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Current Trends and Future Directions for Geoheritage Assessment Methodology in Morocco

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Abstract

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Inventorizing and assessing geoheritage is a prerequisite for developing measures to preserve unique geological and geomorphological sites. Several researchers have developed methods for assessing and determining the value of geological and geomorphological sites. Given rapid environmental and climatic changes, it is crucial to improve the state of geoheritage assessment and inventory development. This overview presents an analysis of research on geoheritage assessment conducted in Morocco over the past 14 years (2008–2022). The objective is to provide an overview of the main methodological approaches. The analysis is based on a search of the Science Direct, Scopus, and Google Scholar databases to identify publications dealing mainly with Moroccan geoheritage sites. We find that most studies have concentrated on the identification and characterization of various geoheritage sites across the country, employing only the descriptive method. However, as the field has progressed, earth scientists are applying quantitative inventory and assessment methods, with some initiatives to propose new methods adapted to the Moroccan context.

Keywords: Geoheritage, Geoconservation, Inventory, Assessment, Morocco.

Introduction

Since the late 1990s, there has been growing interest worldwide in the study of geoheritage sites. Geoheritage sites are objects belonging to abiotic nature, associated with the concept of geodiversity (Gray *et al* 2013; Hobléa *et al.* 2017; Bétard *et al.* 2018; Brilha *et al.* 2018), and are an integral part of natural heritage. These geoheritage sites have been broadly defined by scientists and international organizations, most notably UNESCO, which considers them to be “all natural geological sites possessing, considerable value to humans including their scientific, educational, aesthetic, cultural

significance and humanity’s sense of belonging” (Kubalíková 2013). Geoheritage can be defined as geological facts of global, national or local importance, and geological sites that represent phenomena (volcanism, magmatic segregation, metamorphism, weathering, sedimentation, etc.) and/or bear witness to the Earth’s history (paleontology, global tectonics, climate, sea level, etc.).

The first proposals of quantitative methodologies for assessing geosites date back to the early 1990s (Grandgirard 1997; Panizza 2001; Bruschi and Cendrero 2005; Reynard and Panizza 2005; Pralong 2005; Pereira and Pereira 2007; Reynard

et al. 2007). These initiatives aimed to demonstrate the importance of geoheritage for science and society, and specialists (geographers, geomorphologists, and geologists) took steps to develop scientific methods for the enhancement of these geoheritage sites through a precise popularization process (Cayla 2009; Sellier 2009). Diagnostic and landscape mediation tools were proposed to enhance geomorphosites and make them known to the general public. Mediation targets different categories: specialists, geographers, geologists, geomorphologists, non-specialists, tourists, residents, land managers, etc. Surveys are one of the most interesting tools in landscape mediation in helping to guide measures for the protection and enhancement of geomorphological heritage by bringing together all the players who benefit from and exploit these major elements of nature (Martin 2013).

In Western countries, geoheritage (geosites or geomorphosites) inventory work has been carried out, along with actions and programs to enhance them (Hobléa *et al.* 2017) based on scientific methodologies (Fontana 2008; Kubalíková 2013). Other research has been devoted to geoheritage mapping using different cartographic representation methods: geomorphological maps, thematic maps of scientific and additional values, and geotourism maps (Reynard and Lambiel 2015, Fox *et al.* 2022). Geotourism tours have also been proposed, as a means of enhancing geoheritage, for example, the Danube Gorge guide in Romania (Iosif 2014). Finally, there is research dealing with the perception of local stakeholders towards geoheritage.

In the countries of the greater Maghreb and Africa, on the other hand, interest in geoheritage is relatively absent, and no State inventory initiatives have been carried out to date, despite their often remarkable and unique geological and geomorphological wealth. However, initiatives are beginning in some countries as part of universi-

ty research groups on geoheritage (Errami *et al.* 2013, 2015a). The African Association of Women in Geosciences (AAWG), for example, has developed an “African Geoparks Network (AGN)” project, which has organized, in collaboration with other partners, several activities to promote geoheritage and the geoparks concept in sub-Saharan Africa (Errami *et al.* 2009, 2013, 2015a).

Morocco, situated between the Atlantic Ocean to the west and the Mediterranean to the north, is known for the diversity of its landforms, alternating Saharan reliefs, high Atlas Mountains, high plateaus, and vast plains drained by water basins and river systems, fostering an important ecological and agricultural life. However, despite the enormous importance of its geodiversity, Morocco has not yet made its protection a priority in its heritage policies (El Hamidy *et al.* 2024a, Errami *et al.* 2024). The absence of specific legislation leaves emblematic sites, including world-renowned dinosaur tracks and ancient rock engravings, vulnerable to degradation and exploitation. The absence of a national strategy for cataloging and preserving geoheritage exacerbates this problem, jeopardizing invaluable scientific and cultural resources. Urgent action is needed to implement comprehensive protection measures and raise awareness of the importance of safeguarding Morocco’s geodiversity for future generations (El Hamidy *et al.* 2024c).

