68. The p-value indicates that this correlation is statistically positive, meaning that it is highly unlikely to have occurred by chance, and that a correlation indeed exists between the creation of geoparks and scientific output (unlikely to be attributable to randomness).

3.4. Polynomial regression model

Developing a three-year forecast of publication volume highlights the importance of anticipating future research directions and provides an operational decision-making horizon. Choosing a short forecasting interval reduces the uncertainty inherent in long-term projections and allows for rapid calibration of thematic priorities. The results should be regarded as a forward-looking tool that can be updated as new data emerge, serving purposes of prioritization and planning, as well as guiding the scientific agenda toward efficient and visible research, including the hierarchical structuring of themes.

To generate projections regarding the future evolution of the volume of scientific publications in the field of geoparks, a second-degree polynomial regression model was applied. This choice was grounded in both theoretical and practical considerations related to the nonlinear behavior observed in the temporal data characteristic of bibliometric analyses.

This model was selected because the annual series for the 1999–2024 interval exhibits an accelerated, nonlinear increase, which is more accurately captured by a quadratic curve than by a straight line; the series is relatively small (26 observations), making the use of complex machine learning models unjustified, as such models would require training, tuning, and validation and would carry a high risk of overfitting; moreover, the data do not show seasonality or recurrent cycles, meaning that classical time series models (e.g., ARIMA) do not offer specific advantages. Polynomial regression therefore provides a parsimonious and interpretable compromise, suitable for

short-term projections, with minimal computational effort and a robust fit to the curved trend observed in the data.

Polynomial regression represents an extension of simple linear regression that allows the modeling of curvilinear relationships between variables. In this case, the relationship between the publication year and the number of published articles did not follow a purely linear trajectory, but rather a trend curve with an inflection, which justifies the use of a second-degree polynomial to achieve a more accurate fit to the real data.

The methodological steps began with the preparation of the dataset. The dataset used contained the annual values of the number of publications identified for the period 1999 –2024.

The model obtained through polynomial regression modeling employed the `lm()` function from R's base package, with the specification of a second-order polynomial. The choice of the second degree was made after testing several alternatives (degree 1, 2, and 3) and comparing the values of the coefficient of determination (R^2), as well as through graphical analysis of the residual values. In this case, the second-degree model proved to be the most effective.

Polynomial regression models the dependent variable (y) as a function of the independent variable (x) raised to different powers. The general equation is:

$$y = \beta_0 + \beta_1x + \beta_2x^2 + \dots + \beta_nx^n$$

where,

$\beta_0, \beta_1, \dots, \beta_n$ are the coefficients

n is the degree of the polynomial

The polynomial coefficients are estimated using the least squares method, which minimizes the sum of squared differences between the observed values and the predicted values.

The degree n of the polynomial regression is a critical factor that influences the performance of the model. A higher degree allows greater flexibility but carries the risk of overfitting, whereby the model incorporates noise alongside the underlying trend. Cross-validation is often used to select an optimal degree by splitting the dataset into calibration and testing subsets. According to Aiken (Aiken et al., 1991), the degree should be chosen with regard to the complexity of the data, and researchers use higher-order polynomials only when relationships are complex. In this study, the number of scientific publications was considered the dependent variable. The analysis was conducted in the R statistical environment, testing models with different degrees (Figure 4).

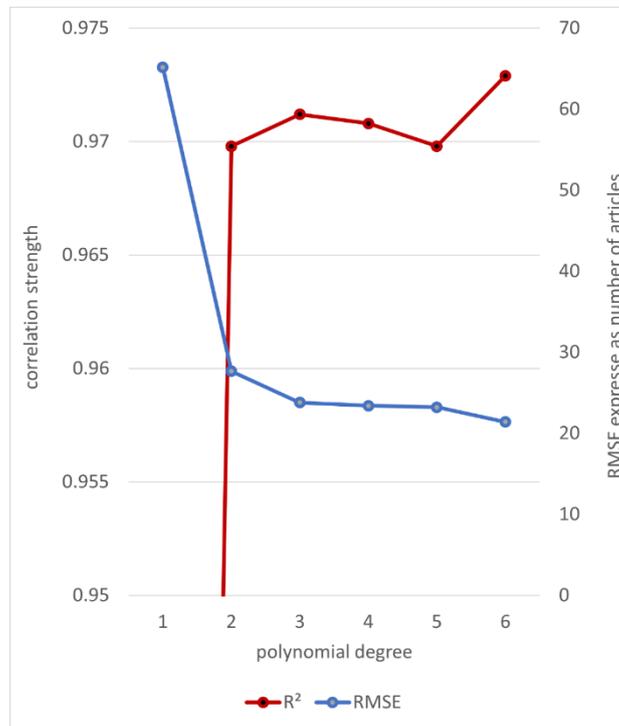


Figure 4. Evolution of R^2 and RMSE for Polynomial Models of Different Degrees (Nyulas et al., 2025)

Based on the evolution of R^2 and RMSE (Figure 4) for the tested models, a third-degree polynomial model was selected, as it displayed the highest R^2 and a stable RMSE before the models began to overfit, starting with the fifth-degree polynomial.

The evaluation of the model's quality demonstrated a good fitting capacity, with no systematic error patterns, which confirms the validity of the statistical assumptions. Subsequently, projections for the period 2025–2027 were generated.

3.5. Attractiveness Evaluation Model

Given the accelerated pace at which geoparks have been established over the past decade, modeling has become essential in decision-making and planning processes. It supports the comparability and replicability of analyses, allowing the same methodology to be applied across territories of varying spatial extent and taxonomic levels, as well as in similar contexts. Therefore, modeling can be regarded as an indispensable tool in contemporary applied research.

Building on these premises, one of the main objectives of the present study is the development of a model for assessing the attractiveness of a natural area proposed for designation as a geopark. The proposed model aims to provide a practical support tool for decision-making in the planning and management of such territories.

The fundamental principle underlying the development of the attractiveness evaluation model was supported by three essential pillars: the assessment methods identified in the specialized literature, the UNESCO criteria list, and a certified geopark used as a benchmark. For the purposes of this study, primary data were extracted from these three pillars and complemented with secondary data required for calculating the parameters, all of which were integrated into a process that generates an overall attractiveness score.

The methodology is based on selecting, from among the various attractiveness characteristics used in previous research, those that correspond to the criteria for the designation of a UNESCO Global Geopark, as established in the checklist – Self-Evaluation Form (Form A)) (*Submit a UNESCO Global Geopark Proposal*, n.d.). Figure 9 illustrates the three fundamental pillars on which the attractiveness evaluation model is built: (I) the methods selected from the specialized literature, (II) the UGGp checklist (Self-Evaluation Form), and (III) the certified geopark used as the etalon (benchmark).

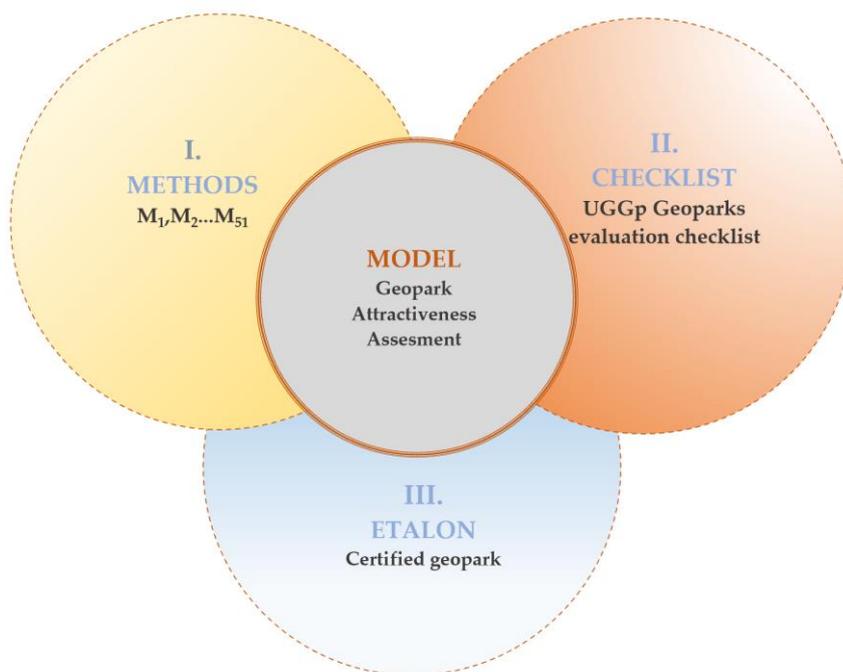


Figure 5. Main pillars underpinning the principle for designing the Geopark Attractiveness Evaluation Model (Nyulas, Dezsi, Haidu, et al., 2024)

The attractiveness evaluation methodology was implemented based on this concept, which was integrated into *five successive stages*: (1) collecting relevant methods, (2) analyzing the elements included in these methods, (3) establishing criteria by correlating the identified attributes with UNESCO requirements, (4) defining the parameters, and (5) developing, testing, and validating the evaluation model.

