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ORIGINAL ARTICLE

Reflecting Experiences of Regional Academic, Tourism, and Education Specialists in Geoheritage Evaluation for Fujairah, UAE and Southeast Arabia

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Abstract
In Southeast Arabia (i.e. the United Arab Emirates [UAE] and Oman), geoconservation is a budding initiative, but to date, there has been limited evaluation of geoheritage sites in this region. Many geoheritage evaluation methods have been developed over the last 20 years, but the most popular methods reflect experiences from experts in Europe. The representativeness of these methods for different regional, cultural, and social contexts requires scrutiny. This study developed the first parametric method for geoheritage evaluation focused on Southeast Arabia, using Fujairah, UAE as a case study. The study applied a novel approach based on questionnaires completed by regional geoscience academics, local nature tourism professionals, and local science teachers. The preferences they expressed for scientific value, educational value, and touristic value, respectively, were used to develop the evaluation method. To test the requirements for informed decisions by tourism professionals and science teachers, the study compared results of questionnaires from two occasions: after a seminar on regional geoheritage sites, and after site visits. The resulting method deviates from previous methods in the relative weight it places on various criteria, substantiating the need to target wider regional voices in methods for geoheritage evaluation in Fujairah and Southeast Arabia. It reflects the need to consider cultural and societal differences, as well as curricular requirements for the educational value, that are not highlighted in existing evaluation methods. The applicability of the method was tested and confirmed by ranking geosites in Fujairah, and the method could be used at a regional scale in the future.

Keywords Geoheritage · Evaluation · Stakeholder Engagement · Arabia · Fujairah · UAE

Introduction

Evaluation Methods for Geoheritage Sites

The field of geological heritage, or geoheritage, conservation has advanced significantly over the past 30 years, including the development of international conservation frameworks such as UNESCO's Global Geoparks program (UNESCO, 2015). Although there is still debate over the definition of some field-specific terms some consensus has emerged (Table 1), and the central theme of protecting sites that help us understand the history of our planet and the roles of humans in it, has been increasingly recognised and celebrated.

A significant catalyst for the increased recognition of the need for geoconservation is the rise of geotourism and the acknowledgment of its economic potential (Farsani et al. 2011; Ruban 2015). As outlined by Ólafsdóttir and Tverijonaite (2018), the number of academic studies on geotourism has steadily grown over the past 20 years, from one or two papers annually at the beginning of the 21st century to more than 50 in 2017. Geographically, studies have been conducted on every continent except for Antarctica, with an expanding scope encompassing a broader range of countries (Ruban 2015). The economic development potential of geotourism has been a central focus, particularly concerning rural geoheritage sites (Farsani et al. 2011; Ólafsdóttir and Tverijonaite 2018). However, while promoting geotourism, concerns have arisen about the overexploitation and degradation of geoheritage sites due to tourism, raising questions about finding the right balance between conservation and

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Table 1 Definition of geoheritage related terms used in this study

Term	Definition
Geoheritage	Globally, nationally, state-wide, to local features of geology, such as its igneous, metamorphic, sedimentary, stratigraphic, structural, geochemical, mineralogic, palaeontologic, geomorphic, pedologic, and hydrologic attributes, at all scales, that are intrinsically important sites, or culturally important sites, that offer information or insights into the formation or evolution of the Earth, or into the history of science, or that can be used for research, teaching, or reference (Brocx and Semeniuk, 2007).
Geosite	A location, area or territory in which it is possible to identify a geological or geomorphological interest for conservation (Wimbledon et al. 1995)
Geotourism	Tourism which focuses on an area's geology and landscape as the basis of fostering sustainable tourism (Newsome and Dowling 2018)
Geoeducation	The process to facilitate learning, or the acquisition of knowledge about Geology through the use of geological sites (Brocx and Semeniuk 2019)

touristic use. This is especially relevant in countries lacking well-established conservation legislations (Kiernan 2013).

In the practice of geoheritage conservation, evaluation or quantitative assessment emerges as the second step following inventory, as outlined by Brilha (2016). This process plays a crucial role in determining which sites merit protection, especially considering the constraints of limited resources. Qualitative evaluation methods, exemplified by Brocx and Semeniuk (2015), offer the advantage of being more descriptive and accommodating for nuanced assessments. Nevertheless, an increasing number of researchers have favoured quantitative methods for their potential to provide more objective and transparent outcomes (see Bruschi et al. 2011 and Mucivuna et al. 2019 for further discussion).

Over the past two decades, numerous quantitative or semi-quantitative, score-based evaluation methods have been proposed and used (Brilha 2016; Bruschi et al. 2011; Coratza and Giusti 2005; Erhartič 2010; Fassoulas et al. 2012; Kubalíková 2013; Pereira and Pereira 2010; Pralong 2005; Reynard et al. 2007; Ruban 2010; Santos et al. 2020). The careful selection of an evaluation method is crucial, as even a slight difference in the assessment or resulting ranking can lead to a large difference in the protection of the site. The merits and drawbacks of various approaches have been a subject of discussion (Brilha 2018; Bruschi et al. 2011; Derafshi and Seyedhamzeh 2022; Mucivuna et al. 2022; Štrba et al. 2015). However, the consensus underscores the importance of parametric features, with a clear rubric that elucidates how a certain score is attained for a given criterion in the evaluation. This has gained widespread acceptance.

Although there is no consensus on a single best method, one of the most commonly cited and used methods is the one devised by Brilha (2016). This method is distinguished by its parametric approach, breaking down the evaluation into three value dimensions: scientific, touristic, and educational. Within each value dimension, a set of criteria is identified, each appointed a varying weight (percentage) that adds up to 100%. For every criterion, a rubric is established, outlining the conditions necessary for sites to earn certain points. Each criterion is scored out of 0,1,2, or 4 points. For example, the weight of the representativeness for the scientific value carries a weight of 30%. If a site meets the condition for 2 points for this criterion, exemplified by being "a good example in the study area to illustrate elements or processes, related with the geological framework under consideration (when applicable)" (Brilha 2016, p. 127), it receives $30 \times 2/4 = 15$ (%) toward the overall scientific value from this criterion. The score 3 is not allotted to any sites, to better distinguish the best sites (given 4-points) for each criterion. The final output yields a numeric value for each of the three value dimensions, calculated through the weighted sum of all criteria. The values are suggested to be considered independently, promoting more flexibility in application than a single combined score encompassing different value dimensions. Similar methodologies have been used in many studies, including those by Bruschi et al. (2011); Pereira and Pereira (2010); Santos et al. (2020); Suzuki and Takagi (2018) from Spain, Portugal, Brazil, and Japan, respectively.

The international adoption of popular evaluation methods offers the advantage of consistency in geoheritage site evaluation. However, the applicability of such methods in diverse contexts have been questioned, given geological, societal, and cultural differences between regions. As highlighted in Sayama (2024), many widely cited methods have been developed by researchers with experience primarily in Europe. Recent studies, including those by Mucivuna et al. (2022); Mucivuna et al. (2019); Santos et al. (2019); Zorlu and Dede (2023) have begun exploring the adaptability of these methods in different geographical settings. Santos et al. (2020) and Zorlu and Dede (2023), in their studies in Brazil and Turkey, respectively, concluded that either a new method or adjustments to the weighting system of existing methods are necessary. In contrast, Mucivuna et al. (2022) found no major differences between specialised methods (in the sense of regionally specialised or typologically specialised) and general methods, suggesting that creating new evaluation methods may hinder consistency. Further research is needed to determine when specialised methods are necessary and when existing popular methods can ensure consistency.

Another infrequently discussed issue in geoheritage assessment, pertains to the representation of different experts in developing evaluation methods. Most geoheritage evaluations have been determined by the experience of only 1 to 3 academic(s). Exceptions, such as works by Bruschi et al. (2011) and Siuki et al. (2012), have integrated stakeholder input into creating the evaluation method. Bruschi et al. (2011) surveyed 20 local experts to develop a new method to assess geoheritage sites in Cantabria, Spain, using the mean of their evaluations, to determine criterion weights on a scale from 0 to10. However, the experts' profiles were unclear, and each was tasked with rating criteria across all geoheritage value dimensions, potentially beyond their expertise.

Siuki and Kowalczyk (2012) ranked geosites in Razavi Khorasan Province, Iran, with a focus on touristic values, incorporating inputs from visitors and academics (professors and students). Despite this, the study lacks clarity on survey methodology and how criteria contribute to the final assessment score. Moreover, it is questionable whether the academics used in this study were familiar with the social and cultural context of Iran and the Razavi Khorasan Province, as they were from Poland, Canada, and Iran (ordered from highest to lowest number of participants). These studies underscore the need for a stakeholder-oriented geoheritage site assessment method with a transparent methodology, drawing inputs from multiple stakeholder groups with expertise in each considered value dimension.

Case Study: Geoheritage Evaluation in Southeast Arabia

In Southeast Arabia (i.e. the UAE and Oman), there is a growing focus on geoheritage conservation and geotourism. Notably in the UAE, the Al Wathba Fossil Dunes Reserve opened in 2022, and the Buhais Geological Park opened in 2020. In Oman, the Duqm Rock Garden has been established as a protected site since 2017, and the Omani Ministry of Tourism launched a geotourism-dedicated mobile application in 2019. From an academic perspective, studies have reported the destruction of geoheritage sites (Atkinson et al. 2011; Kirkham and Evans 2019; Lokier 2013), compiled an inventory of Quaternary geoheritage sites (Sayama et al. 2022), and explored the geotouristic potential of selected sites (Afifi and Negm 2020; Allan 2023; Nasir 2023). Despite these developments, few studies have addressed the evaluation of geoheritage sites in this region. To date, the sole published works on this topic are by Searle (2014, 2019).

