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DEVELOPMENT OF MULTI-CRITERIA AND METHODOLOGY FOR SELECTION OF GEOSITES FOR THE POTENTIAL GEOPARK “KRATOVO-ZLETOVO”

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Abstract

This study examines and applies a multi-criteria evaluation framework to assess micro-geological sites within the Kratovo-Zletovo region and to identify priority localities for prospective designation as part of UNESCO Global Geopark. The Kratovo–Zletovo region in northeastern North Macedonia is a compact but vibrant patchwork of geological, cultural, and mining heritage that has been proposed repeatedly as the country’s first geopark by Lepitkova et al. 2019 [1]. The area’s preserved volcanic landforms, mineral deposits, and traditional towns (most notably Kratovo) create an excellent case for a protected geopark that links earth-science values with local history, education, and sustainable tourism. Beyond dramatic volcanic cones, the region is also an important ore district. Historic mining and mineral occurrences around Zletovo and Kratovo (cerussite, copper, and other ore minerals) are part of the area’s geodiversity and tell how geology shaped local economies and settlements for centuries. The mineralogy and old mine workings are themselves geo-sites of scientific and interpretive interest. Turning Kratovo–Zletovo into a geopark requires addressing several practical issues: securing legal protection for key geo-sites; cleaning and stabilizing old mining areas where safety is a concern; investing in visitor infrastructure (trails, signage, small museums) and creating revenue streams that benefit local communities rather than creating mass-tourism pressure. Any geopark plan should integrate cultural heritage and biodiversity, as well as the needs of residents, to ensure long-term local support. Selecting geosites for geotourism, conservation, education, or research purposes involves a structured, multi-criteria assessment. The selection process ensures that the most significant geological features are identified, documented, protected, and potentially promoted. Using a structured, transparent multi-criteria approach ensures the protection and optimal use of these valuable natural assets as well as appropriate nomination for UNESCO Geopark. In this article, applying multi-criteria evaluation—an approach used in geopark initiatives worldwide—the Kratovo-Zletovo region was assessed to identify priority sites for future inclusion in a Geopark. According to the results obtained from the expert evaluation, we can conclude that three localities, including Earth pyramids near v. Kuklica, Geoarchaeological occurrence Cocev Kamen and Lesново cone and caldera, were ranked with the highest score as key sites for the proposed UNESCO Global Geopark. Other localities received lower scores, mainly due to criteria such as accessibility, infrastructure, and presentation, which can be significantly improved through targeted measures and management activities.

Key words: *Kratovo–Zletovo, Geopark, geoheritage, ecotourism, multi-criteria*

INTRODUCTION

In 2016, a comprehensive study was prepared on the Geodiversity and geoheritage of the Republic of Macedonia, as well as on other components of nature (biological and landscape diversity) by Jovanovski et al. 2016 [2], which aimed to provide a comprehensive overview and analysis of the country's natural resources for the needs of the Ministry of Environment and Physical Planning. This document provides a solid expert basis for assessing the geovalues in our country. In this study, the Kratovo-Zletovo region occupies one of the most representative localities for the nomination of a geopark in our country. The Kratovo–Zletovo region, in northeastern North Macedonia, is among the country's most significant volcanic-tectonic areas. It is distinguished by a complex geological history, active mining potential, and striking geomorphological features. The region spans the middle basin of the Kriva Reka River, the hilly Stracin area with the Crven Kamen elevations, and parts of the middle Zletovska Reka basin. Its landscape consists of both mountainous and hilly units and lies within the Serbo-Macedonian tectonic massif. According to Boev, B. and Yanev, Y (2001) [5], the Kratovo–Zletovo volcanic area stands as the largest paleovolcanic region in North Macedonia, dating back to the Oligocene period (32–29 Ma ago).

The area landscape includes numerous springs, rivers, and small reservoirs. Shaped by tectonic activity, it is crossed by many river valleys: permanent streams flow through the mountainous sections, while intermittent streams appear in the hills. The primary rivers that define the area's hydrography are the Kriva Reka and the Zletovska Reka.