FLUXUL PROCESULUI METODOLOGIC

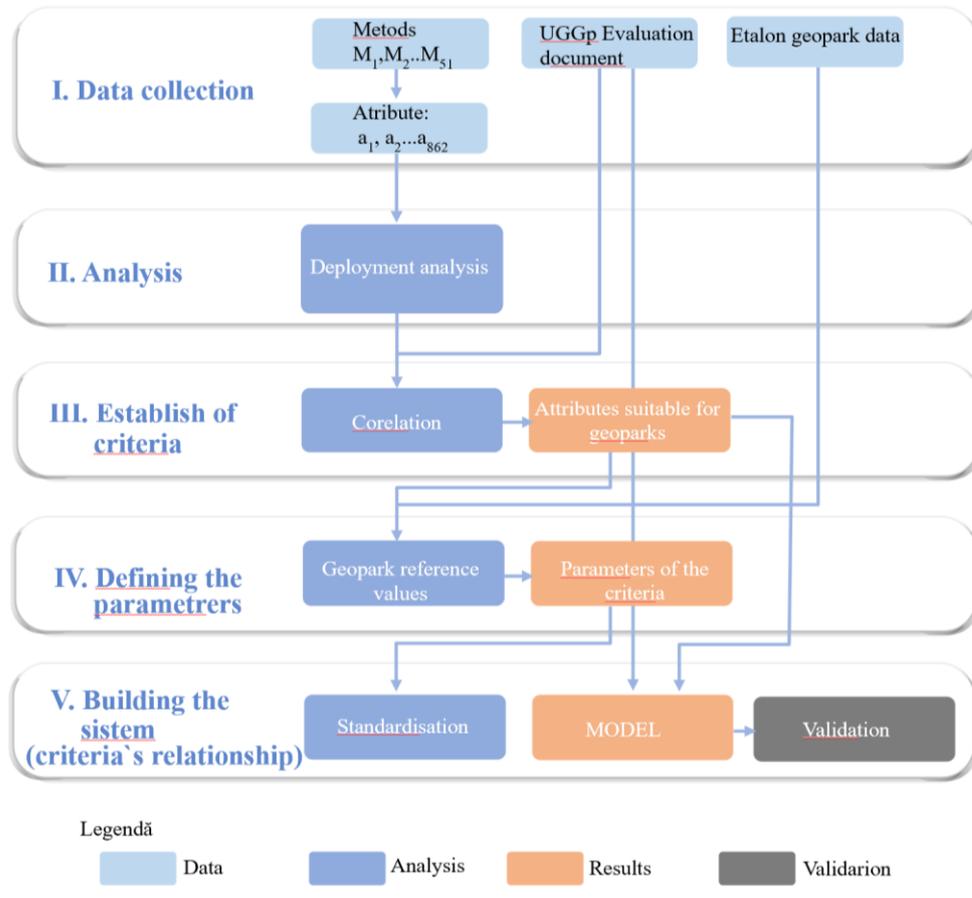


Figure 6. Workflow of the Methodological Process for Constructing the Attractiveness Evaluation Model (Nyulas, Dezsi, Haidu, et al., 2024).

In the *first stage*, data collection, the attractiveness assessment methods used over time in various studies were analyzed, along with information pertaining to the evaluation of UNESCO geoparks and the dataset corresponding to the benchmark geopark. This process enabled the identification of characteristics used to determine attractiveness, followed by the inventory of the criteria.

The *second stage* consisted of analyzing the elements of the methods, with the aim of establishing correspondences between the attractiveness criteria and the requirements of the UNESCO checklist.

In the *third stage*, the criteria were defined by correlating the attributes extracted from the specialized literature with the criteria for defining UNESCO geoparks, selecting those most relevant for the evaluation of attractiveness.

The *fourth stage*, the definition of parameters, consisted of quantifying the criteria based on the reference values of the certified geopark.

In the *final stage*, the actual model was developed by integrating the criteria into a coherent system and calculating the overall attractiveness score (I_A).

For the development of the model, managerial instruments were used (deployment analysis, GAP analysis, Pareto chart, SMART indicators), along with specialized software applications such as QGIS (for spatial analyses) and Microsoft Excel 365 (for statistical processing and data integration).

3.6. Analysis – Multicriteria Evaluation

The sustainable development of tourism, particularly within geoparks, requires the use of rigorous decision-making tools that support the rational and sustainable valorization of territorial resources. In this context, spatial analysis plays an essential role, providing concrete support in the decision-making process related to territorial planning and management. Through GIS technologies, spatial analysis becomes a fundamental instrument for the scientific underpinning of ecotourism development strategies within geoparks.

One of the most widely used methods in this regard is multicriteria evaluation (MCE – Multi-Criteria Evaluation), also known in the specialized literature as multicriteria decision analysis (MCDA – Multi-Criteria Decision Analysis). This method is frequently integrated into geographic information systems (GIS) (Gelan, 2021; Islam et al., 2025; Sarkar et al., 2025), allowing the simultaneous assessment of multiple spatial factors relevant to the issue for which the spatial analysis is conducted.

In this study, we employed the Multi-Criteria Evaluation (MCE) method applied within a GIS environment. This method enables the simultaneous assessment of a set of spatial factors relevant to ecotourism activities, each expressed as measurable and spatially representable criteria.

The applied model is built on a set of standardized spatial criteria that reflect the favorability conditions for ecotourism within the analyzed territory. Examples of such criteria include altitude, slope, accessibility, distance to natural or cultural resources, visibility, and others. Each criterion is converted into a raster layer, and its values are standardized on a common scale, thereby facilitating the coherent combination of criteria within a unified evaluation model.

A distinctive element of our study, compared with many other investigations in the specialized literature, lies in its specific and applied approach to multicriteria evaluation, oriented toward identifying concrete locations for ecotourism facilities or ecotourism-related recreational activities (for example, viewpoints, eco-villages, pontoons, thematic trails, etc.). Unlike generalist approaches that focus on broad analyses such as "suitability for ecotourism" or "suitability for geotourism", applied across entire territories, the methodology proposed in this research aims for fine spatial detailing directly correlated with the potential functionality of each objective.

3.7. Automation of GIS Analyses Using the Model Designer (QGIS)

To facilitate the reapplicability of the multicriteria evaluation analysis using QGIS software (QGIS Development Team, 2024), this study oriented itself toward modeling the methodology. In spatial analysis applied to planning studies within geoparks, the automation of workflows plays an important role by reducing data-processing time, eliminating human errors, and ensuring the replicability of results. In this regard, the QGIS Model Designer (within QGIS 3.22) represents a modern solution for constructing analytical models that enables the integration of multiple GIS operations into a coherent and easily reusable analytical workflow.

Through this application, the spatial multicriteria evaluation analysis—such as raster reclassification, the combination of multicriteria factors, the application of logical operations, and the generation of suitability maps—was sequenced into a single procedural model that can subsequently be applied to other similar datasets without manually repeating each step. The model is constructed according to the workflow principle, in which each methodological step is translated into an operational module connected through logical relations.

A major methodological advantage of using the Model Designer lies in its ability to ensure traceability and transparency throughout the analytical process: all steps are documented and visually represented, which facilitates the scientific validation of the approach and the transferability of the method to other territories or case studies. Moreover, the use of an open-source platform such as QGIS guarantees a high degree of accessibility and reproducibility, thereby enhancing the applied value of this approach in research.

The developed models can be reused either as a "model file", specific to the graphical model builder, or as a Python script, thus ensuring flexibility in applying the methodology to other territorial contexts or similar projects. Running the model ensures not only the faithful reproduction of the initially defined steps but also the possibility of integrating the analysis into automated GIS processing workflows, at both local and regional scales ("small vs. large"). The model's algorithm is automatically exported in *model* format or as a *Python script*, allowing the steps of the process to be translated into executable code, as well as enabling extensions and modifications to the analytical workflow. Regardless of how many steps or distinct algorithms it includes, the model is executed as a single algorithm, saving both time and effort.

4. RESULTS

4.1. Main findings of the Attractiveness Evaluation Model applied to the Maramureş geopark using the Haţeg UNESCO Global Geopark as Benchmark

4.1.1. Synthesis of the Maramureş geopark evaluation and GAP Analysis

The results of the attractiveness evaluation for the territory proposed as a future UNESCO Global Geopark indicate an Attractiveness Index value of $I_A = 0.77$.

The *strengths* of the territory's attractiveness are represented by indicators that display values significantly higher than those of the benchmark geopark. First, these strengths derive primarily from cultural heritage assets, whose value is approximately four times higher (expressed as number per km²) compared with other categories of resources. Additionally, the studied territory is characterized by a high density of tourist attractions at the local level (calculated within a 1 km perimeter), which enhances the area's attractiveness by enabling visitors to access multiple sites with minimal travel effort.

Another strength of the territory is the impressive volume of research conducted in the area - conference papers, scientific articles, and doctoral theses. This extensive body of documentation enhances the region's academic visibility and international profile, increasing its chances of being recognized as a geopark and of participating in national and international projects.

An additional advantage is the high level of safety in the area. The frequency of incidents and accidents is twice as low as the benchmark value (0.024 compared with 0.058), providing both visitors and residents with an elevated degree of protection. Safety is generally a critical criterion, relevant not only for the tourist experience but also for the overall quality of life in the region.

Moreover, the territory benefits from strategic accessibility due to the presence of the Maramureş International Airport. Located near Baia Mare, within the administrative area of the town of Tăuţii Măgherauş, approximately 9 km from the city center, the airport ensures rapid connectivity between the region and other areas of the country and abroad, thereby enhancing the tourism attractiveness of the geopark.

GAP Analysis

The GAP analysis conducted for the geodiversity component revealed that the studied area benefits from a complex relief and includes deposits from four distinct geological periods. In this context, geosites represent a key element. Although both officially protected and unprotected geosites were considered, the resulting index value is significantly lower compared with the benchmark (0.010 versus 0.018). However, this gap is partially offset by the presence of rich and rare mineral deposits, which enhance the geological value and attractiveness of the territory.

