

Proceeding Paper

Inventory and Enhancement of Geological Heritage in the Ouzoud Syncline (M'Goun UNESCO Geopark, Central High Atlas, Morocco): First Step for Promoting Geotourism and Sustainable Development [†]

Elhassan Louz ^{*}, Jamila Rais, Ahmed Barakat, Abdellah Ait Barka  and Samir Nadem

Geomatic, Georesources and Environment Laboratory, Faculty of Sciences and Techniques, Sultan My Slimane University, BP 523 Beni Mellal 23000, Morocco; j.rais@usms.ma (J.R.); a.barakat@usms.ma (A.B.); a.aitbarka@usms.ma (A.A.B.); s.nadem@usms.ma (S.N.)

^{*} Correspondence: Elhassan.louz@usms.ma; Tel.: +212-658299359

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Abstract: The Ouzoud syncline, in central Morocco, is one of the kingdom's wealthiest areas of natural and cultural heritage. This syncline has significant potential for geotourism development; it contains the Ouzoud waterfalls, one of the most coveted tourist attractions, which are part of the geosites listed in the M'Goun UNESCO geopark. The abundance of resurgences, waterfalls, travertine, caves, magmatic rocks, exceptional geomorphological forms, and fascinating panoramic views make this territory a suitable tourist destination for excursions, hiking, and climbing, and a good support for understanding the geological history of the central High Atlas (CHA) of Morocco and paleoclimate changes. The dense and diversified vegetation cover offers a habitat for various animals (magot monkeys, bats, birds), which attracts more nature-loving tourists. This exceptional geo-biodiversity and cultural wealth (traditional mills and the Zaouïa of Tanaghmelt) that may constitute a lever for local socio-economic development remains unknown to the public and not well exploited by managers. Hence, this study attempted to assess and make an inventory of interest sites to provide a database that helps decision-makers in territorial planning and geoheritage conservation and promotion. Thus, about 20 highly attractive geosites were inventoried, eight of which (the most important ones) were selected for evaluation using the Reynard et al. (2016) methodology. This approach considers the scientific value, the additional values, and the use and management values of sites. Such promotion can popularize the geosciences and create income-generating activities, which will improve the economic situation of the local population

Keywords: geoheritage; Ouzoud syncline; geotourism; inventory; assessment; geopark



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1. Introduction

In recent years, several attempts to enhance and protect geoheritage have emerged in several countries around the world [1–8] and particularly in Morocco [9–16]. Geological heritage refers to all geological features and objects (rocks, minerals, geomorphological and geological forms, fossils) or sites, sometimes culturally important, which offer an overview of the history of the earth and testify to the climatic changes or the tectonic evolution of the earth's crust [17,18]. The smallest unit of these systems is called a geosite, a site of interest that allows the exploitation of geological features for geotourism and geodidactic purposes [19,20]. A site can only be considered to be a geosite if it combines several interests at the same time, including the scientific value that is considered central. This makes sites more susceptible to being promoted for geotourism purposes and preserved against natural and anthropic threats. In Morocco, few efforts have been undertaken to

enhance the geoheritage, a large part of which is still unknown and under-exploited by managers. This low level of valorization can be attributed to managers and visitors who are unaware of geological heritage and who are primarily concerned with aesthetics while ignoring the scientific and educational aspects of geological items. This work aims to fill this gap by highlighting the geological heritage of the Ouzoud syncline through an inventory supported by a quantitative assessment to provide a database that would help decision-makers in any development project of local tourism. The choice of this syncline is explained by its particular characteristics that make it a territory of considerable tourist attraction: it contains the Ouzoud waterfalls, a site of international interest listed in the M'Goun UNESCO geopark with good tourist infrastructure.

2. Geographical and Geological Setting

Geographically, the Ouzoud syncline belongs to the Beni Mellal-Khenifra region, to the Azilal province, and more precisely, to the rural commune of Ait Taguella (Figure 1a,b). It has a Mediterranean climate with wet winters and dry summers [21]. This territory is peopled by Amazigh Berber tribes whose main economic activities are agriculture, livestock, and tourism. The vegetation cover consisted of cedar, holm oak, juniper, euphorbia, acacia, and aromatic and medicinal plants, which offer favorable fauna habitats for several species such as the magot monkey, bats, and various bird species [22]. This is the reason this area has been classified as a Site of Ecological and Biological Interest (SEBI).