Searle's work provided a comprehensive scientific overview and inventory of significant geological sites in Oman and eastern UAE, with a focus the Hajar Mountains region. In Oman, over 50 sites were evaluated and categorised as potential World Heritage Sites, National Geoparks, or Sites of Special Scientific Interest (Searle 2014). This evaluation drew upon scientific research and the researcher's experience in the region, establishing a solid foundation for geoheritage conservation. However, there is an opportunity to improve the assessment process by introducing a quantitative evaluation with a clear rubric, offering more precise and transparent rankings and outcomes for the sites. Such a rubric would not only benefit future assessments of sites beyond the existing inventory but also help other researchers or conservation professionals in their work. To our knowledge, no other evaluations have been conducted for geoheritage sites in southeast Arabia. In conducting a new assessment, it is important to consider the touristic and educational values of the sites to ensure a more comprehensive evaluation. To achieve this, involving local stakeholders with expertise in these fields becomes essential. Their insights can provide invaluable social and cultural perspectives that would help reveal the desired features of geosites for different uses. This collaborative approach would not only enrich the evaluation process but also contribute to the burgeoning interest in geoheritage in this region.

Geoheritage Conservation in Fujairah, UAE

The Emirate of Fujairah, situated in the eastern part of the UAE, spans an area of 1450 km^2, accounting for 1.75% of the UAE territory with a population of 316,790 (Fujairah Statistics Centre 2023) (Fig. 1). Fujairah stands out as one of the most geologically diverse emirates in the UAE, showcasing a geological spectrum ranging from the Middle Permian to lower Cretaceous passive margin, carbonate platform sequence (Hajar Supergroup) to late Cretaceous Oman-UAE ophiolite, to Quaternary alluvial and fluvial landscapes (Searle 2019). The geology of Fujairah is also pertinent for the livelihood of its people. It is the most geohazard-prone (e.g. earthquakes, floods, and landslides) emirate in the country (Dhanhani 2010), while 4.4% of its economy is supported by mining and quarrying activities (Fujairah Statistics Centre 2023).

Fujairah has recently demonstrated a commitment to safeguarding its natural heritage, notably evidenced by the protection of Wadi Wurayah National Park (WWNP) since 2009 (Ministry of Culture and Youth, 2021). Covering an area of 225 km^2, which constitutes 16% of the entire emirate, it is one of the few mountainous protected areas in the UAE. WWNP has been designated as a Ramsar site, a UNESCO Man and Biosphere reserve, and is on the tentative lists of UNESCO World Heritage Sites for criteria vii (superlative natural phenomena or exceptional natural

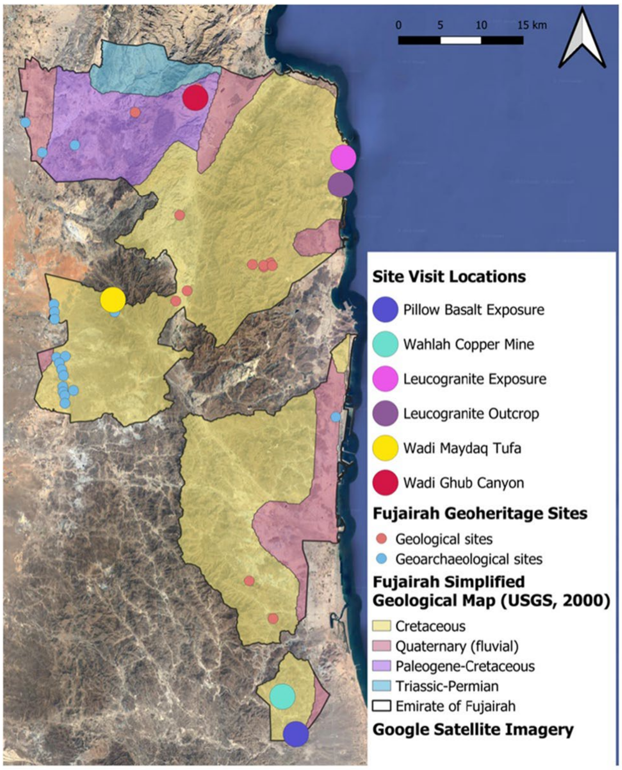

Fig. 1 Map of Fujairah, sites visited by the participants, and sites included in the inventory (Parker and Bretzke 2022). Created using QGIS

beauty), and x (in-situ conservation of biodiversity). The designations underscore WWNP's significance primarily for its rich biodiversity.

Fujairah's commitment to conservation has expanded beyond biodiversity, spearheaded by the Fujairah Natural Resources Corporation (FNRC), Fujairah Adventures, and Fujairah Environment Authority. In 2022, a major step towards geoheritage conservation was achieved when FNRC, in partnership with academic researchers, compiled a preliminary inventory of geoheritage sites in the emirate, based on previous literature and site visits (Parker and Bretzke, unpublished). Fujairah Adventures has also established 10 hiking tracks, including ones that traverse through geoheritage sites included in the inventory, and in 2023, enforced regulations, guidelines, and monitoring activities for the use of these tracks (Al Amir 2023).

This study aims to bridge the gaps and clarify ambiguities in the current literature on geoheritage evaluation, both at regional and international levels. Regionally, using Fujairah, UAE as a case study, it presents the first parametric evaluation of geoheritage sites in southeast Arabia. Internationally, the study presents the first evaluation method to incorporate input from distinct groups of experts for each of the three key dimensions of geoheritage values (scientific, educational, and touristic). The study considers the necessity for regional variations in geoheritage evaluation methods and emphasises the inclusion of multiple stakeholders in the development of these evaluation methods.

Materials and methods

The evaluation method was devised using responses gathered from questionnaires tailored for three distinct groups of stakeholders, each possessing expertise in one of the three main value dimensions of geoheritage sites, namely scientific, educational, and touristic. To assess the scientific value, academics specialising in geosciences from Emirati and Omani universities were recruited through email invitations and answered an online questionnaire. For the educational value, the statistical population were science teachers working in primary and secondary schools (public and private) in Fujairah. They were recruited with the support from Fujairah Education Zone. In evaluating the touristic value, the statistical population were professionals in adventure and nature tourism from companies and organizations operating in Fujairah. They were recruited with support from Fujairah Adventures. The questionnaire was designed in English, with Arabic translations provided upon request. Participants had the option to answer questions in either language.

Regarding the scientific value, as academics in geosciences were presumed to possess subject expertise and visit regional geological sites as part of their work, a single administration of the questionnaire (hereafter referred to as questionnaire S) sufficed. An explanation of the project and its objectives, including a brief explanation of the geoheritage concept attached to the questionnaire was given. A deeper briefing was felt not to be necessary. In contrast, to ensure well-informed decision making and to understand required exposure for stakeholders to make informed evaluations of geoheritage sites, two distinct questionnaires were administered for educational and touristic values (hereafter referred to as questionnaire E and T, respectively) at different times, and their results were subsequently compared. The first questionnaire (E1 or T1) was completed after participants attended a seminar on geoheritage sites of the region. The second questionnaire (E2 or T2) was answered after a follow-up visit to key geoheritage sites in Fujairah. The questionnaires were provided online via a link shared immediately after the seminar and also the site visit trip. The overall study design is outlined in Fig. 2.

The seminar, delivered by the first author, provided an overview of Fujairah's geoheritage sites, emphasising their relevance to tourism and education, tailored to the respective audiences. The contents included a summary of Fujairah's geology (for both education [E] and tourism [T] groups), a visual explanation of deep time (E, T), examples

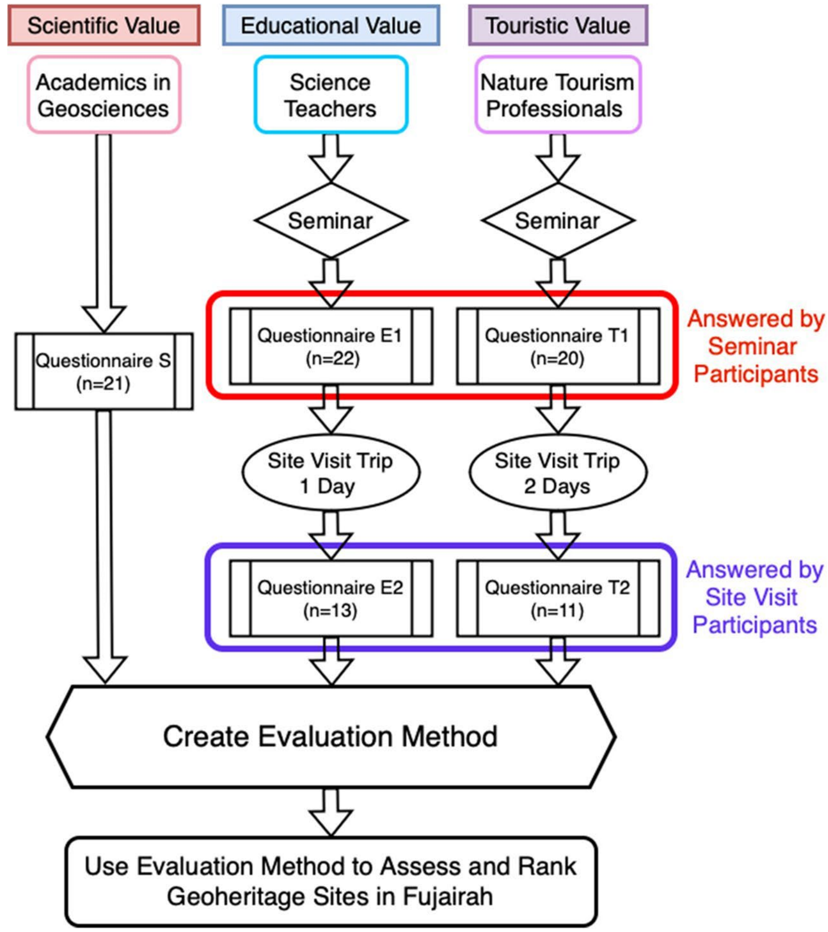

Fig. 2 Flowchart outlining the overall study design. Created using draw.io

of geoheritage sites in Fujairah (E, T), the significance of geoheritage sites for different branches of science (E), and an explanation of the overall research project (E, T). The seminar, conducted in English with Arabic translations, lasted approximately one and a half hours, including Q&As. It took place on 22nd December 2022 for tourism professionals at the FNRC headquarters and on 12th January 2023 for the science teachers at the Fujairah Emiri Court office.