In terms of natural heritage, the GAP analysis reveals a similar shortfall: only 33.8% of the territory is covered by protected natural areas, compared with the benchmark value of 38.16%, indicating the need for additional measures to reinforce the protection and sustainable valorization of the region's natural resources.

The GAP analysis conducted for the geodiversity component revealed that the studied area benefits from a complex relief and includes deposits from four distinct geological periods. In this context, geosites represent a key element. Although both officially protected geosites and those lacking legal protection were taken into account, the resulting index value is significantly lower compared with the benchmark (0.010 versus 0.018). However, this difference is partially offset by the presence of rich and rare mineral deposits, which enhance the geological value and attractiveness of the territory.

In terms of natural heritage, the GAP analysis reveals a similar discrepancy: the proportion of land covered by protected natural areas is 33.8%, below the benchmark value of 38.16%, indicating the need for additional measures to strengthen the protection and sustainable valorization of the region's natural resources.

The expansion of protected areas within a territory is a key component of biodiversity conservation, geodiversity protection, and the promotion of sustainable development. This requires the detailed identification and assessment of elements of interest—geosites, rare ecosystems, priority habitats, endemic species, and cultural landscapes. At present, there are 12 unprotected geosites for which the preparation and submission of the necessary technical-scientific documentation is required in order for them to obtain protected area status.

Although the overall accessibility of the territory is at an optimal level, the attribute “proportion of land covered by road networks” shows a slight GAP (1.05% versus the benchmark value of 1.17%), indicating that a modest improvement is both possible and feasible through targeted investments aimed at increasing the efficiency and protection of the evaluated segment.

From the perspective of infrastructure, the results highlight two shortcomings related to the parameters “visitor center” and “car-free trails.” Functionally, a visitor center provides permanent and temporary exhibitions, presentations, 3D models, explanatory panels, and interactive resources designed to facilitate the understanding of the geological, natural, and cultural context of the area. Moreover, such infrastructure supports educational activities for schools and thematic groups, fostering public awareness of the value of natural and cultural heritage. Consequently, this type of infrastructure represents a critical need, requiring investment for its establishment. At present, this function is partially compensated by the relatively high number of existing information centers (10) within the territory. With regard to “sustainable car-free trails,” the studied area does not yet possess

such routes, underscoring the necessity of developing them to promote sustainable mobility and ecological tourism.

Car-free trails are not only a means of ecological mobility but also an integrated instrument for the conservation and sustainable valorization of the geopark.

Among all partial indicators analyzed, geosites hold the highest importance, having the greatest weighting factor in the model (0.0571) among all included sub-indicators.

4.1.2. Research findings

The main outcome is reflected in:

- I. The *attractiveness evaluation model* developed for the geopark.
- II. The quantitative assessment of territorial attractiveness for determining the Attractiveness Index (AI) of the analyzed area, within the context of the process of obtaining UNESCO Global Geopark status.

Attractiveness evaluation model

The applied methodology is grounded in three principal pillars: the methods selected from the specialized literature, the UNESCO criteria for geopark development, and the certified geopark used as etalon-benchmark (the Hațegului UNESCO Global Geopark).

The combination of these sources enabled the development of an integrated model for assessing territorial attractiveness, expressed through a quantifiable outcome represented by the Attractiveness Index (I_A).

In summary, the main results of the model development process were:

- (1) The identification of 52 methods used by researchers to evaluate attractiveness or the tourism potential of various destinations. By extracting the factors employed in these methods, a substantial volume of data was obtained, totaling 862 variables used for evaluation.
- (2) Deployment analysis was used to examine the components of the methods as well as the categorical levels employed by different researchers in attractiveness evaluation. Furthermore, category types were prioritized, resulting in 334 repetitive variables, largely composed of traditional attributes. It is noteworthy that the distribution of criteria within the methods has become more complex in the last decade: the average number of variables (attributes) used has reached 23 per method, while the levels of categorization range between 1 (single level) and 3 (hierarchical levels: Level 1 — general category, Level 2 — subcategories, Level 3 — specific elements), with an average of 1.85.

- (3) UNESCO requirements for geopark attractiveness assessment were correlated with suitability analysis criteria (matching the attributes used in existing methods with the criteria listed in the UNESCO checklist), in order to identify appropriate evaluation attributes for the geopark domain. This suitability process resulted in a set of 25 evaluable attributes, to which an additional 6 attributes—absent from previously developed methods—were added, yielding a final integrated set of 31 attributes used in the model.
- (4) The Attractiveness Index (I_{Ar}) was calculated using benchmark data from the Țara Hațegului UNESCO Global Geopark, which served as a reference standard. This approach enabled the comparison and evaluation of the territorial potential of the studied area relative to an internationally recognized certified geopark, thus providing an objective standard for determining territorial attractiveness and relevance.
- (5) The values of the resulting sub-indicators were standardized and computed by weighting individual values using the specific coefficients assigned to each criterion. The model was materialized through an indicator termed the Reference Attractiveness Index (I_{Ar}) for a geopark, which holds a value of 0.94.

Territories that aim to obtain geopark status can use this model to evaluate their level of attractiveness. After determining the Attractiveness Index (I_A) for the area, a GAP analysis is carried out. This gap refers to the difference between “where the territory currently stands” in terms of attractiveness and “where it should be” (the target or desired benchmark value). Such an analysis provides the foundation for developing a targeted action plan.

The territory for which the model is applied includes a series of natural areas whose sustainable development strategy envisions their future designation as a geopark. In this context, the model serves as a practical tool for the preliminary assessment of a given area.

A key aspect of this research is related to the UNESCO checklist, a document designed for global use across any territory, country, or continent. Consequently, the model developed here can also be applied globally to any area aiming to obtain geopark status in the future. This demonstrates that the applicability of the model is not restricted to a specific region, reflecting the universal relevance of the UNESCO checklist. Moreover, most of the criteria have a solid, validated foundation, having been employed in at least one scientific study.

The uniqueness of this study lies, first, in the creation of a model specifically designed for a territory intending to become a geopark; second, in establishing the reference value of $I_A = 0.94$;

and third, in the use of the benchmark concept, which allows for reapplication of the model by defining parameters in relation to a chosen reference point.

The Attractiveness Evaluation Result for the Future Geopark in Maramureș

The evaluation of the territory indicates an Attractiveness Index of $I_A = 0.77$ (Table 1), which represents approximately 82% of the benchmark value (0.94). This index reflects the territory's potential to be recognized as a geopark. The result obtained provides the scientific and methodological foundation for developing and substantiating the implementation plan for acquiring UNESCO Global Geopark status.

Overall, the analyzed territory presents three major strengths: a strong cultural heritage, a rich mining heritage, and significant scientific value.

In terms of cultural heritage, the territory scores far above the benchmark value due to its exceptionally rich patrimony, which includes 177 monuments of national or international significance. Moreover, the area contains sites inscribed on the UNESCO World Heritage List (the seven wooden churches). In addition to its substantial tangible heritage, the territory is emblematic at the national level from a cultural perspective, hosting villages where centuries-old traditions continue to shape daily life. The inhabitants of this region have preserved, to a considerable extent, the rural culture and ancestral craftsmanship of their forebears.

The volcanic character of the territory provides an exceptionally rich and diverse geological framework, with rare and unique mineral resources such as the mineral “baiamareite,” which highlights the area's outstanding potential for geological research, conservation, and geo-specific tourism (Mina Săsar–Baia Mare, 2023), as well as “fűlöppite” ($Pb_3Sb_8S_{15}$) identified at Dealul Crucii–Baia Mare in 1929 (Finály & Koch, 1929; Szakáll & Udubasa, 2002). These features confer scientific value to the territory within the geopark network (Kovacs et al., 2025). The mining heritage also holds particular significance, represented by historical mines and the rich history associated with them. Integrating this mining heritage into the global geosite network would significantly enhance the territory's attractiveness, while the scientific valorization of existing mineral deposits strengthens the “geodiversity” component.

The studied territory stands out through its academic visibility and internationally recognized scientific value. Publications in prestigious journals, together with doctoral theses and interdisciplinary research, attest to the fact that the area possesses a distinct scientific identity and demonstrates its capacity to support holistic approaches—an essential characteristic of UNESCO Global Geoparks. This academic visibility significantly enhances the territory's prospects of being recognized as a UNESCO Global Geopark.

In conclusion, the cultural and natural heritage of the area is exceptionally rich, featuring numerous elements of national and international significance, along with a demonstrated degree of safety. The availability of air access further contributes to its tourist attractiveness and to the overall feasibility of its designation as a UNESCO Global Geopark.

In the long term, Romania holds the opportunity to create the first transboundary geopark extending into Ukrainian territory, namely the Romanian–Ukrainian Carpathian Geopark. Although scientific research on natural resources and geological heritage exists in Ukraine with the aim of developing a geopark, such efforts have not yet targeted the establishment of a joint geopark, leaving room for a strategic initiative in regional cooperation (Manyuk, 2006; Yaholnyk & Manyuk, 2017).

From the perspective of a future expansion into a transboundary territory, the valorization of cultural confluences provides significant added value (Prykop, 2024), highlighting local specificity and strengthening the connections between tradition and innovation.

Cultural cohesion across borders represents a priority topic for geoparks located in frontier regions. These cultural ties are reflected both in the shared history along the banks of the Tisa River and in the material heritage, such as the valuable wooden churches of Carpathian Ukraine (Istovan, 2021).

