Evidence-based Roadmap for Geoheritage Conservation in Southeast Arabia:

Inventory, Evaluations, and Communicating Geocultural Connections



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Abstract

Geoheritage, encompassing significant abiotic features and processes that shape our planet, plays a vital role in understanding planetary history, supporting biodiversity, and explaining historic and prehistoric relationships between humans and nature. Over the past 30 years, the need for protecting geoheritage sites has become increasingly recognised, especially in Europe and East Asia, epitomised by the establishment of international frameworks such as the UNESCO Global Geoparks in 2015. However, in some regions, including southeast Arabia, geoheritage sites lack representation in nature conservation frameworks and the future of many valuable sites remains uncertain.

Southeast Arabia boasts a diverse array of geoheritage sites, including rare geological features that help geoscientists understand the structure and development of our planet, as well as newer Quaternary deposits that provide a rich story of the region's environment. These sites have significant interdisciplinary implications, including providing data used by archaeologists/anthropologists to study human migration out of Africa. Nevertheless, geoheritage conservation remains a low priority in this region, with sporadic initiatives implemented over the last 20 years, and very little academic attention.

Through an interdisciplinary, mixed-method approach drawing from fields including archaeology, heritage science, geoheritage research, quantitative social science, and science communication, this thesis examines ways to advance geoheritage conservation in southeast Arabia through an evidence-based, bottom-up approach, with a focus on Quaternary sites.

First, a GIS-based study was conducted to identify the *status quo* of Quaternary geosites that have been studied in this region. Second, a science communication study was carried out to test the efficacy of highlighting the human-nature interconnection in introducing Quaternary geoheritage sites. Finally, two regional knowledge-holder-based evaluation methods for geoheritage sites were produced, with one focusing on Quaternary sites and the other focusing on geoheritage sites in general.

Together, the findings show high demand for geoheritage conservation in southeast Arabia, demonstrated by the high level of destruction and threats to regional Quaternary sites, and the wider public's recognition of their need for protection, especially when introduced to the sites' values. The studies also demonstrate the high potential of geoheritage sites for educational and touristic use. The methods and the findings of this thesis can be adapted for use in different regions, especially in locations with limited resources to kickstart the protection of geoheritage sites.

Together, the findings show high demand for geoheritage conservation in southeast Arabia, demonstrated by the high level of destruction and threats to regional Quaternary sites, and the wider public's recognition of their need for protection, especially when introduced to the sites' values. The studies also demonstrate the high potential of geoheritage sites for educational and touristic use. The methods and the findings of this thesis can be adapted for use in different regions, especially in locations with limited resources exist to kickstart the protection of geoheritage sites.

Although a few key developments, such as the development of related infrastructure and the engagement of local communities, are still required, the findings of this thesis serve as a useful guideline to advance geoheritage conservation in this region.

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Section A: Research Context and Design

Chapter 1 Introduction

1.1 Heritage conservation

In the simplest terms, heritage refers to cultural, natural, or mixed "resources which we value for reasons beyond mere utility" (English Heritage et al., 2008, p. 71). A wide variety of values make humans consider something as heritage, as shown in Table 1.1. Although these values present differing levels of transferability (Azzopardi et al., 2023), with some shared within and across cultures and some limited to individuals or certain communities, the importance of protecting heritage, at least the tangible heritage sites, is recognised globally. This is exemplified by the fact that 191 of 193 UN member states ratified the World Heritage Convention (UNESCO, 2023b). The recognition of heritage is not a recent phenomenon; there are indications of the concept from civilisations such as ancient Greece (Lowenthal, 1994).

Table 1.1 Types of heritage values, as summarised by Azzopardi et al. (2023)

Type of Value		Description
Transcendental Values		Values that are known to be shared within and across cultures. Examples include respect for tradition or unity and harmonious coexistence with nature. Also called basic or held values.
Contextual Values	Intrinsic Value	The value derived from the heritage itself. This value cannot be replaced by another heritage object.
	Instrumental Value	The value of the heritage object for the sake of something else, rather than in itself. Also called extrinsic value.
	Relational Value	Human-centric value that is derived from relationships that humans create with heritage object.

Conventionally, heritage sites are divided into two categories: cultural and natural. This division may be attributed to the philosophical dualism in nature and culture in the Western world (Byrne & Ween, 2015) and the resulting difference in the historical origins of efforts towards protecting nature and protecting antiquity (Lowenthal, 2005). Recently, this binary approach has been criticised for its simplicity, especially for disregarding the relationship between nature and culture (Fredheim & Khalaf, 2016; Harrison, 2015). This historical difference has led to the *status quo* in which the two types of heritages are approached by specialists with different academic backgrounds and training, under separate legislations and government departments/agencies (Phillips & Young, 2017). While recognising the differences in the expertise required to protect natural objects and cultural objects, interdisciplinary approaches have been proposed and advocated as necessary to make heritage conservation more comprehensive (Harmon, 2007; Konsa, 2016; Meffe et al., 2006).

The need to achieve better integration of natural and cultural heritage conservation continues to be discussed, despite more than 30 years of international recognition of its importance. UNESCO spearheaded a system to combine natural and cultural heritage values in 1992, through the introduction of the Cultural Landscapes concept for World Heritage Sites (WHS) (Rössler, 2000). This designation, applied to 126 properties inscribed in the World Heritage List (WHL) today (UNESCO, 2024), acknowledges the value of the interactions between humans and the natural environment in which they live. Despite the establishment of this system, the nature/culture divide in heritage conservation has continued, as exemplified by 42 reports of evictions of residents due to establishment or enforcement of areas protected for natural heritage values (Brockington & Igoe, 2006). Moreover, even in the World Heritage Convention, there is no criterion to

recognise an Outstanding Universal Value for the relationship or interaction between natural and cultural values (UNESCO, 2023a).

1.2 Geoheritage

Geological heritage, or geoheritage, in the simplest terms, refers to “all the significant Earth features and continuing processes that we wish to keep, sustain, conserve, manage and interpret” (Osborne, 2000, p. 149). The importance of these sites varies, from helping us better understand the history of our planet, including the impact of humans on the natural environment, providing us with beautiful scenery, and serving as a foundation for biodiversity (Crofts, 2018; Gray, 2004). As Earth features refer to natural objects (e.g. landforms, rock formations, volcanos, etc.), geoheritage is generally considered a type of natural heritage (Brocx & Semeniuk, 2007).

In the World Heritage Convention, the presence and importance of geoheritage has been recognised from the foundational stage of the programme (UNESCO, 1972). Geoheritage sites are represented by criterion viii, one of the four criteria for assessing the Outstanding Universal Value, a requirement for obtaining a natural World Heritage status. This criterion states that a site can be inscribed as a World Heritage Site for being “outstanding examples representing major stages of earth’s history, including the record of life, significant ongoing geological processes in the development of landforms, or significant geomorphic or physiographic features” (UNESCO, 2023a, p. 29). Today, 96 sites are registered on the WHL under this criterion (UNESCO, 2024).

Beyond the WHL, it is only within the last 30 years that geoheritage sites have started to gain recognition as important sites requiring their own framework for conservation. The most notable advancements have occurred over the last 10 years, including the establishment of global initiatives such as the UNESCO Global Geoparks (UGGp) in 2015 (UNESCO, 2016), and groups such as the International Commission on Geoheritage within International Union of Geological Sciences in 2016 (Pereira & Page, 2017). Moreover, over the last decade, the geographical distribution of these efforts has expanded from Europe and limited parts of East Asia (Reynard & Brilha, 2018) to all continents (except Antarctica), with notable advancements in Southeast Asia and Latin America (Global Geoparks Network International Association, 2024). Nevertheless, it must be noted that the conservation of geoheritage sites remains a low priority in some regions, such as in Africa and the Arab States, where a grant was set up recently by UNESCO to support the creation of Geoparks (UNESCO, 2022b).

The geopark concept, which has helped drive the advancement of geoconservation, takes an interdisciplinary approach at its core (Brilha, 2018a). Rather than focusing solely on protecting geoheritage and the natural environment, it has been developed with an integrated approach, considering cultural assets and sustainable economic development of local communities (UNESCO, 2016). With the success of this approach, the necessity of an interdisciplinary approach in geoheritage conservation has become mainstream in both practice and research (Gordon et al., 2018; Henriques et al., 2011; Reynard & Brilha, 2018).

In thinking about the relationship between culture and geology, Quaternary geoheritage sites are especially relevant. These sites, originating from Earth processes over the last

2.58 million years, have developed and are developing alongside humans (Cayla et al., 2012; Reynard et al., 2009). Some of these sites provide critical materials that can be used to understand past climate change and its effects on the landscape and/or the lives of ancient human populations. The efficacy of using such "geocultural" contexts has started to gain focus in the geoheritage literature as a potential key element to accelerate the conservation of these sites (Kubalíková et al., 2020; Reynard & Giusti, 2018).

Despite these positive developments, geoheritage conservation has often been given a secondary status to biodiversity conservation (Gordon, 2018; Gray, 2008). UNESCO's definition of conservation of natural heritage confirms such a tendency, by defining its scope as "the protection, care, management and maintenance of ecosystems, habitats, wildlife species and populations, within or outside of their natural environments, in order to safeguard the natural conditions for their long-term permanence" (UNESCO Institute for Statistics, 2024). Given this lack of recognition of the need for conservation, most protection efforts toward geological sites remain limited to those with aesthetic appeal (Boylan, 2008; Brilha, 2018a).

1.3 Overview of the thesis

Drawing from approaches used in heritage science, geoheritage studies, and science communication, this thesis investigates the need, potential, and strategies for geoheritage conservation in southeast Arabia. In doing so, the thesis will focus on the integration of natural and cultural heritage values of geoheritage sites, especially those from the Quaternary. The geographical focus of this thesis, southeast Arabia, was chosen based on the fact that geoheritage conservation is still in its infancy in this region and the

need for the protection of sites has been raised by geoscientists (Lokier, 2013; Searle, 2019a). The approaches used in this study, however, are applicable to other regions, especially other arid environments, in the initial stages of implementing geoheritage conservation.

This thesis is structured around four academic articles that have been published or submitted for review in peer-reviewed journals (Sections B–D, Chapters 5–8). These empirical studies are preceded by an introductory section (Section A, Chapters 1–4) which provides a literature review and an outline of the research context and design. These sections are followed by a discussion and conclusions section (Section E) that ties together the findings from the papers. Following the submission guidelines, the four articles are presented in their submitted/published format. Therefore, there are some overlaps in contents between the literature review (Chapters 2–3) and introductory parts of Sections B–D. A statement of author contributions to each paper can be found in Appendix A, confirming that the majority of the work in this thesis has been conducted by myself.

Overall, this thesis includes five sections: 1) Research context, 2) Inventory, 3) Interpretation and promotion, 4) Quantitative Assessment, and 5) Discussion and conclusions (Figure 1.1).

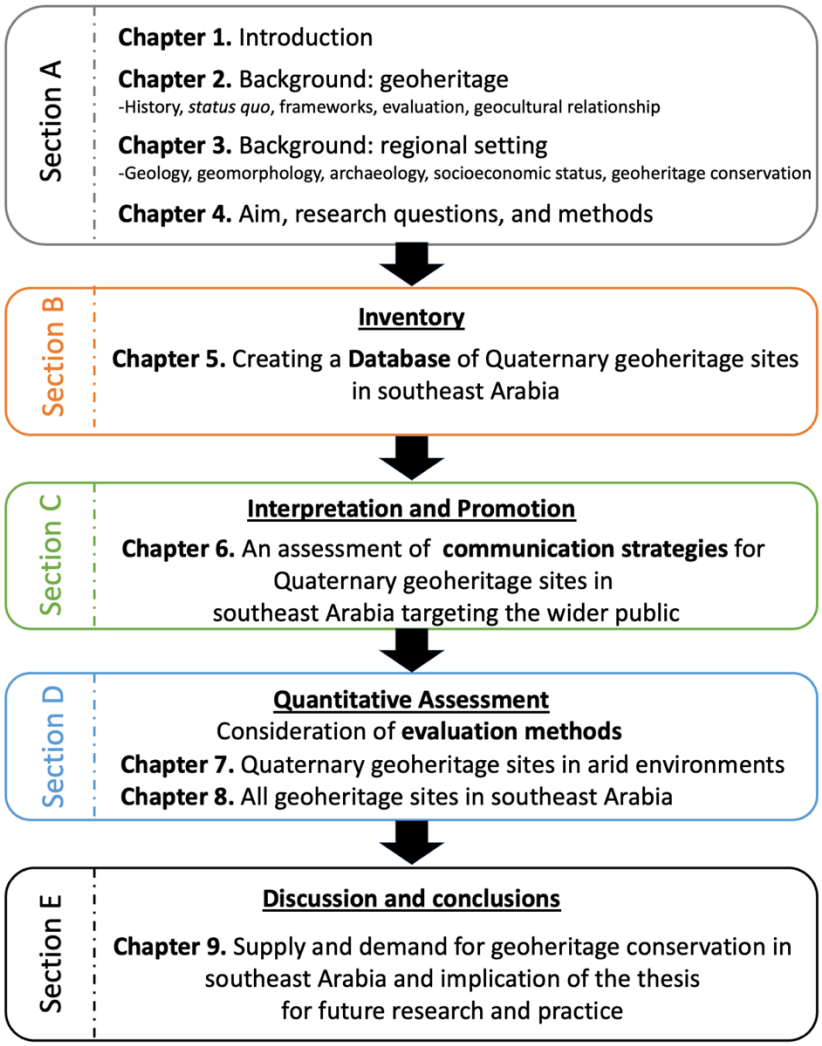


Figure 1.1 Outline of the thesis

Section A sets the scene of the empirical studies through literature review and a summary of the research framework. Chapter 2 presents a review of research in geoheritage conservation and the *status quo* of protection efforts around the world. Chapter 3 provides the regional context by introducing the geology, geomorphology, socioeconomic data, and the current state for geoheritage sites of southeast Arabia. Chapter 4 outlines the aim, research questions, and methods used in the empirical studies.

Section B provides a spatial database of Quaternary palaeoenvironmental sites of southeast Arabia as a contribution towards an inventory for geoheritage sites in this region.

In doing so, the endangerment level of each site is assessed. The results from this section are used in the subsequent sections.

Section C focuses on the communication and awareness-raising of Quaternary geoheritage sites. A science communication study in Chapter 6 analyses the efficacy of using the geocultural context in educational videos towards the wider public in the short- and medium-term. The meaning of the term "public" is contested in social science research and the word must be used with caution (Price, 2008; Warner, 2005). In this thesis, the phrases "general public" and "wider public" are used to refer to all people who do not have specialised knowledge related to geoheritage.

Section D presents evaluation methods for geoheritage sites in two different settings relevant for southeast Arabia. Chapter 7 provides a method to assess the scientific value of Quaternary geoheritage sites in arid environments. Chapter 8 creates a method for geoheritage sites in southeast Arabia with input from local interested parties, using the Emirate of Fujairah, UAE as a case study.

Section E combines the findings from the four empirical papers to consider the potential and ways forward for geoheritage conservation in Southeast Arabia. This uses a supply and demand framework to identify the contributions of this thesis towards advancing geoheritage conservation in southeast Arabia. Also, it will discuss the implication of this thesis towards other regions of the world. Finally, each research question will be addressed to produce an overall set of conclusions.

Chapter 2 Geoheritage conservation in research and practice

2.1 What is geoheritage?

Since the first international symposium on the topic in 1991, geoheritage conservation has become much better studied academically and is increasingly gaining recognition in international heritage conservation frameworks (Brilha, 2018, Henriques et al., 2011). Through the development of the field from both academic and practical perspectives, many terms specific to the discipline have been coined and defined to highlight the details and the nuances required in identifying, protecting, promoting, and utilising geoscientific treasures of the world. However, many of these words lack a standardised definition, with continued discussions on the specificity of each term. Table 2.1 outlines the definition for key terms as used in this thesis. Additional definitions for specialised terms are provided in subsequent chapters when necessary.

The definitions used in this project were selected with the idea of providing a holistic and clear vision of the concept, reducing the number of jargons used, making the terms intuitive for non-specialists, and adhering to standardised definitions by major organisations when available. For example, for geoheritage, the definition by Brocx and Semeniuk (2007) is very descriptive and holistic in its representation of the various dimensions of geoheritage values. Other definitions, although they present their own strengths, were not selected, as they were too vague (e.g. Bradbury, 1993; Gray et al., 2004), too simple (e.g. Osborne, 2000), and/or too limiting (Dixon,1996; Brilha, 2016). In particular, Brilha's definition (2016), although it is well cited and influential, was avoided

as it limits the use of geoheritage to refer to sites with scientific value, which is at odds with the various other ways geoscientific features can be prized, including societal and cultural values (Panizza & Piacente, 2009; UNESCO, 2015).

Table 2.1 Proposed definitions for key terms in the field of geoheritage conservation. The underlined sources indicate the definitions adopted in this DPhil project.

Term	Source	Definition
Geoheritage	Bradbury (1993) [from Brocx and Semeniuk (2007)]	Those aspects of the Earth, which are important to our understanding of Earth history. The nature of geoheritage sites, which are akin to cultural heritage sites or documents, means that they are non-renewable resources.
	Dixon (1996) [from Brocx and Semeniuk (2007)]	Components of natural geodiversity which are of significant value to humans for purposes which do not decrease their intrinsic or ecological values; such purposes may include scientific research, education, aesthetics and inspiration, cultural development and contribution to the sense of place experienced by human communities.
	Osborne (2000)	All the significant Earth features and continuing processes that we wish to keep, sustain, conserve, manage and interpret.
	Gray (2004)	Comprises concrete examples of geodiversity which may be specifically identified as having conservation significance.
	Brocx and Semeniuk (2007)	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.
	The Geological Society of America (2012)	A generic but descriptive term applied to sites or areas of geologic features with significant scientific, educational, cultural, and/or aesthetic value.
	Brilha (2016)	(i) In situ occurrences of geodiversity elements with high scientific value— geosites and (ii) ex situ geodiversity elements that, in spite of being displaced from their natural location of occurrence, maintain a high scientific value (for instance, minerals, fossils, and rocks available for research in museum collections)— geoheritage elements.
Geotourism	Larwood and Prosser (1998)	Travelling in order to experience, learn from and enjoy our Earth heritage.
	Hose (2006)	The provision of interpretative and service facilities to enable tourists to acquire knowledge and understanding of the geology and geomorphology of a site (including its contribution to the development of the Earth sciences) beyond the level of mere aesthetic appreciation.
	Sadry (2009)	[a] Knowledge-based tourism, an interdisciplinary integration of the tourism industry with conservation and interpretation of "abiotic nature" attributes, besides considering related cultural issues, within the geosites for the general public.
	Newsome and Dowling (2010)	A form of natural area tourism that specifically focuses on geology and landscape. It promotes tourism to geosites and the conservation of geodiversity and an understanding of Earth sciences through appreciation and learning. This is achieved through in dependent visits to geological features, use of geotrails and viewpoints, guided tours, geoactivities, and patronage of geosite visitor centres.
	International Congress of Geotourism (2011)	Tourism, which sustains and enhances the identity of a territory, taking into consideration its geology, environment, culture, aesthetics, heritage and the well-being of its residents. Geological tourism is one of the multiple components of geotourism.
Geopark	UNESCO (2016)	[UNESCO Global Geoparks] single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development.
	European Geopark Network (2013)	[European Geopark] a territory, which includes a particular geological heritage and a sustainable territorial development strategy supported by a European programme to promote development.
	African Geoparks Network [from Errami et al. (2015)]	[African Geopark] an area where the geoheritage and all heritage components (archaeological, eco-logical, historical, tangible and intangible cultural elements) should be used as a tool to: (i) improve the infrastructure of rural areas through the development of geotourism by building roads, creating and improving accommodation, supplying remote areas with electricity and drinking water, creating adequate spaces to sell local products, including the development of museums and cultural/information centres; (ii) enhance human development; and (iii) promote sustainable peace in all regions of Africa and the Middle East.
	Brilha (2016)	Well-defined territories with a development plan that aims to integrate the conservation of geological heritage (and other natural assets) with the preservation of the cultural identity of local communities.
Geosite	Wimbledon et al. (1995)	A location, area, or territory in which it is possible to identify a geological or geomorphological interest for conservation.
	Brilha (2016)	In situ occurrences of geodiversity elements with high scientific value.
	Reynard (2013)	Geological or geomorphological objects that have acquired a scientific (e.g. sedimentological stratotype, relict moraine representative of a glacier extension), cultural/historical (e.g. religious or mystical value), aesthetic (e.g. some mountainous or coastal landscapes) and/or social/economic (e.g. aesthetic landscapes as tourist destinations) value due to human perception or exploitation.
Geodiversity	Gray (2004)	The natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landform, processes), and soil features. It includes their assemblages, relationships, properties, interpretations, and systems.
	UNESCO (2022)	the variety of non-living elements of nature, including everything from minerals, rocks, fossils and soils to landforms, rivers, lakes, and wetlands and even the processes that make, modify and destroy these features, such as earthquakes, volcanic eruptions, and floods.
	Ruban (2010)	A broad range of geological phenomena constituting the geological heritage.