Site visits were conducted over two days for both science teachers and nature tourism professionals. Tourism professionals participated in site visits over two consecutive days (10th -11th January 2023), visiting different sites on each day (2 sites on day 1 and 3 sites on day 2). Science teachers, due to their limited availability, joined for a single day, visiting three sites. The site visits for science teachers took place on two separate days (14th and 16th January 2023), with different teachers visiting the same sites with the same itinerary. The itinerary comprised visits, including hikes, to geoheritage sites, accompanied by 5–10-minute geological descriptions at each site. Participants had time for independent exploration and to ask questions. All activities were conducted in English, with translations offered in Arabic. The destination sites in these trips were selected by the author to demonstrate sites with varying characteristics in the study, rather than cluster sampling or random selection. The list of sites visited during the trips and the rationale for their selection are outlined in Table 2. The locations of the visited sites are shown in Fig. 1.

The questionnaire sought participants' input on the relative importance of evaluation criteria within the value dimension corresponding to their expertise. Criteria for each value dimension were chosen through two methods. First, common criteria from geoheritage evaluation methods (e.g. Brilha 2016; Bruschi et al., 2011; Pereira and Pereira 2010; Reynard et al. 2007) were reviewed and selected. Subsequently, to account for factors specific to the Southeast Arabia region, additional criteria were formulated and added by the author. Tables 3 and 4 summarise the criteria considered for the three value dimensions. Table 4 outlines the criteria applicable to both educational and touristic values, acknowledging the common criteria used to assess these two value dimensions. The "vulnerability" criterion, while used in previous methods such as Brilha (2016) and De Lima et al. (2010), was intentionally excluded from the questionnaire. This decision aligns with the practice employed by Bruschi and Cendrero (2005); Pereira and Pereira (2010),

Table 2 Sites visited and reasons for their selection

Site name	***Reason for Selection***	***Visited by***
Wahalah Pillow Basalt 	Part of the ophiolite storyline. Good location for hiking, but the geoheritage site itself does not have striking aesthetics. Selected to understand the importance of scientific value and importance of aesthetics for touristic value.	Tourism
Wahalah Copper mine 	Part of the ophiolite sequence. Good location to show the interaction between archaeology and geology. Trails have not been developed. Included to consider the importance of logistics, interdisciplinarity, and cultural context in touristic value.	Tourism
Ras Dadnah Leucogranite Outcrop 	Part of the ophiolite complex. Rare geological feature, studied and published by geologists (Cox et al., 1999; Searle, 2019). Easy access from a main road. Selected to consider the application of the roadside geotourism concept (Gates, 2006; Strba et al., 2016) in Fujairah.	Tourism
Ras Dadnah Leucogranite Beach 	Part of the ophiolite sequence located at a popular recreational beach. Rare geological feature that is located close to a well-established hiking trail. Selected to consider the importance of rarity and the ease of access.	Tourism, education
Wadi Maydaq Tufa 	An aesthetically striking site within 15–20 minutes (0.7 km) hiking access. Selected to see the importance of the aesthetic features and of easy walking access. This site also has the potential to demonstrate changes in climate and formation of the tufa deposits.	Tourism, education
Wadi Ghub Canyon 	Aesthetically striking site with organised trails, already popular for adventure tourism. Demonstrates implications for sea level change. The section requires 1 hour hike (2 km) to reach. Selected to consider the limits in walking distance and the importance of aesthetic features in educational values.	Education

Table 3 Criteria included in the survey for scientific value, and previous evaluation methods in which each criterion was used. Terms in parentheses describe the shortened terms used to refer to some criteria in this study

Criteria	Previous methods in which the criterion was used
Representativeness: Whether the site demonstrates exemplary characteristics of the geological/geomorphological elements or processes.	Brilha (2016); Bruschi et al. (2011); Coratza and Giusti (2005); De Lima et al. (2010); Panizza (2001); Pereira and Pereira (2010); Reynard et al. (2007)
Integrity: Current state of conservation of the main geological/geomorphological elements of the site.	Brilha (2016); De Lima et al. (2010); Kubalíková (2013); Pereira and Pereira (2010); Reynard et al. (2007); Ruban et al. (2021)
Geological diversity (geodiversity): Whether the site and its surrounding area covers a diverse array of geological/geomorphological features of scientific interest.	Brilha (2016); De Lima et al. (2010); Kubalíková (2013); Pereira and Pereira (2010); Ruban et al. (2021)
Rarity: Whether the feature is rare or unique in the region, the country, or the world.	Brilha (2016); Bruschi et al. (2011); Kubalíková (2013); Coratza and Giusti (2005), Pereira and Pereira (2010); Reynard et al. (2007); Ruban et al. (2021)
Historical value: Importance of the site for the development of the field.	Coratza and Giusti (2005); Reynard et al. (2007)
Scientific knowledge: The extent of scientific knowledge gained from the site.	Brilha (2016); Bruschi et al. (2011); Coratza and Giusti (2005); Kubalíková (2013); Pereira and Pereira (2010); Ruban et al. (2021)
Potential for future research (future potential): Whether there is ongoing research at the site that may lead to new scientific knowledge or if there is specific mention about the need for further research at the site.	Coratza and Giusti (2005)
Connections with modern issues (modern issues): Whether the site has connections with modern issues such as, climate change, flood management, natural disaster management, current land use, etc.	Developed by author for this study
Connection with economic geology (economic geology): How relevant is the site for economic geology including the petroleum industry.	Developed by author for this study
Connection with the regional archaeology/anthropology (arch/anth): Whether the site has significant meaning towards the regional archaeology/anthropology.	Developed by author for this study

and Kubalíková (2013). The rationale behind this exclusion is rooted in the understanding that geoheritage values are not inherently lost due to vulnerability; instead, vulnerability should be considered in the context of how the site's values are utilised.

The questionnaire asked participants to rate the relative importance of each criterion on a five-point scale. The descriptions of the five options were given as below:

Option 1. Should not be included in evaluation.
Option 2. Should be considered to some degree.
Option 3. Should be considered.
Option 4. Very important to determine the [corresponding value dimension].
Option 5. Essential. Most important to determine the [corresponding value dimension].

The Likert-type scale (Carifio and Perla 2008) is designed with an assumption of equal distance between the options for use as interval values. Debate exists on the validity of treating Likert-type data as interval values, and further, using parametric methods (i.e. means, standard deviations, and t-tests for statistical significance) for their analysis (Bishop and Herron 2015; Guerra et al. 2016; Knapp 1990). The conventional approach avoids using parametric methods for analysing ordinal data (e.g. Likert-type item) (Göb et al. 2007). De Winter and Dodou (2010) present evidence justifying the use of parametric methods for analysing five-point Likert-type items, showing little to no difference in error rates between parametric methods and non-parametric methods, regardless of sample size. Also, Knapp (1990) stresses the need to consider the objective of the study to decide on the most appropriate methodology. Given that the scope of this study is to understand the relative importance of each criterion, small differences in the results need to be considered. Therefore, parametric statistical methods were justifiably used for the analysis, with non-parametric tests conducted for robustness and reported in the Appendix i.

For educational and touristic values, participants rated a selection of regional geoheritage sites on an interval scale from 1 (lowest) to 5 (highest). An open-ended question was added to the questionnaire E2, asking for reasons behind their evaluations due to numerous comments received during the site visits. These questions on rating individual sites were excluded from the scientific value questionnaire, be to prevent bias toward sites related to the respondent's area of academic expertise.