Table 1. Attractiveness Evaluation Model for the assessed territory proposed for designation as the UNESCO Global Geopark Maramureş

Segment	Criteria	Attribute	Parameters and Measurement Units	Geopark-etalon		Maramureş		Weighting Factor
				V _E	St _E	V _{MM}	St _{MM}	
Geodiversity	C1. Paleography	A1. Range of geological periods	Number of geological period [#km ²]	0,008	1	0,002	0	0,0303
	C2. Relief structure data	A2. Geomorphological relief types	Number of items per km ² [#km ²]	0,006	1	0,003	0	0,0303
	C3. Protected areas	A3. Geosites	Number of geosites [#km ²]	0,018	1	0,010	0	0,0606
Natural heritage	C4. Natural reserve	A4. IUCN protected areas and UNESCO World Heritage Site	Number of items [#km ²]	0,009	1	0,009	1	0,0303
		A5. Protected natural areas of national and international interest	The proportion of land covered by protected natural areas [%]	38,16	1	33,8	0	0,0303
	C5. Structural quality indicators	A6. Forest area	Overlay [%]	53,13	1	54,95	1	0,0152
		A7. Land cover diversity	Shannon Diversity Index (H)	1,032	1	1,12	1	0,0152
Tangible cultural heritage	C6. Manmade buildings	A8. Tangible World Cultural Heritage (UNESCO)	Number of items per km ² [#km ²]	0,001	1	0,004	1	0,0606
		A9. Museums, churches, monuments, and archaeological sites	Number of items per km ² [#km ²]	0,08	1	0,09	1	0,0303
	C7. Grouping in the territory	A10. Spatial distribution	Density of cultural point groups, d=1km [#km ²]	0,027	1	0,04	1	0,0303
Intangible cultural heritage	C8. Traditions	A11. Intangible cultural heritage and traditions protected at the national/international level	Number of items per km ² [#km ²]	0,003	1	0,004	1	0,0606
	C9. Events	A12. Range of cultural events	Type of events [#year]	4	1	4	1	0,0303
Accessibility	C10. Transport	A13. Public transport (Road and rail)	Number of trips/day/destination [#day/location]	3,95	1	4,08	1	0,0152
		A14. Road and rail networks and associated land	Proportion of land covered by network areas [%]	1,17	1	1,05	0	0,0152
	C11. Number of connections	A15. In-links (inside territory)	Number of trips/day/destination [#day/location]	5	1	6,36	1	0,0152
		A16. Out-links (outside territory)	Number of trips/day/destination [#day/location]	1,95	1	3,62	1	0,0152
Infrastructure	C12. Public information infrastructure(s) in the territory	A17. Visitor center	At least 1/area	6	1	0	0	0,0303
		A18. Information center	At least 1/area	5	1	10	1	0,0303
		A19. Geologic map	1/ area	1	1	1	1	0,0303
	C14. Routes	A20. Sustainable car-free routes	Length of car-free trails within the geopark-designated area; network density [km/km ²]	0	0	0	0	0,0303
		A21. Thematic trails	Total length of trails within the geopark-designated area; network density [km/km ²]	0,3	1	0,3	1	0,0152

	C15. Wide range of excursion offers	A22. Range of tours (geotourism; ecotourism etc)	Variety of trails [#]	4	1	5	1	0,0152
	C16. Gastronomy	A23. Organic and traditional products (bioproducts, geoproducts, and traditional gastronomy with local specificity)	Type/number [#]	3	1	3	1	0,0303
	C17. Shopping	A24. Souvenir shop	Number of shops [# /km ²]	0,001	1	0.004	1	0,0303
Singularity (Rarity)	C18. Rarity of geological heritage	A25. Unique geological heritage	Number of sites [#]	1	1	1	1	0,0909
	C19. Geopark	A26. Distance from other geopark	Distance > 100 km	163	1	182	1	0,0303
Scientific value	C20. International value of the geological and cultural heritage	A27. Sites of international importance (with international recognition or international publications)	Number of items[#/km ²]	0,004	1	0.004	1	0,0606
	C21. Research	A28. Scientific studies	Total number of academic publications: books, articles, academic papers — within the last five years [#]	10	1	26	1	0,0303
		A29. PhD theses	Min 1 phd thesis — within the last three years [#]	0	0	7	1	0,0303
Safety	C23. Site security	A30. Safety level	Incident rate: incidents/accidents per 1,000 inhabitants	0.058	1	0.024	1	0,0303
	C24. Risk	A31. Extreme temperatures (Natural hazard)	Deviation from the mean [°C]	27	1	27	1	0,0303
				Reference Attractiveness Index: I_{Af}=0,94		MM:I_A=0.77		

*V_e = etalon value, Ste = etalon value standardization; I_A = attractiveness index; MM = Maramureş

4.2. Main findings of the multicriteria suitability analysis of the reference territory — the Maramureş Geopark — for ecotourism and the development of the model

4.2.1. Synthesis of the ecotourism potential of the Maramureş geopark

This section provides a synthesis of the main ecotourism development opportunities identified through the territorial analysis of the future UNESCO geopark. Building on the results of the previous stages—specifically the spatial suitability assessment for different types of activities—the proposed ecotourism facilities and recreational interventions are integrated and prioritized. The findings highlight a wide range of possibilities for valorising the natural and cultural resources of the area, including the development of viewpoints, eco-villages, scientific camps, lake pontoons, thematic hiking trails, and kayaking routes on rivers and lakes. This integrated approach supports the design of a sustainable ecotourism strategy tailored to the local context, oriented toward heritage conservation and community involvement.

In this phase, the results of the multicriteria evaluation are synthesised to provide an integrated overview of the ecotourism potential of the study area. By combining and reclassifying the thematic layers generated in the analytical stage, it became possible to identify the most favourable zones for different types of ecotourism activities, in line with principles of sustainable development and the conservation of natural and cultural heritage. The resulting synthesis map consolidates all suitability categories identified in the analysis. The following categories of elements supporting ecotourism activities were included: viewpoint (A), eco-village (B), pontoon (C), scientific camp (D), and thematic hiking trails (E), the latter comprising routes focused on geodiversity (E.I), biodiversity (E.II), and cultural-historical heritage (E.III).

The results obtained by integrating the eight polygon layers are illustrated in Figure 7.a, providing an overview of the spatial distribution of the most suitable areas for ecotourism development. The territorial analysis indicates that the largest surface corresponds to areas suitable for biodiversity exploration, totaling 430.5 km². These are followed by areas favorable for cultural–historical hiking (151.03 km²), eco-village development (42.9 km²), and scientific camp locations (23.3 km²). Geodiversity-focused hiking routes cover 18.4 km², while kayaking routes along the Tisa and Iza rivers and Lake Firiza amount to 5.2 km². Viewpoint locations occupy 0.34 km², and the areas suitable for pontoons cover only 0.003 km².