On the other hand, national and regional recognition of the importance of geoheritage is growing, notably with the establishment of the M’Goun Geopark in 2004, located in the Béni Mellal Khénifra region. It was the first geopark in the Maghreb to be designated by UNESCO in 2014 and approved in 2018, confirming the remarkable geodiversity represented by the central High Atlas in which the geopark is located.

In parallel with this regional dynamic around geoheritage, several university initiatives have led

to the production of a series of geological guides covering the whole of Morocco, and other initiatives led by geologists and geographers with the inventory and evaluation of around 100 geosites as part of research groups associated with universities (Fig. 1, 2; Table 1). There is growing interest in the inventory, protection, and enhancement of these geoh heritage sites, in line with Morocco's new ambition to become one of the world's 20 top

tourist destinations, according to the 2020 tourism development strategy. This focuses on diversifying the tourism offer, in particular by exploiting and enhancing natural, cultural, and human assets.

The main objective of this article is to provide a comprehensive review of the current state of geoh heritage and geosite evaluations in Morocco. By synthesizing the relevant literature, the study aims to elucidate the main methodological approaches

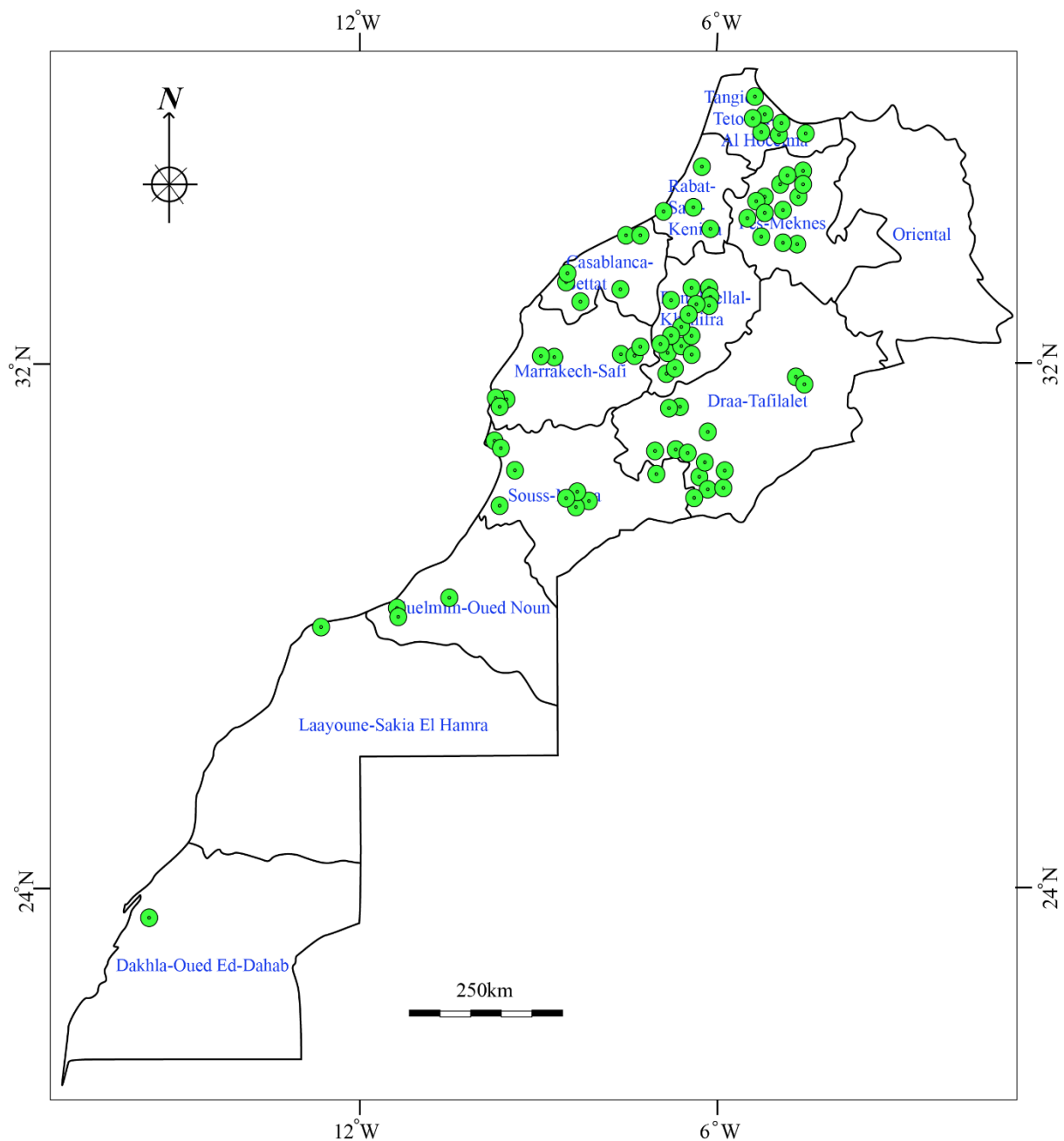


Figure 1. Map illustrating the geographic distribution of studies related to geoh heritage across Morocco from 2008 to 2022.