In questionnaires E2 and T2, participants were asked if their opinions on evaluating geoheritage sites had changed

Table 4 Criteria used in the questionnaire for educational and touristic values, and previous evaluation methods in which each criterion was used. The included for column specifies the value dimension(s) for which the criterion has been used. Terms in parentheses describe the shortened terms used to refer to some criteria in this study

Criteria	Previous methods in which the criterion was used	Included for
Accessibility: How easy is it to access the site? (Separated for touristic value to understand whether there is a difference in the relative importance of accessibility from Fujairah and from other major cities in the UAE, such as Dubai and Abu Dhabi)	Brilha (2016); Bruschi et al. (2011); De Lima et al. (2010); Kubalíková (2013)	Educational, Touristic
Safety: How safe is it to visit the site and to see around the place?	Brilha (2016); Kubalíková et al. (2020)	Educational, Touristic
Logistics: Are there restaurants, toilets, etc. around the site?	Brilha (2016); De Lima et al. (2010); Kubalíková (2013)	Educational, Touristic
Population density: Do many people live around the area?	Brilha (2016); De Lima et al. (2010)	Educational, Touristic
Association with other disciplines/values (other values): Are there different disciplines with which the site has connections with? How important are these connections?	Brilha (2016); De Lima et al. (2010); Kubalíková (2013)	Educational, Touristic
Scenery: How beautiful is the scenery of the site?	Brilha (2016); Reynard et al. (2007)	Educational, Touristic
Uniqueness: How rare is the type of site?	Brilha (2016); De Lima et al. (2010)	Educational, Touristic
Observational Conditions: How visible the geological elements are and how easily visitors can observe them.	Brilha (2016); Bruschi et al. (2011); De Lima et al. (2010); Kubalíková (2013)	Educational, Touristic
Geological diversity (geodiversity): Does the site and its surrounding area cover a diverse array of geological/geomorphological features of interest?	Brilha (2016); Bruschi et al. (2011)	Educational
Interpretive potential: Whether it is easy to understand the geological elements of the site?	Brilha (2016); De Lima et al. (2010)	Touristic
Didactic potential: Is the site and its surrounding area suitable for teaching students at different age groups?	Brilha (2016); Coratza and Giusti (2005); De Lima et al. (2010); Kubalíková (2013); Reynard et al. (2007);	Educational, Touristic
Relationship with modern human issues (modern human issues): Do these sites tell you something about modern issues that humans face in today's world?	Bruschi et al. (2011)	Educational, Touristic
Economic level: Is the local area affluent with potential source of visitors?	Brilha (2016); De Lima et al. (2010)	Touristic
Proximity to other tourist attractions/recreational areas (other tourist attractions)	Brilha (2016); De Lima et al. (2010)	Touristic

after the site visit. The participants were asked to answer from the following three options:

1. No
2. Yes, a little bit
3. Yes, a lot

To gain a more nuanced insight into the influence of the site visits to the decision-making abilities of the participants, participants who answered 2 or 3 were then asked to explain what made their opinions change. These qualitative answers were coded and analysed using NVivo based on mentions of specific sites and specific evaluation criteria. Each statement expressing preferences was coded based on the nature of the statement, with the following options: positive, negative, or "yes, but", which comprised positive statements followed by negative statements or expression of reservations.

After analysing the data, a new evaluation method was developed, considering the summary statistics (i.e. mean, standard deviation), significance testing results (i.e. two-sample and paired t-tests), qualitative data from open-ended questions, and context-based decision making. First, for educational and touristic values, the most appropriate dataset (after-seminar [E1/T1] or after-site-visit [E2/T2]) was selected to be used in developing the new evaluation method. This process involved an analysis of the necessity of the site visits for informed decision-making by education and tourism professionals. Then, for simplicity and practical applicability (Bruschi et al. 2011; Mucivuna et al. 2019), reduction of the number of criteria was considered. To do this, principal component analysis (PCA) was used, following the approach by Bruschi et al. (2011). The appropriateness of PCA was evaluated using the Kaiser-Meyer-Olkin (KMO) index and Bartlett's sphericity (BS) test (Dziuban and Shirkey 1974).

In addition to PCA, correlation coefficients between criteria were determined. A high positive correlation between criteria indicates similarity in the way they were assessed by the participants. While such a similarity could be coincidental, it could also be due to these criteria being considered as similar criteria that are closely related. In the latter case, these criteria could be combined to be considered as one criterion. Therefore, criteria with high positive correlation were combined, if and when the resulting combined criterion could plausibly be defined and characterised without losing sense of the original criteria. For this analysis, correlation matrices were created using the polychoric correlation, the preferred method of calculating correlation coefficients for Likert scale data (Holgado–Tello et al. 2010).

The final list of criteria for each value dimension was determined, and proxies and parameters for evaluating of each criterion were selected. The most suitable weighting scale for the evaluation method was chosen based on the relative importance of each criterion. Finally, with the evaluation method developed, the authors assessed and ranked geoheritage sites in Fujairah for scientific, educational, and touristic values.

Results

The questionnaire for scientific value was completed by 21 regional academics. The expertise of these academics covered fields such as geochemistry (3), geomorphology (3), geophysics (3), sedimentology (3), structural geology (3), environmental geology (1), geospatial sciences (1), hydrogeology (1), and stratigraphy (1). For touristic value, questionnaire T1 was answered by 21 participants and questionnaire T2 by 11 participants. For educational value, questionnaire E1 was completed by 24 participants, and questionnaire E2 completed by 14 participants. After filtering for incomplete answers, participant profile criteria, and survey satisficing (e.g. answering everything as 5), the number was reduced to 20 for scientific value, 20 (T1) and 11 (T2) for touristic value, and 22 (E1) and 13 (E2) for educational value. The reliability of the questionnaires was evaluated using the intra-class correlation (ICC) coefficient. This measure is commonly used to test reliability of questionnaires by analysing the variation in answers between multiple raters assessing the same group of subjects (Koo and Li 2016). The reliability of the questionnaires was all within the moderate range, with ICC values between 0.57 and 0.74. This moderate reliability indicates that the assessors had a rather diverse range of opinions in evaluating the criteria.

Figure 3 outlines the mean and standard deviation of the relative importance of each criterion for the three value dimensions. Due to a lack of responses to the survey question asking for an email address, which was used to connect the respondents of the two surveys, the data from questionnaires T1 and T2 could not be paired. This means any changes in answers between the two datasets could only compared at the level of the entire dataset. For educational value, the pairing of datasets was possible, allowing for an analysis of changes at the individual level. As such, the data coded in green in the following figures show the summary statistics from questionnaire E1 by participants who also answered questionnaire E2.

Results of after-seminar and after-trip Questionnaires

The summary of answers to questions related to site rank and the self-reported change on opinions toward geoheritage evaluation from questionnaires E1, E2, T1, and T2 are shown in Figs. 4 and 5. Figure 4 shows the results of the site evaluation that are comparable between the tourism and education datasets. For tourism professionals, the after-trip data demonstrate a clearer difference between the site preferences. The rank of Wadi Maydaq Tufa and Wahalah Copper Mine had flipped in the after-trip data. The difference between the highest-rated site and the lowest-rated site increased from 0.09 in T1, to 1.28 in T2. The gap between the top two sites and the leucogranite site is also evident, at 1.00. For science teachers, the ranking of the evaluation for the three sites reversed completely after the trip, with the leucogranite site being ranked first after the site visits, despite having been ranked last after the seminar.

Figure 5 shows the participants' responses to the question about whether the site visit changed their views on evaluating geoheritage sites. For tourism professionals, 8 out of 11 participants answered that their views did not change, or only changed a little, whereas for the science teachers, 9 out of 13 participants answered that their views changed a lot. Only one science teacher answered that the site visit did not change their view on geoheritage evaluation.

The t-tests revealed statistically significant differences between the post-seminar and post-site-visit datasets only in two cases: the paired t test of the evaluation of the Leucogranite site (p value = 0.04) for the educational value, and the two-sample t test of the site evaluation of the Wahalah Copper Mine site (p value = 0.01) for the touristic value. For other values, including the relative importance of all evaluation criteria, no statistically significant difference could be observed. Appendix i provides the full results of the significance testing, including specific p-values for each site and criterion, and corresponding non-parametric tests for checking data robustness.

Analysis of the qualitative data from open-ended questions offered insights into a few evaluation criteria. For the educational value, the most common references were to accessibility ($n = 21$), didactic potential ($n = 10$), Wadi Ghub Canyon ($n = 8$), Wadi Maydaq Tufa ($n = 7$), safety ($n = 6$), and aesthetics ($n = 6$). For the touristic value, multiple references were made to potential ($n = 5$), accessibility ($n = 2$), and aesthetics ($n = 2$). Less qualitative data is available for touristic value, due to the smaller number of participants who reported a change of opinion after the site visits, and the lack of the open-ended question regarding the site evaluation.

PCA and Correlation Matrix

The result of the BS test and the outcome of the KMO index showed that the only dataset suitable for PCA was for the scientific value. None of the datasets for the educational value or the touristic value met the 0.5 threshold for appropriate use of PCA in the KMO index (Abdi and Williams 2010). Data from questionnaires E2 and T2 did not meet the threshold for BS test either.

Table 5 provides a summary of the results of the PCA analysis for the scientific value dataset. Five components that explain 83.4% of the variability of the total variance can be extracted from the data. Component 1 is highly correlated to five (economic geology, scientific knowledge, historical value, rarity, and archaeology/anthropology) criteria, whereas the others include none (components 2, 4, 5) or 2 (component 3, with geodiversity and representativeness).

For the correlation matrix, as shown in Table 6, few evaluation criteria have high correlations to each other, except in the T2 dataset, with 8 occurrence of correlation coefficients above |0.6|. Most high correlations were positive, with only one high negative correlation coefficient above the |0.6| threshold. None of these strong correlations, however, were statistically significant at the 5% level, with all p-values between 0.1 and 0.15. (See Appendix ii for the complete correlation matrices and the corresponding p-values for each dataset.)

Discussion

Necessity of the Site Visits

To select the most appropriate dataset for developing the evaluation method, it is essential to consider the differences between the post-seminar and post-site visit data. Analysis of participants' responses regarding opinion changes after site visits revealed significant differences in the impact on educational value. About 70% of the participants stated that the site visits changed their opinion a lot, with only 1 participant reporting no change. The site evaluations exhibited a complete reversal of site rankings after the site visit, with the mean evaluation of the leucogranite site increasing at a statistically significant level in the paired analysis by 33%, while Wadi Ghub Canyon decreased by 13%. This contrast is supported by the answers to the open-ended questions, which showed only positive association with comments on the leucogranite site (5/5 mentions), as opposed to 75% of comments on the Wadi Ghub site being associated with either negative or "yes, but" sentiments.