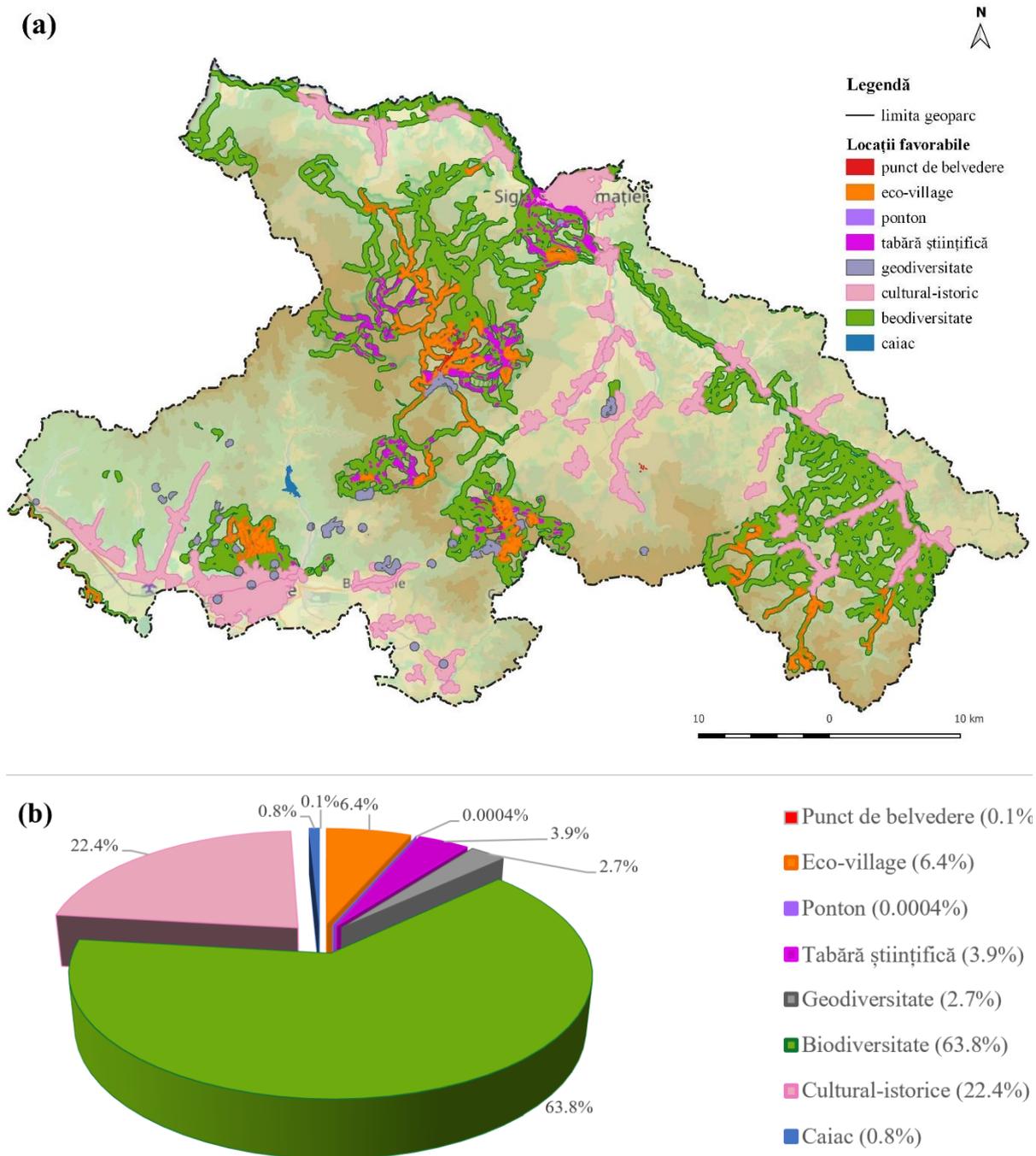


Figure 7. **a)** Integrated suitability map of the study area for the ecotourism activities assessed; **b)** Proportional distribution of the analysed ecotourism activities.

The results indicate a high level of suitability within the study area for the development of thematic hiking activities, which account for the largest spatial extent among all ecotourism activities analyzed. The percentage distribution of the areas associated with each activity is presented in detail in Figure 7.b.

Although the cumulative surface area associated with the eight ecotourism activities reaches 671.65 km², the integrated suitability map reveals a substantially smaller actual spatial extent. This is due to the significant overlap among the resulting polygons, as many areas simultaneously meet the suitability conditions for multiple types of activities. To address this, the spatial intersections of favorable zones were analysed and mapped, highlighting the degree of overlap between different ecotouristic functions.

This approach serves a dual purpose: first, it enables a more accurate estimation of the overall ecotourism potential of the study area; second, it reflects the fact that territories offering favorable conditions for multiple activities concurrently possess higher strategic value. Such areas are therefore of particular importance and should be prioritized within territorial planning and ecotourism development processes.

Consequently, identifying these areas with significant spatial overlap is essential for informed decision-making in the development of sustainable policies aimed at valorizing the ecotourism potential of the territory. Based on this analysis, the territory was zoned accordingly, with the resulting categories of areas illustrated in Figure 8.

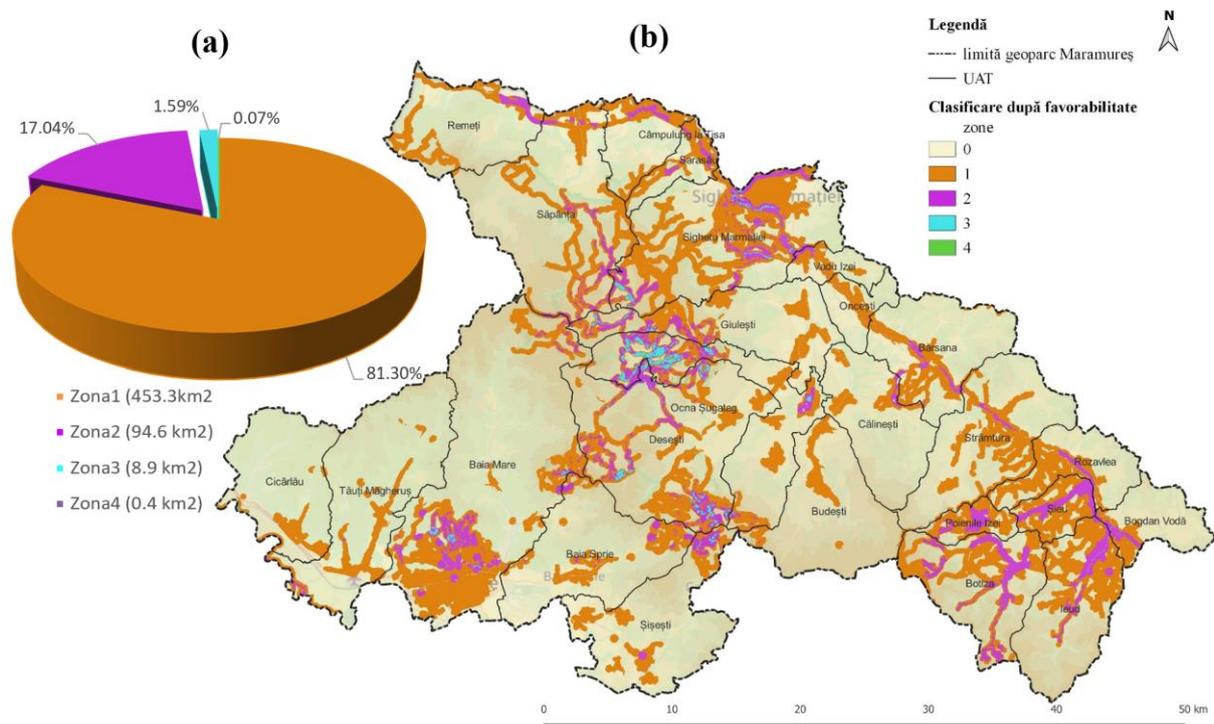


Figure 8. Zoning of the territory into ecotourism suitability classes (0–4) based on the spatial analysis of thematic results and their weighted distribution (a and b).

Thus, the zones identified in relation to their potential to support different forms of ecotourism are as follows:

zona 0 – unfavourable area for ecotourism – shows no suitability for any of the ecotourism activities analysed;

zona 1 – favourable area for ecotourism – shows suitability for one activity;

zona 2 – moderately favourable area – shows suitability for two activities;

zona 3 – highly favourable area – shows suitability for three activities;

zona 4 – the most favourable area for ecotourism – shows suitability for four activities.

The results of the analyses illustrated in the figure show that a large proportion of the favourable areas are concentrated in the orange-marked zone, which accounts for 454 km² (81.3%) of the territory identified as having ecotourism potential. Consequently, for planning purposes, priority should be given to an area of approximately 104 km², corresponding to zones 2, 3, and 4.

To provide a robust informational basis for establishing planning priorities for ecotourism development in the Maramureş Geopark, the territory was also classified at administrative-unit (UAT) level. This approach is grounded in the premise that community involvement represents a key factor both in the development of sustainable ecotourism and in supporting the establishment of a geopark. Active engagement of local communities not only enhances the conservation of natural and cultural heritage but also strengthens the acceptability and long-term sustainability of ecotourism initiatives.

The diversity of ecotourism activities that can be carried out within the same territory represents a significant advantage in developing comprehensive strategies for tourism valorization. Starting from the premise that ecotourism capitalizes on natural and cultural resources through responsible and participatory use, it is essential that the benefits generated by ecotourism activities be directly experienced by local communities (*Rezultate definitive RPL 2021 – Recensământul Populației și Locuințelor*, n.d.). Moreover, the larger and more favourable the integrated area is for ecotourism development, the greater its long-term development potential.

Accordingly, spatial analysis was employed to identify favourable zones as well as the suitability of each administrative unit (UAT) for ecotourism, together with the population living in these areas—those who are expected to benefit from ecotourism development. The results of the UAT-level analysis are presented in Table 2.

Table 2. Territorial distribution of zones by ecotourism suitability classes at the UAT level

Locality name (km ²)	[km ²]	Population [nr/loc.]	Zone 1 [km ²]	Zone 2 [km ²]	Zone 3 [km ²]	Zone 4 [km ²]	Suitable for Ecotourism	
							Total Area [km ²]	[%]
Bârsana	72	4122	14.3	1.90	0.030	–	16	23%
Baia Mare	234	108759	55.4	12.30	0.682	–	68	29%
Baia Sprie	93	14329	15.2	2.15	0.007	–	17	19%
Bogdan Vodă	34	2619	4.8	1.67	0.005	–	7	19%
Botiza	74	2373	23.4	10.26	0.008	–	34	46%
Budești	85	2894	8.9	0.04	–	–	9	10%
Câmpulung la Tisa	34	2308	9.2	1.51	–	–	11	31%
Călinești	66	3049	6.3	0.70	–	–	7	11%
Cicârlu	75	3751	7.1	0.16	0.193	–	7	10%
Desești	142	2179	37.1	10.73	1.967	0.13	50	35%
Giulești	78	2841	19.5	4.54	0.550	0.01	25	31%
Ieud	76	4061	25.0	5.61	–	–	31	40%
Ocna Șugatag	91	3617	18.8	8.43	3.799	0.20	31	34%
Oncești	21	1519	4.7	0.07	–	–	5	23%
Poienile Izei	16	792	9.1	3.00	–	–	12	76%
Remeți	68	2981	13.6	2.13	–	–	16	23%
Rozavlea	43	2986	14.9	1.40	0.016	–	16	38%
Săpânța	140	3031	32.6	4.98	0.004	–	38	27%
Sarasău	20	2433	8.8	1.44	–	–	10	51%
Șieu	21	2240	12.9	4.91	0.002	–	18	85%
Sighetu Marmăției	137	32793	55.3	12.40	1.312	0.08	69	50%
Șișești	90	5556	14.0	2.42	0.200	–	17	19%
Strâmtura	92	3254	23.3	0.88	0.012	–	24	26%
Tăuți Măgheruș	121	8463	14.7	0.67	–	–	15	13%
Vadu Izei	17	2542	4.6	0.64	0.009	–	5	31%
Geopark territory	1941		453	95	9	0.42	558	29%

Data source: 2021 Census (Rezultate definitive RPL 2021 – Recensământul Populației și Locuințelor, n.d.); OSM platform (OpenStreetMap, n.d.)