Figure 2. Examples of ge heritage sites: **A)** Jbel Irhoud Geosite, the Cradle of Humanity, Youssoufia Province (El Hamidy et al. 2024b); **B)** Source of Ain Sebou in Boulblane (Baadi et al. 2020); **C)** Issafen's flatirons in SW of the Issafen city (Berred et al. 2019b); **D)** Ras El Oued cave in the Northern Middle Atlas (Baadi et al. 2021a); **E)** Giant trilobite specimens from the locality of Ouled Slimane (Zagora) (Beraouz et al. 2019), Examples of one of the landscape paintings performed by the Belgian artist Jean Verame in granitic landforms near Tafraoute, known as the "Roches Peintes" (Druguet et al. 2015).

Table 1. Publications related to geoheritage in Morocco

Publication	Methodology	Site type	Aim
El Wartiti et al. 2008	Descriptive	Geomorphosites	Inventory
De Waele et al. 2009	Descriptive	Geomorphosite	Inventory
El Wartiti et al. 2009	Descriptive	Geomorphosites	Inventory
Beraaouz et al. 2010	Descriptive	Geosites	Inventory
Camara et al. 2011	Descriptive	Geosites	Presentation
El Hadi et al. 2011	Descriptive	Geosites	Inventory
Tahiri et al. 2011	Descriptive	Geosites	Inventory
Zahra et al. 2011	Descriptive	Geomorphosites	Inventory
Belkhatab 2012	Descriptive	Geosites	Presentation
El Hadi et al. 2012	Descriptive	Geosites	Presentation
Albab et al. 2013	Descriptive	Geosites and geomorphosites	Inventory
Errami et al. 2013	Descriptive	Geosites	Presentation
Abioui et al. 2014	Descriptive	Geosites	Presentation
Belkhatab et al. 2014	Descriptive	Geosites	Presentation
Enniouar et al. 2014	Descriptive	Geosites	Presentation
Bourchich et al. 2015	Descriptive	Geosites and Geomorphosites	Inventory
Druguet et al. 2015	Descriptive	Geosites	Inventory
El Hadi et al. 2015	Descriptive	Geosites	Inventory
Enniouar et al. 2015	Descriptive	Geosites and Geomorphosites	Inventory
Errami et al. 2015a	Descriptive	Geosites and Geomorphosites	Presentation
Errami et al. 2015b	Descriptive	Geosites	Inventory
Noubhani 2015	Descriptive	Geosites	Presentation
Saddiqi et al. 2015	Descriptive	Geosites	Inventory
M'Barki et al. 2016	Descriptive	Geomorphosites	Inventory
Sadki et al. 2016	Reynard et al 2016	Geosites and Geomorphosites	Inventory and quantitative assessment
Eddif et al. 2017	Descriptive	Geosites	Presentation
El Hassani et al. 2017	Descriptive	Geosites	Inventory
Hili and El Khalki 2017	Reynard et al 2016	Geomorphosite	Inventory and quantitative assessment
Achkir et al. 2018	Reynard et al 2016	Geomorphosite	Presentation / quantitative assessment
Alilou et al. 2018	Reynard et al 2016	Geomorphosite	Inventory and quantitative assessment
Amine et al. 2018	Descriptive	Geosites	Inventory