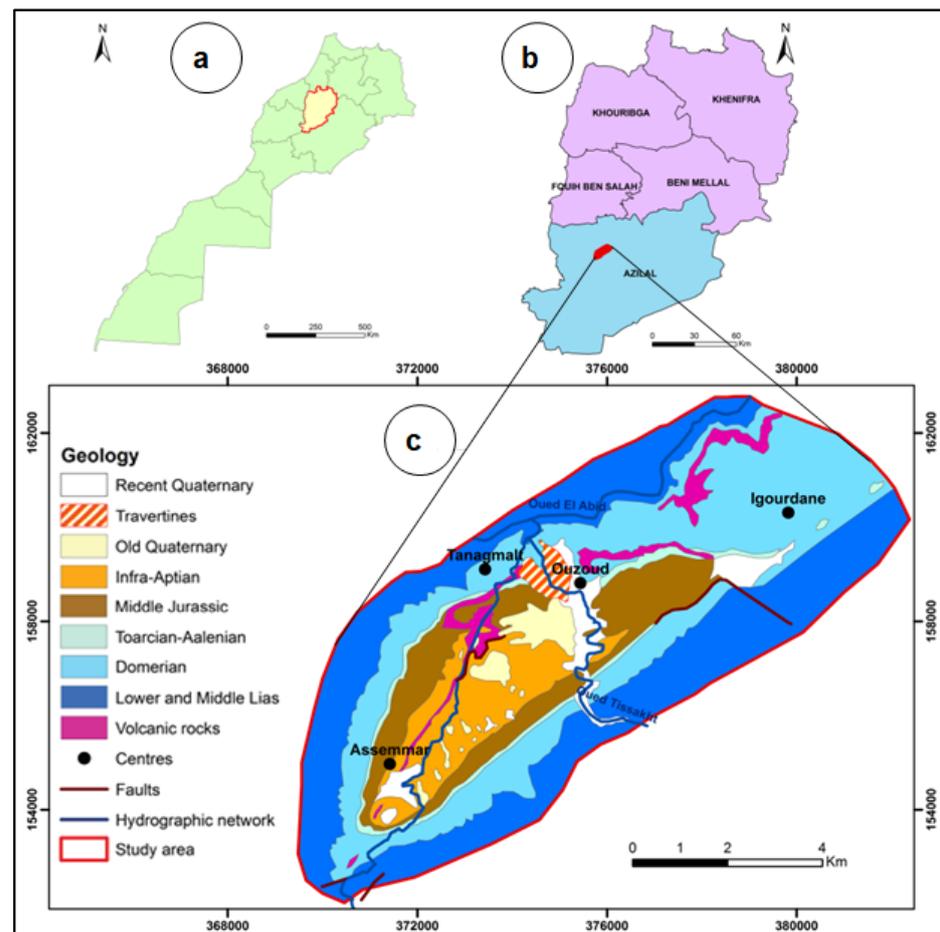


Figure 1. (a) Geographical situation of Beni Mellal-Khenifra region (yellow color) on the regional boundaries of Morocco (green color); (b) Geographical situation of the study area in Beni Mellal-Khenifra region; (c) Geological map of study area extracted from a geological map of Afouer 1/100,000 and Azilal 1/100,000.

Geologically, the Ouzoud syncline is one of the central High Atlas synclines whose implementation is linked to differential subsidence and brittle tectonics of the Middle and Upper Jurassic [23]. It is a small basin, oriented North-East–South-West (Figure 1c), and located south of the Ait Attab syncline. It has the form of a more or less folded plateau occupied, in its majority, by marine Jurassic limestones (Ait Boulli, Jbel Rat, Aganane, and Bine El Ouidane group) which alternate with continental red formations (Azilal and Iouaridene). This succession of transgressive and regressive mega-sequences thus attests to a great change in the deposit environments. In addition, the syncline presents two types of magmatic rock deposits, notably doleritic sills and basaltic flows of 124 ± 2 Ma age [24], as well as quaternary deposits, the most important of which are the travertine concretions.

3. Materials and Methods

Recently, several attempts to inventory and valorize geosites have emerged by applying different methodologies that all agree on the importance of scientific value [5,7,25,26]. The inventory of geosites in the Ouzoud syncline began with a bibliographical study to highlight the study area's main geological and geomorphological characteristics. Then a series of field visits were carried out to collect information used in selecting and evaluating potential sites; these data are represented in the form of a data sheet including general data, description, morphogenesis, and synthesis. Sites representative of the regional geology and geomorphology and with significant scientific value are selected for quantitative assessment.