The spatial analysis indicates that most UATs within the study area include surfaces suitable for at least three types of ecotourism activities (Zone 3).

Among the UATs with the largest such areas are Baia Mare, Ocna Șugatag, and Desești. Additionally, the results show that, to varying extents, nearly all analyzed UATs contain territories suitable for at least two ecotourism activities, highlighting a diversified local potential.

Furthermore, the results show that, to varying degrees, almost all analyzed UATs include territories suitable for at least two ecotourism activities, indicating a diversified local potential.

At the scale of the entire Maramureș Geopark territory, the synthesized results reveal an ecotourism-suitable area of approximately 558 km², representing 29% of the total study area—a proportion that highlights a substantial potential for the sustainable valorization of the region's natural and cultural resources.

A detailed analysis of the 25 UATs highlights the presence of territorial disparities in terms of ecotourism suitability. The spatial distribution of these data enables a comparative assessment of both the ecotourism-appropriate surface area (in km²) within each UAT and its proportional share (%) relative to the total administrative territory.

According to Figure 52.a, the UATs of Sighetu Marmației, Baia Mare, and Desești stand out as having the most extensive areas suitable for ecotourism, with values ranging from 69.1 km² to 49.9 km². These results can be attributed to the multifunctional character of urban centers, the presence of diverse cultural and ethnic heritage (a multicultural profile), the historical influence of mining activities (particularly in the Baia Mare area), as well as favorable relief and geographical positioning.

In contrast, when examining the degree of territorial valorization (choropleth representation), a concentration trend is observed in the northeastern sector (Șieu, Poienile Izei) (Figure 9.b). This pattern can be explained by the suitability of these areas for viewpoints and eco-villages (A, B), and it should be noted that these UATs are significantly smaller than others, with areas of only 16 km² and 21 km², respectively. Conversely, lower values are recorded in the northern sector of the Maramureș Geopark territory (Sarasău, Sighetu Marmației).

Overall, the favorability maps generated through the multicriteria evaluation clearly indicate that the ecotourism development potential within the study area is differentiated both geographically and at the UAT level. This differentiation is reflected in the variable extent of ecotourism-suitable areas, the differing ecotourism potential of each UAT, the spatial overlaps among various forms of ecotourism activities, and the density and distribution of the population, which directly influence the capacity to valorize local resources.

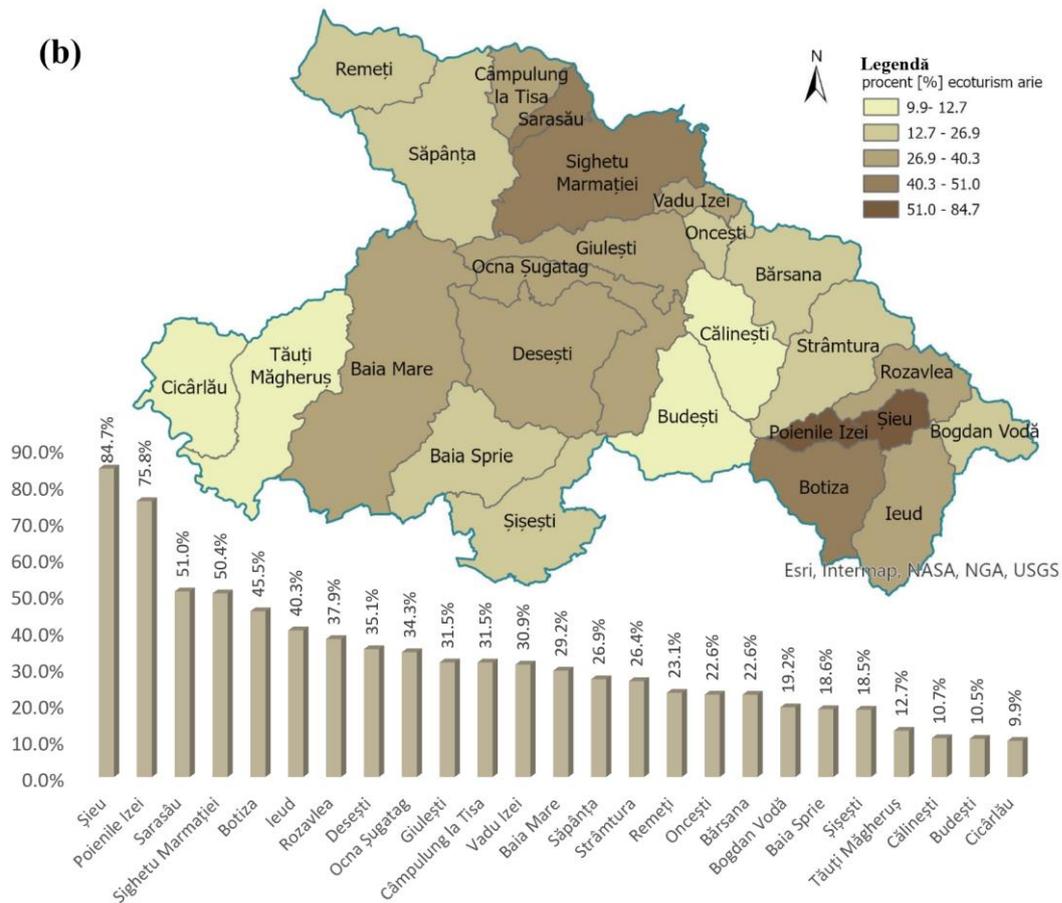
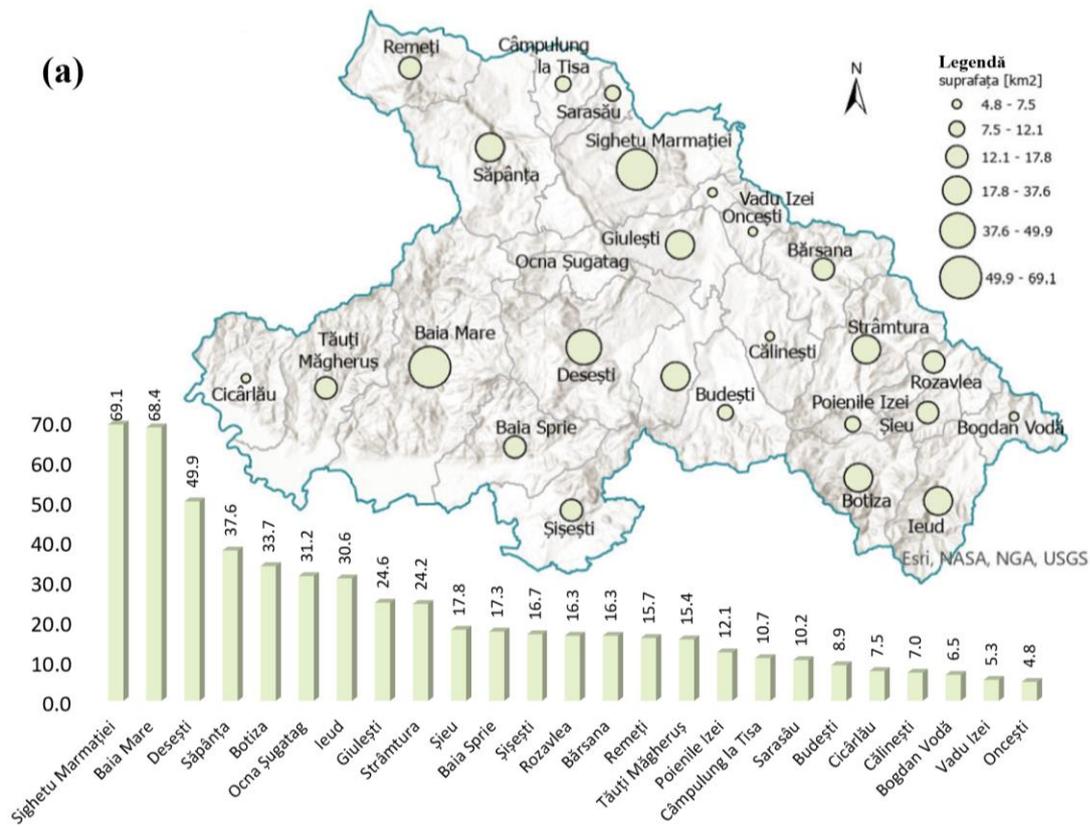


Figure 9. **a.** Distribution of ecotourism-suitable areas [km²] across UATs. **b.** Percentage level [%] of ecotourism suitability relative to the total UAT area.

In conclusion, the territorial distribution of ecotourism potential provides a solid decision-making foundation for local authorities, stakeholders involved in the conservation of natural and cultural heritage, and investors interested in developing sustainable tourism. This approach enables strategic planning based on spatial data and objective criteria, contributing to the sustainable valorization of territorial resources.

Thus, the results support an integrated perspective on the sustainable development of the natural and cultural resources of the study area, while also considering the local community. This approach not only identifies areas with high potential but also substantiates decisions regarding investment prioritization and the development of infrastructure specific to sustainable ecotourism, in alignment with the principles of geopark development.