Bouzekraoui et al. 2018a	Reynard et al 2016	Geomorphosites	Inventory and quantitative assessment
Bouzekraoui et al. 2018b	Descriptive	Geosites	Presentation
Bouzekraoui et al. 2018c	Descriptive	Geosites	Presentation
Eddif et al. 2018	Descriptive	Geosites	Presentation
Khoukhouchi et al. 2018	Reynard et al 2016	Geomorphosite	Presentation / quantitative assessment
Tahouri et al. 2018	Reynard et al 2016	Geosites and Geomorphosite	Presentation / quantitative assessment
Abioui et al. 2019	Descriptive	Geosites	Presentation
Ait Omar et al. 2019	New proposal	geomorphosites	Inventory and quantitative assessment
Aoulad Sidi Mhend et al. 2019	Brilha 2016	Geosites	Inventory and quantitative assessment
Beraaouz et al. 2019	Descriptive	Geosites	Inventory
Berred et al. 2019a	Descriptive	Geosites	Presentation
Berred et al. 2019b	Descriptive	Geomorphosite	Inventory
Kaid Rassou et al. 2019	Reynard et al 2016	Geosites	Inventory and quantitative assessment
Mounir et al. 2019	Descriptive	Geosites	Presentation
Milu et al. 2019	Descriptive	Geosites	Inventory
Oukassou et al. 2019	Descriptive	Geosites and Geomorphosites	Inventory
Oulmakki et al. 2019	Descriptive	Geosites	Presentation
Amine et al. 2020	Descriptive	Geosites	Presentation
Arrad et al. 2020a	Reynard et al 2016	Geomorphosite	Inventory and quantitative assessment
Arrad et al. 2020b	Reynard et al 2016	Geomorphosite	Inventory and quantitative assessment
Arrad et al. 2020c	Descriptive	Geosites	Presentation
Baadi et al. 2020	New proposal	Geosites	Inventory and quantitative assessment
Berred et al. 2020	Descriptive	Geosites	Presentation
Lahmidi et al. 2020	Brilha 2016	Geosites	Inventory and quantitative assessment
Lkebir et al. 2020	Descriptive	Geosites	Presentation
Mehdioui et al. 2020	Brilha 2016	Geosites	Inventory and quantitative assessment
Mirari et al. 2020a	Brilha 2016	Geosites and geomorphosites	Inventory and quantitative assessment
Mirari et al. 2020b	Descriptive	Geosites and geomorphosites	Inventory and quantitative assessment
Salhi 2020	Reynard et al 2016	geomorphosites	Inventory and quantitative assessment
Sayad et al. 2020	Descriptive	Geomorphosite	Presentation

Ait Omar et al. 2021	Descriptive	Geosites and geomorphosites	Presentation
Baadi et al. 2021a	New proposal	Geosites	Inventory and quantitative assessment
Baadi et al. 2021b	New proposal	Geosites and geomorphosites	Inventory and quantitative assessment
Bouari et al. 2021	Descriptive	Geosites	Presentation
Lahmidi et al. 2021	Brilha 2016	Geosites	Inventory and quantitative assessment
Mounir et al. 2021	Descriptive	Geosites	Presentation
Mountaj et al. 2021	Descriptive	Geosites	Presentation
Rais et al. 2021	Descriptive	Geosites/geomorphosites	inventory
Aichi et al. 2022a	Descriptive	Geosites	Presentation
Aichi et al. 2022b	Descriptive	Geosites	Inventory and quantitative assessment
Ait Barka et al. 2022a	Reynard et al 2016	geosites	Inventory and quantitative assessment
Ait Barka et al. 2022b	Descriptive	Geosites	Presentation
Ait Omar et al. 2022a	New proposal	Geosites and geomorphosites	Inventory and quantitative assessment
Ait Omar et al. 2022b	New proposal	Geosites and geomorphosites	Inventory and quantitative assessment
Aoulad Sidi Mhend et al. 2022	Reynard et al 2016	geosites	Inventory and quantitative assessment
Berred et al. 2022	Reynard et al 2016	geomorphosites	Inventory and quantitative assessment
Bussard et al. 2022a	Reynard et al 2016	geomorphosites	Inventory and quantitative assessment
Bussard et al. 2022b	Descriptive	Geosites	Presentation
Ech-charay et al. 2022	New proposal	Geosites and geomorphosites	Inventory and quantitative assessment
Lahmidi et al. 2022	Descriptive	Geosites	Presentation
Louz et al. 2022	Reynard et al 2016	geosites	Inventory and quantitative assessment
Mehdioui et al. 2022	Brilha 2016	Geosites	Inventory and quantitative assessment

employed in the evaluation of geoh heritage sites in the Moroccan context. In addition, it seeks to identify gaps and challenges in existing methodologies, paving the way for future research directions and the development of more objective and universally applicable evaluation criteria.

Materials and Methods

Geoconservation cannot be successful without the development of a geosite inventory and assessment as a first step. Several methodologies have been proposed (Grandgirard 1995, 1996, 1999; Cendrero 1996; Wimbledon 1995, 1996; Alexandrowicz and Kozłowski 1999; Panizza 2001; Bruschi and Cendrero, 2005; Coratza and Giusti 2005; Pralong, 2005; Pralong and Reynard 2005; Zouros 2007; De Wever *et al.* 2006; Pereira *et al.* 2007; Reynard *et al.* 2007, 2016; Panizza and Piacente 2008; Bruschi and Cendrero 2009; García-Cortés and Carcavilla 2009; Erhartič 2010; Fuertes-Gutiérrez & Fernández-Martínez 2010; Lima *et al.* 2010; Pereira and Pereira 2010; Ruban 2010; Pereira *et al.* 2010; Bâca & Schuster 2011; Poirier and Daigneault 2011; Bruschi *et al.* 2011; Feuillet

and Sourp 2011; Vujičić *et al.* 2011; Wimbledon *et al.* 2011; Bollati *et al.* 2012, 2013, 2016; Fassoulas *et al.* 2012; Doktor *et al.* 2015; Brilha 2016, 2018; Sellier 2016).