2.2 Geoheritage conservation in practice

Currently, two major frameworks— World Heritage and Global Geoparks —exist to protect geoheritage sites of international significance. This chapter provides an overview of the ways in which geoheritage sites are currently protected around the world, including the differences in the scope of the two UNESCO frameworks. It focuses on the geographical distribution of the geoheritage conservation movement, and the types of sites protected under the current frameworks.

2.2.1 Geoheritage in the World Heritage Convention

Currently, 96 sites are inscribed as a WHS under criterion viii, the “geological criterion”, with 23 sites inscribed solely for this criterion (UNESCO, 2024). To be inscribed under criterion viii, a site must “be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features” (UNESCO, 2023, p.30). Geographically, these sites are most concentrated in Europe, followed by Australia and North America. In comparison, Central Asia, South Asia, Middle East, and Northern (Saharan) Africa lack representation, with no sites located in the Arabian Peninsula (Fig 2.1).

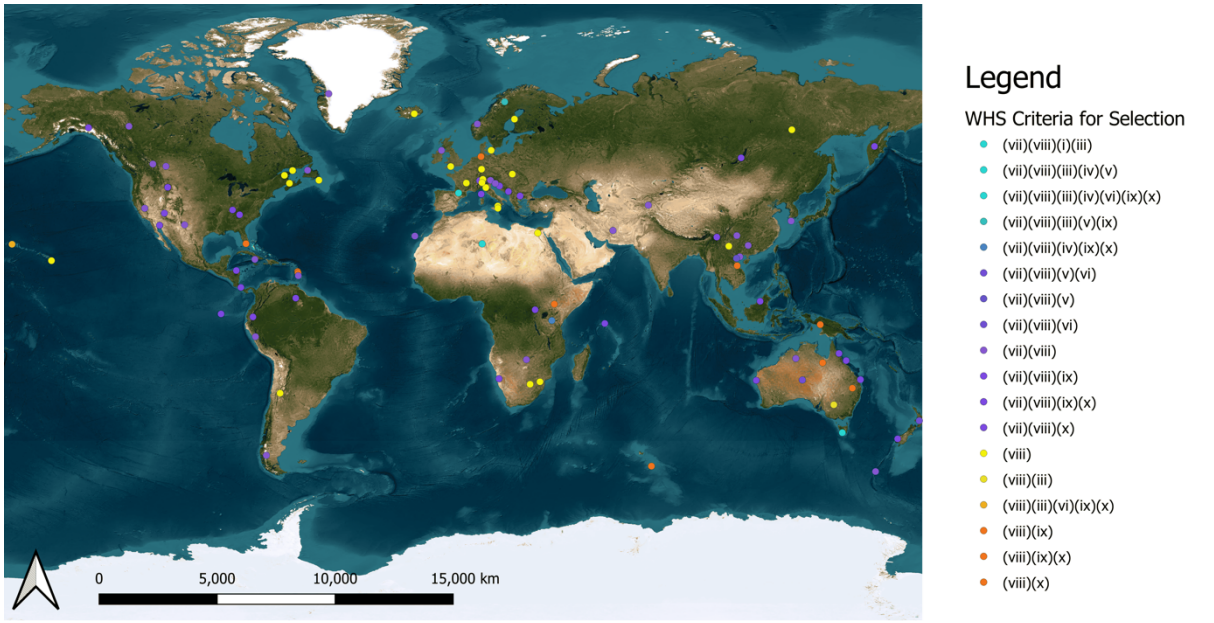


Figure 2.1 Distribution of WHS inscribed under criterion viii coloured based on the overall criteria for selection. Sites in blue-purple scale indicate those selected under both criteria vii and viii and sites in yellow-red scale indicate those selected without criterion vii (data from UNESCO, (2024))

Another potential criterion for which geological sites can be inscribed onto the WHL is criterion vii, which requires a site "to contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance" (UNESCO, 2019a, p.26). Sixty-one sites are inscribed on the WHL with both criterion vii and viii, in addition to the seven sites with geological features enlisted only with criterion vii. This overlap suggests a prioritisation of sites with high aesthetic qualities in protecting geoheritage.

In terms of the type of geology represented, as shown in Figure 2.2, 68% of WHS inscribed under criterion viii include at least one of the four most common types of geological sites— glacial, volcanic, karst, and fossil —as part of their justification for possessing Outstanding Universal Value (OUV). Otherwise, sites that possess superlative and/or unique geological features tend to be featured in these frameworks. Boylan (2008) and Brilha (2018) attribute the popularity of these four types of sites to their appeal with tourists, due to their "dramatic" and "spectacular" aesthetic value.

In Popa et al. (2017), the importance of aesthetics is emphasised to the extent that the authors propose different management models based on the level of aesthetic qualities of the site. In differentiating sites with high or low aesthetic values, the authors suggest a simple method of observing the popularity of the site without any interpretation efforts. According to this logic, if a site is popular without interpretation, it must have some sort of aesthetic appeal. Similarly, in analysing the prioritisation of aesthetic values, Chylińska (2019) argues that the picturesqueness of geoheritage landscapes is the prime factor that draws casual geotourists.

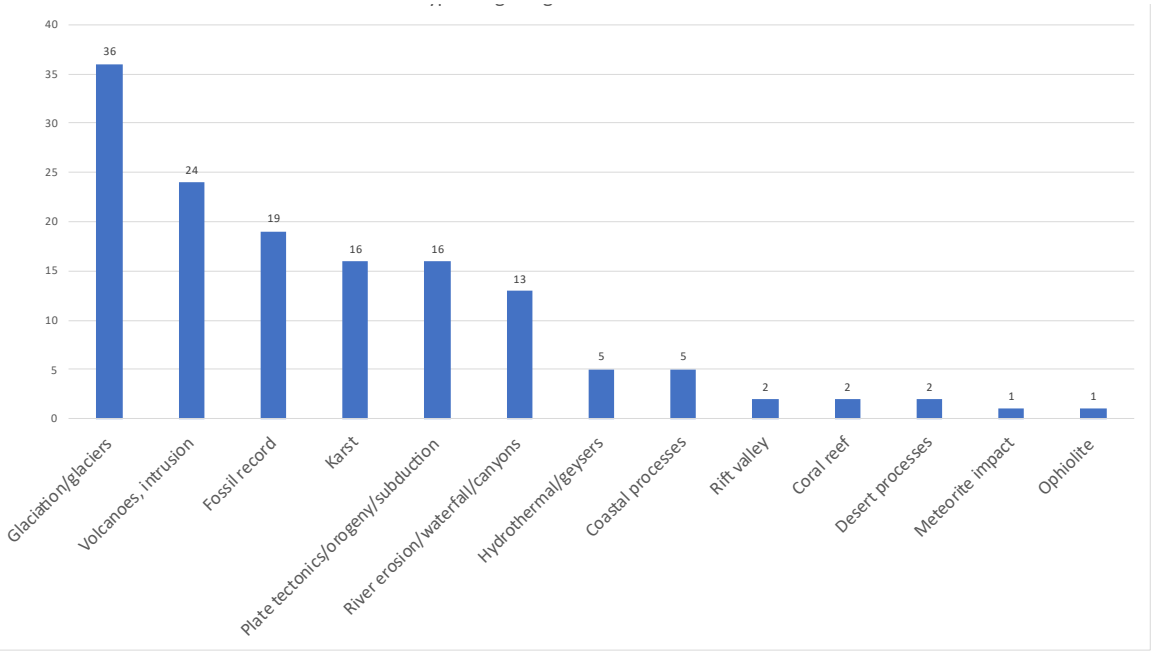


Figure 2.2 Types of geology represented in the WHS list by sites inscribed under criterion viii. A single site may represent multiple types (graph created by author using data from Boylan (2008)).

2.2.1.1 Aesthetics of geoheritage sites on the World Heritage List

To better understand this prioritisation of aesthetic sites, it is necessary to understand why aesthetic values are justified as a cause for heritage conservation. The philosophical field of environmental aesthetics, although no work has specifically targeted geological sites, helps in understanding the role of natural aesthetic values in environmental

conservation. From the perspective of liberal political philosophy, employed in most of the Western world, the priority for political institutions is to provide liberty and fair opportunity, which encourages them to prioritise the protection of basic rights (Welchman, 2020). As aesthetically rewarding experiences are considered among the factors required in human psychology for us to flourish— along with factors such as education, social relationships, or cultural membership —governments are justified in protecting features that provide aesthetic values as a part of protecting basic human rights (Welchman, 2020).

To protect aesthetically pleasing sites, there needs to be an understanding of features in nature that humans recognise as highly aesthetic. The common saying that "beauty lies in the eye of the beholder" implies that aesthetics is merely an expression of personal preference. Nevertheless, many philosophers disagree with this statement, pointing out that debates on the accuracy of aesthetic judgements are commonly considered sensible (Newman et al., 2017). For example, in discussing a waterfall, some people might argue the merit of a particular waterfall for its size and the amount of water, while others could criticise its aesthetic value for the deteriorated water quality and heavily commercialised tourist-trap-like setting. The fact that these arguments seem reasonable implies that we have some shared understanding of what constitutes an aesthetic feature. In fact, studies have identified common denominators in human perception of aesthetics in various contexts (Davies, 2012; Wilson, 1984).

The most relevant findings from this field for the discussion of geoheritage are those on the aesthetics of landscapes, in which five key features have been identified (Churchward et al., 2013; Mitchell, 2013). These features include:

a. **Surface water (lakes, streams, open water wetlands)**: the presence and/or amount of surface water viewed is associated with higher visual quality.

b. **Relief:** greater relief is associated with higher visual quality.

c. **Woodlands:** the presence of trees is associated with spaciousness, as can be represented by area/edge index, proportion of view occupied by woodlands.

d. **Land use:** while 'land use' classification systems vary among studies and among places across time, this concept is associated with visual quality. Landscape preference improves with more natural-looking land use.

e. **Naturalness:** what people consider as natural appear more aesthetically appealing.

When applied to the considerations of geoheritage sites in international conservation frameworks, these characteristics generally serve as accurate guidelines. As demonstrated in Table 2.2, five of the six most common types of internationally represented geoheritage sites epitomise at least one of these preferred characteristics.

Table 2.2 Preferable landscape characteristics, as specified by Churchward et al. (2013) and Mitchell (2013), applicable to highly represented geoheritage sites. Red letters refer to strong display of that characteristic (table compiled by author)

Type of site	Applicable characteristics
Glacial	Surface water, naturalness, relief
Volcanic	Relief, naturalness
Tectonic	Relief, naturalness
Karst/cave	Relief, naturalness
River erosion/waterfall/canyon	Surface water, relief, naturalness
Fossil	naturalness

Glacial, volcanic, karstic, and fluvial sites each incorporate multiple features identified by landscape aesthetic research as appealing to humans across history and cultures (Churchward et al., 2013; Mitchell, 2013). This underscores the significance of aesthetic considerations in the selection of geoheritage sites deemed worthy of protection.

An outlier to this aesthetic-driven trend is the popularity of palaeontological geoheritage sites. Despite representing only 15% of all WHS inscribed under criterion viii, they account for 39% of sites inscribed solely under this criterion. In fact, nine of 15 palaeontological sites in the WHL are inscribed only for their outstanding geological value, while only two of them inscribed together with criterion vii, the aesthetics criterion. Given that 65% of all sites inscribed under criterion viii are also inscribed under criterion vii, fossil sites present themselves as a clear outlier.

The existing literature lacks critical analysis of this situation beyond mentioning the popularity of fossil sites in media and tourism (Migoń, 2018, Stewart and Nield, 2013). However, a potential explanation could be that the popularity of fossils (especially those of dinosaurs) provides people with knowledge that allows them to make cognitive

connections leading to an appreciation of these sites beyond aesthetics. If this is the case, it suggests an opportunity to explore whether other types of geosites with relatively low aesthetic values could enhance their geoheritage recognition by highlighting their connections with fields that are more familiar to the wider public.

2.2.1.2 Geological periods represented in the WHL

As analysed by Boylan (2008), there is a skewed representation of geological periods among sites inscribed on the WHL for geological significance. Specifically, 17% of all WHS inscribed under criterion viii primarily feature landscapes or features formed during the Quaternary, despite this period representing only 0.057% of Earth's history. Conversely, stratigraphical sites are generally underrepresented, with few type locality sites acknowledged in the WHL, despite their importance in understanding transitions between geological periods.

The popularity of the Quaternary sites can partly be attributed to the aesthetic prioritisation in geoheritage conservation. Approximately 80% of Quaternary sites on the WHL include one of the four common types of features— glaciological, volcanological, palaeontological, and/or karstic. This prioritisation, termed the "mask of the picturesque" by Cayla et al. (2012), often occurs at the expense of protecting other sites that possess high scientific value but do not conform to conventional ideas of beautiful landforms. This situation is problematic from scientific and educational perspectives as it narrows the scope of geoheritage conservation and distorts the public perception of important geoheritage sites.

Moreover, even within the category of Quaternary sites, other types such as palaeoenvironmental sites and desert landscapes remain under-protected. This situation

deserves further attention, as these sites are considered high-maintenance due to their exposure of unconsolidated sediments, making them vulnerable to both natural and anthropogenic weathering processes (Goudie & Seely, 2011; Bridgland, 2013).

2.2.2 Geoparks

As discussed briefly in Chapter 1.2, the concept of geoparks has significantly advanced the field of geoheritage conservation over the past three decades. Originating with the establishment of the first geopark in Germany in 1989, the initiative gained international momentum with the formation of the European Geoparks Network (EGN) in 2000 (Zouros, 2004). Despite an initial setback in 2001 when an attempt to establish an international geoparks programme failed due to resistance from UNESCO questioning its necessity (Brilha, 2018a), the EGN collaborated with Chinese geoparks to establish the Global Geoparks Network (GGN) in 2004 (Mc Keever & Zouros, 2005). This led to rapid development in Europe and China, with China alone establishing more than 130 national geoparks by 2011 (Yang et al., 2011). Finally, in 2015, the concept was integrated into the UNESCO framework as the UGGp (UNESCO, 2015).

Currently, the UGGp includes 213 parks from 48 countries (Global Geoparks Network International Association, 2024). A distinctive characteristic of the UGGp is its adoption of a community-led approach, emphasising the conservation and promotion of geological significance while also addressing local economic and social needs (UNESCO, 2015). This approach contrasts with the World Heritage Convention's focus on natural sites of outstanding universal value primarily from scientific, conservation, or natural beauty perspectives (UNESCO, 1972).

The UGGp principles highlight the integration of science, education, culture, and sustainable economic development, particularly through responsible tourism. This differs significantly from the World Heritage Convention's narrower focus on conservation alone. However, this broader consideration also necessitates careful assessment of which sites are suitable for various forms of use, balancing conservation imperatives with socioeconomic benefits (Brilha, 2016).

Geographically, geoparks are most concentrated in Europe and China, reflecting the movement's historical development. Recently, there has been a surge of geoparks in Southeast Asia and South America. On the other hand, there is a notable underrepresentation in regions such as Central Asia, South Asia, Middle East, and Northern Africa, with no Global Geoparks currently in the United States and Australia (Figure 2.3).

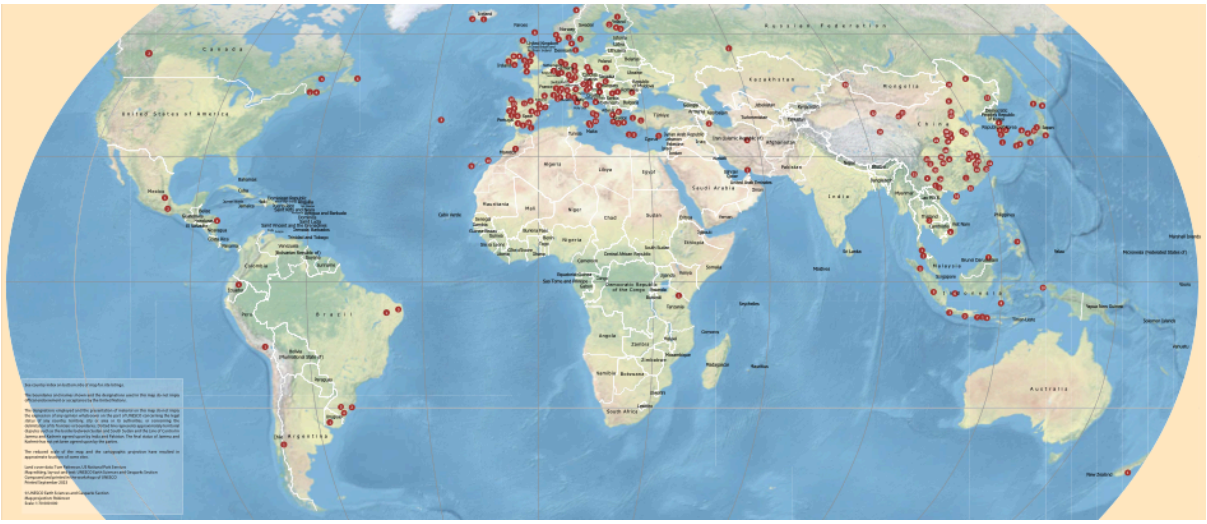


Figure 2.3 Locations of UNESCO Global Geoparks (from UNESCO (2023c))

The development and expansion of national geoparks alongside the UGGp have marked significant progress in geoheritage conservation globally. Several countries, including Australia, Brazil, Iran, Malaysia, Vietnam (Jones, 2008), China (Yang et al., 2011), Japan

(Watanabe, 2011), and Indonesia (Ansori et al., 2022), have established national networks of geoparks, with aspirations for some to achieve “Global” status.

National geoparks offer communities the opportunity to develop geoheritage initiatives, even if the sites do not meet the criteria for “international significance” required to attain the Global Geopark status (Németh et al., 2021). The rapid development of the geoparks programme at both the national and international scales implies the success of the framework, but the extent of its success has not often been reported in the academic literature. The few existing studies report benefits such as local empowerment and increasing visitors from geoparks in Japan, Korea, Vietnam (Lee & Jayakumar, 2021), and Sweden (Shander, 2014).

However, challenges and criticisms also accompany the geoparks initiative. Reports indicate uneven distribution of benefits among communities, particularly in developing countries. Issues such as conflicts over land use and commercial rights, as seen in Indonesia’s Ciletuh UGGp, have underscored the importance of equitable and transparent management and governance frameworks (Ristiawan et al., 2023).

For the continued development of the geoparks programme, there remains a need to improve equitable and transparent management and governance frameworks created with the approval of all relevant communities.