For the touristic value, 4 out of 11 answers reported no change in opinion after the site visit. Participants did not find the site visits very influential in the way they evaluated geoheritage sites. Only three participants answered that it changed their opinion a lot and interestingly, these three participants were all working in the only government-run adventure tourism company operating in Fujairah. All participants from private companies answered "No", or "Yes, little bit".

On the other hand, the evaluation of sites did change after the trips, with a statistically significant change for the Wahalah Copper Mine site, with a ~ 30% improvement in evaluation score after the site visit. Looking at the site rank, Wahalah Copper Mine rose from second to first after the trip, with Wadi Maydaq Tufa falling from first to second, and the leucogranite site remaining third. Furthermore, the post-site visit data exhibit a much wider difference in the preferences demonstrated toward the sites.

Significance testing offered limited insight into changes in the relative importance of evaluation criteria, with no statistically significant results. In a dataset with smaller sample size, however, it is important not to completely disregard differences that were not statistically significant (Fritz and Berger 2015; Leppink et al. 2016). For instance, for educational value, the mean of the relative importance of the logistics increased by 0.5 for the site visit participants after attending the trip (an increase of 14%), despite not being statistically significant. These trends warrant further investigation through qualitative approaches, such as interviews, to conduct a more nuanced analysis, especially where the sample size of the study is small.

Considering these factors, the results illustrate the benefits of the site visits for science teachers to make informed decisions on evaluating the educational value of geoheritage sites. On the other hand, for the touristic value, although small changes could be observed, the ambivalent outcomes make it difficult to establish the necessity of site visits. Therefore, the after-seminar dataset was deemed more representative due to its larger sample size. Therefore, data from questionnaire E2 will be referred to as the educational value data, and the data from questionnaire T2 will be referred to as the touristic value data in the subsequent sections.

Inclusion and Exclusion of Criteria for Evaluation

To select the most appropriate evaluation criteria, eliminate redundancy, and simplify the evaluation process, three methods (comparison of relative importance scores, PCA, and correlation matrix) were employed to reduce the number of criteria. The distribution of the relative importance questions was initially considered, focusing on the descriptions associated with the options used in the questionnaire. Option 3, indicating that the criterion "should be considered" in the evaluation was chosen as the threshold for inclusion and exclusion. Using this criterion, the population density criterion in the education dataset, with a mean of 2.42 (see Fig. 3), was excluded from the assessment.

The use of PCA was considered for further reduction of evaluation criteria, but its application was deemed inappropriate for the educational and touristic values. Although Bruschi et al. (2011) advocated for the use of PCA even with a KMO index below 0.5, this practice is discouraged in statistical literature (Dziuban and Shirkey 1974). For the scientific value, while the application of PCA was statistically valid, the resulting components did not align with logical justifications outlined by Bruschi et al. (2011), rendering the outcome unsuitable for this study.

Finally, combining criteria with high correlation coefficients was considered. In touristic value, a high positive correlation was found between the "other touristic attractions", and the "other values". Although not statistically significant, these criteria were logically related and were combined to form the criterion "additional values" in the touristic value evaluation method.

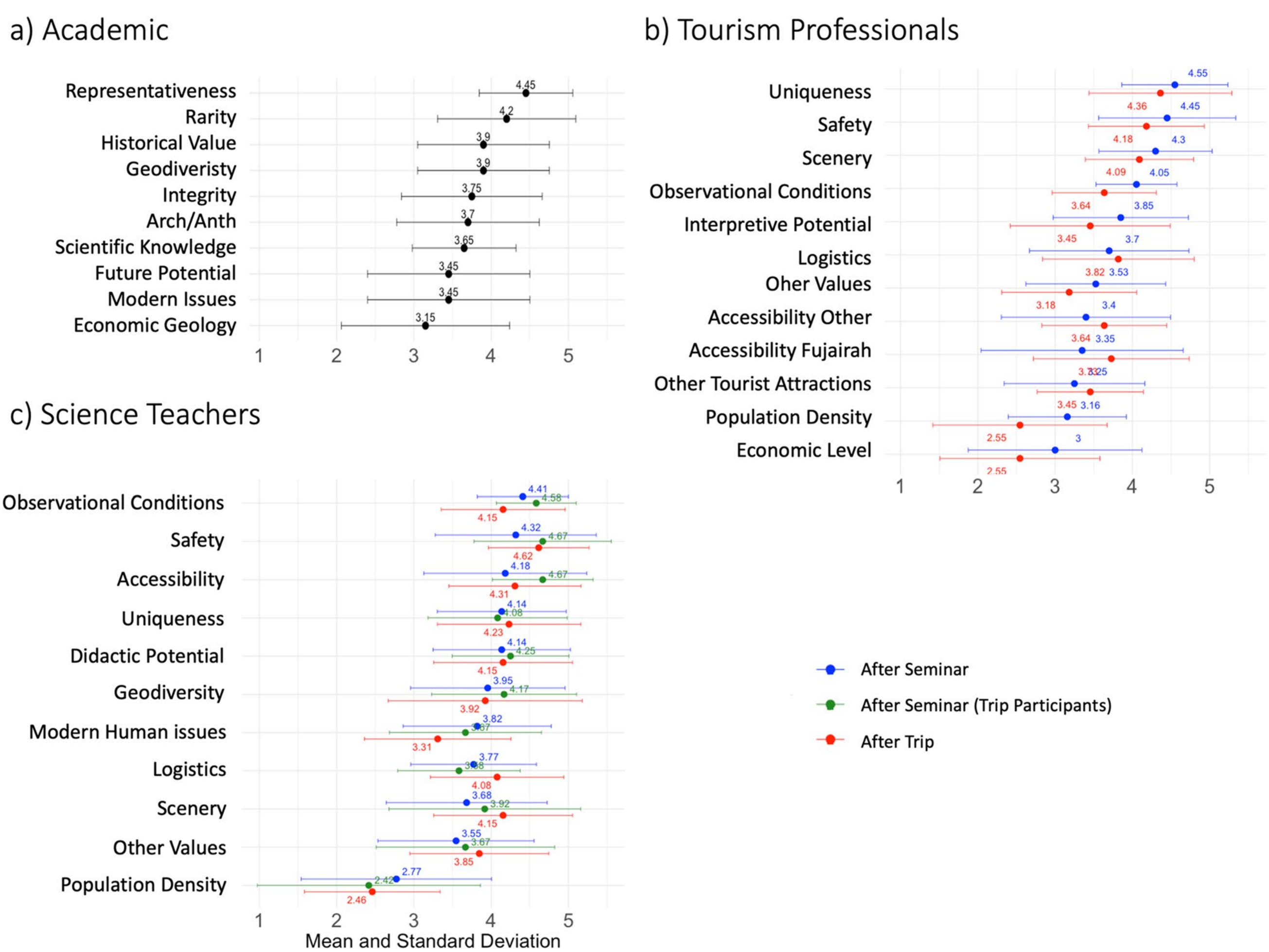

Fig. 3 Means and standard deviations of the relative importance of each criterion for **a**) educational value, **b**) touristic value, and **c**), scientific value. For **a**) and **b**), the results from the questionnaire T1/E1 are colour coded in blue, and the results from the questionnaire T2/E2 is colour coded in red. For **c**), the summary statistics from a subset of questionnaire E1, answered by the participants who joined the site visits and answered questionnaire E2, are colour coded in green. The circle represents the mean, and the error bars represents the standard deviation for each criterion. For each value dimension, the criteria are ordered from the highest to the lowest mean (for touristic and educational values, the mean in the after-seminar dataset in descending order is used to organise the criteria). Created using R

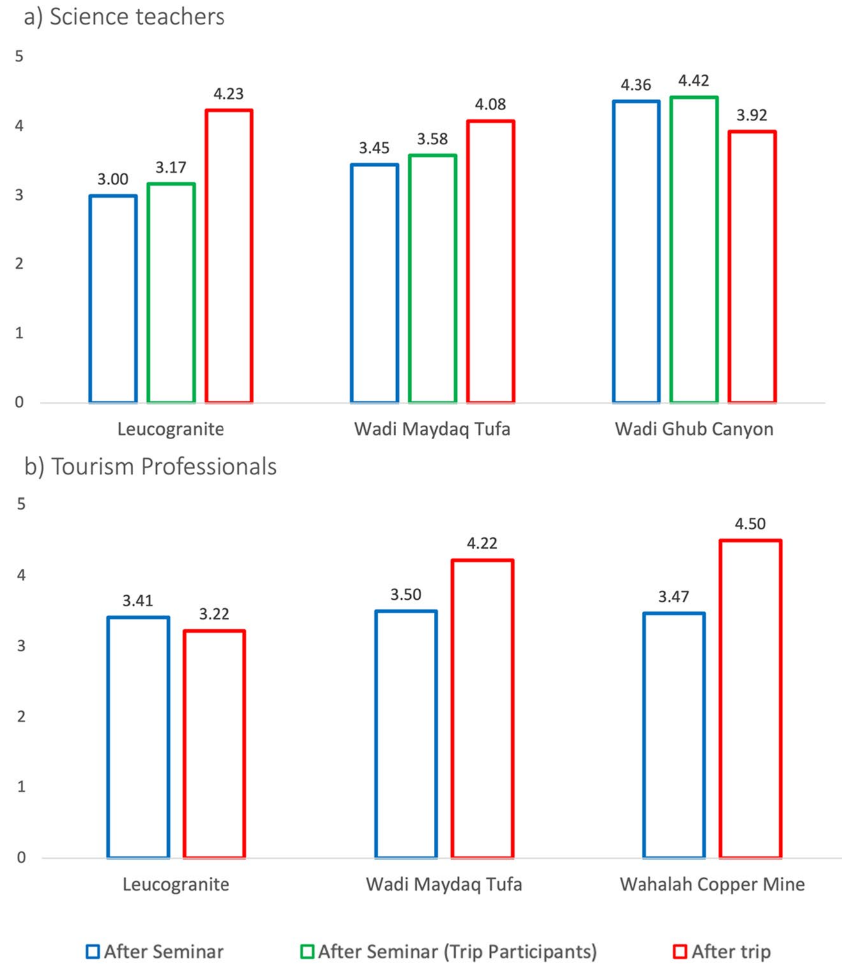

Fig. 4 Bar graphs demonstrating the means of site evaluation values for education value and tourism value. After lecture and after site visit trip data are demonstrated for both values, with an additional bar for the educational value showing the answers of the trip participants after the seminar. Created using R

For educational value, excluding the population density criterion, two high positive correlations were observed: between "uniqueness and geodiversity", and between "interpretive potential and scenery". However, given the lack of logical relationships, these sets of criteria were not combined in the educational value evaluation method.