In this study, we chose to evaluate these geosites by the method of Reynard et al. (2016) because of its simplicity and relevance; it is based on the justification of geosites through the appreciation of their scientific, aesthetic, ecological, and cultural values. The scientific value is evaluated based on four criteria: integrity, representativeness, rarity, and palaeogeographical interest, each of these criteria is scored from 0 to 1 (a step of 0.25). Thus, the scientific value equals the arithmetic average of the four criteria mentioned above. The additional values are based on three values: ecological, aesthetic, and cultural, highlighting the close link between the geosite and its environment [7]. Ecological value is assessed based on two criteria: ecological impact and protection status, while aesthetic value is assessed based on two values: viewpoint and structure. Cultural value is associated with the criterion of the highest value, be it religious, historical, artistic, literary, geohistorical, or economic [7]. The assessment also includes a diagnosis of the current state of site protection, specifying the possible impacts and threats to propose protection measures that will ensure the sustainability of this heritage. This diagnosis also describes certain parameters about safety, accessibility, tourist infrastructures, the natural environment, and development to promote these heritage assets better.

4. Results

4.1. Presentation of the Selected Geosites

The inventory of the geological heritage in the study area reveals the existence of over 20 potential sites, from which the most representative ones are chosen to illustrate the remarkable geodiversity of the syncline (Figure 2). Table 1 presents the geological characteristics of the selected sites.

Table 1. Geological characteristics of the selected geosites.

Name (Code)	Main Features	Photos
The dolerite sill of Ouzoud (OUZmag001)	<p>The Ouzoud sill is in the North-East, 3 km from the center of Ouzoud. It is a greenish dolerite layer of Lower Cretaceous age [27] which intrudes the massifs limestones of the Dogger. It extends over 3.5 km and has a texture that tends to be microlithic with phenocrysts of olivine and pyroxene [28]. The same sill intersects the chocolate marls of the Aalenian-Toarcian and the last benches of the Domerian towards the west [28]. This site constitutes an educational station that can be used to teach the magmatism process and stratigraphic principles.</p>	
Ouzoud waterfalls (OUZhyd002)	<p>The Ouzoud waterfalls are falls that occur when the Oued Tissakht crosses the Bajocian limestone cliffs, the most spectacular fall is about 110 m high at the bottom of a chasm covered with beautiful travertine concretions. This picturesque landscape constitutes an internationally known tourist attraction; it is one of the geosites of the M'Goun UNESCO geopark and a SEBI. At the top of the waterfalls, tourists can visit small grain mills that rotate by exploiting the speed of the waterfalls. In some places, the speed of the river current has carved Giant's kettle in the limestone bedrock, forming basins that overflow into each other.</p>	
The Ouzoud travertines (OUZKar003)	<p>Important travertine stripping on the limestone cliffs dominates the Ouzoud waterfalls and along the Oued Tissakht. These concretions result from the precipitation of calcium carbonates dissolved in the river water following the degassing of CO₂ in the open air [29]. These changes in the physicochemical parameters of water are closely related to hydrogeological, morphological, bioclimatic, and anthropogenic conditions. The Ouzoud travertines, particularly the oldest ones, have yielded beautiful leaf, root, and twig imprints of various sizes that can characterize the Plio-quaternary ecological, climatic, and hydrological paleoenvironment of the study area.</p>	
The Estuary of Oued Tissakht (OUZflu004)	<p>The estuary of the Oued Tissakht is located only 3 km from the Ouzoud waterfalls. This Tissakht watercourse descends quickly among the limestone cliffs about 15 m high, covered with travertine. The rapid flow between these structures forms a turbulent eddy that joins the Oued El Abid, thus digging beautiful cavities of different sizes, known locally as the Ouzoud caves. These structures give this site an undeniable aesthetic interest.</p>	
The Oued El Abid Gorges (OUZGeo005)	<p>The Oued El Abid Gorges, located 7 km NNW of the Ouzoud waterfalls, are exceptional geomorphological forms carved out of the massive Lias limestone by the Oued El Abid, forming a very deep valley that exceeds 100 m. This river has succeeded over centuries of erosive events to shape a stratigraphic column from the Domerian to the Upper Jurassic. The caves lining the gorge provide a habitat for monkeys, birds, and bats. This site attracts hundreds of hikers annually to enjoy unique and admirable landscapes.</p>	
Azilal formation intruded by the Tanaghmelt sill (OUZmag006)	<p>About 800 m west of Tanaghmelt, we find a particular geological structure; it is a doleritic sill that cuts the reddish-brown marls of the Azilal Fm, leaving traces of contact metamorphism [24,28]. The Azilal Fm is underlain by Domerian marine limestone; this transition from carbonate to terrigenous sedimentation is considered a good benchmark of marine regression. In addition to this geological wealth, the site contains an ancient religious building called the Zaouïa of Tanaghmelt that accumulated an impressive religious heritage dating back to the 7th century.</p>	