2.3 Geoheritage research

2.3.1 History

The increasing recognition and conservation efforts of geoheritage sites have accompanied a significant growth in academic research on the topic. Since the term

“geoheritage” was first used in an international academic context in 1991 (Brocx & Semeniuk, 2007), there has been substantial growth in scholarly publications. According to Herrera-Franco et al. (2022), this growth began to accelerate around 1994, with a notable exponential increase post-2010. By 2022, there have been approximately 2,565 publications focused on geoheritage.

The establishment of specialised journals such as *Geoheritage* in 2009 has contributed significantly to the field's academic recognition and development. Duarte et al. (2020) has shown how *Geoheritage* accelerated the number of articles, particularly on topics related to geotourism, underscoring its role as a central publication venue for geoheritage research.

Geographically, most publications originate from countries in the global north including Italy, Spain, Portugal. However, significant contributions also come from China and Brazil, highlighting their growing involvement in geoheritage research. Overall, studies have been conducted in nearly 100 countries worldwide, (Herrera-Franco, Carrión-Mero, et al., 2022), reflecting a global interest and effort in understanding, documenting, and conserving geoheritage sites. Table 2.3 provides an overview of the diversity of topics covered in geoheritage research and their geographical distribution.

Table 2.3 Characteristics, focus, target countries, and approaches of geoheritage studies. For studies focused on quantitative assessment, the method used in the study is specified.

Author	Year	Country	Stages considered			Focus; Assessment method used
			Inventory	Assessment	Interpretation promotion	
Trend	1998	UK			X	Knowledge, Questionnaire
Panizza	2001	Italy		X		Quaternary; Original method
Trend	2001	UK			X	Knowledge, Questionnaire
Cronin et al.	2004	Vanuatu			X	Community-based, Quaternary, Hazard management
Pralong	2005	France		X		Geotourism, Quaternary; Original method
Coratza & Giusti	2005	Italy		X		Quaternary, Scientific value; Original method
Zouros	2007	Greece		X		Quaternary; Original method
Reynard et al.	2007	Switzerland		X		Quaternary; Original method
Liverman	2008	Canada			X	Community-based, Creative, Digital tool, Focus group, Pre-post test, Questionnaire
Knapik et al.	2009	Poland		X		Original method
Reynard	2009	Switzerland		X		Quaternary; Reynard et al. (2007)
De Lima et al.	2010	Brazil	X	X		Original method
Ruban	2010	Russia		X		Geodiversity; Original method
Erhartič	2010	Slovenia		X		Quaternary; Original method
Reis	2010	Portugal			X	Questionnaire, Visitor experience
Vujičić et al.	2011	Slovenia		X		Original method
Bruschi et al.	2011	Spain		X		Questionnaire; Original method
Fassoulas et al.	2012	Greece		X		Original method
Siuki & Kowalczyk	2012	Iran		X		Questionnaire; Original method
Moreira	2012	Brazil			X	Interpretive panel, Questionnaire, Visitor experience
Costa-Casais & Alves	2013	Spain	X	X		Quaternary; García-Cortés & Carcavilla (2009)

Kubalíková et al.	2013	Czechia		X		Geotourism; Original method
Ren et al.	2013	China			X	Descriptive
Zgłobicki & Baran-Zgłobicka	2013	Poland			X	Geotourism, Motivation, Questionnaire
Pica et al.	2014	Italy	X	X		Cultural, Geotourism; Original method
Norrish et al.	2014	Australia			X	Community-based, Perception, Interview
Fanwei	2014	China			X	Community-based, Knowledge, Perception, Questionnaire
Hoblea et al.	2014	France			X	Digital tool, Geotourism, Quaternary
Lansigu et al.	2014	France			X	Creative, Descriptive
Reis et al.	2014	Portugal			X	Museum, Review, Visitor experience
Bollati et al.	2015	Italy		X		Ecological value, Quaternary; Original method
Pica et al.	2015	Italy	X	X		Pica et al. (2014)
Moufti et al.	2015	Saudi Arabia	X			Archaeology, Cultural, Geotourism
Brocx & Semeniuk	2015	Australia		X		Qualitative; Original method
Štrba et al.	2015	Slovakia		X		Comparison of assessment methods
Tavares et al.	2015	Angola			X	Community-based, Questionnaire
Allan et al.	2015	Australia			X	Geotourism, Motivation, Quaternary, Questionnaire
Kiernan	2015	Australia			X	Cultural
Avelar et al.	2015	Brazil			X	Community-based, Interview, Knowledge, Perception
Lagally et al.	2015	Germany			X	Descriptive
Lugeri et al.	2015	Italy			X	Creative, Media
Brilha	2016	Portugal	X	X		Review; Original method
Reynard et al.	2016	Switzerland	X	X		Quaternary; Original method
Plyusnina et al.	2016	Egypt	X			Quaternary
Alcalá et al.	2016	Spain		X		Palaeontology; Specialised original method
Koike & Kikuchi	2016	Japan			X	Photography, Preference
Mani et al.	2016	St Vincent & the Grenadines			X	Community-based, Creative, Digital tool, Focus group, Pre-post test, Questionnaire
Ickert & Stewart	2016	Turkey			X	Community-based, Hazard management, Workshop

Štrba et al.	2016	USA			X	Geotourism, Roadside Geoheritage
Shahhoseini et al.	2017	Iran			X	Community, Geotourism, Interview, Questionnaire
Pasquaré Mariotto & Venturini	2017	Italy			X	Interpretive panel, Review
Gravis et al.	2017	New Zealand			X	Archaeology, Cultural, Quaternary, Observational
Migoń & Pijet-Migoń	2017	New Zealand			X	Geotourism, Observational. Quaternary
Kortz et al.	2017	USA			X	Descriptive, Textbook; Review
Sallam et al.	2018	Egypt	X	X		Geotourism; Ruban (2010)
Sallam et al.	2018	Egypt	X	X		Geotourism; Ruban (2010)
Mauerhofer et al.	2018	Ethiopia	X	X		Quaternary; Reynard et al. (2016)
Pourahmad et al.	2018	Iran	X	X		Quaternary, Geotourism; Pralong (2005)
Brilha	2018	Portugal	X	X		Review
Bouzekraoui et al.	2018	Morocco	X			Geotourism
Suzuki & Takagi	2018	Japan		X		Geotourism; Original method
Woo & Kim	2018	South Korea		X		Quaternary; Specialised original method
Różycka & Migoń	2018	Poland		X		Geotourism; Original method
Pica et al.	2018	Italy			X	Digital tool, Geotourism
Gordon	2018	UK			X	Cultural, Geotourism, Descriptive
Dollma	2019	Albania	X	X		Geotourism; Knapik et al. (2009)
Maghsoudi et al.	2019	Iran	X	X		Brilha (2016)
Beraaouz et al.	2019	Morocco	X			Geotourism
Berred et al.	2019	Morocco	X			Geotourism, Quaternary
Mucivuna et al.	2019	Brazil		X		Quaternary; Original method
Finzi et al.	2019	Israel		X		Aesthetics; Specialised original method
Clifford & Semeniuk	2019	Australia			X	Archaeology, Cultural, Quaternary
Farsani et al.	2019	Iran			X	Geotourism, Motivation, Questionnaire, Satisfaction
Pescatore et al.	2019	Italy			X	Cultural, Descriptive, Quaternary
Hellqvist	2019	Sweden			X	Informal education, Sustainability

Tormey	2019	USA			X	Digital tool, Review
Scriven	2019	UK			X	Cultural, Creative
Bruno & Wallace	2019	USA			X	Review
Naimi & Cherif	2020	Algeria	X	X		Knapik et al. (2009)
Santos et al.	2020	Brazil	X	X		Quaternary; Original method
Kharbish et al.	2020	Egypt	X	X		Cultural, Geotourism; Pica et al. (2014)
Sallam et al.	2020	Egypt	X	X		Geotourism; Ruban (2010)
Moradipour et al.	2020	Iran	X	X		Quaternary; Brilha (2016)
Mehdioui et al.	2020	Morocco	X	X		Brilha (2016)
Azil et al.	2020	Algeria	X			Cultural
Elassal	2020	Saudi Arabia	X			Cultural, Geotourism
Kubalíková et al.	2020	Czechia		X		Cultural, Geotourism, Quantitative, Urban; Specialised original method
Sanz et al.	2020	Spain		X		Educational value; Original method
Tibaldi et al.	2020	Italy			X	Digital tool, Quaternary
Chrobak et al.	2020	Italy/Slovakia			X	Geotourism, Knowledge, Motivation, Questionnaire, Visitor experience
Subedi et al.	2020	Nepal			X	Community-based, Focus group, Pre-post test, Questionnaire, Workshop
Gravis et al.	2020	New Zealand			X	Community-based, Cultural, Observational
Matias et al.	2020	Portugal			X	Creative, Questionnaire
Ruban et al.	2021	Egypt	X	X		Geotourism; Original method
Moradi et al.	2021	Iran	X	X		Quaternary; Reynard et al. (2016)
Mehdipour Ghazi et al.	2021	Iran	X			Geotourism
Soltan	2021	Iraq	X			Quaternary
Fepuleai et al	2021	Samoa	X			Community-based
Mikhailenko et al.	2021	Russia		X		Accessibility; Specialised original method
Kubalíková et al.	2021	Czechia			X	Interview, Perception, Preference, Visitor experience
Tomić et al.	2021	Iran			X	Geotourism, Motivation, Quaternary, Questionnaire

Clary	2021	USA			X	Descriptive, Palaeontology
Khalaf	2022	Egypt	X	X		Quaternary; Vujičić et al. (2011)
Hussain	2022	Iraq	X	X		Vujičić et al. (2011)
Abou Arrage & Chamra	2022	Lebanon	X	X		Cultural, Geotourism; Knapik et al. (2009)
AbdelMaksoud et al.	2022	Libya	X	X		Cultural, Geotourism, Quaternary; Reynard et al. (2016)
Mehdioui et al.	2022	Morocco	X	X		Brilha (2016)
Joshi et al.	2022	India	X			Archaeology
Khoshraftar & Farsani	2022	Iran	X			Geotourism
Al Mohaya & Elassal	2022	Saudi Arabia	X			Cultural, Geotourism
Mucivuna et al.	2022	Brazil		X		Scientific value; Comparison of assessment methods
Datta & Sarkar	2022	India		X		Quaternary; Original method
Derafshi & Seyedhamzeh	2022	Iran		X		Comparison of assessment methods
Herrera-Franco et al.	2022	Ecuador			X	Geotourism, Perception, Questionnaire, Visitor experience
Fox et al.	2022	UK			X	Photography, Visitor experience
Jones & Washko	2022	USA			X	Field trip, Review
Zawacki et al.	2022	USA			X	Experiment, Social media
Luan & Wang	2023	China			X	Geotourism, Questionnaire, Visitor experience
Coratza et al.	2023	Italy			X	Community-based, Descriptive, Informal learning
Rodrigues et al.	2023	Portugal			X	Expert-based, Questionnaire
Rodrigues et al.	2023	Portugal			X	Review
Illingworth	2023	UK			X	Creative, Descriptive
Rogers et al.	2024	UK			X	Perception, Questionnaire

In the last 30 years, geoheritage research has evolved significantly, focusing on several key themes and witnessing shifting trends that reflect broader conservation and societal interests. Based on keywords used in publications, Németh et al. (2021) identified seven key topics in geoheritage research as: geoheritage, geotourism, geodiversity, conservation, quantification, and education. The inclusion of geotourism and education as key topics reflects the influence of frameworks like UGGp, which emphasise the integration of tourism, education, and cultural aspects into geoheritage conservation strategies (UNESCO, 2015). This holistic approach not only seeks to protect geological features but also to leverage them for sustainable development and community empowerment. Recent studies (e.g. Herrera-Franco et al., 2022; Németh et al., 2021) highlight an emerging trend towards increased emphasis on cultural connections and community engagement in geoheritage conservation. This trend underscores the importance of interdisciplinary approaches that integrate geosciences with social sciences, anthropology, and cultural studies. Such approaches are essential for ensuring that conservation efforts respect and incorporate local knowledge, values, and traditions associated with geoheritage sites. These trends reflect a growing recognition of the multidimensional values of geoheritage sites and the need for inclusive, community-centred approaches to their conservation and management. However, beyond theoretical considerations, community-based approaches on geoheritage conservation have not yet been well studied (Stoffelen, 2020).

2.3.2 Framework for geoheritage conservation

In geoheritage research, two guidelines have been proposed as frameworks to establish geoheritage conservation in a given area. Brilha (2005) proposes a five-stage process that involves:

1. **Inventory:** Identification and cataloguing of geoheritage sites within a given area.
2. **Quantitative assessment:** evaluation of the scientific, cultural, and aesthetic values of geoheritage sites using quantitative methods.
3. **Conservation:** implementation of specific measures to protect and manage geoheritage sites, often involving legal frameworks and management plans.
4. **Interpretation and promotion:** development of strategies to communicate the significance of geoheritage sites to different audiences, including educational programs and tourism initiatives.
5. **Monitoring:** regular assessment and monitoring of geoheritage sites to track changes and ensure conservation efforts are effective.

In contrast, Reynard and Giusti (2018) advocate a three-step process.

1. **Awareness within the Scientific/Conservation Community**: recognition among experts and stakeholders of the importance of conserving geoheritage sites.

2. **Translation into Specific Conservation Measures:** development and implementation of legal and practical measures to protect and manage geoheritage.

3. **Recognition by Society:** broader societal acknowledgment and appreciation of the value of geoheritage sites, often through education, outreach, and cultural promotion.

Although the wording is quite different, there is a general correspondence between the two frameworks. The first two steps in Brilha (2005) correspond to the first step in Reynard and Giusti (2018), then the third step in the former with the second step in the latter, and finally the fourth step in the former with the third step in the latter. Also, these frameworks share the commonality of viewing geoheritage conservation as a top-down effort, with promotion and awareness-raising towards the wider public considered after the recognition of geoheritage values by the scientific community and the relevant parties who implement the conservation measures. Most geoheritage studies have focused on the first two stages of the process by producing an inventory and a quantitative assessment of specific sites (Table 2.3). In comparison, the academic literature has not addressed conservation, interpretation and promotion, and monitoring as much. In the last decade, however, there have been developments in geoheritage interpretation through public engagement (Gravis et al., 2020, Tavares et al., 2015) and the creation of educational materials (Scriven, 2019).

Beyond the stages of geoheritage conservation, researchers have proposed the utility of considering supply and demand for geoheritage conservation (Hose, 2012; Siuki et al., 2012; Štrba, 2019), following similar analyses conducted towards other types of heritage

sites (e.g. Hutter & Rizzo, 1997). A supply and demand framework can be useful, as it can help identify and balance the level of potential, expectation, and preparedness of a region (and its residents) before advancing heritage conservation efforts (Frey, 1997). For geoheritage conservation, an essential component of supply is the identification of geosites through an inventory (Brilha, 2016), including scientific and contextual information from specialists (Hose, 2012). Furthermore, the supply for geoheritage conservation also entails frameworks and tools, such as assessment methods and interpretation strategies, to support protection and promotion of geosites identified in the inventory (Siuki & Kowalczyk, 2012). On the other hand, the demand for geoheritage conservation requires the identification and consideration of different parties, including researchers (Mucivuna et al., 2022), potential visitors (Sánchez-Martín et al., 2019; Štrba, 2019), and local communities (Popa et al., 2017), who would likely be influenced by conservation efforts.

Discussions on supply and demand towards geoheritage conservation, however, tend to be restricted to certain elements of this framework. For supply, the scope of academic studies is often limited to one or two key stages of geoheritage conservation (see Table 2.3), and in many regions, the availability of supply is often limited to the provision of geosite inventories. For demand, although different parties have been considered in the literature (Bruschi et al., 2011; Różycka & Migoń, 2018; Searle, 2014; Stoffelen, 2020), most studies tend to focus only on one party, and rarely consider the overall demand towards geoheritage conservation. To truly benefit from this framework, a holistic assessment of supply and demand is necessary. Chapter 9 provides such an assessment in southeast Arabia to identify the most appropriate steps for geoheritage conservation in this region.

2.3.3 Inventory

At the national level, many countries, especially in Europe, maintain an inventory of geoheritage sites and promote their conservation (Brilha, 2016). The UK can be considered the global leader (Brocx & Semeniuk, 2007) with conservation efforts that include the statutory protection of Sites of Specific Scientific Interests and local-scale protection of Regionally Important Geological and Geomorphological Sites (Mason and Stanley, 2000). These frameworks have been successful in conserving important geoheritage sites under threat of development (Bridgland, 2013), as well as in facilitating collaborations between researchers and developers to allow geological data collection before the destruction of a site (Burek, 2012). On the other hand, in many developing parts of the world, such an inventory, considered the first stage in geoheritage conservation (Brilha, 2005), does not exist, which helps explain the regional imbalance in both WHS and UGGp (Errami et al., 2015).

2.3.4 Assessment

Various methods have been developed over the past two decades to assess the values and endangerment status of geoheritage sites (e.g. Coratza & Giusti, 2005, Pereira et al., 2007, Ruban, 2010, Bruschi et al., 2011, Brilha, 2016, Reynard et al., 2016). Qualitative methods, such as those of Brocx and Semeniuk (2015b), can be useful for a more nuanced analysis, especially in situations where cultural values of geoheritage sites require consideration. However, due to their crucial weakness of subjectivity, this thesis will mainly discuss quantitative methods (Chapter 7 provides a more detailed discussion on this topic). In early studies (e.g. Coratza & Marchetti, 2002, Carcavilla Urquí, 2007), comprehensive evaluation and ranking of sites by a single researcher or a group of

regional specialists were conducted frequently. Recently, quantitative or semi-quantiative methods have been developed to reduce subjectivity in comparing and prioritising sites for conservation (Brilha, 2016). Popular “schools” of quantitative assessments include the approaches of Reynard et al. (2007), Pereira et al. (2007), and Bruschi et al. (2011) (Siuki & Kowalczyk, 2012). Beyond these three methods, Fassoulas et al.’s method (2012) is noteworthy for its comprehensive consideration of geoheritage values and Brilha’s method (2016), developed through a review of past methods, has gained considerable attention and popularity. Table 2.4 outlines the specifics of some of the commonly used geoheritage evaluation methods.

Table 2.4 Comparison of quantitative assessment methods for geoheritage values

Study	Weighting method	Factors considered in the assessment method							Pros				Cons		
		Aesthetic value	Cultural value	Ecological value	Touristic (economic) value	Educational value	Endangerment	Scientific value	Clear parameters used in assessment	Involvement of regional specialists	Reduced subjectivity	Simplicity	Resource and time intensive	Subjective weighting	Uncritical weighting strategy
Reynard et al. (2007)	Mean of each factor	X	X	X	X	X	X	X				X			X
Pereira et al. (2007)	Determined by researcher's experience	X		X	X		X	X	X			X		X	
Brilha (2016)	Determined by researcher's experience				X	X	X	X	X			X		X	
Bruschi et al. (2011)	Input from 20 regional experts			X	X	X	X	X	X	X	X		X		
Fassoulas et al. (2012)	Determined by researcher's experience	X	X	X	X		X	X				X		X	

These methods consider various factors to quantify different geoheritage values. For instance, factors like scientific value, representativeness, rarity, integrity, extent of scientific knowledge, and geological diversity are common in all five studies mentioned above. Although these methods use similar types of factors, their weighting strategies differ. Of the four methods with considerations of the representation of the relative importance of each factor, Brilha's method (2016) is likely the most commonly applied in geoheritage studies. The popularity of this method could be attributed to its simplicity and clarity in its implementation. It provides clear instructions and evaluation parameters to quickly evaluate sites. Bruschi et al. (2011), however, arguably employ the least subjective method for weighting the relative importance of each factor by incorporating inputs from 20 local experts. In regions with limited relevant expertise, methods like those by Brilha (2016), or Pereira et al. (2007) may be justified, but their reliance on a single researcher's experience introduces inherent subjectivity, which should be minimised in the evaluation process.