In 2019, an expert study was completed for the proposed Kratovo–Zletovo Geopark to serve as the foundation for a UNESCO application. The research combined scientific findings with administrative and technical requirements to support potential inclusion in the UNESCO Global Geoparks Network. However, the effort ultimately stalled, and no formal application was submitted.

As emphasized in the research by Kubalíková, L. et al. (2023) [4], geodiversity and geoheritage encompass intrinsic as well as societal values. UNESCO Global Geoparks are single, unified geographical areas recognized by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) for their internationally significant geological heritage. They are more than just places with interesting rocks—they combine geology, culture, biodiversity, and local communities in a way that promotes sustainable development.

A UNESCO Global Geopark uses its geological heritage, in connection with all other aspects of the area's natural and cultural heritage, to enhance awareness and understanding of key issues facing society, such as using the Earth's resources sustainably, mitigating the effects of climate change, and reducing natural hazard-related risks.

The Geopark has clearly defined boundaries and usually has a large area that is managed by a competent entity that is obliged to protect all objects of the geological heritage from their destruction or sale. Namely, the Geopark is managed by an entity that is most often determined by the act of proclamation of the Geopark. The entity, which can be a competent body of the central or local government or a specially formed or existing entity or organization, should have the appropriate ability, financial and personnel, to implement protection measures, to lead and improve the policy of sustainable development on the territory of the Geopark. Within the framework of the Geopark, geological knowledge, objects of the geological heritage, as well as all aspects of the natural and cultural heritage, should be recorded, described, and made available to the general public.

To establish a geopark and organize its work and activities, it is necessary to include representatives of the local government, local population, local private companies, as well as representatives of state bodies, scientific, educational, and cultural institutions, including representatives of the non-governmental sector, in the management structure of the geopark.

Recently, Goce Delcev University, with the support of the Ministry of Environment and Physical Planning, undertook a systematic analysis in 2023 of potential geopark sites in North Macedonia. This initiative involves a comprehensive assessment of the geological, cultural, and natural values of each site, which will serve as the foundational baseline documentation for several localities' future applications to the UNESCO Global Geoparks Network. Within the scope of this assessment, the Kratovo–Zletovo region has been identified as a priority area for potential inclusion by Leptikova et al. 2019 [3]. In that direction, this article was focused on this area.

Multi-Criteria Decision Making (MCDM) or new methods provide techniques for finding a compromise solution. They differ in that they place the decision maker at the center of the decision-

making process. They are also not methods that lead to the same solution for every decision maker but include subjective information. Furthermore, as stated by Govindan, K. et al. (2016) [7-10], MCDA methods are used to solve decision-making problems in several areas, including information and communication technology; business intelligence; environmental risk analysis; environmental impact assessment and environmental sciences; water-resource management; solid-waste management; remote sensing; flood-risk management; health-technology assessment; healthcare; transport; nanotechnology research; climate change; energy; international law and policy; human resources; financial management. Subjective information, known as choice information, is provided by the decision maker and leads to a compromise solution. In Europe, Multi-Criteria Decision Making (MCDM) methods have been widely adopted for evaluating natural resources, ranking geosites, and guiding the establishment of UNESCO Global Geoparks. Similar case Studies in Europe were used: MCDM / Similar Assessment Methods are: Beigua UNESCO Global Geopark (Liguria, Italy), Slovak Karst (potential Geopark), Slovakia, Hațeg UNESCO Global Geopark, Romania, Sesia Val Grande UNESCO Geopark (Pogallo Valley), Italy, Villuer-cas-Ibores-Jara Geopark, Spain.

MATERIAL AND METHODS

Study Area

As already stated, the study area covers the municipalities of Kratovo (376 km²) and Probištip (326 km²), located in the northeast part of North Macedonia. This area is characterized by remarkable geodiversity, rich biodiversity, and significant cultural heritage.

There are 66 settlements on the territory of the municipalities of Kratovo and Probištip, from which 31 are in the municipality of Kratovo and 35 are in the municipality of Probištip, Lepitkova et al (2016) [1]. Of all these, only Kratovo and Probištip are urban settlements, while the rest are villages and, with the exception of Zletovo, all others are small villages with a population of less than 300 inhabitants.