These proposals for quantifying elements of geodiversity attempt to establish criteria for assessment and to define priorities for site conservation and enhancement. Researchers have attempted to minimize, if not eliminate, the subjectivity inherent in quantifying elements of geodiversity. Most methodologies present a set of values that are subdivided into a set of criteria to be scored and assessed through a formula that enables geosites to be compared.

In our study, we carry out a literature review to provide a framework for future research efforts through a comprehensive review of the literature, data and subsequent evaluation. There are three phases: (1) an exhaustive search, (2) a selection of relevant publications related to Morocco, and (3) a review and analysis of the selected literature (Fig. 3).

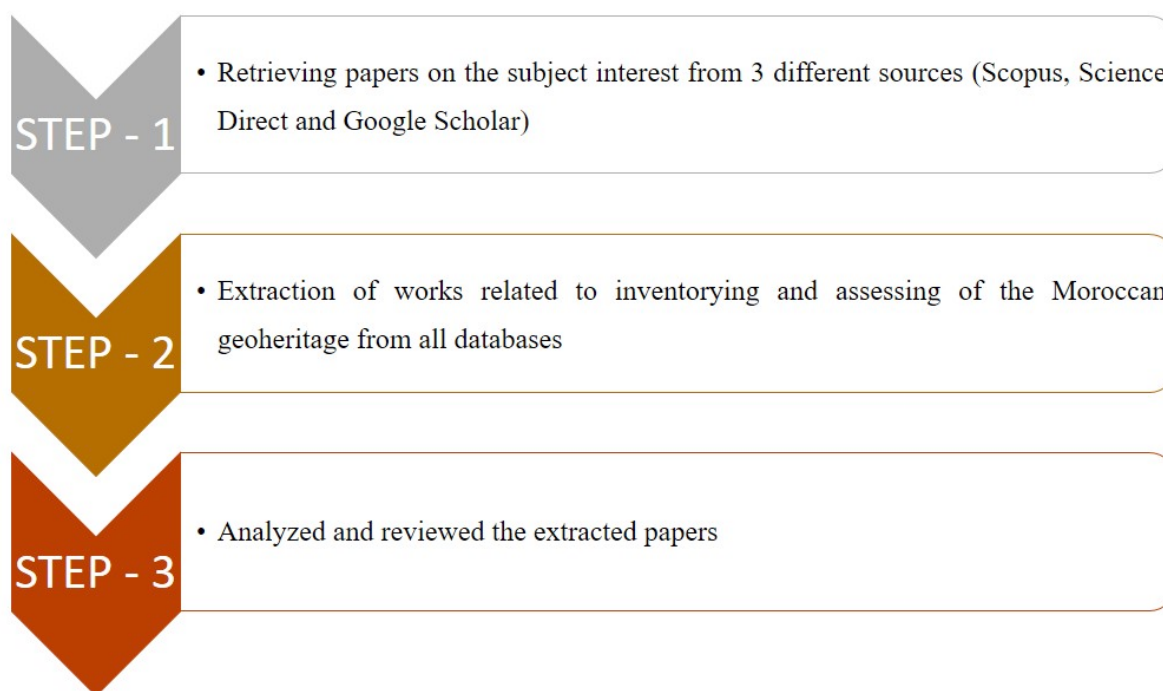


Figure 3. Methodology adopted for the study.

We used three online scientific literature databases: Science Direct, Scopus, and Google Scholar, searching articles, conference papers, editorials, commentaries, and book chapters. These three databases were chosen to guarantee the quality of the literature selected. The keywords used for the search were (ALL = (“Inventory” OR “Geosites” OR “Geomorphosite” OR “Geoheritage assessment” OR “Geosite assessment” OR “Geoconservation” OR “Geotourism” OR “Geoeducation”)), examining the title, abstract, and keywords of each. The literature identified was then fed into the second phase of the study, in which we extracted information on the inventory and assessment of Moroccan geoheritage sites.

Results

We identified 84 relevant documents published

since 2008 (Table 1). In these, different authors have tried to inventory and present geosites and areas with geological heritage, where 50 papers (59.5%) focus on geosites, 18 (21.5%) on geomorphosites, and 16 (19%) on both (Fig. 4).

In the papers, different approaches are used to identify geosites and evaluate them: 55 (65.5%) used the descriptive method, 16 (19%) used the Reynard *et al.* (2016) method, 6 (7.5%) used the Brilha (2016) method, and 7 (8%) proposed new approaches (Fig.5). These results suggest that the literature in general is insufficient as most use only the descriptive method.