It is important to note that all these methodologies have been developed by researchers with experiences primarily in Europe. Assessing heritage values is a social process that requires involvement of local influenced parties (Azzopardi et al., 2023). Environmental and cultural conditions specific to regions must be taken into account when applying these methods elsewhere (Fredheim & Khalaf, 2016; Zorlu & Dede, 2023). This aspect will be discussed further in Chapters 7 and 8.

2.3.4.1 Cultural value of geoheritage

Geoheritage sites are highlighted in the various assessment schemes, not only for their geoscientific significance but also for their cultural values. The relationship between geoheritage and culture is multifaceted and can be categorised into four main aspects.

First, geoheritage sites, as integral parts of landscapes, hold significance in cultural traditions. This connection is evident in religious beliefs, that attribute sacred status to geological features such as rocks (e.g. Uluru, Australia) and caves (e.g. Lourdes, France) (Kiernan, 2015). These features have inspired interpretations and explanations of the natural world within human societies.

Secondly, geological events have been embedded in the collective memories of certain communities. Oral traditions recount geological events, such as volcanic eruptions in Samoa (Fepuleai et al., 2017), earthquakes in Japan and indigenous North America (Ludwin et al., 2007), and historical tsunamis in New Zealand (King & Goff, 2010). These traditions have not only passed on historical accounts but also helped communities prepare for and mitigate natural disasters, sometimes in conjunction with modern scientific data (Cashman & Cronin, 2008). Similarly, place names often reflect geological and geomorphological features (Sousa et al., 2010), serving as reminders of past natural disasters and aiding in local risk awareness (Planas-Batlle et al., 2023). For example, in the Tohoku region of Japan, place names mark areas that have historically been exposed to tsunamis (Fontanella Pisa, 2024). Although place names indicating tsunami-risk can sometimes exaggerate the danger, they play an important role in raising awareness about potential disasters and may have contributed to the local custom of building houses on higher ground (Isoda et al., 2019).

Thirdly, geoheritage sites can provide information to archaeological studies to help understand the landscape and palaeogeographic settings of ancient archaeological sites (Panizza & Piacente, 2009). This contribution is especially important to understand the historical changes in the relationship between human and nature, and to understand the

role of environmental changes in guiding, shaping, and sometimes destroying ancient societies (Melelli et al., 2016). Quaternary geomorphological sites are especially important in this regard, as these sites have been formed and are forming alongside humans. These sites present us with various landforms that provide unique records of the natural changes that have occurred alongside the development of humans (Coratza & Hobléa, 2018). For example, speleothems serve as important, high-precision data source for regional rainfall over time, as their growth relies on having sufficient water supply (Fairchild & McMillan, 2007). This important role of Quaternary geoheritage sites will be discussed in more detail in Chapters 6 and 7.

Finally, geological materials have been used to construct historical and modern human society, including cities, building, farming infrastructure, etc. In ancient times, geological features such as caves (Boukhchim et al., 2018) and sinkholes (Coratza et al., 2016) have been used as shelters, and the availability of natural workable stones have helped many societies built their cities (Reynard & Giusti, 2018). The use of stones and other materials can also be observed in modern cities, which has led to the development of the urban geoheritage concept along with urban geotourism (Kubalíková et al., 2020). Urban geoheritage provides an opportunity to connect the wider public with geosciences by introducing geoscientific features that prove relevant to their day-to-day lives, but are unnoticed by most people (Pica et al., 2018).

Overall, the intricate connections between geoheritage, culture, and cultural heritage underscore the necessity of a holistic approach to geoheritage conservation. These connections demonstrate the multidimensional values of geoheritage sites, where their geoscientific importance often intertwines with broader cultural values. To fully

appreciate, protect, and promote the entirety of geoheritage values, interdisciplinary evaluations incorporating diverse perspectives are essential.

2.3.5 Interpretation and promotion (community engagement)

As emphasised in Chapter 2.3.1, recent studies on geoheritage sites (Avelar et al., 2015; Sagala et al., 2018; Stoffelen, 2020) have pointed out the importance of adopting a bottom-up approach with public engagement. This approach is especially valuable in studies targeting locations where the importance of geoheritage sites is not well recognised.

Formal education in geology has historically received less emphasis compared to other science subjects like biology, chemistry, and physics on a global scale. For instance, in many African countries, earth science education is introduced only at the end of secondary education or in universities, although other science disciplines are taught earlier (Gaines et al., 2012). A weaker focus on geology education exists in many other countries including the US (Lewis, 2008), Spain, Greece (Melendez et al., 2007), and the Netherlands (Van Loon, 2008). Although geography education can supplement knowledge in earth sciences, this global trend might serve as an explanation for the secondary status of geoheritage conservation to biological conservation.

In informal settings, most types of geoscientific topics in the media correspond very well with the types of features available at well-represented types of geoheritage sites, as identified in Table 2.2. In analysing the number of viewers of nature documentary programmes in the UK, Stewart and Nield (2013) found that out of the top 10 films related to geosciences, four were on dinosaurs, three were on earthquakes, and the rest were on volcanoes, caves, and a lake (with toxic water due to a volcanic eruption). Other than the

one film on the lake, all films were related to well-represented types of geosites. As relevant knowledge enhances the appreciation of these sites, the media exposure seems to be creating positive feedback for the promotion and conservation of already protected sites. This could be seen as bad news for other sites as they remain insufficiently understood and therefore underappreciated by the public, while the limited budget for geoheritage conservation keeps on being spent on already popular types of sites.

Despite the skewed representation in media, most geoscientists do seem to believe that their research is interesting and understandable by the wider public. In their survey of 171 geoscientists from 48 countries, Liverman and Jaramillo (2011) found that 79% think that their research is interesting to the non-specialist public and 83% believe that their research would make sense for the non-specialist public. Despite these high numbers, popular geoscientific media coverage remains limited to a small fraction of geosites.

Given their lack of the preferred aesthetic characteristics, the communication of interesting contexts has been identified as a viable strategy to promote under-represented geosites to the non-specialist public. In order to achieve such effective science communication, as Stewart and Nield (2013) argue, rather than aiming to be purely educational, a narrative must be established to communicate the importance of these sites. A deeper discussion on the requirements of a successful geoscientific communication will be provided in Chapter 6.

Despite advancements in related studies and the establishment of specialised journals like *Geosciences Communication* in 2018 (Illingworth et al., 2018), there remains a lack of robust quantitative evidence and long-term impact assessment in this field (Rodrigues, Costa e Silva, et al., 2023). With the lack of evidence, many geoscientists rely on

anecdotal evidence for public engagement efforts, highlighting the need for more empirical research to guide effective strategies that enhance public recognition of geosciences and geoheritage.

2.3.6 Visitors to geoheritage sites

With improved protection and promotion through opportunities like the UNESCO Global Geoparks Programme, the number of visitors to geoheritage sites has been increasing around the world (Lee & Jayakumar, 2021; Ólafsdóttir & Tverijonaite, 2018). To capitalise on this growth, studies on geotourism have analysed the profile of visitors to geoheritage sites and the motives behind their visit. Theoretically, these visitors, or geotourists, can be divided into dedicated visitors and casual visitors (Božić & Tomić, 2015; Hose, 2016; Moufti et al., 2013) The former group refers to visitors who are primarily interested in visiting the site for its geology, with the intent to fulfil intellectual curiosity and achieve educational enjoyment. They generally have an academic background in geology and can gain pleasure from geological features with little interpretation (Chylińska, 2019). On the other hand, the latter group includes tourists who visit geoheritage sites for a fun recreational experience, without an expectation for a learning experience (Hose, 2016). In many cases, casual geotourists end up at geoheritage sites serendipitously or accidentally, without a clear intent or recognition of visiting a geological site (Dowling, 2013; Hurtado et al., 2014). Interpretation plays a key role for this group, as they generally lack a background in geology and have limited capacity to understand a geological landscape. Balancing the demands of these two types of visitors is an important and difficult task for geoheritage managers.

Empirically, studies over the last 20 years have identified some common themes in the demographics and motives of geotourists. In terms of demographics, more than 60% of geotourists are adults under 40 years (Dowling & Allan, 2018; Grobbelaar et al., 2019; Jaafar et al., 2014; Kim et al., 2008; Štrba, 2019) with undergraduate level education or above (Dowling & Allan, 2018; Jaafar et al., 2014; Kim et al., 2008; Štrba, 2019). A rare exception to this trend was a study focused on identifying dedicated geotourists, which found the main age group to be above 45 (Robinson, 2008). In terms of motivation for visits, the commonly identified reasons include escape from day-to-day life (e.g. Dowling & Allan, 2018; Fung & Jim, 2015; Kim et al., 2008), seeking novelty (e.g. Allan & Shavanddasht, 2019; Aquino et al., 2018; Štrba et al., 2018), socialisation (e.g. Cheung et al., 2014; Dowling & Allan, 2018; Fung & Jim, 2015), exposure to nature (e.g. Amaro et al., 2023; Aquino et al., 2018; Tessema et al., 2022) and knowledge gain (e.g. Božić & Tomić, 2015; Robinson, 2008; Štrba, 2019). The motive of visitors has been identified as a major indicator of their willingness to pay for guide services (Cheung, 2016; Cheung et al., 2014) or learn about the landscape (Fung & Jim, 2015). Visitors who go to geoheritage sites for exposure to nature and novelty seem to demonstrate the least willingness to learn or to pay for services compared to other groups. These findings highlight the importance of targeted strategies in developing geoheritage sites.

To respond to geotourists' needs, some specialised methods for geoheritage evaluation (e.g. Kubalíková, 2013; Suzuki & Takagi, 2018; Vujičić et al., 2011) have been created. A notable example of such an evaluation method is the M-GAM evaluation framework developed by Tomić and Božić (2014). This method combines input from experts and visitors in calculating the geotouristic value of each site. Input from tourists is collected via a survey conducted at geosites and its outcomes are incorporated in the process of

determining the relative importance of relevant factors. This method has been used in countries such as Serbia (Božić & Tomić, 2015; Bratić et al., 2020), Indonesia (Reinhart et al., 2023) and Iran (Derafshi & Seyedhamzeh, 2022) to help prioritise the development of geoheritage sites based on tourist demands.

The visitor perspective is very important for the success and impact of geoheritage conservation. This thesis has used input from nature tourism professionals in Chapter 8 as a proxy to understand the priorities and preferences of the visitors. However, due to time and resource constraints, it did not consider direct input from visitors to geoheritage sites.

2.3.7 Critical perspectives towards geoheritage conservation

The increased risk towards potential heritage sites has been demonstrated in studies from many fields. For archaeological sites, the Endangered Archaeology in the Middle East and North Africa (EAMENA), a project focused on monitoring the conditions of archaeological sites in the Middle East and North Africa (MENA) region through a remote quick survey methodology, which involves a visual analysis of satellite imagery (Bewley et al., 2016). This project has identified at least 12,500 out of the 216,000 registered sites[1] as either destroyed or in very bad condition (EAMENA Project Team, 2024). For natural sites, deforestation and biodiversity loss is occurring rapidly, with more than 3.7 million hectares of forest lost in 2023 (Global Forest Review, 2024). With the accelerated rate of

[1] The number of destroyed sites in the EAMENA database is an underestimate as more than 122,000 sites lack input in the endangerment field.

destruction in both cultural and natural heritage sites, the extent of protected areas is expanding rapidly worldwide (Brockington et al., 2006).

As discussed in Chapter 2.2, an accelerating trend of conservation is evident for geoheritage sites as well. From the perspective of protecting valuable geological features, this is indeed a positive development. Nonetheless, as indicated by the development of critical heritage studies over the last decade (ACHS, 2012), a deeper engagement with the sociocultural impact of heritage conservation has been challenging the ways in which sites or landscapes are transformed into heritage sites that are protected and managed.

As Vaccaro and Beltran (2010) summarise, the protection of natural sites as heritage sites brings forth cultural, economic, and political alterations. These transformations, even when implemented with good intentions, can result in potentially detrimental outcomes for local residents. By territorialising, or demarcating, a site as protected land, governments can impose regulations onto these areas with legitimacy provided through scientific evidence. In doing so, land management becomes dominated by elite researchers and administrators with expert knowledge, taking away the power and sense of agency from local populations who have served as the custodians for centuries. As sites become recognised as rare and unique representations of nature, they become appreciated as a commodity, consumed by visitors and tourists. To protect the economic interest identified in the commodification process, governments can impose further legislations to limit the rights of the original residents.

In the worst-case scenario, the restrictions due to the making of a natural heritage site can lead to the eviction of local communities. In analysing reports from 1980 to 2005, Brockington and Igoe (2006) have identified more than 250 cases of such evictions of

local residents for the sake of natural conservation. This has been a large issue especially in developing countries, such as Tanzania (Sirima and Backman, 2013) and Mongolia (Gauthier and Pravettoni, 2016). Eviction causes fundamental changes in the lives of residents, forcing them to forego their traditional livelihood and often leaves them no choice but to engage in the tourism industry. This change may benefit evicted communities in the short term, but there have been many cases in which the perceived effect has been negative, as can be seen from the lack of perceived benefits indicated by communities living in or around protected areas in Tanzania (Newmark et al., 1993) and Colombia (De Pourcq et al., 2017).

The academic geoheritage conservation literature has seldom considered these critical perspectives. From peer-reviewed articles, Pediaditi and Moquay (2022) provide one of the very few studies which demonstrates a perceived sense of landscape injustice by local communities at Sitia UGGp, Greece. Through semi-structured interviews with 45 workers in regional/local authorities and workshops attended by 150 local residents, this study identified the overwhelming dissatisfaction of the local community towards the geopark management. The analysis revealed very limited evidence of either collaborative processes involving rights and/or knowledge holders or community initiatives including engagement, empowerment, and/or capacity building. With a sense of overall satisfaction demonstrated only by the mayor of the municipality, who is in charge of the management of the geopark, this study revealed the top-down reality of this geoheritage initiative. Consequentially, the study concludes that the developments in this region ultimately led local people to feel marginalised in the decision-making process, with a reduced sense of land ownership.

Beyond peer-reviewed journals, Girault's edited book (2020) provides a critical overview of the s*tatus quo* of geoparks programme and suggests good practices for its success. In this book, Babou (2020) presents the case study of the top-down establishment and management at Lanzarote UGGp, Spain, similar to the situation in Greece, in which the local residents were not aware of the project until it was established. As found in many heritage projects around the world, local people started off with excitement and high expectations towards the new opportunity, experienced disenchantment due to poor communication and/or engagement with the managing authority, and ultimately disengaged, feeling powerless and marginalised in decision-making processes. The need for meaningful engagement with the local community is further emphasised by Tebaa and Boujrouf (2020), through a case study in Morocco. This case study is unique in that it focuses on a country where geoheritage conservation remains a new concept that is poorly understood by the non-specialist public. Reflecting the voices of local residents living in the study area, the authors emphasise the need to encompass the local demand and perception of meaningful regional development, rather than imposing an institutionalised model without informed consent. The study highlights the key point, that in many cases and especially in the case of geoheritage, the local people may not be aware of the value of key sites as places worthy of protection. Therefore, the study suggests the need for dialogue to identify the common ground and knowledge gaps between geoheritage and the local perception of heritage, to bridge the conceptual gaps.

These studies, although few in number, have elucidated the reality of geoheritage conservation today, which is at odds with the "bottom-up", "community led" ideology of the UGGp programme. On the other hand, no clear guideline is available to achieve successful grassroots development of geoparks. As observed in Chapter 2.3.5, it is also

true that there are very few examples in which data have been collected from community members to support these ideological principles. In advancing geoheritage conservation, especially in disseminating the concept and its potential benefits in new regions, more evidence is required to establish good practices for meaningful involvement of and communication with different knowledge holders and influenced parties.

Chapter 3 Regional setting: Southeast Arabia

This chapter introduces the environmental, archaeological, and socioeconomic background of southeast Arabia, the regional focus of this thesis. In this thesis, southeast Arabia refers to the two countries in the Southeast of the Arabian Peninsula, UAE and Oman (Figure 3.1), following the definition used by many researchers (Atkinson et al., 2013; Glennie, 1998; Parton, Farrant, et al., 2015b; Tikriti, 2002). The chapter also provides a focused description of the Emirate of Fujairah, the case study region of Chapter 6, and explain the process behind this selection.

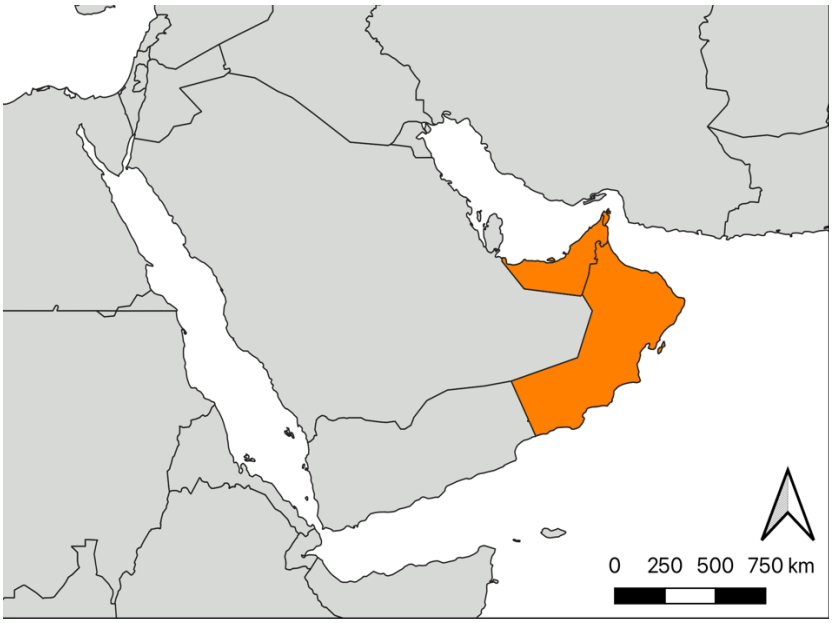


Figure 3.1 Location of southeast Arabia (i.e. Oman and the UAE) within the Arabian Peninsula

3.1 Geology

The geology that can be observed in southeast Arabia spans over 830 million years from the Late Proterozoic (Gass et al., 1990) to the Quaternary. The geological map of the region is presented in Figure 3.2. The oldest geological formation is the crystalline basement, created in the process of continental growth during the Late Proterozoic. This same

material can be found in the Arabian Shield, a formation with a mixture of igneous and metamorphic rocks that dominates most of the geology of the Arabian Peninsula (Powers et al., 1966).

One of the most characteristic geological features of the region is the Semail ophiolite. The formation stands as the largest and best exposed section of oceanic crust thrust onto land in the world, spanning over 10,000 km^2, with dimensions of approximately 550 km in length and 150 km in width (Searle & Cox, 1999). The formation of ophiolites is rare; typically, oceanic crust subducts and is recycled into the mantle when colliding with the continental crust due to its higher density (Hoffmann et al., 2016). However, in rare cases, such as when the oceanic crust is relatively young, hot, and therefore less dense, the reverse process of obduction occurs, resulting in ophiolite formations like the Semail Ophiolite (Searle & Cox, 1999).

The Semail Ophiolite was formed initially as a large nappe by the collision between the African Plate (continental crust, the part which later becomes the Arabian plate) and the relatively young Tethyan Oceanic crust around 108 Ma in a location that was a several kilometres away from the continent. Over the next 20 million years or so, this oceanic crust migrated and was completely obducted onto northeastern Arabia by around 80 Ma, in the mid-Cretaceous period (Hoffmann et al., 2016). This ophiolite provides a comprehensive record of the oceanic crust's various layers, including pillow basalts, dolerites (sheeted dikes), massive gabbros, mafic cumulates, ultramafic cumulates, and ultramafic tectonites, in order from top to bottom (Searle, 2019b). The Semail ophiolite exposure in the Hajar Mountain range along the eastern side of southeast Arabia makes it

an important locale for geoscientists seeking to understand the characteristics and processes of oceanic crust formation (Glennie, 1974; Searle & Cox, 1999).