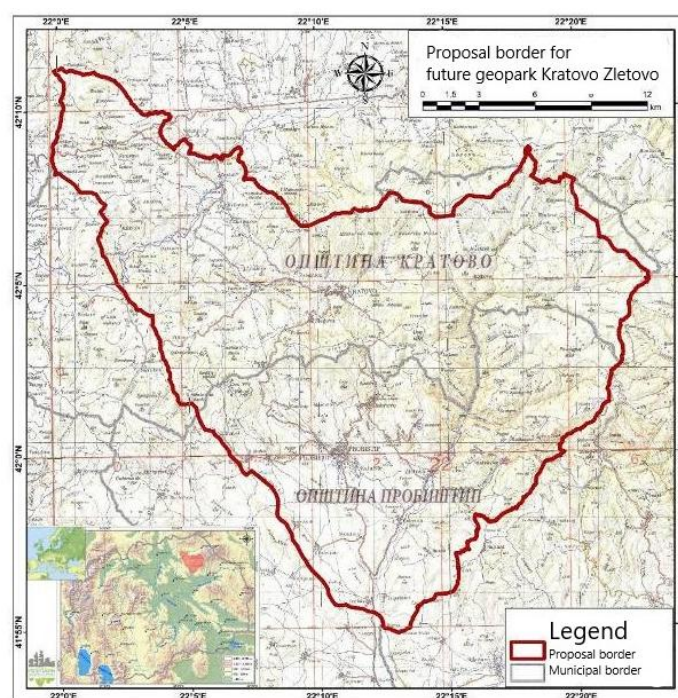


Figure 1. Location of the proposed Kratovo-Zletovo geopark area within the municipalities of Kratovo and Probištip by Jovanovski, M. et al. (2016) [2]



Figure 2. Panoramic view of the Kratovo-Zletovo volcanic area – a potential geopark
(photo Mileski I. 2019)

Methodology

A multi-criteria approach is a methodology used for decision-making or problem-solving in cases where it is necessary to take into consideration multiple criteria or factors (Mendoza, G. et al., 2003) [6]. This approach is useful in various fields, such as business, engineering, planning, and public policy, where decisions do not depend on just one but on several relevant aspects. The elements of geodiversity should be digitized in GIS in order to create a digital morphographic and geological map. Some of the elements of geomorphological and hydrological geodiversity from the morphographic map may overlap and, at the same time, generate areas with high potential for the identification of geoparks.

A multi-criteria approach for geopark evaluation or development is a method that considers several factors simultaneously to assess, plan, or manage a geopark. This approach is widely used in geoconservation, sustainable tourism, and land-use planning. Here is a structured multi-criteria approach for selection per locality:

Table 1. Structured multi-criteria approach for Kratovo-Zletovo geosites assessment

Criteria	Sub-Criteria	Description	Scoring/Weighting
Geological Value	Uniqueness & Rarity	Presence of unique rock formations, fossils, or geomorphological features	1–5 (1 = low, 5 = exceptional)
	Scientific Importance	Contribution to research, paleontology, or earth sciences	1–5
	Representativeness	How well it represents regional or global geological heritage	1–5
	Vulnerability to erosion or human impact	How is the location affected by erosion or humans	1-5
	Geological GIS map location	Are the locations mapped on GIS	1-5
Ecological & Biodiversity Value	Flora & Fauna Diversity	Presence of rare, endemic, or protected species	1–4
	Ecosystem Integrity	Level of ecosystem preservation and minimal human impact	1–4
	Conservation status of habitats	Level of conservation	1-4
Cultural & Historical Significance	Archaeological & Cultural Sites	Historical monuments, indigenous heritage, or cultural landscapes	1–3