In further detail, 24 (28.5%) of the papers focused on inventory, 29 (34.5%) on presentation of a geosite or an area containing geological and/or geomorphological heritage, 28 (33.4%) on inventory

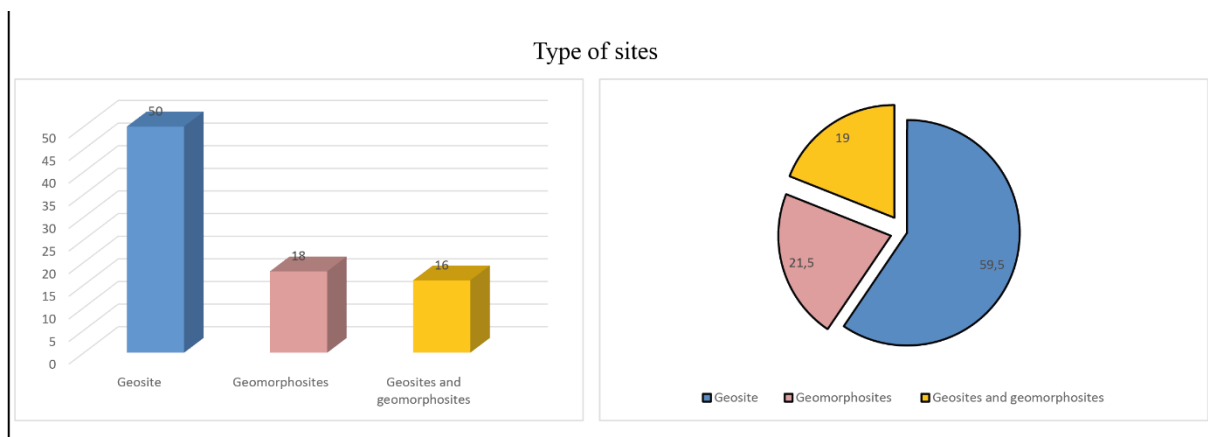


Figure 4. Type of sites.

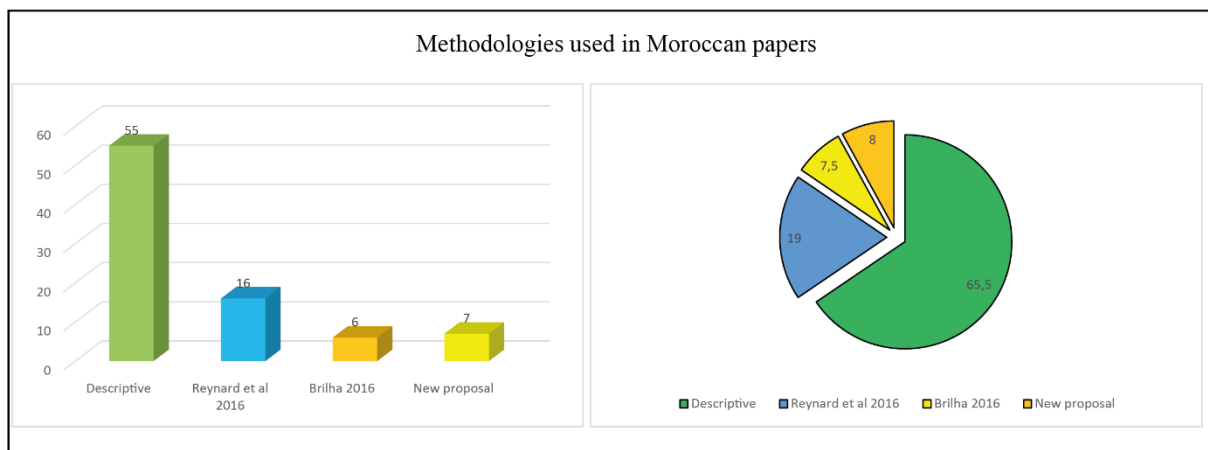


Figure 5. Methodologies used in Moroccan papers.

and quantitative assessment, and only 3 (3.6%) presented a geosite with a quantitative assessment (Fig. 6).

We identify two distinct periods in the study of Moroccan geoheritage: the introductory phases (2008–2015) and the growth phase (2016–2022) (Fig. 7).

- During the introductory phases, there was limited growth in publications focusing on Morocco’s

geological heritage. The authors relied mainly on descriptive methods to describe aspects of the geological inventory and the presentation of specific regions of the country.