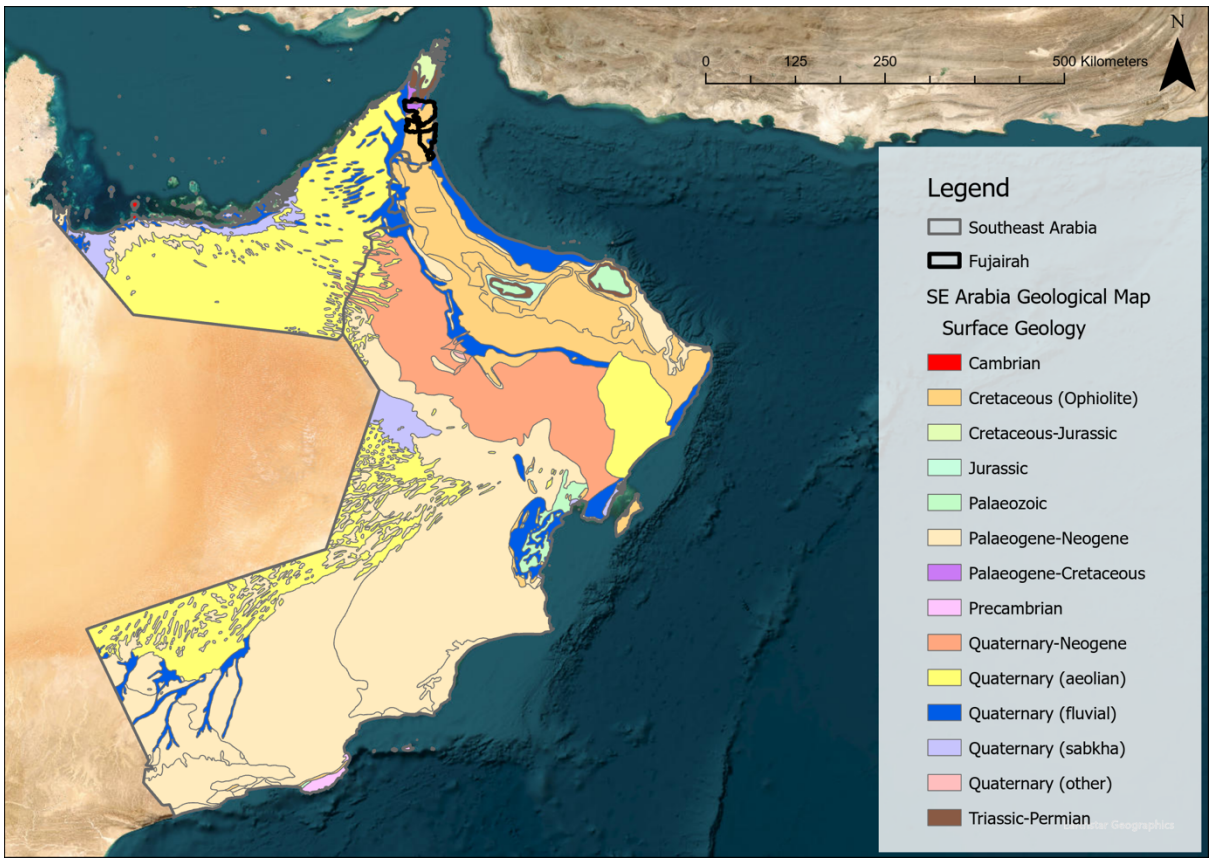


Figure 3.2 Geological map of southeast Arabia (geological data from Pollastro et al. (1999))

From an economic geology perspective, the presence of hydrocarbons, essential for oil and gas production, has been a key driving factor in the economic development of southeast Arabia. In Oman, hydrocarbons are primarily extracted from Mesozoic carbonate reservoirs located in the north of the country, as well as from Palaeozoic sandstone reservoirs in the southern region (Clarke, 1988). These reservoirs have proven to be substantial sources of oil and gas, contributing significantly to Oman's economy.

Similarly, in the UAE, oil and gas reserves can be found in Permian, Jurassic, Cretaceous, and Oligocene-Miocene layers (Alsharhan, 1989). The UAE ranks prominently in the global

oil industry, particularly with substantial reserves in Abu Dhabi. Both Oman and the UAE are significant players in the global oil market, with Oman ranked 25th and the UAE 7th of proven reserves (U.S. Energy Information Administration, 2022).

Hydrocarbon extraction in southeast Arabia occurs across both onshore fields (in Oman and the UAE) and offshore fields (primarily in the UAE). These operations generate substantial revenue for the respective countries, supporting various sectors of their economies (Morad et al., 2012; Rollinson et al., 2014). Despite the economic benefits derived from hydrocarbons, there is a notable imbalance in investment in human capital, largely skewed towards fields related to oil and gas industries (Ewers, 2016). This has resulted in a predominant focus on petroleum-related education and training within the region, often at the expense of broader geological studies.

3.2 Quaternary geology and palaeoenvironment

3.2.1 The climate today

The present climate of southeast Arabia is generally considered hyper-arid with a mean annual rainfall of around 120 mm per year, although the precipitation tends to be higher towards the north-eastern part in the UAE (Böer, 1997), and on the Hajar Mountains (250–400 mm) and the southern Dhofar region (100–400 mm) in Oman (Kwarteng et al., 2009). The rainfall occurs in the form of short and strong rainstorms, which lead to flash floods, especially in the eastern parts of the region (Rizk & Alsharhan, 2003). Recent intensification of rainfall patterns has been observed at varying degrees in both the UAE (Yilmaz et al., 2020) and Oman (Gunawardhana & Al-Rawas, 2016), and this trend is predicted to continue with climate change in the future (Gunawardhana et al., 2018).

In this region, four main mechanisms for rainfall exist (Kwarteng et al., 2009):

1) Localised convective rainstorms that occur spontaneously, mostly during the summer
2) The *seif* (winter) rain that serves as the most constant source of rainfall from November to April due to cold front troughs coming from the North Atlantic or the Mediterranean Sea
3) Tropical cyclones in two seasons: May–June and October–November. This mechanism, although not so frequent (occurring once every three to five years), bring intense rain to the region
4) Indian Ocean Summer Monsoon from the southwest providing rainfall between June and September. This summer monsoon, called the *khareef* (autumn) rain, is especially influential in the Dhofar region, turning the region into a lush green landscape during this season

These mechanisms are prominent at various levels in different parts of the region and contribute to the diversity of landscapes, as well as biological endemism in southeast Arabia (Feulner, 2014; Meister et al., 2006; Patzelt, 2015). Furthermore, due to its location at the interface of Mid-Latitude Westerly and Monsoonal climatic systems, the climate of southeast Arabia has been susceptible to large swings of wetter and drier conditions over the Quaternary (Jennings et al., 2015).

3.2.2 Palaeoenvironment and Quaternary geoheritage

Many Quaternary landforms can be used as palaeoenvironmental archives to understand the environmental conditions of this region over the last 2.58 million years of the Earth's history. Quaternary palaeoenvironmental archives in southeast Arabia are found in

landforms such as alluvial fans (e.g. Blechschmidt et al., 2009; Parton & White et al., 2015), caves (e.g. Fleitmann, 2003; Immenhauser et al., 2007), palaeolakes (e.g. Rosenberg et al., 2012), sabkha (e.g. Heathcote and King, 1998; Matter et al., 2015), and sand dunes (e.g. Atkinson et al., 2013; Goudie et al., 2000; Radies et al., 2005). The landscape of southeast Arabia has been periodically alternated between wetter and drier conditions throughout the Quaternary period. In warmer and wetter conditions, rivers, lakes and grasslands developed (Jennings et al., 2015). On the other hand, drier conditions transformed fluvial and pluvial landscapes over time and led to the development of arid landforms such as sand dunes. Palaeoenvironmental studies are continuing to provide a clearer picture of the timing, frequency, and amplitude of climate fluctuations of this region (Parton, White, et al., 2015). Moreover, recent studies (Groucutt et al., 2018; Parton, White, et al., 2015; Petraglia et al., 2020) have shown that in this region, the timing of the early settlement of anatomically modern humans (AMH) corresponds well with the pluvial climatic periods, making Quaternary geoheritage sites not only important as palaeoenvironmental archives, but also as “geocultural” sites that provide important lines of evidence for archaeological research. A more detailed discussion on this topic is provided in Chapters 5 and 6.

3.3 Archaeology

Archaeologically, southeast Arabia is a region of global interest for the study of the early development of modern human populations. The earliest human fossil evidence of anatomically modern humans (AMH) dispersal out of Africa is recorded in Israel at around 194-177 ka (Hershkovitz et al., 2018). Beyond the Levant, AMH fossils dated to 70-46 ka

have been found in Southeast Asia (Demeter et al., 2017) and human presence has been documented in Australia ~65 ka (Clarkson et al., 2017). However, the route that our ancestors took beyond the Levant is still contested due to the paucity of fossil evidence in Arabia (Groucutt et al., 2018).

In the past two decades, the debate surrounding the migration routes of AMH out of Africa has primarily focused on two main hypotheses: northern routes and southern routes through Arabia (Petraglia et al., 2010; Rosenberg et al., 2011). These hypotheses suggest that favourable environmental conditions would have been crucial for ancient populations to successfully migrate and expand into and through Arabia, especially considering the hyper-arid conditions prevalent in many areas today. However, recent research has begun to challenge this simplistic view (Nicholson et al., 2021).

Understanding the role of the environment as a significant factor influencing human settlement and migration requires delving into Quaternary palaeoenvironmental studies (e.g. Lézine et al., 2010; Parker, 2009; Parton et al., 2013). Compared to more modern populations, prehistoric humans were more directly affected by harsh environmental conditions (Petraglia et al., 2020). However, recent studies have also demonstrated evidence of the adaptive capability of ancient humans to withstand arid conditions (Bretzke & Herkert, 2023; Clarke et al., 2016; Welsby, 2021). Southeast Arabia holds particular significance in this context, as it preserves some of the earliest evidence of AMH occupation outside of Africa, dating back approximately 210,000 years at Jebel Faya, UAE (Bretzke et al., 2022). Chapter 5 of the thesis will explore the Palaeolithic findings from this region in depth, focusing on Jebel Faya and discussing the role of Quaternary geoheritage sites in contextualising the environmental settings of early human habitation.

After the Palaeolithic, the first evidence of the Neolithic period in southeast Arabia is found from around 10,000 BP (Uerpmann et al., 2013) and the transition to the Bronze Age, characterised by sedentary agricultural settlements, occurred at around 5,000 BP (Magee, 2014). Notably, southeast Arabia boasts two prehistoric WHS: the Cultural Sites of Al Ain (UAE) (el-Masri et al., 2010) and the Archaeological Sites of Bat, Al-Khutm, and Al-Ayn (Oman) (Cotto et al., 2000). These sites primarily feature Bronze Age artifacts and structures, providing insights into human occupation in the region. The site in the UAE showcases funerary traditions with over 120 tombs, establishing it as the type-site for the Hafit period (5,200–4,700 BP). Conversely, the Omani site offers a comprehensive and well-preserved assemblage of settlements from the same era, with cuneiform texts detailing southeast Arabia (Magan) as a significant hub for copper production with an export network across Mesopotamia to the Indus Valley (Potts, 2000).

After the Bronze Age, advancements in water management technologies, notably the falaj system introduced around 3,000 BP (Tikriti, 2002), revolutionised agricultural productivity in the region. The falaj system, still in use today, facilitates the transport of water and supports approximately 30–50% of Oman's total water usage (Al-Suleimani, 2006). This system underscores the intricate connection between archaeological sites and their natural environment, highlighting southeast Arabia's rich geoheritage resources.

3.4 Social and cultural context

The UAE and Oman are both absolute monarchies that achieved major economic development with the oil and gas industry at its centre. The UAE is a federation of seven emirates with a degree of autonomy and judicial power with a population of about 10

million, consisting of 12% Emiratis and 88% immigrants from South Asia, Egypt, the Philippines, etc. (CIA, 2024b). The dominant religion is Islam, making up about 75% of the population. The country's GDP has increased by over 800% in the last 30 years, boosted by the growth of its oil industry (World Bank, 2022b). Today, the oil industry consists of 26% of the country's GDP (Federal Competitiveness and Statistics Centre, 2023).

Oman is an absolute monarchy ruled by the Sultan with a population of about 3.8 million, consisting of 54% Omanis and 46% immigrants mostly from South Asia (CIA, 2024a). The dominant religion is also Islam, at about 86% of the population. At USD 88 billion, Oman's GDP has multiplied by eight times as well in the last 30 years (World Bank, 2022a). The ratio of the oil revenue accounts for about 30% of the country's GDP today (International Trade Administration, 2024).

Both countries boast a rather well-educated population, with a secondary school enrolment rate higher than 90% since 2010 (World Bank, 2022a, 2022b). For higher education, however, the UAE fares better with 47% of the population over 25 attaining a Bachelor's degree, compared to Oman's rate of 19% (World Bank, 2023).

In discussing heritage in southeast Arabia, the high ratio of foreign population poses an interesting question on defining local heritage. Many residents, especially in the UAE, may not associate themselves as part of the local culture and/or traditions, due to their lack of long-term connections with the region. On the other hand, countries in this region have increasingly been using heritage sites as places where citizens can foster their sense of national and patriotic pride (Freer & Kherfi, 2020). In this regard, heritage sites have been selected and presented to promote a distinct "national" identity, which in many cases ignores the expatriates who may be local to the area, in terms of the geographical location

of residence (Picton, 2010). Therefore, it must be noted that heritage sites in this region may not always be representative of what all residents consider as sites with values beyond its mere utility.

3.5 Natural heritage conservation

In southeast Arabia, the designation of natural areas as protected lands has seen significant progress along with some challenges over the years. (Figure 3.3). In the UAE, protected areas include 19% of its total land area as well as 11% of marine and coastal areas. Although there are no World Natural Heritage Sites in the country, several sites have gained international recognition. Presently, the UAE boasts 10 Ramsar sites dedicated to wetland conservation and two UNESCO-MAB Biosphere Reserves. These recent developments are noteworthy, considering that the number of protected areas has nearly doubled since 2011 (UNEP-WCMC & IUCN, 2024). Beyond the number of protected sites, the high quality of the conservation management in the UAE has started to gain international recognition with Al-Wathba Wetland Reserve listed in the IUCN Green List of Protected and Conserved Areas. This list recognises sustainable practices in nature conservation, and three other sites in the country are currently candidates for future inscription as well (IUCN, 2024).

In Oman, around 22% of the terrestrial land and 17% of coastal and marine areas are under protection. In terms of sites with international recognition, three sites are registered as Ramsar sites, but the country has an uncomfortable past in terms of World Natural Heritage Sites. The Arabian Oryx sanctuary in Oman, was inscribed as a World Heritage Site in 1994 for its importance in protecting and rewilding of the Arabian Oryx, as

well as other rare animal species (UNESCO, 1994). However, in 2007, this site became the first and only natural WHS to be revoked of its World Heritage Status, due to its mismanagement related to the construction of a pipeline, including the reduction of the size of the protected area by around 90%, within the designated area (UNESCO, 2007). This oversight may indicate the secondary status of nature conservation to economic development in Oman, but conservation efforts have been steadily growing in the country, with the number of protected areas doubling in the last five years (UNEP-WCMC & IUCN, 2024).

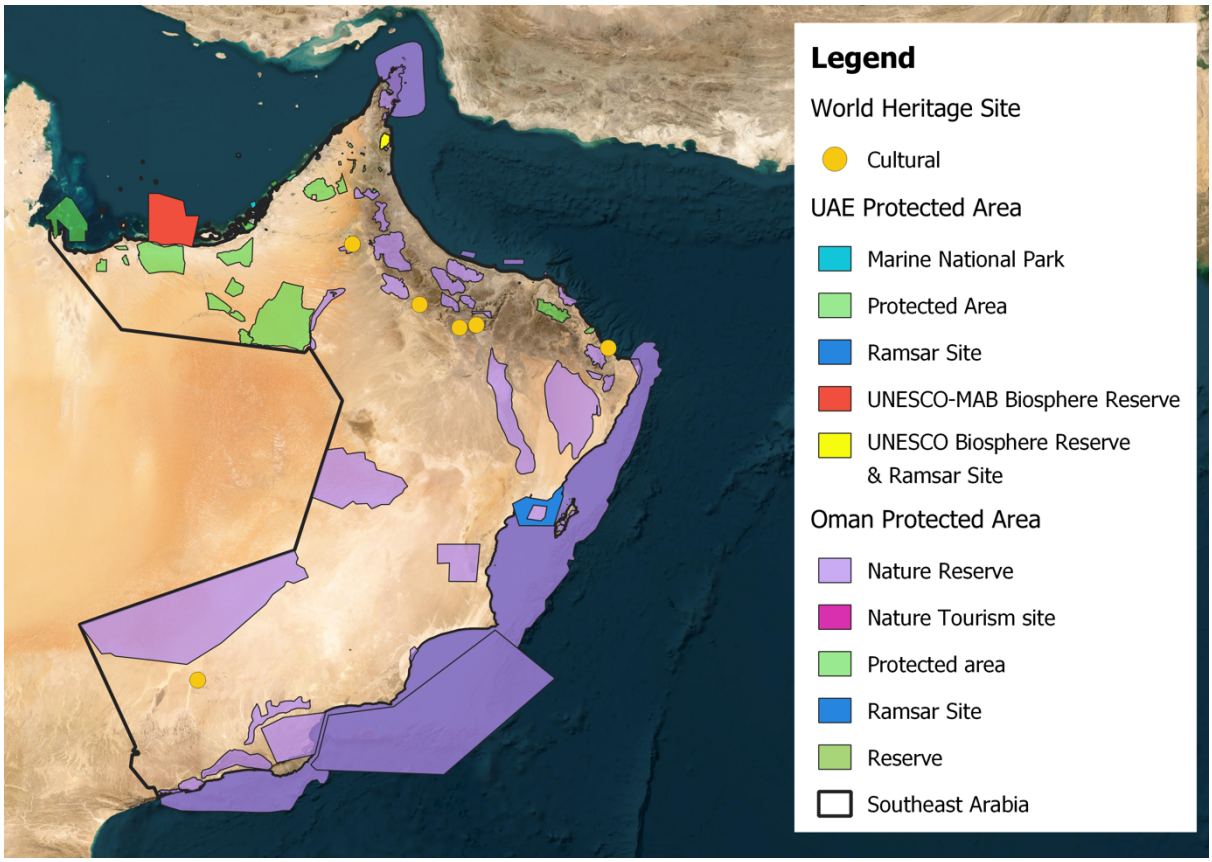


Figure 3.3 Protected areas in southeast Arabia (data from UNEP-WCMC and IUCN (2024); UNESCO (2024)).

3.6 Geoheritage conservation

The conservation of geoheritage sites in southeast Arabia presents several challenges and opportunities, reflecting broader trends in the region's approach to balancing conservation with economic development. Despite the exceptional geological significance of sites like the Semail ophiolite and Abu Dhabi Sabkha, legal protections for many of these areas remain inadequate or non-existent, which exposes them to threats from industrial activities.

One notable instance is the Al Huqf Geopark project in Oman, which was abruptly suspended (Searle, 2020, personal communication). Similarly, activities such as petroleum extraction and civil engineering continue at the Abu Dhabi Sabkha in the UAE, despite its unique geological attributes (Kirkham & Evans, 2019). These examples illustrate how geoheritage conservation is not currently prioritised in policy and regulatory frameworks in the region.