	Traditional Knowledge	Local practices or cultural links to geology	1–3
Educational & Research Potential	Education Programs	Availability of visitor education, interpretation centers, and guided tours	1–3
	Research Opportunities	Potential for ongoing scientific study	1–3
Tourism & Socio-Economic Impact	Accessibility & Infrastructure	Transportation, trails, visitor centers, and facilities	1–3
	Local Economic Benefits	Contribution to local employment and income	1–3
Management & Sustainability	Environmental Management	Measures for conservation, monitoring, and impact mitigation	1–3
	Community Engagement	Involvement of local communities in decision-making and operations	1–3

Interpretation:

- 51-61 points = Excellent locality to enter into the broader nomination for UNESCO Global Geopark
- 41-50 points Strong candidate, may require improvements
- 25-40 points Moderate, significant improvements needed
- <25 = Weak locality candidate

A **multi-criteria approach** is a decision-making method used when you need to evaluate or prioritize options based on **several different factors at once** - not just a single measure like cost or size. It is common in environmental planning, conservation projects, policy analysis, and other complex fields where trade-offs are inevitable. Geoparks in developing regions often lack reliable and up-to-date data. A Multi-Criteria Approach in geoparks ensures **informed, transparent, and balanced management**, allowing decision-makers to consider scientific, social, economic, and environmental factors simultaneously, leading to sustainable and effective geopark development. The purpose of a **Multi-Criteria Approach (MCA) in geoparks** is to provide a systematic and comprehensive framework for evaluating, managing, and planning geoparks by considering multiple factors simultaneously. Geoparks are complex systems that involve geological, ecological, cultural, social, and economic dimensions, so decisions cannot rely on a single criterion.

An inventory of geological sites is a structured list or database that identifies, describes, and evaluates areas of significant geological interest. It is an essential foundation for geoconservation, geopark nomination, land-use planning, and geoheritage tourism.

Within the framework of this research, we are implementing and testing multiple criteria scoring for geosites in the Kratovo-Lesnovo region through 3 expert evaluations: Geology, geomorphology, and environmental experts.

RESULTS AND DISCUSSION

The Kratovo-Zletovo region is a geological treasure of great scientific and economic value (Aleksova et al., 2024) [11]. The region is part of the Tertiary volcanic-tectonic belt of the Balkans, formed during the Neogene (about 10–20 million years ago). The main processes that shaped it include: volcanic activity (the region is of volcanic origin, with explosive eruptions that led to the creation of magmatic and pyroclastic deposits), tectonic movements (active faults and cracks contributed to the circulation of hydrothermal solutions, which resulted in ore deposits) and erosive processes (long-term erosion has formed the famous natural forms, such as the Kratovo Stone Towers).

The area is composed of various rock types, including igneous rocks such as intrusive granodiorites and diorites, also volcanic rocks like andesites, dacites, rhyolites, and tuffs, as well as sedimentary rocks such as conglomerates, sandstones, and marls are also present.

The geomorphological features of the region include the Kratovo Stone Towers, which are volcanic formations shaped by specific erosional processes, then old volcanic cones, which are remnants of former volcanic craters, and a relief with deep valleys and faults, formed as a result of intense tectonic movements.

As for literature, the geosites that were identified in the Kratovo Zletovo area are shown in Table 2.

Table 2. Identified geosites in the Kratovo Zletovo area

Paleo-volcanic occurrences, forms, and complexes	Lesново cone and caldera
	Volcanic neck Zdravči Kamen
	Complex paleo-volcanic structure Plavica
	Complex paleo-volcanic structure Uvo-Bukovec
	Complex paleo-volcanic structure Crn Vrv
	Volcanic bombs near v. Neokazi
	Volcanic bombs near v. Gorno Kratovo
	Volcanic bombs between Dobrevo and Kratovo
Mostly fluvial forms (polygenetic fluvial-paleo-volcanic) and complexes	Ratkova Skala (canyon gorge on Stalkovica)
	Kratovska Reka valley
	Gorge on Kratovska Reka upstream of Kratovo
	Gorge on Kriva Reka near v. Trnovac
	Vakufska Gorge of Kriva Reka near v. Vakuf
	Sharp turn of the Povišnica River
	Tectonic-faulted area between v. Mushkovo and v. Jamište
	Preserved river terraces with river sediments near v. Zivalevo
Geomorphological-hydrological occurrences	Jamiški waterfall on Zletovska Reka
	Small waterfall on Babakarina Reka
	Waterfall on Emirička Reka
	Occasional waterfalls on Raskovski Potok
	Waterfalls on Kratovska Reka upstream of Kratovo
	Kundinsko Ezero
	Deep gorge on Lesnovska Reka
Denudation occurrences, forms and complexes	Earth pyramids near v. Kuklica
	Locality Ploče near v. Stracin
	Geoarchaeological occurrence Cocev Kamen
	Badland terrain near v. Tursko Rudare
	Rock seas and talus cones in the gorge of Zletovska Reka
Fossil lake forms	Spacious fossil lake terrace near v. Šlegovo