4.2.2. Research findings

The main outcomes of the multicriteria analysis consist, first, in identifying the degree of suitability of the Maramureş Geopark territory for ecotourism development. Second, the analysis led to the creation of a replicable multicriteria model that can be applied in similar contexts. In addition, a coherent set of relevant criteria was developed—an essential component of the proposed methodology—which provides a solid foundation for decision-making in sustainable ecotourism planning.

Result of the ecotourism suitability assessment for the Maramureş Geopark territory

The analysis was conducted using a GIS-based methodology grounded in spatial thinking and the multi-criteria suitability assessment approach. By integrating multiple levels of criteria and the specific parameter values, eight types of ecotourism activities and infrastructures were evaluated to identify the most suitable areas for ecotourism development.

The results were represented cartographically, highlighting the spatial distribution of favorable locations for each activity type: viewpoints, eco-villages, pontoons, scientific camps, thematic trails (focused on geodiversity, biodiversity, and cultural-historical heritage), and kayaking routes along the hydrographic network. Each activity corresponds to distinct surface areas, according to the degree of suitability identified across the territory.

The quantified surface areas for each category are as follows: viewpoints – 0.34 km²; eco-village – 42.9 km²; pontoons – 0.003 km²; scientific camps – 23.3 km²; geodiversity-based trails – 18.4 km²; biodiversity-based trails – 430.5 km²; cultural-historical trails – 151.03 km²; and kayaking – 5.2 km².

The integrated suitability map for ecotourism summarizes the final outcome of the evaluation, reflecting all eight potential ecotourism activities identified in the study area. Overall, the multi-criteria assessment indicates an ecotourism potential of 29%, corresponding to a surface of 558 km² suitable for ecotourism out of the total 1,941 km² of the study area, with a differentiated distribution across administrative units.

The analysis also reveals spatial overlaps between areas suitable for various ecotourism activities. The following overlapping zones were identified: the most favorable zone (suitable for 4 activities – zone 4): 0.42 km²; the highly favorable zone (suitable for 3 activities – zone 3): 9 km²; and the moderately favorable zone (suitable for 2 activities – zone 2): 95 km². Based on the premise that territories supporting multiple ecotourism activities simultaneously have higher strategic value, these areas represent priority levels within the ecotourism planning process. Moreover, structuring the results at the UAT level provides a robust foundation for their strategic valorization (Table 2).

Modelele rezultate

The development of the model using GIS was based on the experience gained from two distinct territories: one located within a national geopark—Carpaterra Geopark in Braşov County—and another representing a potential future geopark proposed in Maramureş County. In the first stage, the methodology was designed through the analysis of ecotourism activities carried out in the Racoş Geological Complex, an integral part of the Carpaterra National Geopark. Subsequently, this methodology was adapted and applied to assess a new territory, supporting the initiative to establish a UNESCO Global Geopark in Maramureş County.

The two case studies confirmed both the functionality and robustness of the developed model. Based on the results obtained, a suitability analysis model for ecotourism activities was constructed, grounded in a terrain evaluation aligned with the specific requirements of each activity type. The model incorporates a coherent set of criteria and evaluation factors—an essential component of the methodology—which enables the scientific and reproducible estimation of the degree of suitability for ecotourism development.

This study aimed to integrate a systematic, hierarchical approach (from local to regional scale) into a geospatial decision-support model. This was accomplished using the Model Designer tool within the QGIS platform, following a structured methodological framework. The final purpose was the generation of ecotourism suitability maps, designed to highlight the areas recommended for ecotourism development within the analyzed region.

Within the model, the geospatial analysis workflow was fully automated. The use of the Model Designer enabled the integration and combination of multiple algorithms into a coherent workflow, structuring a complex process composed of several interconnected sub-processes. This unified process flow incorporates all operations required for the territorial suitability assessment of ecotourism activities. Consequently, each activity-specific analysis can be executed through a single run, significantly increasing the efficiency of the analytical procedure. The integrated analytical platform developed in this study allows the model to be reused with different sets of spatial input data, ensuring high flexibility and broad applicability in similar contexts.

The territorial suitability modelling process resulted in eight replicable models. Thus, individual models were developed for identifying suitable locations for: viewpoints; eco-villages; pontoons; scientific camps; thematic hiking routes (including geodiversity-oriented, biodiversity-oriented, and cultural-historical hikes); and kayaking on hydrographic networks.

The models can be reused either as a “.model” file specific to the graphical model builder or as a Python script, ensuring methodological flexibility for application in other territorial contexts or similar projects. Exporting the model guarantees faithful reproduction of all predefined steps while also enabling integration into automated GIS processing workflows at both local and regional scales.

This approach offers significant advantages through process automation, enabling the entire analysis to be executed in a single step. Beyond the reusability of the model, the solution also provides a high level of adaptability by allowing parameter adjustments according to the specificities of each case. At the same time, it ensures transparency and traceability in the application of the methodology, facilitating validation and replication of results.

Another essential feature of the model is its scalability, which allows the analysis to be extended to large geographic areas and voluminous spatial datasets. Through the integration of multicriteria evaluation within an efficient modelling system, the process remains functional and accurate even under conditions of substantially increased data volume. For example, applying the same model to extensive territories such as the UNESCO Global Geopark Ngorongoro Lengai in Tanzania, with an area of 11,886 km² (*About – NLUGG – Ngorongoro Lengai Geopark*, n.d.) or the Tabas UNESCO Global Geopark in Iran, covering 22,771 km² (*Tabas UNESCO Global Geopark | UNESCO*, n.d.), would involve considerably larger datasets, yet the model remains applicable and robust.

By running the model in either .model format or as a Python script, the multicriteria analysis becomes entirely reproducible. This is achieved by loading the project in QGIS,

selecting the desired model, and providing the thematic layers corresponding to the territory of interest. The resulting output consists of a polygon vector layer highlighting the areas suitable for ecotourism.

The models developed, as well as the mechanism for applying and replicating the multicriteria suitability evaluation for ecotourism activities using GIS, are illustrated in Figure 11.

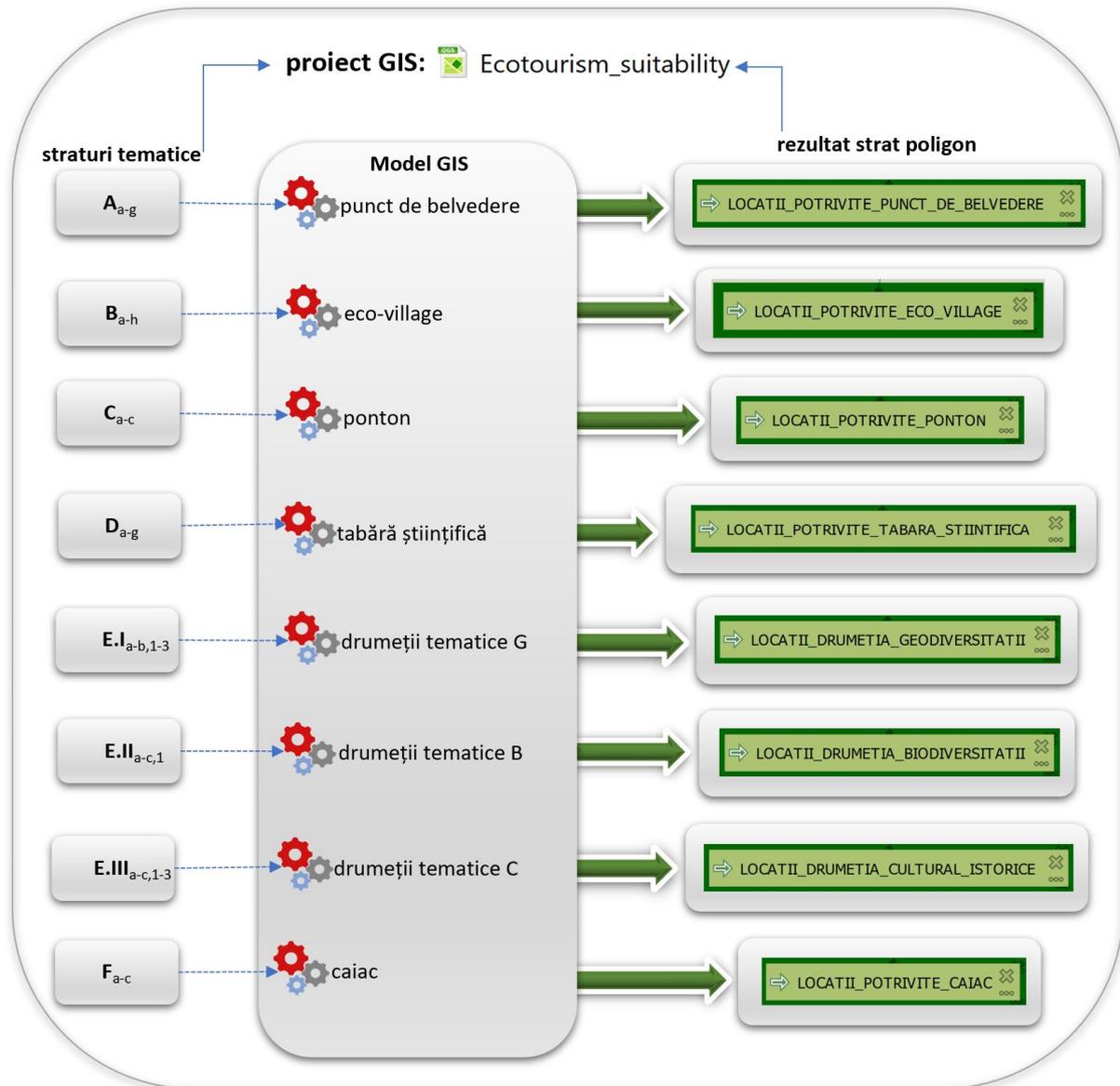


Figure 10. Mechanism of the workflow for applying or reapplying multicriteria suitability evaluation models for ecotourism

The input thematic layers correspond to the criteria defined within the analytical model and are represented by the layers listed in Table 3, each associated with a relevant factor for

assessing ecotourism suitability. The spatial data corresponding to each criterion, together with the input datasets used in the GIS model, are materialized as thematic layers.