Nevertheless, there have been positive steps towards protecting some geoheritage sites. For instance, Oman has developed the Al Hoota Cave, and the UAE has established the Al Buhais Geological Park, both aimed at promoting geotourism and raising awareness of geological values (Dowling, 2011; Oman Ministry of Tourism, 2019). These initiatives highlight the recognition of the economic potential of geoheritage through tourism.

In the last 15 years or so, the academic community has also started to advocate for the protection of geoheritage sites in this region (Figure 3.4). In Oman, several studies (e.g. Lawrence, 2010; Searle, 2014) and a book (Hoffmann et al., 2016) have identified key sites with geoheritage values in the country. Of these inventories, Hoffmann et al. (2016) and Searle (2014) provide the most extensive and detailed description of the sites, with an

assessment of their relative importance using their experience and expertise. However, these inventories often lack comprehensive analyses of site endangerment and may not fully encompass Quaternary geological features.

Geotourism has also emerged as a potential avenue for promoting geoheritage conservation in the region, particularly in the aftermath of the COVID-19 pandemic (Afifi & Negm, 2020). In the UAE, Allan (2013, 2016) has identified a few key geoheritage features in the country, and other studies have focused on the conservation of the Abu Dhabi Sabkha (e.g. Kirkham & Evans, 2019; Lokier, 2013). The efforts at Abu Dhabi Sabkha, despite a large proportion of the site already being lost for hydrocarbon related development, have led to the site's inclusion in the Tentative List for the WHS. However, it is unclear when this site will officially be warranted a protection status.

The emergence of inventories and evaluations of key geoheritage sites marks a significant step forward in southeast Arabia; however, the literature on geoheritage conservation in this region remains underdeveloped. Especially, the limited number of case studies (Afifi & Negm, 2020; Lokier, 2013) hinders the development of comprehensive conservation strategies. In Oman, the research focus tends to be biased towards geological aspects familiar to individual authors with no available studies considering the voices of local knowledge holders and relevant parties. Overall, academic focus on geoheritage conservation in this region is rather limited and fragmented, without much success in connecting the research outcomes to the protection of key sites. A systematic approach with a robust methodology and an understanding of the regional context is necessary to establish a robust roadmap that encourages and realises the protection of geoscientific treasures of this region.

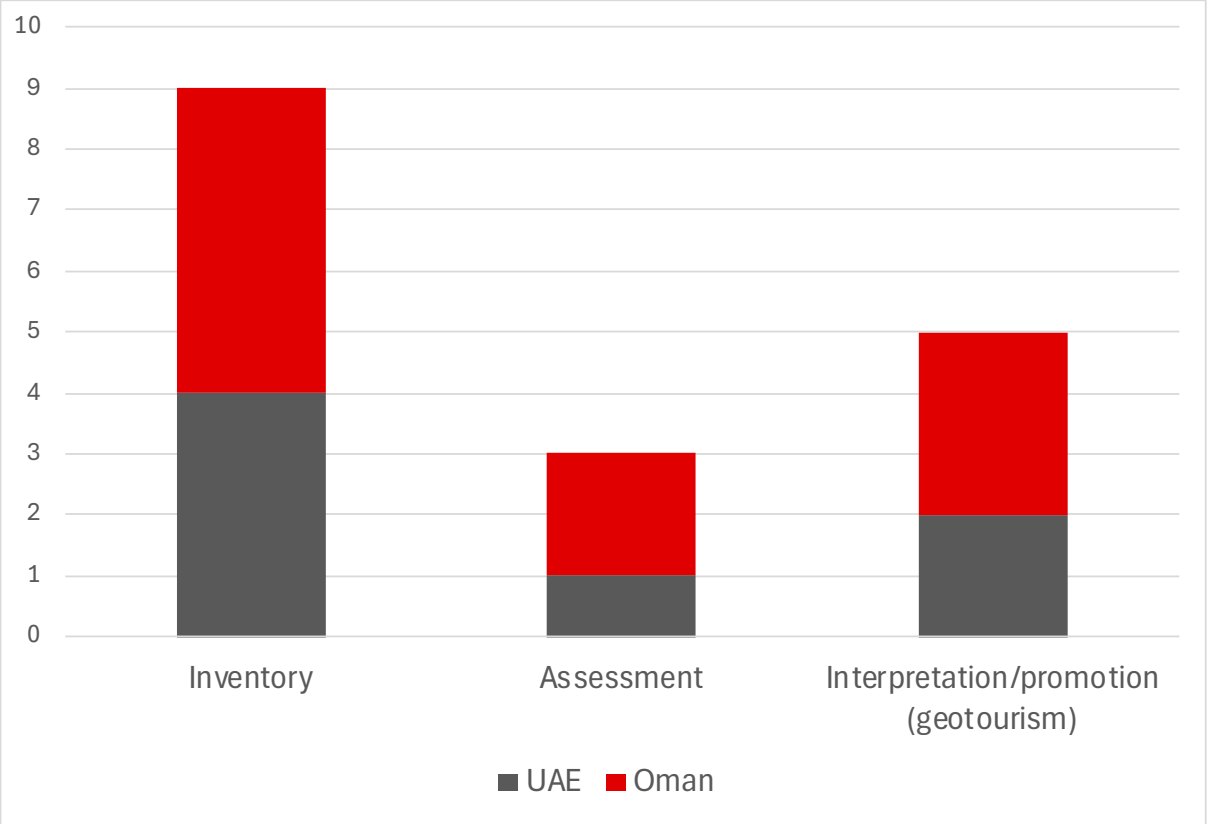


Figure 3.4 Number of geoheritage related publications in southeast Arabia categorised by the stages of geoheritage conservation

3.7 Emirate of Fujairah, UAE

Fujairah is one of the seven emirates of the UAE, and is located on the eastern coast of the country (Figure 3.4). In terms of its size, population, and the economy it is one of the smaller emirates at 1,450 km^2 (1.7% of whole country), 316,790 inhabitants (3.1%), and GDP of around USD 7.5 billion (1.1%) (CIA, 2024b; Fujairah Statistics Centre, 2023). The main industries of Fujairah are manufacturing (16.7 %), construction (12.0 %), and wholesale and retail trade (including motor vehicles and motorcycle repair) (11.3 %) (Fujairah Statistics Centre, 2023). The geology of Fujairah is one of the most diverse in the UAE and can largely be divided into four types of materials: Cretaceous ophiolitic formations, metamorphic sole, Triassic-Permian limestone formations, and Quaternary

deposits (Thomas & Ellison, 2014). Mining and quarrying is steadily growing in Fujairah, and these activities make up 4.4% of the emirate's GDP (Fujairah Statistics Centre, 2023). The geology of Fujairah has been studied by the British Geological Society (BGS) (Styles et al., 2006) as well as researchers such as Searle (2019b) and Cox et al. (1999). A deeper description of key sites will be provided in Chapter 8.

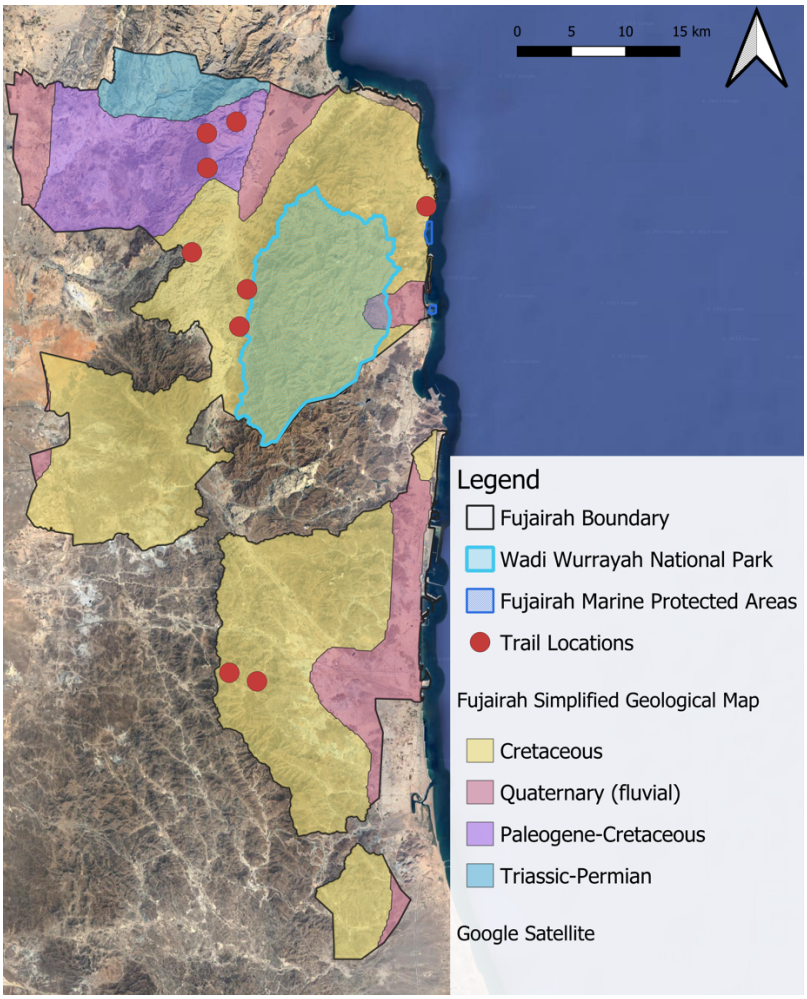


Figure 3.5 Map of Fujairah, UAE with its surface geology and protected areas (geological data from Pollastro et al. (1999))

In terms of nature conservation, Wadi Wurrayah National Park is a large protected area that is inscribed as one of two UNESCO-MAB Biosphere Reserves in the UAE due to its importance for protecting and rehabilitating endemic species and migratory birds (Feulner, 2014; Tourenq et al., 2009). Currently, the National Park is closed to the public

for rehabilitation purposes. Furthermore, the emirate has two small marine reserves which are protected under local legislatures.

Beyond formal protection, the government nature tourism company, Fujairah Adventures, has recently organised 11 hiking trails and have implemented a code of conduct, with guidelines for all nature tourism companies operating within the emirate (Al Amir, 2023). Many of these trails traverse the mountainous areas of Fujairah with various geological features. Nevertheless, to date, there are no geoheritage sites formally protected in the emirate.

Fujairah was selected as the case study site for Chapter 8, due to its rich geology, lack of existing measures for geoheritage conservation, and availability of logistical support to conduct the research. Given the importance of non-Quaternary geoheritage in Fujairah, the scope of this thesis expanded to encompass all geoheritage sites in the region, from the original idea of focusing primarily on Quaternary elements.

Chapter 4 Aim, research questions, and methods

4.1 Aim and research questions

In southeast Arabia, more empirical data are required to build the foundation for successful geoheritage conservation. This thesis aims to address this knowledge gap by developing new methods and strategies that focus on three key processes of geoheritage conservation, inventory, interpretation and promotion, and quantitative assessment, with a focus on Quaternary geoheritage sites. Three guiding research questions encapsulate the objectives necessary to achieve this aim:

1. What is the nature, scale, and conservation status of southeast Arabian Quaternary geosites? (inventory)
2. What are the benefits of a geocultural approach, if any, in interpreting and better communicating to non-specialists about Quaternary geoheritage sites in southeast Arabia? (interpretation and promotion)
3. How do the values and significance of geoheritage sites in southeast Arabia perceived by specialists and knowledge holders differ from those identified in other parts of the world? (quantitative assessment)

Each of these questions corresponds to a stage (described in parentheses) required in a systematic approach to geoheritage conservation. The four academic papers which form the basis of the thesis structure address these three questions. Paper 1 answers question 1 by creating a database that demonstrates the endangerment status of Quaternary geosites in southeast Arabia. Paper 2 tackles question 2 by analysing differences in the

way people living in this region react to videos on Quaternary geoheritage sites with and without mention of the relationship between these sites and the regional cultural heritage.

Papers 3 and 4 address question 3 by providing assessment methods for Quaternary geoheritage sites in arid environments and geoheritage (general) sites in southeast Arabia, respectively, using input from relevant regional experts.

This interdisciplinary project has been developed with the intention to:

i. Facilitate bottom-up geoheritage conservation efforts in southeast Arabia by identifying the endangerment of sites and creating methods for their evaluation with a regional perspective;
ii. Contribute to the fields of geoheritage research, Quaternary science, and geosciences overall by advancing the understanding of the “geocultural” heritage concept and by identifying effective methods and narratives for popularisation of Quaternary geoheritage sites and landscapes;
iii. Contribute to the fields of Quaternary science and archaeology by providing a spatial database that connects palaeoenvironmental records from southeast Arabia with regional archaeological records.

Therefore, the implications of this thesis are relevant for a range of researchers (geoheritage scientists, Quaternary scientists, archaeologists, geoscientists) as well as heritage professionals (practitioners, government officials, nature conservation societies, etc.) working with geoheritage sites and wider nature conservation efforts in southeast Arabia and beyond.

4.2 Methods

4.2.1 Overall framework

The framework of this thesis is based on a modified version of the five stages for geoheritage conservation proposed by Brilha (2005). As discussed in Chapter 2.2, currently popular frameworks for geoheritage conservation, such as this one, take an inherently top-down approach, considering the recognition of geoheritage values as an established concept. Although these approaches have been successful in regions and countries where the value of geoheritage conservation is well-established, the *status quo* in southeast Arabia warrants an approach that starts from establishing this recognition of values. To enable a bottom-up oriented approach to geoheritage conservation, this thesis has been developed under a framework in which 'interpretation and promotion', identified as the fourth stage by Brilha (2005), has been considered an overarching theme that extend throughout all stages of the geoconservation process, as described in Figure 4.1. In implementing this framework, an important assumption made is that geoheritage conservation, when done properly, can bring benefit, rather than harm, to society.

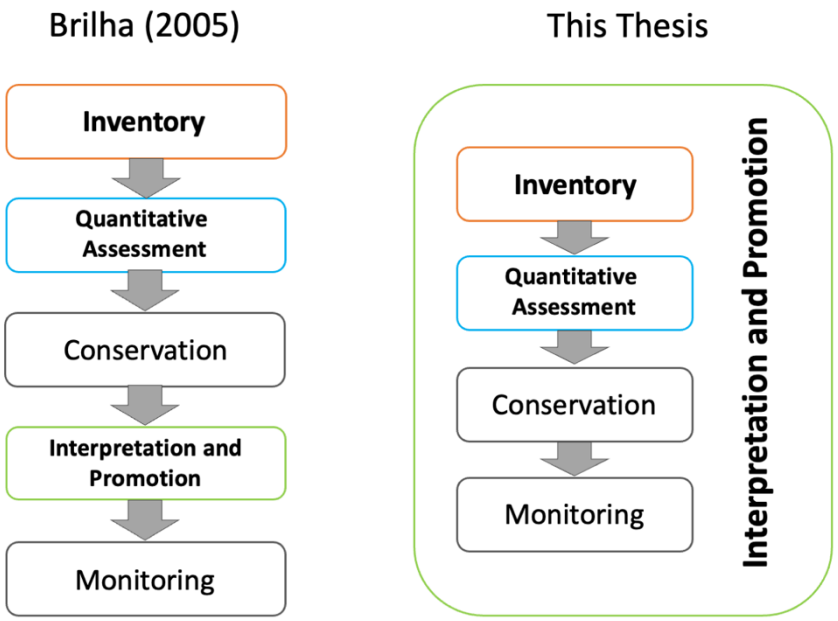


Figure 4.1 Differences between the stages in geoheritage conservation between this thesis and Brilha (2005). Stages addressed in empirical studies of this are shown in colours and bold letters.

The three research questions of this thesis, addressed in Chapters 5 through 8, correspond to the first three stages of the modified scheme (as shown on the right side of Figure 4.1), that precede formal conservation of the sites. As an inventory of Quaternary geoheritage sites in southeast Arabia, a spatial database of sites studied in academic literature was created with an endangered assessment for each site (Paper 1). For interpretation and promotion, the information about sites and their endangerment identified in the database was communicated to university students and highly educated professionals living in the region through videos in ways identified as effective by relevant academic and museum experts (Paper 2). Here, a geocultural approach and a geosciences-focused approach in communicating Quaternary geoheritage sites was compared and analysed. To conduct quantitative assessments of geoheritage sites in

southeast Arabia, a method for the evaluation of scientific values of Quaternary sites in arid landscapes was developed (Paper 3), alongside a method for evaluating scientific, educational, and touristic values of all geoheritage sites in southeast Arabia (Paper 4). The latter was used in Fujairah, UAE to rank geoheritage sites within this emirate for each value dimension. Figure 4.2 shows how the four papers of this thesis align with the stages of geoheritage conservation used as the guiding framework of this thesis. Chapter 9 summarises the findings from Chapters 5 to 8 through a supply and demand framework and discusses ways forward for geoheritage conservation in southeast Arabia.

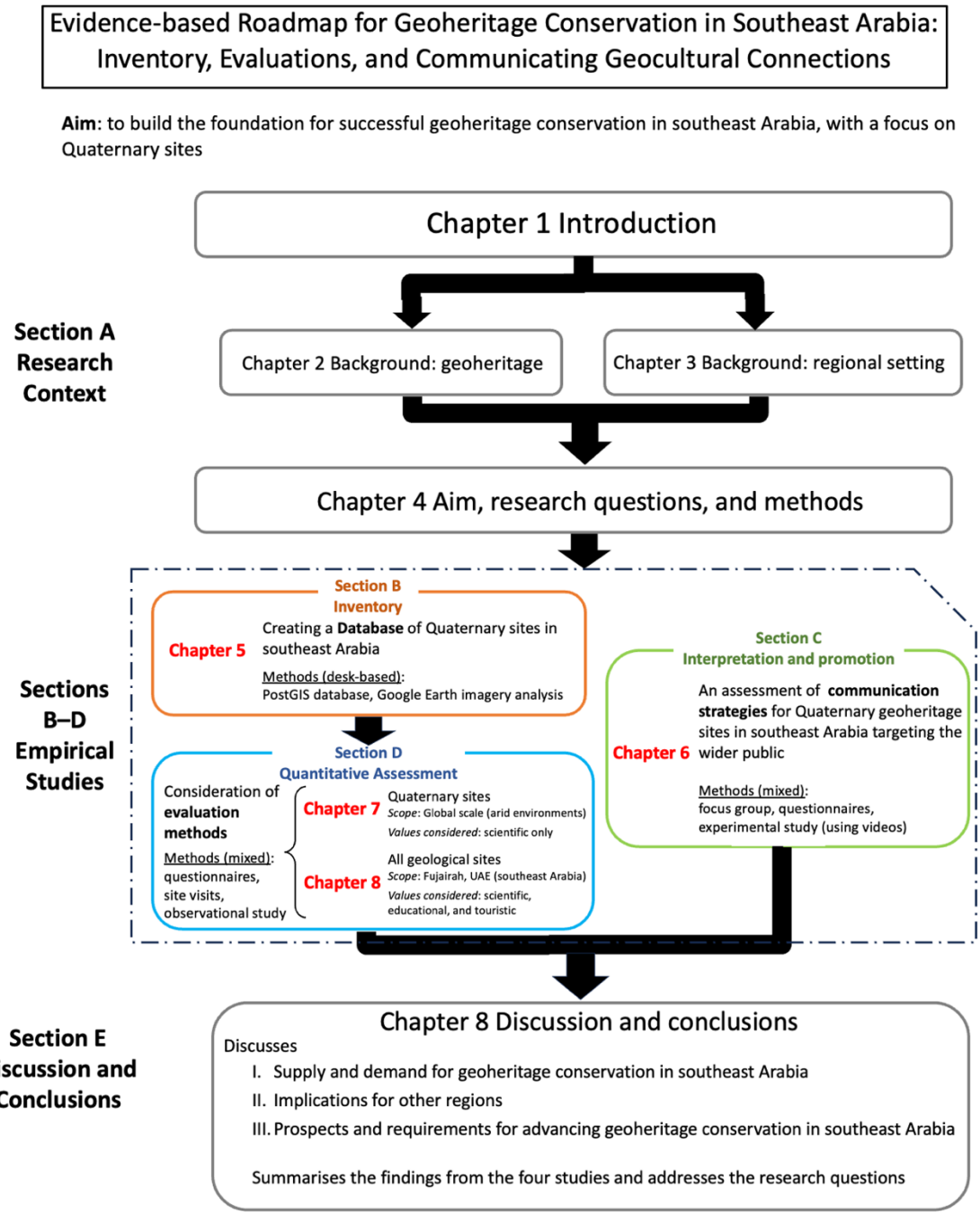


Figure 4.2 Research framework and thesis structure

4.2.2 Methodology and geographical scale

To address the three research questions, a combination of methods has been used, as outlined in Figure 4.2. A distinctive element of this project is the use of diverse methods,

combining quantitative and qualitative data analyses with interdisciplinary perspectives. This chapter provides an overview of the methods used and the reason for their selection. Further details will be provided in the methods sections of Chapters 5–8. As outlined in Figure 4.2, studies in this thesis consider different geographical scales. While Chapters 5 and 6 focus on southeast Arabia overall, Chapter 7 focuses on Fujairah, UAE, and Chapter 8 focuses on arid environments around the world. In Chapter 7, the study used Fujairah as a site of case study to develop a quantitative assessment method for geoheritage conservation in southeast Arabia. As discussed in Chapter 3.7, Fujairah was chosen due to its wide variety of geological features, and the availability of support towards the project from Fujairah Emiri Court, the governing body of the emirate. Chapter 8 targeted arid environments around the world, due to the limited number of specialists in Quaternary science and related fields within southeast Arabia.