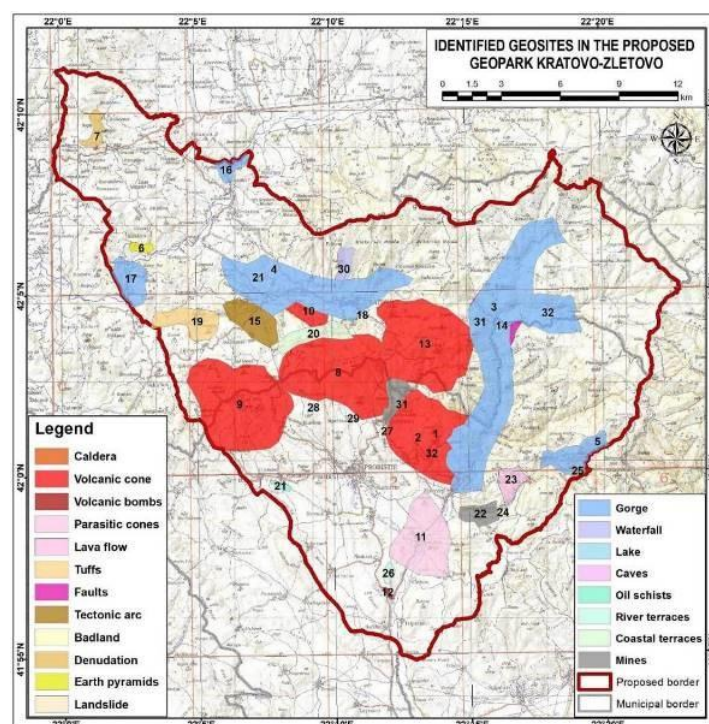


Figure 3. Position of identified significant geo-localities within the boundaries of the municipalities Kratovo and Probištip.

Table 3. The total scores according to MCDM based on three expert evaluations

	GEO LOCALITY	Criteria						
		Geo- logical Value	Eco- logical & Bio- diversity Value	Cultural & Historical Significance	Educational & Research Potential	Tourism & Socio- Economic Impact	Management & Sustainability	Total score * Top rank
Excellent locality to enter into the broader nomination for UNESCO Global Geopark	Earth pyramids near v. Kuklica	22	10	6	7	7	5	57
	Geoarchaeological occurrence Cocev Kamen	21	10	7	7	6	5	56
	Lesново cone and caldera	23	9	6	5	6	6	55
Strong candidates may require improvements	Ratkova Skala (canyon gorge on Stalkovica)	20	10	4	5	4	5	48
	Rock seas and talus cones in the gorge of Zletovska Reka	19	8	5	6	6	4	48
	Kratovska Reka valley	20	7	5	5	5	4	46
	Locality Ploče near v. Stracin	19	8	5	5	4	5	46
	Gorge on Kratovska Reka upstream of Kratovo	20	8	5	5	3	4	45
	Jamiški waterfall on Zletovska Reka	18	9	5	4	5	4	45
	Deep gorge on Lesnovska Reka	19	8	4	5	5	4	45
	Spacious fossil lake terrace near v. Šlegovo	17	9	5	5	5	4	45