The criteria employed to determine the ecotourism potential of the analysed territory were formulated based on the spatial datasets available in the pilot phase and were subsequently validated for the Maramureş Geopark. This implies that, when applying the model to a different geographical area, alternative datasets must be used to reflect the specific territorial and dimensional conditions of that region (e.g., 113 km² in the pilot phase versus 1,941 km² for the entire study area).

Validation of the criteria within the Maramureş Geopark required minor adjustments and refinements to those previously defined for the area included in the Carpaterra Geopark. Improvements concerned, on the one hand, the criteria established for scientific camps and eco-villages by introducing an additional criterion regarding built-up zones, namely the exclusion of dispersed buildings located outside built-up areas through the application of a 5 m buffer, in accordance with current legislation. On the other hand, modifications were made to one of the criteria used for the placement of pontoons, replacing the south–west orientation criterion with one based on visibility, thereby offering a more objective and relevant foundation for site selection by considering visual perspectives and landscape integration (focusing on visible points of interest). Furthermore, to avoid strictly local references (e.g., the Racoş Geological Complex or the Castle), the description of the criteria was generalized, ensuring applicability across multiple destinations by emphasizing the type of spatial thematic layer used.

As a result, a unified set of criteria for assessing ecotourism suitability was developed and is summarized in Table 3. This set integrates the relevant criteria and factors for various ecotourism facilities and activities and can serve as a transferable criterion model for other destinations.

Table 3. Criteria and factor set for assessing territorial suitability for ecotourism.

#	Criterii/factori	Valoare parametru propus	Strat (layer)
A. PUNCT DE BELVEDERE			
A.a	elevation	$h > 700$ m	 raster
A.b	vegetation	cod 2; 6 (excluded)	 vector poligon
A.c	terrain slope	degree $< 3^0$	 raster
A.d	distance from tourist attractions	$d < 5$ km	 vector poligon
A.e	visibility	 toward tourist attractions	 vector punct
A.f	distance from roads	$d < 200$ m	 vector linie
A.g	built-up area	$S_{\text{buildings}} + S_{\text{buffer}}$ (excluded)	 vector poligon
A.h	area	$A \geq 64$ m ²	 vector poligon

B. ECO-VILLAGE			
B.a	terrain slope	degree < 17° (30%)	 raster
B.b	built-up area	S _{intravilan} (excluded)	 vector poligon
	buildings outside the urban boundary (extravillan)	S _{buildings} + S _{buffer} , d= 5 m (excluded)	 vector poligon
B.c	industrial zone (mining area)	S _{mine} + S _{buffer} , d = 200m (excluded)	 vector poligon
B.d	geosites zone	S _{geosites} (excluded)	 vector poligon
B.e	distance from roads	d < 200 m	 vector linie
B.f	distance from primary and secondary roads	d > 3 km	 vector linie
B.g	distanța față de râuri	d < 750 m	 vector linie
B.h	protected natural areas	S (included)	 vector poligon
B.i	area	A ≥ 3 ha (30.000 m ²)	 vector poligon
C. PONTON PE LAC			
C.a	above the lake surface	S _{lake}	 vector poligon
C.b	distance from routes + length of the pontoon	D < 30m, where D = d ₁ + d ₂ d ₁ = 20 m; d ₂ = 10 m	 vector linie
C.c	visibility	 points of interest	 vector punct
D. TABĂRĂ ȘTIINȚIFICĂ			
D.a	terrain slope	degree < 5°	 raster
D.b	scientific reserves	S _{rezervații} (excluded)	 vector poligon
D.c	built-up area	S _{intravilan} (excluded)	 vector poligon
	scattered buildings (extravilan)	S _{clădiri} + S _{buffer} , d= 5 m (excluded)	 vector poligon
D.d	industrial zone (mining area)	S _{minier} + S _{buffer} , d = 200m (excluded)	 vector poligon
D.e	distance from scientific reserves	d < 5 km	 vector punct
D.f	protected area zone	S _{arii_protejate} (included)	 vector poligon
D.g	distance from roads	d < 200 m	 vector linie
D.h	area	A =1.5 ha (15000 m ²)	 vector poligon
E. DRUMETII TEMATICE			
E.a	terrain slope	degree <35°	 raster
E.b	distance from roads	d < 300 m	 vector linie
E.c	major hydrographic network (rivers and lakes)	S _{hydrographic network} (excluded)	 vector linie
E.I ₁	distance from geodiversity attractions: G ₁ - G _n	d < 300 m	 vector poligon
E.I ₂	distance to mining heritage and mineral deposits: M ₁ - M _n	d < 500 m	 vector punct
E.I ₃	distance from the industrial/mining area: M _n - M _m	d < 300 m	 vector poligon
E.II	distance from biodiversity attractions: B ₁ -B _n	d < 300 m	 vector poligon
E.III ₁	distance from tangible cultural-historical sites: C ₁ -C _n	d < 500 m	 vector punct
E.III ₂	distance from intangible cultural-historical sites: C _m -C _p	d < 500 m	 vector punct
E.III ₃	distance from attractive cultural villages: C _r -C _s	d < 200 m	 vector poligon
F. CAIAC PE REȚELE HIDROGRAFICE			
F.a	navigable waterways network	S _{hidrografică}	 vector poligon

F.b	islands or features on the water surface	S_{features} (excluded)	 vector poligon
F.c	risk zone	$d = 2m$	 vector poligon

The results of the analyses not only provide scientifically grounded data for the ecotourism development of the studied territory, but also serve as valuable information for the broader and complex process of geopark planning. Moreover, the models developed ensure their transferability, allowing their application in other territories as well, with the necessary adaptations to local specificities. Consequently, the findings support the formulation of a long-term sustainable ecotourism strategy both for the studied area and for other territorial entities, regardless of their spatial extent or their position within the tourism hierarchy.

1. CONCLUZII

This study examined the attractiveness of geoparks from a proactive perspective, anticipating planning needs and supporting evidence-based decision-making. Within this framework, the research aimed to develop scientifically grounded models, built on objective and methodologically validated criteria, capable of ensuring a robust and comparable assessment of territories aspiring to geopark designation. Through their replicable and transferable nature, the models contribute to the expansion of the geopark network and provide practical tools for identifying, planning, and strengthening areas with high potential for obtaining UNESCO Global Geopark status. Furthermore, integrating ecotourism suitability analysis reinforces the sustainable development dimension of geoparks and addresses a significant gap in the literature regarding the development and application of modelling methodologies—including GIS-based modelling—thus offering an original contribution to consolidating the methodological framework.

Applying the multicriteria evaluation model to the target territory in northern Maramureş County resulted in an attractiveness index of $I_A = 0.77$. This value indicates a high level of attractiveness relative both to the benchmark reference and to UNESCO’s designation criteria. The territorial analysis highlights three major strengths: an exceptionally rich cultural heritage, a valuable mining heritage, and a strong scientific profile. The presence of air accessibility provides an additional competitive advantage, enhancing the tourism appeal of the area and supporting the feasibility of its designation as a UNESCO Geopark. These results

constitute a rigorous scientific and methodological foundation for developing the implementation plan required for the official recognition of the Gutâi–Maramureș Geopark. In the long term, the emergence of a Romania–Ukraine cross-border geopark—the Romanian–Ukrainian Carpathian Geopark—represents a strategic opportunity for regional cooperation.

The assessment of ecotourism potential, conducted to further explain the attractiveness of the geopark, was based on a GIS-supported methodology grounded in spatial reasoning and multi-criteria suitability analysis. Integrating multiple levels of criteria and their specific parameter values enabled the evaluation of eight types of ecotourism activities and infrastructures, leading to the identification of the most suitable zones for ecotourism development.

Results show that 29% of the studied territory possesses significant ecotourism potential, including priority areas capable of supporting several types of activities simultaneously. This confirms both the validity and the practical relevance of the developed model, providing not only a scientific basis for ecotourism planning and geopark development but also a replicable methodological framework transferable to other territories and geographical contexts.

Overall, the research demonstrates the relevance of modelling as an emerging territorial instrument for sustainable development and spatial planning. The findings confirm that attractiveness assessment constitutes an objective and indispensable foundation for geopark designation and consolidation, while also serving as a concrete support tool for ecotourism management and regional development policies.

The main conclusions of the study underline the following: (i) the integrated methodology proposed is scientifically valid and adaptable to any territory; (ii) the use of a benchmark reference represents a methodological innovation with global applicability; and (iii) the attractiveness assessment functions both as a scientific analytical tool and as a decision-support mechanism.

In summary, the research shows that the models developed not only meet the objectives initially formulated but also generate replicable and scalable tools for analysing, planning, and promoting geoparks at national and international levels, providing an applied and valuable framework for decision-makers, local authorities, and the communities involved.

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