Regarding touristic value, a question was asked about accessibility from Fujairah and accessibility from other major Emirati cities to determine if they needed separate consideration. Although the correlation coefficient between these two criteria was low (0.31), this can be explained by differences in the operational centre of participants' companies. With the relative importance of 3.35 and 3.40, respectively, the very similar outcome indicates that the two do not have to be considered separately and were combined in one accessibility criterion.

In summary, through the analysis of the data distribution, PCA, and the correlation coefficients, the population density criterion was excluded from the educational value evaluation, and the other values and the other touristic attractions criteria were combined in the touristic value evaluation. For the scientific value, no criteria were excluded or combined. Although the scientific evaluation involved a relatively high number of criteria, it remained similar to others in educational and touristic values. The study results indicated that most evaluation criteria, including those added for regional considerations, were necessary for a full evaluation of geoheritage values.

Parameters to Evaluate each Criterion

To develop a parametric method for geoheritage evaluation, a rubric explaining how points are awarded must be established for each criterion. In this study, as stakeholder input was not used to develop the parameters, existing parameters from previous studies were adopted for most criteria, following (Sayama 2024). For some criteria, however, adjustments to the parameters were made based on insights from the open-ended questions.

In the open-ended questions related to educational value, accessibility and didactic potential emerged as the most referenced criteria. Accessibility was mentioned by 8 out of 13 respondents. Interestingly, the answers stressed the importance of both road access ($n=4$) and walking access ($n=9$).

Fig. 5 Bar graph showing the distribution of answers to the question, "Did your ideas about evaluating the sites change after you went on the field trip?" for educational value and touristic value. Created using R

Table 5 Summary of components created by the PCA for the scientific value dataset and their correlation with each evaluation criterion. The percentage in parenthesis demonstrate the percentage of variance explained by each component. The highest correlation for each component is presented in bold and underlined, and correlations above 0.6 is highlighted in blue with a darker shade for a higher value

		Components				
		1 (34.6%)	2 (16.9%)	3 (15.9%)	4 (8.5%)	5 (7.5%)
Evaluation Criteria	Representativeness	-0.25	**<u>0.59</u>**	0.63	0.19	0.01
	Integrity	0.53	0.39	-0.39	0.19	**<u>0.47</u>**
	Geodiversity	0.33	-0.23	**<u>0.81</u>**	0.26	0.11
	Rarity	0.66	0.30	0.39	-0.42	-0.08
	Historical value	0.71	0.14	0.05	0.24	0.34
	Scientific knowledge	0.77	-0.11	-0.27	-0.30	0.12
	Potential for future	0.34	-0.83	0.18	-0.09	0.03
	Modern issues	0.57	-0.07	-0.30	**<u>0.59</u>**	-0.46
	Economic geology	**<u>0.80</u>**	-0.24	0.18	0.02	-0.08
	Archaeology/ Anthropology	0.63	0.51	-0.03	-0.18	-0.40

Table 6 High positive and negative correlation coefficients observed in each dataset for the relative importance of evaluation criteria

Correlation coefficient	Tourism post-seminar (T1)	Tourism post-site visit (T2)	Education post-seminar (E1)	Education post-site visit (E2)	Science (S)
≥0.8	NA	Population density/Accessibility Fujairah (0.88) Population density/Observational conditions (0.87) Other touristic attractions/Uniqueness (0.80)	NA	NA	NA
<0.8 ≥0.7	NA	Geodiversity/Uniqueness (0.79) Observational conditions/Accessibility Fujairah (0.72)	NA	Uniqueness/Geodiversity (0.73), Interpretive potential/Scenery (0.71)	NA
<0.7 ≥0.6	Other touristic attractions/Other values (0.68)	Logistics/Other values (0.697) Observational conditions/Other values (0.62)	NA	Population density/Logistics (0.61)	NA
< -0.6	NA	Economic level/Interpretive potential (-0.62)	NA	NA	NA

These responses, coupled with changes in site rankings after the site visits, indicated that the 2 km walking distance at Wadi Ghub Canyon was deemed unsuitable for educational use. Even the 800 m walking distance at the Wadi Maydaq Tufa site was considered less preferable. Additionally, for road access, participants highlighted that school visits would typically be conducted by bus, emphasising the significance of bus accessibility.

For didactic potential, previous parameters focused on rating a site on teaching content for different educational levels (Brilha 2016; García-Cortés et al. 2019). However, responses from this questionnaire emphasised variety of content that could be taught at the site. This difference could be attributed to geology not being taught as an independent subject in UAE's national curriculum for science education, making it necessary for educational content provided at geoheritage sites to extend beyond the geological domain.

Tables 7 and 8 present the parameters used for the assessment of each criterion in the evaluation method for scientific value, and educational and touristic values, respectively. In Table 8, insights from science teachers are incorporated to distinguish the description of parameters for educational and touristic values for the accessibility criterion. Original parameters were developed for criteria introduced in this study, which have not been utilised in previous parametric evaluation methods. The point system follows the 0,1,2,4 point system used in Brilha (2016) and García-Cortés et al. (2019).

The Weight of each Criterion used in the Evaluation

After identifying the appropriate dataset, criteria, and parameters, determining the weight of each criterion was the final step in creating the evaluation method. An essential consideration was how to compare the relative importance of each criterion. To achieve this, the five options from the relative importance questions were converted into a scale ranging from − 1 to 3 (Table 9.). The values were assigned based on the text description of each option, reflecting the stance of each description regarding whether the criterion should be included in the evaluation process. Options 3–5, which support the necessity of the criterion, were assigned positive values, with a higher number for increasing degrees of support. Conversely, option 1 was assigned a negative value as its description clearly opposes the use of the criterion in the evaluation. Finally, the option 2 was assigned the value 0, representing a degree of ambivalence towards the necessity of the criterion.

Using this scale, the mean value of each criterion was calculated and compared to finalise the weighting system out of 100 as presented in Table 9. The values were rounded to the first decimal point to create whole numbers. In cases when the rounding led to a combined value above or below

Table 7 Rubric of the parameters used to evaluate criteria for the scientific value. The parameters are adopted from Brilha (2016), García-Cortés et al. (2019), Bruschi et al. (2011), and Sayama (2024). The asterisks indicate criteria developed in this study with original parameters

	0 point	1 point	2 points	4 points
Representativeness	Little use as a model to represent, even partially, a feature or process	The site reasonably illustrates elements or processes in the study area	The site is a good example in the study area to illustrate elements or processes	The site is the best example in the study area to illustrate elements or processes
Rarity	There are more than five examples of similar sites in the study area	In the study area, there are four to five examples of similar sites	In the study area, there are two to three examples of similar sites	The site is the only occurrence of this type in the study area
Historical value	It does not meet the following three criteria	The site is used by national science, directly related with the geological framework under consideration	The site is used by international science, directly related with the geological framework under consideration	The site is recognised as a GSSP or ASSP by the IUGS or is an IMA reference site
Geological diversity	Sites with only one type of distinct geological/geomorphological features with scientific relevance	Site with two types of distinct geological/geomorphological features with scientific relevance	Site with three types of distinct geological/geomorphological features with scientific relevance	Site with more than three types of distinct geological/geomorphological features with scientific relevance
Integrity	Strongly degraded: the site is practically destroyed	Site with preservation problems and with the main geological elements quite altered or modified	Site not so well preserved, but the main geological elements are still preserved	The main geological/geomorphological elements are very well preserved
Archaeology/ Anthropology	No data from the site, or no data that corresponds with archaeological or anthropological records	Site provides relevant archaeological or anthropological features with importance at the local level	Site provides relevant archaeological or anthropological features with importance at the national level	Site provides relevant archaeological or anthropological features with importance at the international level
Scientific knowledge	There are no published studies, grey literature, conference abstracts, or doctoral theses on the site	There are abstracts presented in events about this site, or in grey literature, directly related with the geological framework under consideration	There are papers in national scientific publications about this site, directly related with the geological framework under consideration	There are papers in international scientific journals about this site, directly related with the geological framework under consideration
Future potential	No ongoing or planned projects on the site, or mention of potential for future research in academic and/or grey literature	One mention of potential for future research at the site, but no ongoing project	Multiple mentions of potential for future research at the site and/or a plan or proposal to conduct research at the site	Project(s) ongoing currently at the site
Modern issues*	The site has no relationship with modern issues	The site demonstrates moderate relationship with one modern issue	The site demonstrates strong relationship with one modern issue, or moderate evidence for multiple modern issues	The site demonstrates strong relationships with multiple modern issues
Economic geology*	The site has no relationship with economic geology	The site has a moderate relationship with economic geology	The site has a strong relationship with economic geology	The site is a key regional locality for economic geology