- In contrast, the growth phase saw a remarkable increase in scientific output, indicating growing interest and commitment within the Moroccan scientific community. Researchers employed a range of methodological approaches to quantify,

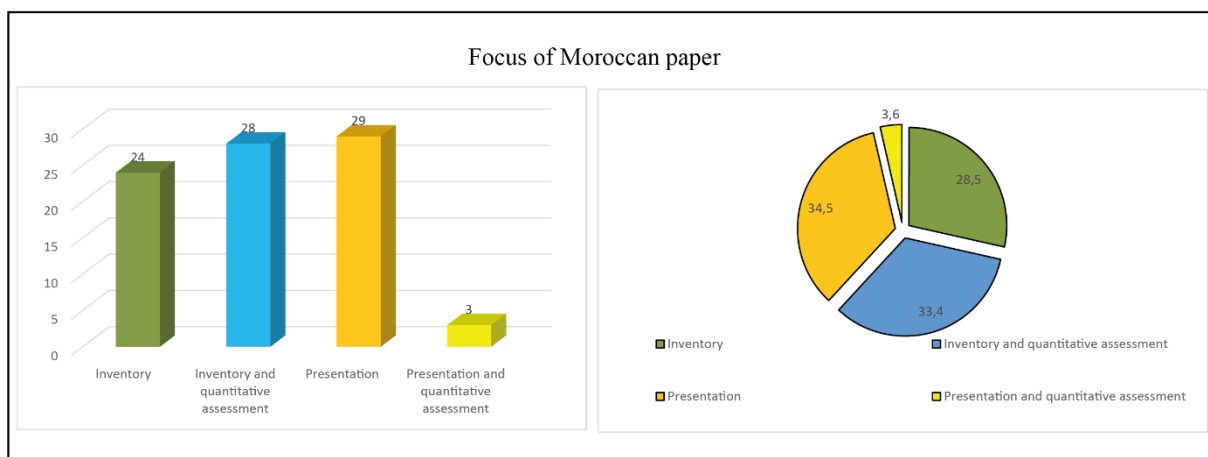


Figure 6. The focus of Moroccan paper.

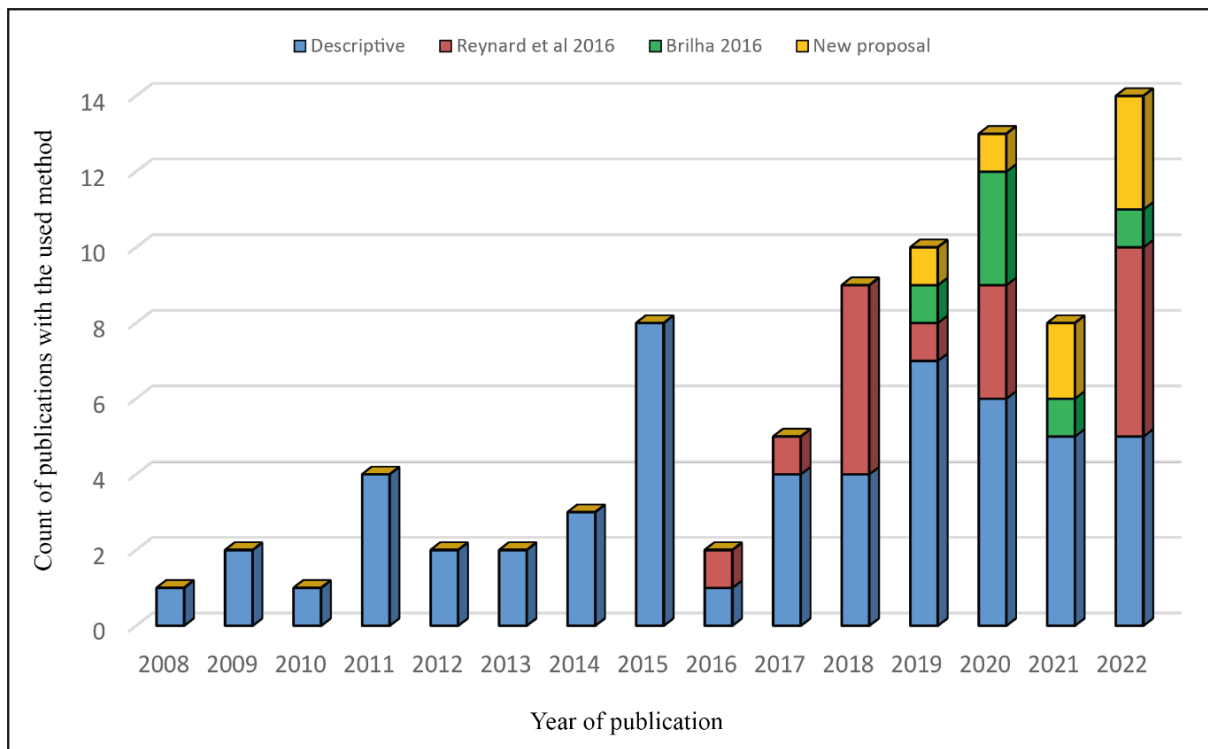


Figure 7. Trends in the assessment method used in publications from 2008 to 2022.

assess, and manage geosites and geomorphosites, including those of Reynard *et al.* (2016) and Brilha (2016). In addition, some new methods adapted to the inventory and assessment of Moroccan geosites and geomorphosites were proposed (Ait Omar *et al.* 2019; Baadi *et al.* 2020; Ech-charay *et al.* 2022).