4.2.3 Desk-based methods

In Chapter 5, desk-based methods, close to the approach of the EAMENA project (Flohr, 2017) were used to create a database that serves as an inventory for Quaternary geoheritage sites in southeast Arabia. As discussed in Chapter 2.3, the most commonly used method in the geoheritage literature for inventory, including condition assessment, has been a combination of literature review and observations through site visits (e.g. AbdelMaksoud et al., 2022; Beraaouz et al., 2019; Dollma, 2019; Mauerhofer et al., 2018; Mehdioui et al., 2020; Nguyen-Thuy et al., 2019; Qureshi et al., 2021; Reynard et al., 2018; Sen et al., 2024). However, as demonstrated by De Lima et al. (2010), this approach may not be realistic at larger geographical scales. Given the number of sites identified in the literature review stage, an alternative approach was deemed necessary to create a

database for Quaternary geoheritage sites in southeast Arabia. The quick survey approach of EAMENA (as introduced in Chapter 2.3.7), although developed originally for archaeological sites, was considered most appropriate given the comparatively static nature of both geosites and archaeological sites, geographical overlap in the two projects, its overall success in identifying endangerment of sites over time (Flohr, 2017), and logistical ease in its implementation. Similar to the EAMENA database, the database was developed to be accessible using free software, to ensure maximum accessibility.

4.2.4 Mixed methods

In Sections C and D (Chapters 6–8), mixed methods are used to collect and analyse data from study participants. Mixed methods are used commonly in social science research. Mixed-method approaches take advantage of qualitative methods in gaining a detailed understanding to a problem and utilises quantitative methods in obtaining a more general understanding towards the research topic (Creswell & Plano Clark, 2017). Five justifications for the use of mixed methods (as shown in Table 4.1), proposed by Greene et al. (1989), have been widely supported (Bryman, 2006).

Table 4.1 Five justifications to use mixed methods in research, as identified by Greene et al. (1989)

Justification	Description
Triangulation	Uses results from different methods to link, corroborate, and correlate the findings.
Complementarity	Using the results from one method with the results from another to elaborate, enhance, illustrate, or clarify the findings.
Development	Using the results from one method to help develop or inform the other method, in various stages of the study, including sampling implementation, and measurement.
Initiation	Using the results from one method with another to discover paradoxes and contradictions, or to gain new perspectives of frameworks.
Expansion	Using different methods to extend the breadth and range of enquiry for different inquiry components.

In studies related to heritage or nature conservation, mixed methods have been widely employed, particularly in those with an interdisciplinary nature that focus on the social values of protected sites (Hattam et al., 2015; Hoare, 2020; Kinnebrew et al., 2021; Parga Dans & Alonso González, 2019). In this thesis, qualitative data was used as a tool for development in the initial stages of studies, particularly in Chapter 6, in which focus groups led to the development of the video design. Then, both qualitative and quantitative data were collected and analysed for complementarity through surveys, to elucidate a range of results from a diverse group of participants while ensuring statistical robustness and reliability.

Similar approaches have been taken in the geoheritage literature, although less frequently in comparison to other types of heritage. As will be described in Chapters 7 and 8, most decisions in the geoheritage literature have been determined by the researchers without consultation of the wider public, especially in developing evaluation methods, and in the

few cases that local-scale perspectives are consulted, they tend to be used exclusively in a quantitative (e.g. Bruschi et al., 2011; Farsani et al., 2019; Štrba, 2019) or a qualitative (Fepuleai et al., 2017) manner. However, in some cases, mixed methods have been used to gain nuanced understandings of visitor experiences (Moreira, 2012), local perspective towards geotourism development (Shahhoseini et al., 2017), or community involvement in geoconservation (Tavares et al., 2015). These mixed-method studies provide valuable findings on the reason behind the trends found from quantitative data, beyond mere conjecture.

Mixed methods were adopted in this project to answer the second and third research questions of this thesis, as the required consultation with study participants could benefit greatly from both statistical robustness and nuanced explanations. Both study designs employed online questionnaires as the main mode for data collection but took different approaches to collect the most appropriate data in each case.

4.2.4.1 Focus groups

Focus groups were conducted in Section C (Chapter 6) to elucidate the perceptions and current understanding of potential strategies for effective communication on Quaternary geoheritage sites from relevant specialists (i.e. academics and museum professionals). The data from the focus groups were collected and used to inform the structure and the content of the videos produced for this study. Although perceptions and knowledges from relevant parties can also be collected through questionnaires and/or interviews, focus groups were preferred in this thesis for several reasons. Most importantly, focus groups provide a unique advantage of creating a group dynamic that leads to the production of data developed from the interaction between the participants (Morgan & Krueger, 1993). It is considered especially effective as a method when there is an identified knowledge

gap between experts and the target audiences, as the discussion enables the experts to learn from diverse attitudes, beliefs, perceptions, perspectives, and value systems (Onwuegbuzie et al., 2009). The interaction between academics and museum professionals fit this case nicely, as museum professionals serve as an intermediary between experts and non-experts. Therefore, focus groups were considered effective as a method to understand the extent of shared/opposing experiences and thoughts as well as to foster revelations about the topic through interdisciplinary discussion.

Another benefit of the focus group is that it is an established method used to develop a new product or programme, as discussions and reactions to discussions can be valuable indicators to identify a product's strengths and weaknesses (Greenbaum, 1998). As the collection of data was to develop videos for the study, this method was preferred over methods that collect answers individually. Furthermore, compared to questionnaires or individual interviews, focus groups have been shown to provide more in-depth information (Morgan, 1996), which was considered necessary for this study, especially due to the limited number of geosciences/archaeology academics and museum professionals available in this region.

In implementing the focus groups, the script and guidelines were produced with emphasis on the need to set ground rules at the very beginning. Based on instructions by Krueger and Casey (2000), the focus group was conducted with utmost care to maintain confidentiality of all participants, encourage discussions on points of disagreements, and balance speaking opportunities. As moderators of focus groups should be trained to lead an open, honest, and smooth discussion (Greenbaum, 1998), a rehearsal round was conducted in October 2022 with the Oxford Resilient Buildings and Landscape Lab, a

group of heritage conservation related researchers at the University of Oxford, and the feedback received in this session was reflected in conducting the focus groups for the study. The content of the focus groups was transcribed, translated (when necessary), coded, and analysed using NVivo to identify relevant themes.

4.2.4.2 Questionnaires

A questionnaire is a tool that consists of a set of questions on a certain topic, used to gather a specific range of information. It is a commonly used tool in survey studies, as it allows collection of data in a highly structured and straightforward ways (De Vaus et al., 2013). The main advantages and disadvantages of using questionnaires, as identified by Patten (2016) and Krosnick (1999), are outlined in Table 4.2. The primary strength of questionnaires is their convenience and efficiency, as they can be distributed to many respondents at once, while allowing them to answer questions at their own pace. It also has the advantage of being able to collect both qualitative and quantitative data, through open-ended and closed-ended questions, respectively (De Vaus et al., 2013). Moreover, as questionnaires do not need to be answered in person, they can be answered anonymously, which allows participants to answer questions freely, with less fear of social repercussions. Finally, because it can be distributed to many participants at once, without need for personal interactions, questionnaire research is economical in terms of personnel cost. In this thesis, online questionnaires were chosen for the method of data collection, mostly for the first and third points, as both Sections C and D had elements that required data collection from a relatively large number of participants, with limited funding available. To conduct online questionnaires, the Jisc platform was used in Chapters 7 and 8, and the Qualtrix platform was used in Chapter 6.

Table 4.2 Advantages and disadvantages of using questionnaires in research, as identified by Patten (2016) and Krosnick (1999)

Advantages	Disadvantages
Efficiency in collecting data	Lower response rate compared to interviews and other methods that involve direct interactions with the study participant
Ability to provide privacy by maintaining anonymity	Comparatively superficial nature of collected data
Economic and effective remotely	Risk for obtaining answers that the participants think that the survey administrator would like to hear, responses confined to the choices given, and/or satisficed answers

In using questionnaires, researchers must be aware of their potential disadvantages. One of such shortcomings is the potential lower response rate, which can be as low as 50–60%, compared to in-person interviews, for which the expected response rate is around 80% (Grønmo, 2019). In general, this rate is lower when the person answering the questionnaire has less personal stakes or interest in the topic being asked (Patten, 2016). Another limitation is the risk of obtaining relatively superficial data, as it is difficult for a questionnaire to obtain the same level of depth in its answers, compared to an interview or a focus group (Patten, 2016). The quality of answers can also be compromised by social pressure, restricted choices, or "satisficing". In many cases, participants feel the pressure to answer in ways that would be most praised by the society (e.g. feeling compelled to answer no to a question asking whether you have ever committed a small crime), or in ways that they think the administrator of the questionnaire would appreciate the most (Grønmo, 2019). Satisficing refers to a behaviour in which respondents choose to answer questions in less thorough ways that require less energy (Krosnick, 1999).

In this thesis (Chapters 6–8), questionnaires were carefully designed to address the potential impact of the method's weaknesses. To improve the response rate towards the questionnaires, four strategies were used. First, whenever possible, participants were encouraged in person to answer the questionnaire, although they answered the questions online. Second, all studies contacted a larger number of potential participants than needed to offset low response rates. Third, participants were encouraged to answer the questionnaires through a systematic approach with up to three reminders per questionnaire. These reminders were sent via email and/or WhatsApp, based on the preferences of the participant, given advice from Omani and Emirati partners on the communication habits of regional residents. Finally, in Section C, incentives in the forms of a chance to win merchandise from the University of Oxford were provided to the participants to encourage complete participation. This was considered necessary, as this study required participants to answer three questionnaires over the course of more than three months, and targeted participants with no particular interest in the topic of study.

The risk of obtaining superficial data was addressed through meticulous design of the questionnaire. By using a combination of open-ended and closed-ended questions in good balance, the questionnaires attempted to collect more nuanced and in-depth answers, while maintaining the method's advantages of convenience and simplicity (De Vaus et al., 2013; Grønmo, 2019). In structuring the questionnaires, the required depth of answers for each question was assessed, and those with the highest need for nuance and interpretation were asked as open-ended questions.

Similarly, issues related to the quality of answers was addressed through the questionnaire design and instructions. To reduce confusion and avoid answers biased by

social expectations, the questions followed the guideline provided by Grønmo (2019) to be neutral, one-dimensional, unambiguous, and understandable by the audience. To make the questions more accessible, questionnaires were made available in both English and Arabic in addressing the local residents in Section C. Furthermore, to discourage respondents from selecting answers that they think would be most desired by the society and/or survey administrators, most questions were made optional, and instructions were given specifically to individual questions to encourage honest answers. These measures also helped address the main causes of satisficing, which include high task difficulty, low respondent comprehension, and low motivation (Krosnick, 1999).

4.2.4.3 Experimental study

In Section C, an experimental design was used to test the impact of different contexts in communicating about Quaternary geoheritage sites in southeast Arabia, targeting adults residing in Oman and the UAE. An experiment is a scientific test conducted under controlled conditions to reveal information about some hypotheses or principles (Coleman, 2019; Creswell, 2017). Experiments have a few distinctive features such as the manipulation of conditions between the control and treatment group by the researcher, randomisation of assigning experimental conditions to study participants, and careful and systematic analysis of the outcomes (Kirk, 2013). When conducted with care, it is a robust method that enables the establishment of causality, showing how a treatment has changed the outcomes while everything else remains the same (Coleman, 2019).

In science communication research, experimental design has been identified as a key methodology that needs further investigation (National Academies of Sciences & Medicine, 2017) and is being used increasingly more often to assess how different approaches to communicate science can influence the audience's knowledge, interest,

or application of the topic communicated (Dudley et al., 2023). In geosciences communication, however, experimental designs have seldom been used. To fill this research gap and provide robust, potential causal relationships to substantiate the impact of different communication strategies in geosciences and geoheritage, an experimental study was devised. The specific design of the study and the tested hypotheses are reported in Chapter 6.

4.2.4.4 Observational study

In Chapter 8, a type of observational study with characteristics of non-equivalent control-group design and a one-group pre-test post-test design (Cochran & Chambers, 1965) was used to analyse the impact of a site visit trip towards the participants' view of evaluating geoheritage sites. An observational study examines a relationship between sets of variables in cases where controlled experiments are difficult to implement (Lu, 2009). A key feature of this research design, when compared to a true experiment, is that it does not randomly assign the control group, which leads to difficulties in deciphering pre-existing differences between the groups (Rogers & Révész, 2020). Because this study design compares results between a comparison group (with data collected before the site visit) and a treatment group (data collected after the site visits), and because the participants decided whether they wanted to participate in the site visit, it can be considered a non-equivalent control-group design. However, at the same time, as this method does not have a separate pool of participants as the control group, it could also be considered a type of pre-experimental design called one-group pre-test post-test design (Campbell et al., 1963). Given the lack of a control group to which the effects of the treatment can be compared, a study with a pre-experimental design cannot claim

cause-and-effect relations, and is only recommended as a tool for inferring potential relationships in scoping exercises, before conducting a true experiment (Mauldin, 2020).

The method in Chapter 8 was selected due to the small number of relevant specialists that met the participation requirement, as well as their limited availability. As such, data collected using this method were used with caution, not to draw cause-and-effect relationships or to make decisions based on the results on its own, but to help contextualise the findings, make nuanced qualitative decisions on the methodology to structure the evaluation method, and to suggest avenues for future research.

Section B: Inventory

Chapter 5 Developing a Geocultural Database of Quaternary Palaeoenvironmental Sites and Archaeological Sites in Southeast Arabia: Inventory, Endangerment Assessment, and a Roadmap for Conservation*

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Abstract

Quaternary palaeoenvironmental (QP) sites in southeast Arabia are important not only to understand the history of global climate change but also to study how ancient humans adapted to a changing natural environment. These sites, however, are currently missing from conservation frameworks despite reports of destroyed sites and sites under imminent threat. This study presents the Geocultural Database of southeast Arabia, the first open-access database on QP sites in this region, created as a comprehensive inventory of regional QP sites and a tool to analyse QP records and archaeological records. The endangerment assessment of QP sites in this database reveals that 13% of QP sites have already been destroyed and 15% of them are under imminent threat of destruction, primarily due to urban development and infrastructure development. Chronological and spatial analyses of QP and archaeological sites and records highlight the intricate relationship between palaeoenvironment and archaeology and emphasise the need for

* Minor changes have been made to this manuscript to aid the readability and continuity within the thesis. For example, the number of the figures and tables have been changed.

sub-regional-scale studies to understand the variation of climatic conditions within the region, especially to study changes in the ancient human demography. This database illustrates the potential of a geocultural approach that combines archaeological heritage with Quaternary geoheritage as a way forward for the conservation of QP sites at risk.

5.1 Introduction

Internationally, geoheritage conservation has advanced greatly in the past three decades, as is evident from the development of various international frameworks. Following the success of continental networks, such as the European Geoparks Network (established in 2000) and Asia-Pacific Geoparks Network (established in 2007), in promoting the protection of geological sites, UNESCO established its Global Geopark programme in 2015, overwriting its decision in 2001 to not pursue such a programme for geoheritage sites (Henriques & Brilha, 2017). Academically, the five key stages of geoheritage conservation have been identified as: inventory, quantitative assessment, conservation, interpretation and promotion, and monitoring (Brilha, 2005). The volume of research has grown significantly, especially for the first three stages (Barettino et al., 2000; Brilha, 2005; Brocx & Semeniuk, 2007; Gray, 2004; Panizza, 2001; Reynard et al., 2007; Wimbledon et al., 1995).

Various quantitative evaluation methods have been created to assess geoheritage values (e.g. Brilha, 2016; Bruschi et al., 2011; Coratza & Giusti, 2005; Pereira et al., 2007; Reynard et al., 2016; Ruban, 2010). The most common criteria used for assessment in these methods include scientific value, aesthetic value, representativeness, rarity, integrity, extent of scientific knowledge, and geological diversity. In some studies,

however, the need to consider the cultural relevance of geoheritage sites has been emphasised, especially as an antidote to the prioritisation of sites with high aesthetic values (Gordon et al., 2018; Panizza & Piacente, 2009).

With growing interest and efforts, 169 Geoparks from 44 countries have thus far been registered as UNESCO Global Geoparks (UNESCO, 2021b). Geographically, however, most of these geoparks are concentrated in Europe and East Asia, although a rapid growth is observed in Latin America. The lack of representation from African and Arab states, as well as Small Island Developing States, is evident and is highlighted by the fact that UNESCO has recently started offering grants to aid the establishment of geoparks in these regions (UNESCO, 2022b, 2022c).

In southeast Arabia (i.e., the UAE and Oman), although no sites have yet been recognised in UNESCO frameworks, geoheritage conservation and geotourism are budding initiatives. In Oman, Al Hoota cave has been developed and promoted as a show cave (Dowling, 2011) and in the UAE, Buhais Geological Park opened in 2020. Moreover, the Ministry of Tourism in Oman has developed a mobile app dedicated to promoting the geotourism resources of the country (Oman Ministry of Tourism, 2019). An inventory of regional geoheritage sites has been conducted by Searle (2019a) for the establishment of geoparks in the region. These inventories are extensive in their coverage of geological sites, especially those related to the Semail ophiolite, but apart from a few caves and wadis, Quaternary palaeoenvironmental (QP) sites lack representation.

Southeast Arabia boasts a wide variety of Quaternary landscapes that enables studies on Quaternary palaeoenvironments, the complexity of their variability over time, and their impact on the human demographics. Throughout the Quaternary, the landscape of this region alternated between wetter and drier conditions. Archaeological and

palaeoclimatic evidence (e.g. Lézine et al., 2010; Parker, 2009; Parker et al., 2004; Parker et al., 2016; Parton et al., 2013; Parton, Farrant, et al., 2015b; Parton, White, et al., 2015) has shown that early human settlement in the region is closely associated with environmental variability. This makes Quaternary palaeoenvironmental sites not only important as climatic archives, but also as "geocultural" sites that provide important lines of evidence for archaeological research. Indeed, many palaeoenvironmental studies from Arabia (e.g. Atkinson et al., 2013; Bar-Matthews & Ayalon, 2011; Farrant et al., 2015; Nicholson et al., 2020; Preston et al., 2015; Rosenberg et al., 2012; Zerboni et al., 2020) include archaeological relevance as one of the main motives for the research.