	Tectonic-faulted area between v. Muškovo and v. Jamište	19	8	4	5	4	4	44
	Complex paleo-volcanic structure Plavica	20	6	3	5	4	4	42
	Complex paleo-volcanic structure Crn Vrv	20	7	3	4	5	3	42
	Gorge on Kriva Reka near v. Trnovac	17	8	4	4	5	4	42
	Kundinsko Ezero	16	9	4	5	4	4	42
	Waterfall on Emirička Reka	15	8	5	4	5	4	41
Moderate, significant improvements needed	Volcanic neck Zdravci Kamen	20	7	3	4	3	3	40
	Vakufska Gorge of Kriva Reka near v. Vakuf	16	8	4	3	5	4	40
	Complex paleo-volcanic structure Uvo-Bukovec	18	7	4	4	3	3	39
	Preserved river terraces with river sediments near v. Zivalevo	15	8	4	4	4	4	39
	Waterfalls on Kratovska Reka upstream of Kratovo	15	7	4	4	4	4	38
	Badland terrain near v. Tursko Rudare	15	6	5	4	4	3	37
	Sharp turn of Povisnica River	16	6	3	4	4	3	36
	Volcanic bombs near v. Uper Kratovo	16	5	6	3	3	2	35
	Small waterfall on Babakarina Reka	15	7	4	3	3	3	35
	Volcanic bombs near v. Neokazi	17	5	3	3	4	2	34
	Volcanic bombs between Dobrevo and Kratovo	16	4	3	4	4	2	33
	Occasional waterfalls on Raskovski Potok	13	6	3	3	3	3	31

Based on the multi-criteria assessment, 3 locations qualify as "Excellent" candidates for inclusion in a broader nomination for UNESCO Global Geopark status. Other localities received lower scores, mainly due to criteria such as accessibility, infrastructure, and presentation, which can be significantly improved through targeted measures and management activities. Thus, 14 locations are considered "Strong" candidates but may require certain improvements, while 12 locations fall under the "Moderate" category, indicating that significant improvements are needed. Notably, no location scored below 25 points, and therefore, none are classified as "Weak" candidates.

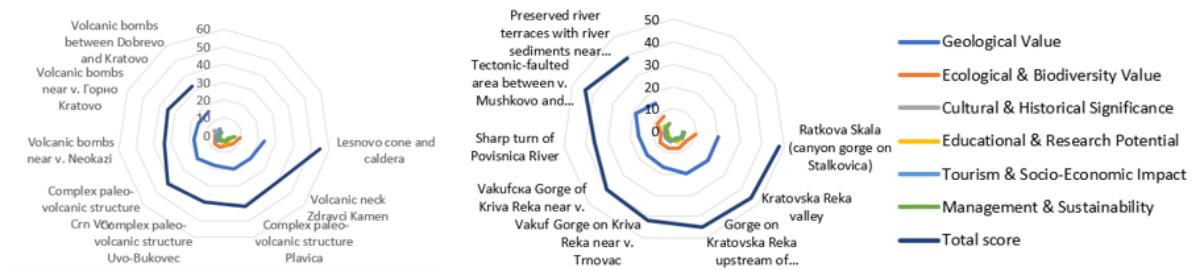


Figure 4. Total scoring in the geo localities in Paleo-volcanic occurrences, forms and complexes and mostly fluvial forms (polygenetic fluvial-paleo-volcanic) and complexes

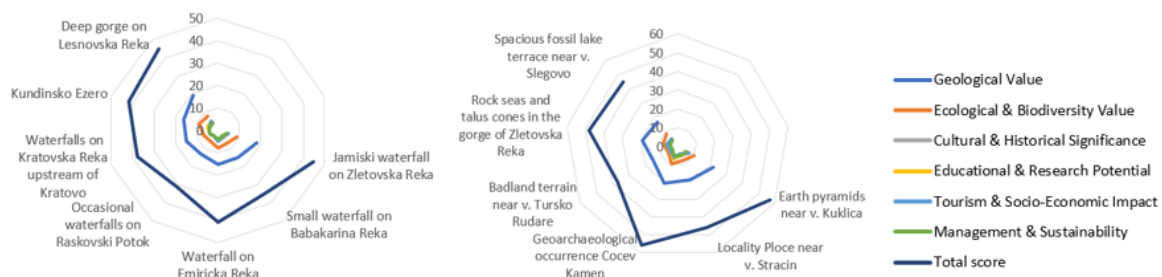


Figure 5. Total scoring in geolocality in Denudation occurrences, forms and complexes and Fossil-lake forms