Discussion

Geoheritage assessments based on qualitative methods in Morocco range from very general studies, such as the inventory of geosites in a given area, to detailed studies, such as the presentation of a single geosite or geomorphosite. In Morocco, two quantitative methodologies are commonly employed:

- Brilha (2016): the method evaluates geoheritage according to four criteria: scientific value, educational value, tourist value, and risk of degradation. Each criterion is divided into sub-indices (from 5 to 13), and the scores are then added together. The maximum possible score is 400 points.
- Reynard *et al.* (2016): the procedure includes four steps. First, a comprehensive description of the site under consideration is provided, detailing its geological and geomorphological features. Second, the assessment examines the intrinsic value of the site, considering its scientific significance alongside additional values such as cultural, ecological, and aesthetic attributes. Third is documentation of the current use and management status of the site, including evaluation of the site's protection measures, ownership, existing damage, and potential threats. Fourth is synthesis of the collected data and observations to provide a comprehensive overview of the site's characteristics and suitability for various purposes, such as conservation, tourism, and education.

The methodologies proposed by Ait Omar *et al.* (2019), Baadi *et al.* (2020), and Ech-charay *et al.* (2022) are built upon previously established evalu-

ation criteria, combined to enable their application to various types of sites to provide a comprehensive assessment of all aspects of a geomorphosite or geosite's value in Morocco.

For the geoheritage inventory of a large area with many geosites, the presentation of the results of the assessment (tables, graphs, thematic map...) is an important step in securing and supporting the next steps in the geoconservation strategy, as it helps managers to prioritize protection and management. It is recommended that sites with a high potential for a particular type of use and a high risk of degradation be given higher priority in management and planning. However, it should be noted that such a presentation is not necessary for the assessment of a single geosite.

The results of the quantitative assessment of geoheritage sites constitute an invaluable tool for the effective management of these sites, which is a fundamental aspect of any action plan for geoconservation (Prosser *et al.* 2018) and geotourism development (Newsome and Dowling 2018).

In general, inventories are based on the researcher's perspective, retaining only those geosites that the researcher is aware of or has previously visited, while other geosites that have scientific value are ignored, which means they will also be ignored during the legal protection process. The inventory must be systematic and include all geosites within the region.

It is essential to recognise the lack of clarity surrounding the application of geoconservation strategies, particularly in the context of geosite evaluation methodologies. This lack of clarity could potentially lead to the unintentional exclusion of important sites or the inclusion of less significant sites. Awareness-raising and training can help to address this issue and ensure more effective conservation efforts.

Conclusion

Morocco is home to a multitude of areas that are of significant scientific, cultural, touristic, and educational value. However, the development of these sites has been constrained by the lack of adequate identification and documentation. Consequently, a significant proportion of the population is unaware of the aesthetic, cultural, geological, and economic importance of these sites. Recognizing and understanding the diversity of these sites is crucial. Comprehensive studies aimed at identifying and documenting these sites in Morocco are essential to provide detailed insights into the significance of geoheritage sites, thereby empowering local communities and government officials at both the state and central levels to manage them effectively and responsibly. By gaining insights into the value and potential uses of these sites, stakeholders can make informed decisions regarding conservation, tourism development, and educational initiatives. Ultimately, effective management and promotion of these sites will not only preserve Morocco's rich heritage but also contribute to local economies and promote cultural appreciation and awareness.

The study of geoheritage is an important field of geographical and geological research in environmental protection. Preserving the natural creations of the past is the key to preserving the present for the future. Researchers are currently at the scientific research stage, as no general methodology for evaluating geoheritage sites has yet developed.

The diversity of methods for evaluating geoheritage sites is due to the particularities of their structure and conditions of formation in different parts of the world. There are three groups of assessment methods for geoheritage sites: qualitative, quantitative, and quantitative-qualitative. Qualitative evaluation methods consist of a general scientific description and justification of the objects in terms of their conformity with the criteria for belong-

ing to the geological heritage. These methods are not precise, as they rely mainly on the subjective opinion of the researcher. Quantitative assessment involves defining clear criteria, classifying them, and assigning them a corresponding weight. These methods are more reasonable, but they do not exclude the subjective evaluation factor.

Conflict of Interest

The authors declare that they have no competing interest

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Conflict of interest statement

The authors declare that there are no conflicts of interest associated with this study.

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