Table 1. Cont.

Name (Code)	Main Features	Photos
The basaltic flows of Ouzoud (OUZmag007)	The basaltic flows of Ouzoud are located west of the syncline; they are associated with the upper part of the Iouaridene Fm, which corresponds to the second magmatic outpouring B2 of the Lower Cretaceous [24]. These flows, of 10 m thickness, present reddish grey facies, with vacuolated surfaces of prismatic structure at the top. Unfortunately, these magmatic rocks are being excessively exploited as building materials, which risks destroying this magmatic heritage.	
Ouzoud springs (OUZkar008)	Ouzoud springs are karstic resurgences; there are 22 of them, which gush out through a complex karstic system formed by carbonates of the Lias. Underground waters from these springs feed the Oued Tissakht and give rise to a favorable environment for developing diversified freshwater fauna (fish, gastropods, crabs, and insects). This geosite has constituted for a long time a favorite tourist destination to practice bivouac and camping within a picturesque, soft, and calm landscape.	

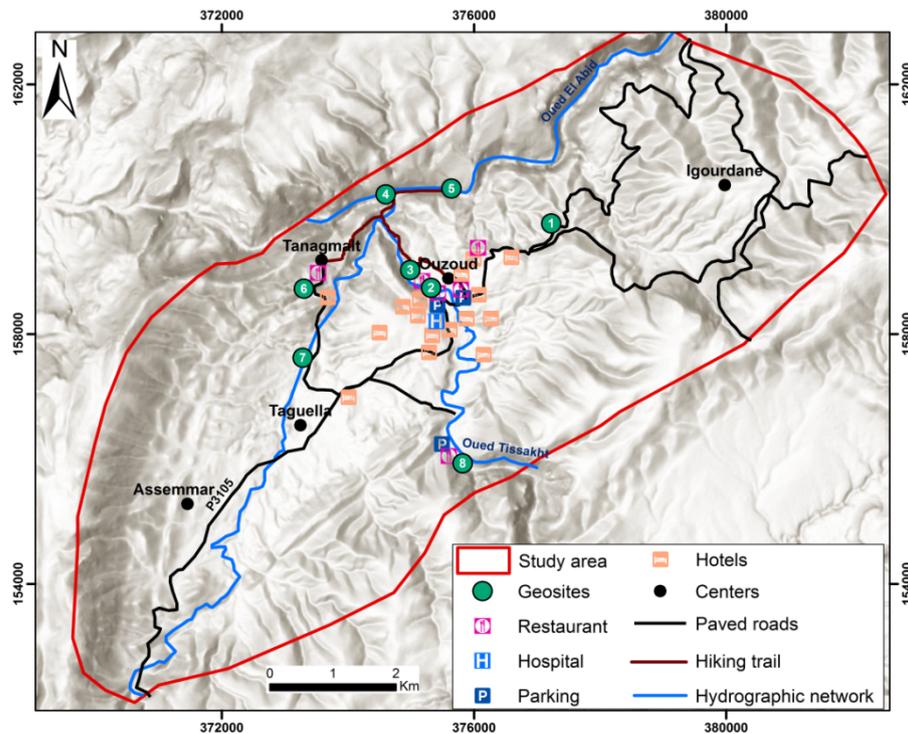


Figure 2. Map of inventoried geosites in the Ouzoud syncline.

4.2. Assessment of the Scientific and Additional Values of Selected Geosites

The inventory of geosites in the Ouzoud syncline is carried out in two phases. The first one includes selected potential sites through the analysis of geological and topographical maps and an in-depth bibliographical study. The next step is to confirm the scientific, educational, and geotourism interests of potential sites through the organization of field visits and consulting experts. Thus, eight geosites of scientific interest were selected for the quantitative assessment using the [7] methodology.