Table 8 Parameters and point system used to evaluate criteria for the educational and touristic values. The parameters are adopted from Brilha (2016), García-Cortés et al. (2019), and Bruschi et al. (2011). The asterisks indicate criteria developed in this study with original parameters. Minutes away indicate time distance with automobiles unless specified otherwise

	0 point	1 point	2 points	4 points
Accessibility	Sites that require > 20-minute (education)/>2 km (tourism) walk from the nearest road accessible by bus (education) or car (tourism)	Site with no direct access by road but located < 20-minute (education)/2 km (tourism) walk from a road accessible by bus (education)/car (tourism)	Site accessible by bus (education)/car (tourism) through a paved (education)/unpaved (tourism) road	Site located < 100 m from a paved road and with Bus (education)/car (tourism) parking
Safety	Sites with no safety facilities in a difficult environment with no mobile phone coverage and/or located more than 30 min away from emergency services	Site with no safety facilities and not so easy environment but with mobile phone coverage and located less than 30 min away from emergency services	Site with no safety facilities but at easy location with mobile phone coverage and located less than 30 min away from emergency services	Site with safety facilities (fences, stairs, handrails, etc.), mobile phone coverage and located less than 30 min away from emergency services
Logistics	No toilets and restaurants for groups of 30 persons less than an hour away from the site	Toilets and restaurants for groups of 30 persons less than an hour away from the site	Toilets and restaurants for groups of 50 persons < 30 min away from the site	Toilets, and restaurants for groups of 50 persons < 15 min away from the site
Population density	Less than 100,000 inhabitants within a radius of 50 km	More than 100,000 but less than 200,000 inhabitants within a radius of 50 km	Between 200,000 and 1,000,000 inhabitants within a radius of 50 km	More than 1,000,000 inhabitants within a radius of 50 km
Other values/ [Additional values]*	There is no occurrence of association with ecological or cultural value or another touristic site < 30 min away from the site	There is an occurrence of association with one ecological or cultural value or one other touristic site < 30 min away from the site	There are multiple occurrences of associations with ecological and/or cultural values or several other touristic sites < 30 min away from the site	There are multiple occurrences of associations with ecological and/or cultural values and several touristic sites < 15 min away from the site
Scenery	Site not used as a tourism destination or known by locals as a scenic destination	Site occasionally used as a tourism destination or known by some locals as a scenic destination	Site currently visited/or known as a scenic destination locally	Site currently visited a scenic destination by visitors around the country or internationally
Uniqueness	The site does not show any common features found across the country	The site shows common features in this region, but they are uncommon in other regions of the country	The site shows unique and uncommon features in the country	The site shows unique and uncommon features nationally and in neighbouring countries
Observational conditions	There are obstacles that make difficult the observations of the main geological elements	There are some obstacles that make difficult the observation of the main geological elements	There are some obstacles that make difficult the observation of some geological elements	All geological elements can be observed in good conditions
Geodiversity	There is no geodiversity element at the site	There is only 1 type of geodiversity element at the site	There are 2 types of geodiversity elements at the site	There are > 3 types of geodiversity elements at the site
Interpretive potential	The public needs to have expert geological knowledge to understand the geological elements of the site	The public needs to have good geological background to understand the geological elements of the site	The public needs to have some geological background to understand the geological elements of the site	The site presents geological elements in a very clear and expressive way to all types of publics
Didactic potential	The site does not present features that can be used to teach students	The site presents features that can be used to teach a content for a single academic discipline	The site presents features that can be used to teach a content for multiple academic disciplines, or multiple contents for a single academic discipline	The site presents features that can be used to teach multiple contents of multiple academic disciplines
Modern human issues*	The site does not clearly relate to any modern human issues	The site presents teaching opportunities for a modern human issue	The site presents teaching opportunities for multiple modern human issues	The site presents excellent teaching opportunities for multiple modern human issues
Economic level	The site is in a municipality with a household income lower than the national average	The site is in a municipality with a household income similar to the national average	The site is in a municipality with a household income higher than the national average	The site is in a municipality with a household income at least the double of the national average

Table 9 The scale used in the questionnaire to the scale used to determine the weight

Description of the option	Should not be included in evaluation	Should be considered to some degree	Should be considered	Very important to determine the value	Essential. Most important to determine the value
	Negative	Neutral	Positive		
Scale used for weight	-1	0	1	2	3

100, the criterion with the first decimal point value closest to 5 was either rounded up or down. In the case of educational value, where there was a three-way tie at 10.37 with a need to round up, the value was converted to 10.33 to respect the tie instead of rounding up (Table 10).

The weighting system developed in this study demonstrated several key differences to commonly used existing methods. Overall, compared to methods such as Brilha (2016), which are decided based on the perspective of a single academic, differences between the weight of criteria are less pronounced. This is likely an outcome due to consulting a larger sampling population with a greater diversity of viewpoints. This result resembles the outcomes of other evaluation methods created using a larger sample population, such as Bruschi et al. (2011), using insights from 20 regional experts, or Božić and Tomić (2015), where opinions of 293 tourists were incorporated.

For scientific value, representativeness and historical value were of lower importance, while scientific knowledge and geodiversity were given higher importance. The reduced weight of the representativeness can be explained by the overall trend of less pronounced differences between criteria. For historical value, the relatively young history of geoscientific studies [add source] in this region may be a contributing factor, leading to a lower overall importance. This young history, in turn, could be the reason for the high evaluation of scientific knowledge, as the relatively few sites that have been studied are considered important sources of scientific data. The connection with archaeology and anthropology, despite its lack of consideration in most other methods (e.g. Brilha 2016; Bruschi et al. 2011; Vujičić et al. 2011), also gained importance. This result demonstrates the interdisciplinary relevance of geoheritage sites in this region, and the recognition of the need to reflect this connection in evaluating the scientific importance of each site. The remit of scientific value of geoheritage sites is not limited to implications for geosciences alone. Many of these findings align with those from Sayama (2024), who studied the scientific evaluation of Quaternary geoheritage in arid regions, suggesting that geoscientists with experience in arid regions share similar ideas on the scientific evaluation for geoheritage sites.

The weighting for the educational value resulted in a system closest to that reported by Brilha (2016). Nevertheless, the lower importance of didactic potential and the higher importance of scenery and uniqueness suggest different priorities in evaluating the education value. This result indicates that the educational experts consider site scenery as an important draw to inspire students in their place-based learning experience, rather than didactic potential alone. Furthermore, for science teachers, safety is the most important consideration for science, which could reflect the site visits in which the participants felt that some locations included “many potential hazards” on “risky” and “arduous” paths. The relatively higher weight for logistical concerns most likely reflects the experiences from the site visits in which sites, such as the tufa site, were considered logistically “too difficult” for school visits.

Finally, for touristic value, similar to educational value, safety, uniqueness, and logistics were considered more important than in previous methods. This highlights the differences in priority between academics and stakeholders directly engaged in related fields. Surprisingly, observational conditions were considered more important than in previous methods, and nearly as important as scenery. A potential explanation for this could be their clients’ eagerness to take photos for social media etc. when they visit the sites. Another characteristic of this weighting system is the relatively low importance of accessibility. Adventure tourism companies own and use 4-wheel-drive vehicles, are trained to drive in rough terrains, and cater for clients willing to walk further or to access more challenging sites. Therefore, they may not find accessibility an essential consideration.

Overall, the evaluation method developed in this study showed characteristics and preferences different from or rarely captured in previous methods. This result emphasises the importance of input from stakeholders in creating evaluation methods for geoheritage sites.

Ranking of Geoheritage Sites in Fujairah

Using the evaluation method developed in this study, the geoheritage sites in Fujairah, UAE listed in the inventory by Parker and Bretzke (unpublished), were ranked for the three value dimensions by the authors. Table 11. presents the weighted overall values and ranks of the sites. Ras Dadnah Leucogranite site was the highest ranked site for scientific value, featuring a very rare type of leucogranite studied by various researchers (Cox et al. 1999; Rollinson 2015; Searle

Table 10 Breakdown of the weighting system developed for each value dimension in this study, compared to the weighting system developed by Brilha (2016)

Scientific Value			Educational Value			Touristic Value		
Criteria	Weight (this study)	Weight (Brilha 2016)	Criteria	Weight (this study)	Weight (Brilha 2016)	Criteria	Weight (this study)	Weight (Brilha 2016)
Representativeness	14	30	Safety	13	10	Uniqueness	15	10
Integrity	12	15	Accessibility	11	10	Safety	14	10
Geodiversity	11	5	Uniqueness	11	5	Scenery	13	15
Rarity	11	15	Didactic Potential	10.33	20	Observational Conditions	12	5
Historical Value	10	20	Scenery	10.33	5	Interpretive Potential	11	10
Scientific Knowledge	10	5	Observational Conditions	10.33	10	Logistics	10	5
Archaeology/Anthropology	10	NA	Logistics	10	5	Additional Values	8	10 (proximity of recreational areas + association with other values)
Modern Issues	8	NA	Other Values	9	5	Accessibility	7	10
Future Potential	8	NA	Geodiversity	9	10	Population Density	6	5
Economic Geology	6	NA	Modern Human Issues	6	NA	Economic Level	4	5
Others		10 (use limitation)	Others		5 (population density) 5 (use limitations) 10 (vulnerability)	Others		5 (use limitations) 10 (vulnerability)
Total	100	100	Total	100	100	Total	100	100