The top 3 ranking geolocalities represent a rich geoheritage corridor, showcasing erosion, volcanism, and human interaction with geology in North Macedonia. They are prime candidates for a UNESCO Global Geopark nomination. The most important values for them are:

- Kuklica pyramids: erosional landforms shaped by weathering and differential erosion. It is a nationally protected area, a Monument of nature according to IUCN category 3 (Lepitkova et al., 2024) [12].
- Cocev Kamen: geoarchaeological site combining rock formations with prehistoric human activity,
- Lesnovo cone and caldera: volcanic structures illustrating Neogene volcanic activity and caldera formation processes.

Across all geosites, the most underperforming criteria were those about Ecological and Biodiversity Value, Educational and Research Potential, and Tourism and Socio-Economic Impact, highlighting priority areas that necessitate targeted enhancement in future management and development strategies by the country.

The remaining 14 geo-locations are considered as Strong candidates but may require certain improvements, and 12 locations fall under the Moderate category. They have been systematically strengthened through the establishment of formal management structures, reinforced legal protection, comprehensive scientific documentation, targeted educational programs, sustainable tourism frameworks, and active community engagement initiatives. These targeted improvements ensure that the sites fully comply with UNESCO Global Geopark criteria, demonstrating effective geoconservation, high-quality educational outreach, sustainable socio-economic development, and robust participation in international scientific and cultural networks.

CONCLUSION

A multi-criteria approach to assessing the values of a geopark can be used to identify, analyze, and prioritize the development, protection, and management of resources within a geopark. Geoparks, which often contain unique geological, cultural, historical, and biological values, require an integrated approach to decision-making.

The Kratovo-Zletovo region, covering about 950–1,000 km² in northeast North Macedonia, hosts one of the Balkans' most striking palaeovolcanic complexes according Ivica M. (2010) [13].

It features well-preserved volcanic cones and calderas, rich mineral deposits, distinctive geomorphological forms, and exceptional cultural heritage—from megalithic sanctuaries to medieval stone architecture. Designating this area as a UNESCO Global Geopark will conserve outstanding geoheritage, foster sustainable geotourism, and strengthen local livelihoods.

A multi-criteria approach shows that most of the locations can be part of the future UNESCO geopark. Some of the new ones need improvement, which should be paid attention to in the coming period.

The Earth pyramids near Kuklica, the Cocev Kamen geoarchaeological site, and the Lesново volcanic cone and caldera, collectively the top 3 ranking geosites according to a multi-criteria approach, represent one of the most exceptional geoheritage locales in the Kratovo-Zletovo region, as well as in the whole of North Macedonia. This region offers a unique convergence of geological formations, archaeological significance, and cultural heritage, making it a premier destination for geoscientists, archaeologists, and eco-tourists. This local tapestry of natural formations and archaeological sites provides invaluable insights into the interplay between natural processes and human activities over millennia. These sites not only serve as open-air laboratories for scientific research but also as cultural landmarks that connect visitors to the ancient past. Their preservation and study are crucial for understanding the dynamic history of the region and for fostering a deeper appreciation of its unique geoheritage.

Other geo-localities that initially received lower evaluations have been improved through the implementation of formal management structures, legal protection frameworks, rigorous scientific documentation, comprehensive educational programs, sustainable tourism strategies, and structured community engagement. These enhancements should ensure that the sites satisfy the UNESCO Global Geopark criteria for geoconservation, educational outreach, sustainable regional development, and international scientific and cultural cooperation.

A multi-criteria approach can be strengthened in the future by including more scientists as well as local communities, authorities, and the tourism sector, in scoring and weighting, as well as Field verification, GPS/GIS mapping, literature review, and remote sensing.

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