The quantitative assessment results revealed a high scientific value (average of 0.83) (Table 2) for all selected geosites because they are relatively preserved, unique, and representative of the regional geomorphology. These geosites also showed high paleogeographic value, which testifies to a long geological history from the Lias to the recent quaternary. The site of Ouzoud waterfalls seems to be the most valuable of the syncline; it has the highest

scientific value score due to its representativeness of fluvial and karstic processes, the splendor of its unique well-preserved outcrops, and its exceptional biodiversity. It should be noted that this site is part of the M’Goun UNESCO geopark and is also named a SBEI. The Ouzoud basaltic flows have the lowest score (0.69) due to their damaged condition caused by rock extraction activities.

Table 2. Quantitative assessment of the scientific and additional value of inventoried geosites (According to Reynard et al., 2016).

Geosites		Scientific Value				Additional Value				
Code	Name	Int	Rep	Rar	Pal	Sci Val	Eco Val	Aes Val	Cul Val	Add Val
OUZmag001	Doleritic sill of Ouzoud	0.75	0.75	0.5	1	0.75	0.62	0.87	0.25	0.58
OUZhyd002	Ouzoud waterfalls	1	1	1	1	1	0.87	1	1	0.96
OUZkar003	Ouzoud travertines	1	1	0.5	1	0.87	0.87	1	0.75	0.87
OUZflu004	Estuary of Oued Tissakht (Ouzoud caves)	1	1	0.75	0.75	0.87	0.5	1	0.5	0.66
OUZgem005	Oued El Abid Gorges	1	1	0.75	0.5	0.81	0.5	1	0.5	0.66
OUZmag006	Chocolate marl intruded by Tanaghmelt sill	1	1	0.75	0.75	0.87	0.5	0.75	1	0.75
OUZmag007	Basaltic flows of Ouzoud	0.5	1	0.5	0.75	0.69	0.5	0.5	0.25	0.42
OUZkar008	Karstic spring of Ouzoud	0.75	1	0.75	0.5	0.75	0.87	0.75	0.75	0.79

The assessment showed that the average ecological value of the geosites is moderate (0.65). Indeed, the fertile soil of the study area and the relatively dense hydrographic network have contributed to the development of a dense and diversified vegetation cover represented by a forest of thuja, juniper, holm oak, euphorbia, and acacia. The latter constitutes a habitat for several rare animal species, such as the magot monkey and some bird and bat species. This explains the classification of Ouzoud as a site of biological and ecological interest, which means that the selected geosites are protected except for the sites of magmatic interest due to their location outside the wetland. Concerning the aesthetic value, we note that most geosites present several points of view with a rather important vertical development, particularly in the cascades of Ouzoud, the Estuary of Oued Tissakht, and the gorges of Oued El Abid. The contrast of the water’s blue color with the green vegetation and the reddish, greyish, and dark geological formations gives these geosites a high aesthetic value (0.86). The cultural value is very important and reflects the authenticity of the Berber tribes of the HAC. This heritage is represented by architectural sites such as the traditional mills at the top of the waterfalls and the traditional earthen and adobe houses in the surrounding douars. The Zaouiïa (religious building) and the mosque of Tanaghmelt represent a religious and spiritual destination that annually receives students who come to profit from the old library containing one of the oldest and most precious book collections. The study area also contains socio-cultural sites (Souk) where the people exchange their often-traditional products without neglecting the customs related to traditional hammams and irrigation. Among the selected geosites, the site of the Ouzoud waterfalls and the chocolate marls intruded by the Tanaghmelt dolerite sill are the most important, with a high cultural value (1). The increase in tourist offering around the waterfalls and the development of hiking tourism have led to the development of accommodation structures, so the province of Azilal has more than 107 tourist establishments with a total of 57,915 arrivals in 2018 (Provincial Delegation of Azilal 2020). These tourist infrastructures offer many jobs contributing to developing the local population’s economic situation. Table 2 represents the quantitative assessment results of scientific and additional values of the selected geosites.

4.3. Use and Management Characteristics

The assessment of use and management characteristics is a method to evaluate the level of protection and potential uses of geosites. Protection is associated with the current status of integrity and vulnerability of the site, while the promotion is based on accessibility, visit conditions, security, and infrastructure. Table 3 shows an appreciation of the use and management value of geosites.

Table 3. Quantitative assessment of use and management value.