Table 11 Ranks and total value in the evaluation for the scientific, educational, and touristic values of geoheritage sites in Fujairah, UAE listed in Parker and Bretzke (2022). Nearby sites are combined and considered as one site. Sites are ordered in the rank for the scientific value. The colours on the background of the rank columns provide a blue to red scale ranging from the highest ranked (blue, highest opacity) sites to the lowest ranked (red, highest opacity) sites. The total value is rounded at the first digit

	Scientific value		Educational value		Touristic value	
	Total (weighted)	Rank	Total (weighted)	Rank	Total (weighted)	Rank
Ras Dadnah Leucogranite	62	1	69	2	61	5
Wadi Wurayah Outcrops and Quaternary Fluvial Deposits	61	2	85	1	77	1
Sheikh Khalifa bin Zayed Highway Moho Transition Zone Outcrop	51	3	30	16	36	14
Wadi Maydaq - Tufa Formations	51	4	55	4	62	4
Wadi Ghub Canyon (Chert and Limestone)	50	5	53	5	63	3
Wahalah Copper Mine and Sheeted Dyke Complex	49	6	53	6	54	6
Silicified Serpentinite Outcrops	48	7	38	10	44	10
Al-Habhab Rock Shelters	44	8	42	9	49	9
Masafi Schist and Metamorphic Window	40	9	52	7	50	8
Wadi Midnah Rock Shelters	40	10	44	8	42	11
Tawiyayn Shamal Chert Formation	36	11	37	11	35	15
Al Hala Alkaline Volcanic Formation	33	12	34	13	38	13
Wadi Sayraq Rock Shelters	32	13	33	14	35	16
Wadi Mai Sheeted Dyke Complex	31	14	36	12	51	7
Al-Aqah Rock Shelters	29	15	58	3	63	2
Wadi Liban Ophiolite Complex and Tonalite Body	29	16	20	17	23	17
Wahalah Pillow Lava	25	17	31	15	41	12
Qurayyah	18	18	2	18	12	18

2019). For touristic and educational values, Wadi Wurayah Outcrops and Quaternary Fluvial Deposits site received the highest evaluation. Although currently unavailable public access, the site has parking and infrastructure for visits, with different ecological and cultural connections that can be explored, leading to the high evaluation It is located inside a UNESCO biosphere reserve and is on the tentative list for a UNESCO World Heritage site (Ministry of Culture and Youth, 2021).

With varying ranks of sites, this outcome demonstrates the importance of evaluation for different value dimensions. One of the most prominent differences in the ranks is that of the Moho Transition Zone Outcrop at the Sheikh Khalifa bin Zayed Highway. This site, a roadside outcrop studied by Ambrose and Searle (2019), serves as an excellent example of the transition zone between the Earth's mantle and the crust. Although scientifically significant, its scientific importance may not easily be interpreted by the public, and it is not suitable for public access due to its location alongside a busy highway with no consideration for observation. In contrast, the Al-Aqah Rock Shelters site is ranked highly for educational and touristic values at 3rd and 2nd, respectively, but ranked 15th for scientific values. This site, featuring rock shelters formed in fossil beach sediments and consolidated aeolianite, may not be highly significant from a scientific perspective. However, its formation, coastal setting, archaeological evidence, location within the Al-Aqah Heritage Village, and proximity to other tourist attraction (i.e. beach and hiking trail) make it a favourable site for educational and touristic use.

Even for educational and touristic value, although the ranks may appear similar at a first glance, the ranking provides important differences. The most prominent difference is the rank of the Ras Dadnah Leucogranite site, ranked 2nd for educational value and 5th for touristic value. This relative rank corresponds to the evaluations observed in the questionnaire, demonstrating the evaluation method's capability to reflect the different priorities of the two stakeholder groups. The ranks of the sites demonstrated in Table 10 mostly respects the relative ranks of the sites given by the study participants, except for the case of the disproportionately high rank of the leucogranite site in the touristic value. Its higher rank compared to the Wahalah Copper Mine site is at odds with the results of the questionnaire. This could be due to the small difference (i.e. 0.03) observed between the site evaluations in the dataset used to base this evaluation method, but it could also be due to different factors that were not considered as criteria in this evaluation method.

One important issue to note in this evaluation method is that for educational and touristic values, the values of the site may not always be representative of the potential of the site. The potential of a site can be evaluated by excluding three criteria (i.e. accessibility, safety, and logistics) that can be improved by investment in infrastructure towards and around the site. Some key differences can be observed when comparing the ranks of educational/touristic value and educational/touristic potential, as can be seen in Table 12. For example, the rank of Al-Aqah Rock Shelter goes down when considering the potential, most likely because its accessibility and the infrastructure around the site contributes to its high value. Conversely, the ranks of sites such as Wadi Ghub Canyon, Wadi Maydaq Tufa Formation, and Wahalah Copper Mine go up, showing that with the right investment, these could be sites with high values for education and tourism. This information may be important for

Table 12 Comparison of the rank of geosites in Fujairah for educational and touristic values (evaluation with all criteria) and potential (evaluation without consideration of accessibility, safety, and logistics) the colours on the background of the rank columns provide a blue to red scale ranging from the highest ranked (blue, highest opacity) sites to the lowest ranked (red, highest opacity) sites

(a)	Educational value		(b)	Touristic Value	
	Rank (Value)	Rank (Potential)		Rank (Value)	Rank (Potential)
Wadi Wurayah Outcrops and Quaternary Fluvial Deposits	1	1	Wadi Wurayah Outcrops and Quaternary Fluvial Deposits	1	1
Ras Dadnah Leucogranite	2	2	Al-Aqah Rock Shelters	2	8
Al-Aqah Rock Shelters	3	10	Wadi Ghub Canyon (Chert and Limestone)	3	1
Wadi Maydaq - Tufa Formations	4	3	Wadi Maydaq - Tufa Formations	4	1
Wadi Ghub Canyon (Chert and Limestone)	5	4	Ras Dadnah Leucogranite	5	4
Wahalah Copper Mine and Sheeted Dyke Complex	6	5	Wahalah Copper Mine and Sheeted Dyke Complex	6	4
Masafi Schist and Metamorphic Window	7	6	Wadi Mai Sheeted Dyke Complex	7	6
Wadi Midnah Rock Shelters	8	14	Masafi Schist and Metamorphic Window	8	9
Al-Habhab Rock Shelters	9	9	Al-Habhab Rock Shelters	9	7
Silicified Serpentinite Outcrops	10	7	Silicified Serpentinite Outcrops	10	10
Tawiyayn Shamal Chert Formation	11	13	Wadi Midnah Rock Shelters	11	16
Wadi Mai Sheeted Dyke Complex	12	11	Wahalah Pillow Lava	12	10
Al Hala Alkaline Volcanic Formation	13	8	Al Hala Alkaline Volcanic Formation	13	12
Wadi Sayraq Rock Shelters	14	14	Sheikh Khalifa bin Zayed Highway Moho Transition Zone Outcrop	14	14
Wahalah Pillow Lava	15	12	Tawiyayn Shamal Chert Formation	15	15
Sheikh Khalifa bin Zayed Highway Moho Transition Zone Outcrop	16	16	Wadi Sayraq Rock shelters	16	13
Wadi Liban Ophiolite Complex and Tonalite Body	17	17	Wadi Liban Ophiolite Complex and Tonalite Body	17	17
Qurayyah	18	18	Qurayyah	18	18

future development of geoheritage conservation planning. Overall, however, the ranking provides a robust evidence-based tool to guide geoheritage conservation and geotourism development in Fujairah.

Conclusions

This study developed a new evaluation method for assessing geoheritage sites in Southeast Arabia, incorporating inputs from various stakeholder groups to reflect the geological, cultural, and social characteristics of the region. The resulting method demonstrated distinct features compared to previous approaches, including the relatively lower importance assigned to representativeness and historical value for the scientific value, and the relatively high importance of safety and uniqueness for both the educational and touristic values. Notable differences between touristic and educational value were also observed, particularly in the importance and definition of accessibility where educational value placed higher importance on factors like bus access. Such large differences, along with the inclusion of region-specific criteria developed for this study in the weighting system, add to the growing evidence that regional methods for geoheritage evaluation are necessary for better results.

Stakeholder engagement played a crucial role in method development, revealing the significance of site visits for informed decision-making, particularly for science teachers. Changes in data before and after visits indicated a shift in perceptions and evaluations, especially considering accessibility, safety, and didactic potential. While evidence for touristic value was less conclusive, larger sample sizes and more qualitative data are recommended for future studies to explore potential differences between stakeholder groups.

Application of the method to geoheritage sites in Fujairah showcased its utility in representing stakeholders. The site ranking from the method closely aligned with participant evaluations, underscoring the robustness of the combination of parameters and weighting system. This ranking offers a valuable tool to develop geoheritage and geotourism projects in Fujairah.

In conclusion, the results underscore the significance of stakeholder engagement, on-site experiences, and context-specific considerations in geoheritage evaluation. The newly developed method has broader applicability in Southeast Arabia and neighbouring regions as a practical decision-making tool for diverse uses of geoheritage sites. The approach employed in this study stands as a model for geoheritage evaluation in other regions, emphasising the value of incorporating stakeholder perspectives to create a more representative evaluation rooted in diverse experiences and expectations.

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Declarations

Ethical Approval This study was approved by the Central University Research Ethics Committee (CUREC) at the University of Oxford to have followed the research protocols set out by the committee with the approval references: SOGE IA 22 254 and SOGE C1A 23 5.

Conflict of Interest The authors declare no conflict of interest regarding this research project.

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