Geosites	Use and Management Values					
	Protection Status	Eventual Threats	Touristic Infrastructure	Conditions of Visit	Access Road	Enhancement Installation
Doleritic sill of Ouzoud	**	***	**	****	****	Absent
Ouzoud waterfalls	****	***	****	****	****	Present
Ouzoud travertines	***	**	****	***	***	Absent
Estuary of Oued Tissakht (Ouzoud caves)	***	**	**	**	**	Absent
Oued El Abid Gorges	**	**	**	**	**	Absent
Chocolate marl intruded by Tanaghmet sill	**	**	**	***	***	Absent
Basaltic flows of Ouzoud	**	****	**	***	***	Absent
Karstic spring of Ouzoud	***	***	***	***	***	Present

** : Low; *** : Medium; **** : High.

In the Ouzoud locality, the demographic pressure is generally low, which means limited threats. However, the tourist flow reaches its maximum during the summer period, which increases the degradation risks of the site. The most vulnerable geosites are the waterfalls and springs of Ouzoud because they receive a considerable flow of tourists. At the same time, the magmatic sites present another risk of degradation linked to rock extraction work. The selected geosites present, in general, good conditions for a visit with better accessibility and tourist offer, only the geosites of “Estuary of Oued Tissakht” and “Oued El Abid gorges” which are accessible through footpaths but well traced and secured. Visitors can stay overnight in about 15 hotels and guesthouses or with local inhabitants. The tourism infrastructure is good, generally based on commercializing attractive sites and drawer products such as olive oil, honey, and traditional crafts. These tourism activities can positively impact the local population, by creating considerable economic inputs that will improve the general quality of life in the syncline.

5. Conclusions and Discussion

The present study aimed to carry out an inventory and quantitative evaluation of the Ouzoud syncline geoheritage. The results showed that the study area is dominated by geosites of high scientific and additional value suitable for scientific, tourist, and educational use; it is a territory rich in geosites of international interest that deserves to be preserved and promoted for the benefit of the local population. However, these geosites do not benefit from any legal protection as geological heritage despite being part of the UNESCO M’Goun geopark and a SEBI. A national heritage protection law and comprehensive heritage management are missing. This management must consider the significance of geological forms, cultural buildings, and socio-economic activities concerning biological diversity [30]. Geotourism and geoeducation are vital tools that could be essential in protecting and enhancing national heritage. Thus, the Ouzoud waterfalls have benefited in recent years from extensive development to ensure sustainable and non-destructive tourism. As a result, the site has become cleaner, with rehabilitated restaurants and boutiques that respect the natural environment and the Amazigh architecture. Access has become easier with several footpaths equipped with interpretation panels. However, the development of regional geotourism requires good management and the best decisions to attract more

visitors while ensuring the sustainability and conservation of the interest sites. This can only be achieved by promoting geoheritage to the local population and visitors; such action will provide the appropriate tools to make the local population more aware of the threats that may affect the heritage that belongs to them. It is, therefore, one of the essential steps in the concept of geoconservation [31]. On the other hand, geoeducation aims to disseminate geosciences to the public to conserve geodiversity and ensure its sustainability for future generations. Indeed, the geosites of the syncline offer a range of educational activities that can be applied outside the classroom. Thus, teachers can teach the principles of geology, such as stratigraphy, karstology, hydrology, magmatism, and the restitution of regional paleogeography. Field visits can therefore be beneficial in stimulating learning about various geological phenomena.

In this sense, the UGGp of M’Goun seems to be the main actor who contributes directly to the socio-economic development of the region, it supports all tourism development projects, in particular geotourism. As a result, several mountain sports are mapped and listed (hiking, canyoning, climbing, etc.), and local products are encouraged through the social and solidarity economy (cooperatives), as well as producing digital tools that facilitate geopark location and the discovery of these geosites and tourist circuits. The geopark managers also organize training courses, webinars, events, and national and international conferences as tools for promoting and enhancing the territory.

In conclusion, to make the geosites more profitable within the M’Goun geopark, it is recommended that new footpaths should be established to cover all sites in the syncline to reduce tourist concentration around the waterfalls and springs of Ouzoud; these footpaths should contain interpretive panels that explain the potential of this area as a tourist and geoeducational destination. The tourist infrastructure and offer should also be improved to attract different categories of tourists.

Supplementary Materials: The presentation materials can be downloaded at: <https://www.mdpi.com/article/10.3390/IECG2022-13878/s1>.

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