Despite their scientific importance, only a few studies have considered QP sites in this region as heritage sites in need of conservation. A rare exception is the Abu Dhabi Sabkha, UAE, where Lokier et al. (2015) and Kirkham and Evans (2019) have emphasised its unique heritage values, and reported how recent years have witnessed the destruction of this site due to petroleum and civil engineering activities. The loss of QP sites has also been reported in a few palaeoenvironmental studies, such as the sites studied by Atkinson et al. (2011) being destroyed by industrial development (Preston et al., 2015).

To draw attention to the heritage values of QP sites and to help prevent further loss, we present the Geocultural Database of Southeast Arabia (GDSA), the first database on QP sites in southeast Arabia, designed to fulfil the first of the five stages of geoheritage conservation. The primary objectives of this database are to catalogue southeast Arabian palaeoenvironmental archives and their endangerment status and to facilitate the identification of their scientific values, including their geocultural aspects. Additionally, it aims to help palaeoenvironmental scientists and archaeologists find relevant data from past research efficiently. To create such an inventory, it is good practice to first define the

database's topic (type of heritage), scale, values (for what values these sites are evaluated), and use (goal), as outlined by De Lima et al. (2010) and Brilha (2016). As the topic of this database is QP sites its scale includes two countries: Oman and the UAE. The consideration of values for QP sites in southeast Arabia is difficult, as most evaluation methods have been developed by researchers with experiences predominantly in Europe (e.g. Brilha, 2016; Bruschi et al., 2011; Coratza & Giusti, 2005; Pereira et al., 2007; Reynard et al., 2016; Ruban, 2010). In fact, an evaluation method does not yet exist for QP sites in arid regions. Therefore, this database collates available scientific data from each site as qualitative scientific values and does not attempt to quantify the data as relative values. The database also includes data on archaeological sites in the region as a response to the fact that connections with regional archaeology have been identified as a part of the scientific significance of palaeoenvironmental research in this region.

5.2 Regional setting

Southeast Arabia is located in the arid subtropical climate belt, with the Rub'al Khali desert to the west and the Hajar Mountains to the east. Today, most of the region receives an annual rainfall below 100 mm except for the area around the Hajar Mountains, where it reaches up to 400 mm (Kwarteng et al., 2009). The main mechanisms producing precipitation are convective rainstorms, tropical cyclones, cold frontal troughs, and the southwesterly monsoon (Kwarteng et al., 2009). Rainfall occurs mainly in the winter for much of the region (Glennie & Singhvi, 2002), but in the southern part it occurs as monsoon rainfall in the summer months (Hoffmann et al., 2016). Geologically, about 44%

of the land surface of this region is covered by Quaternary sediments (Figure 5.1). Quaternary landscapes in the region are divided into aeolian (57%), alluvium and gravel (24%), fluvial (14%), sabkha (5%) and others (>0.1%). The Rub'al Khali and the Wahiba sands are the main areas covered by aeolian sediments in this region. Both UAE and Oman have experienced major economic development over the past 20 years, with GDP growth of over 300% (Pirlea, 2023a, 2023b), boosted by the growth of the oil industry.

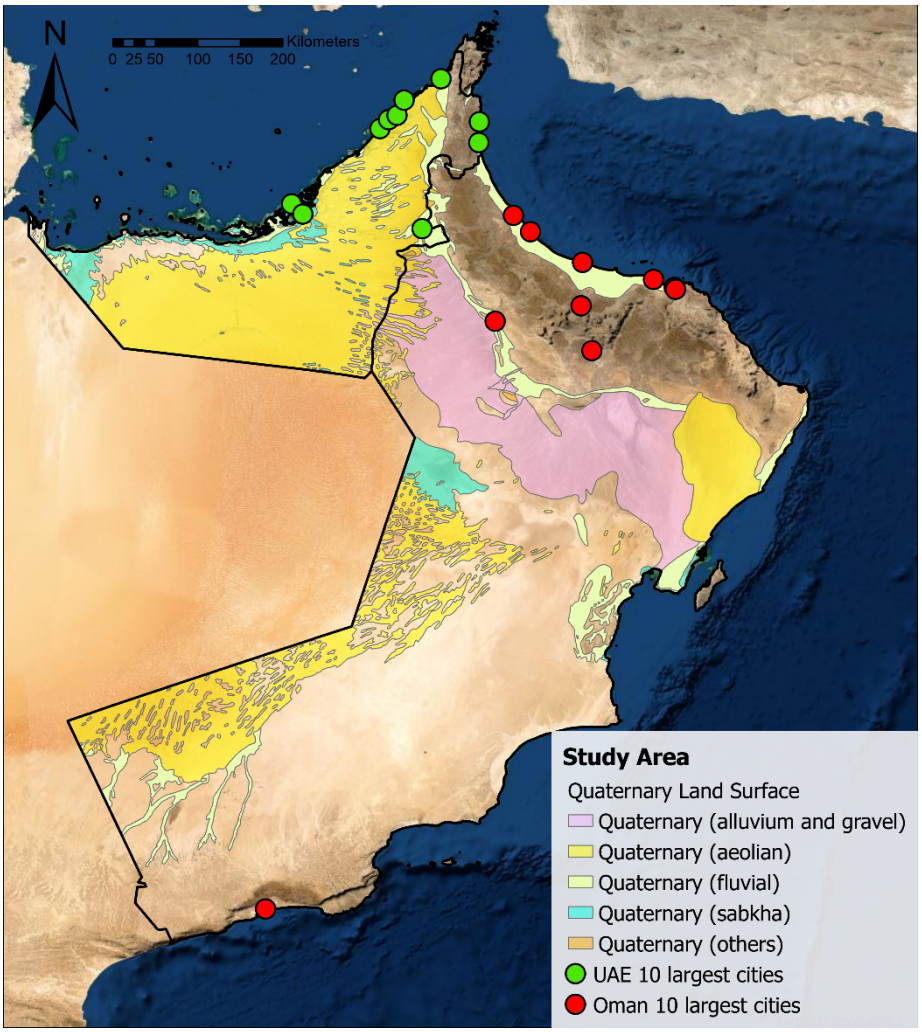


Figure 5.1 Satellite imagery of the study area and its Quaternary surface geology (geological data from Pollastro, et al., (1999)). Satellite imagery from Esri, Maxar, Earthstar Geographics, and the GIS User Community (data on the largest cities in Oman are from the National Centre for Statistics & Information (2022), and data on the largest cities in the UAE are from the Populated Places map by open-source data from Humanitarian OpenStreetMap).

5.3 Palaeoenvironment and prehistoric archaeology in southeast Arabia

As the landscape of southeast Arabia has periodically alternated between wetter and drier conditions throughout the Quaternary period, the region contains a wide variety of landforms that reflect regional and, by extension, global climate variability. These landforms provide records of changes in the regional climate, which is regulated by the interplay of several atmospheric systems, including the mid-latitude westerlies and the summer monsoon system. Palaeoenvironmental records from this region are also important for the understanding of global climate change, as the variability in the monsoon system has been considered as a teleconnective response to global climate variability (Rohling et al., 2009).

A wide range of palaeoenvironmental studies have been undertaken across the region to establish the nature and timing of climatic changes and corresponding landscape responses, with chronologies derived from three main dating methods. Optically stimulated luminescence dating (OSL) has been used for samples from sand dunes (Atkinson et al., 2013; Goudie et al., 2000; Radies et al., 2005); palaeolakes (Rosenberg et al., 2012); alluvial fans (Blechschmidt et al., 2009; Parton, Farrant, et al., 2015b); and sabkha (Heathcote & King, 1998; Matter et al., 2015). For biological materials such as shell middens (Parker & Goudie, 2007) and palaeomangroves (Berger et al., 2013), radiocarbon dating (^{14}C) has been used. Finally, Uranium-thorium dating (U-Th) has been used to date the formation of speleothems (D. Fleitmann et al., 2003; Immenhauser et al., 2007). In addition to the collection of chronometric data, recent projects such as the PalaeoEnvironments and ARchaeological Landscapes (PEARL) research project are attempting to apply new techniques, including the collection of palaeoecological data

from the region using ancient sedimentary DNA (Parton & Bretzke, 2020), for a more holistic palaeoenvironmental reconstruction.

Palaeoenvironmental research in this region has a relatively short history. Most of the research has been conducted in the past 30 years, and it is only in the past 20 years that development and refinement in chronometric dating techniques have enabled the construction of a robust chronology of environmental changes (Figure 5.2).

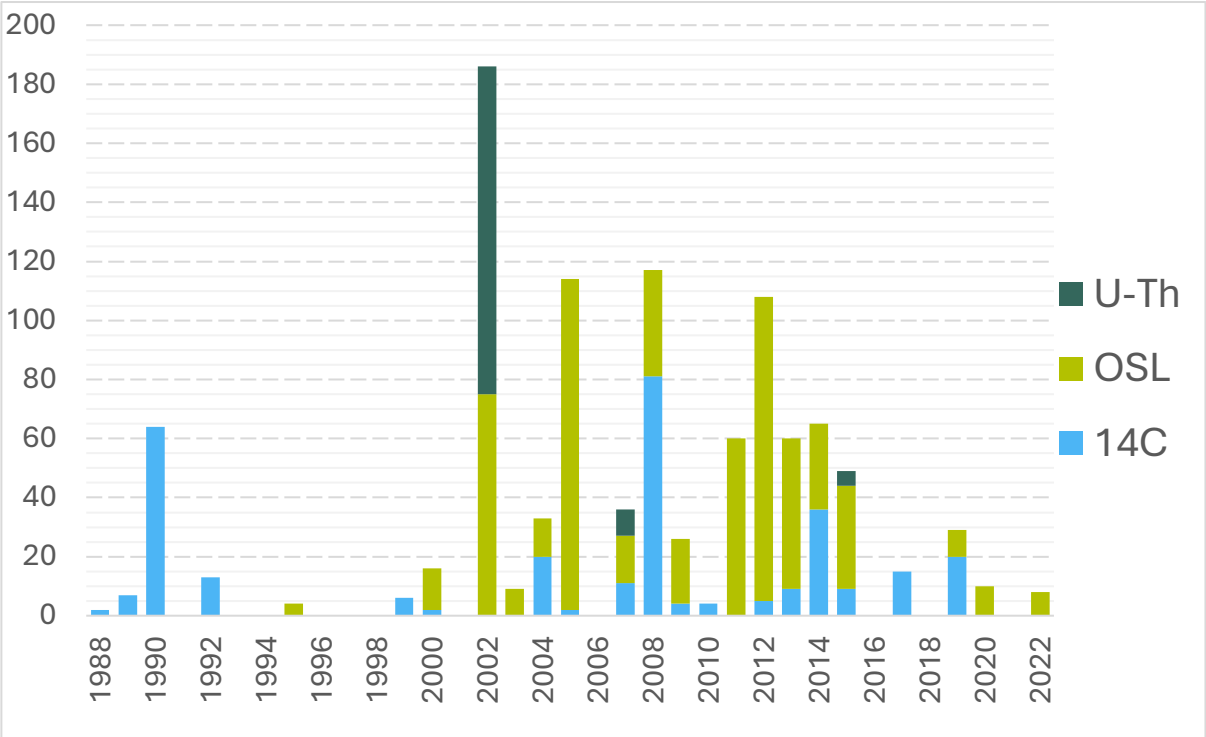


Figure 5.2 Number of published Quaternary palaeoenvironmental (QP) records and the dating method used in southeast Arabia per year (data derived from the Geocultural Database of Southeast Arabia, GDSA).

The 30 years of research have elucidated the complexity of climatic fluctuation in this region. Until about 10 years ago, the palaeoenvironment of this region (especially wetter periods) was thought to be driven mostly in correspondence with the dominant forces that drive climate change at a global scale. In particular, climatic variability was attributed to eccentricity-paced northern hemispheric glaciation over a 100 k-year cycle

(Fleitmann & Matter, 2009; Parker, 2009). Also, marine isotope stages (MISs) are commonly used indicators of climatic variability over the Quaternary, in which odd numbers indicate periods with warmer, wetter climate with limited global ice volumes (interglacial periods) and even numbers indicate colder, drier periods with larger global ice volumes (glacial periods) (Aitken & Stokes, 1997). More recently, however, it has been demonstrated that the nature and timing of environmental changes in southeast Arabia are far more complex; alluvial fan records indicate a strong correspondence with the ca. 23 ka precessional cycle (Nicholson et al., 2020; Parton, White, et al., 2015), while archaeological records suggest that human occupation was not strictly limited to strong "wet" phases (e.g. (Bretzke et al., 2022; Rose et al., 2019). In addition, the broad heterogeneity of the Arabian landscape and the spatio-temporal variability of climate systems are becoming increasingly apparent. Regional complexity governed by localised geological and climatic factors is also considered a key component in understanding the history of regional climate change (Woor et al., 2022) and, by extension, human occupation.

Archaeologically, southeast Arabia is a region of global interest for the study of the early development of modern human populations. The earliest evidence of anatomically modern humans (AMH) dispersal out of Africa is recorded in Israel at around 194-177 ka (Hershkovitz et al., 2018). In Al Wusta, Saudi Arabia, human fossil evidence has been identified in close association with lacustrine sediments and dated as older than 85 ka (Groucutt et al., 2021). Beyond the Levant and Arabia, AMH fossils dated to 70-46 ka have been found in southeast Asia (Demeter et al., 2017) and human presence has been documented from lithics in Australia ~65 ka (Clarkson et al., 2017). However, the route

that our ancestors took beyond the Levant is still contested due to the paucity of fossil evidence in Arabia (Groucutt et al., 2018).

For the past two decades, archaeologists have been debating over the routes that humans took out of Africa into Arabia and beyond (Petraglia et al., 2010; Rosenberg et al., 2011); two main hypotheses, involving a southern route and a northern route have been proposed. Recently, however, this simplistic notion involving one route or the other is being called into question (Nicholson et al., 2021) with an acknowledgement that landscape heterogeneity plays an important role in ancient demographic change. In addition, it is important to note that the relationship between the environment and human settlement/migration is neither causal nor linear, but the role of the environment as an important contributing factor makes palaeoenvironmental studies highly relevant for studying archaeological hypotheses (Lézine et al., 2010; Parker, 2009; Parton et al., 2013).

5.4 Materials and methods

In discussing geoheritage, most terms lack an internationally recognised definition (Brocx & Semeniuk, 2019). Table 5.1 presents definitions of geoheritage-related terms as used in this study. There is a need for a critical analysis of these and other terms within the geoheritage field, but the definitions presented here are well-established and well-cited definitions taken from the international literature.

Table 5.1 Definition of geoheritage-related terms used in this study.

Term	Definition
Geoheritage	The heritage or legacy of geological features on the Earth and recognises important or significant features of the Earth via a process of identification, categorisation, and evaluation, ultimately for their preservation for heritage, research, education, and tourism (Brocx & 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)
Geopark	Well-defined territories with a development plan that aims to integrate the conservation of geological heritage (and other natural assets) with the preservation of the cultural identity of local communities (Brilha, 2016)
Geodiversity	The natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landform, processes), and soil features. It includes their assemblages, relationships, properties, interpretations, and systems (Gray, 2004)
Geotourism	Tourism which sustains and enhances the identity of a territory, taking into consideration its geology, environment, culture, aesthetics, and heritage and the well-being of its residents (The International Congress of Geotourism, 2011)

5.4.1 Data collection

Palaeoenvironmental records from southeast Arabia which range from the present to approximately 934 ka, near the technical limitation of luminescence dating (Liritzis et al., 2013), were collected predominantly from published and unpublished articles. For unpublished sources, only those with clear metadata obtained by the authors (e.g. Stokes et al. unpub.) were used. In addition, archaeological records from periods older than the Iron Age (~2200 BP) (Magee et al., 2009) were collected based on a literature review. However, due to the spatial nature of this database, archaeological sites without clear indications of their location (either in coordinates or in maps) in their publication are currently not included. Table 5.2 provides a breakdown of the types of information collected for paleoenvironmental records and archaeological records, respectively. ^{14}C

ages in the database have been calibrated using the latest IntCal20 and Marine20 calibration curves (Reimer et al., 2020). The database includes two inputs from the SCAPE database, a database on the chronological robustness of Holocene Quaternary palaeoenvironmental sites in southeast Arabia (Woor et al., 2022). The landform type classification has been developed to distinguish common types of geomorphological, sedimentological, and biological characteristics of Quaternary palaeoenvironmental sites for a nuanced analysis of their climatic implications. The robustness of chronology is a traffic light system that classifies the quality of the chronological data based on their data collection methods.

Table 5.2 Types of information collected for QP records and archaeological (Arch) records in the GDSA.

Information	Details	Information Available for
Location	Latitude and longitude of the site	QP, Arch
Precise location	Yes/no question of if the precise location of the site is provided	QP, Arch
Nearest populated place	Nearest populated place, derived from Thiessen polygons and populated place data from OpenStreetMaps	QP, Arch
Country	Country of the location	QP, Arch
Emirate/ governorate	Emirate (for UAE) and governorate (for Oman) where the site is located	QP, Arch
Wilayat	(Only for Oman) Wilayat (sub-region) where the site is located	QP
Protection status	Whether the site is protected under an established framework	QP
Protected area name	Name of the protected area	QP
Designation type	Type of designation that protects the site	QP
Landform type	Landform type (sensu) of the record	QP
Record type	What dating method was used to find the chronology of the QP record (QP) Type of archaeological record (Arch)	QP, Arch
Record information	Additional information on the setting of the record	QP
Record age	The age of the record in BP. (Mean of the upper and lower error range values)	QP, Arch
^{14}C 2 sigma old	The older of the 2 sigma range ages of the record in BP	QP, Arch
^{14}C 2 sigma new	The newer of the 2 sigma range ages of the record in BP	QP, Arch
OSL error range	The ± error range of the record in BP	QP
Archaeological period	Archaeological period to which the record belongs. Classification of periods based on [74]	Arch
Climatic implications	Climatic implications (wet, arid, transition, etc.) of the record as described in the source	QP
Robustness of chronology	Traffic light assessment system for the robustness of the chronological data (data available for records younger than 20 ka)	QP

5.4.2 Endangerment assessment

An endangerment assessment for palaeoenvironmental sites in the database was conducted to understand the *status quo* of each site and as a first step to develop a list of endangered sites for conservation purposes.

Endangerment Criteria

The endangerment level of each site was evaluated based on a visual assessment of historic and current satellite imagery on Google Earth Pro and Bing Maps. These

platforms were used because they provide free high-resolution colour imagery of the past 20 years (Rayne et al., 2017), the period in which most palaeoenvironmental studies have been conducted in this region (Woor et al., 2022).

As the purpose of the assessment is to create a list of endangered sites, rather than to create a ranking of sites in most danger, first, the types of disturbances were categorised. Then, a semi-quantitative scale was created to summarise the likelihood and the severity of disturbances. This approach allows a more nuanced, case-by-case comparison of sites in danger, compared to a fully numerical scale that appoints a definite value and ranking to each site, even if they are in similar conditions.

Disturbances to palaeoenvironmental sites can be either anthropogenic or natural. Anthropogenic disturbances were categorised based on the main types observed in the Endangered Archaeology in Middle East and North Africa (EAMENA) database (Flohr, 2017), a database that documents archaeological sites in the Middle East and North Africa (MENA) region using satellite imagery. Quarrying was added as an additional type of disturbance, as many palaeoenvironmental records have been collected from quarries (Atkinson et al., 2012; Herrmann et al., 2012; Parton, Farrant, et al., 2015b).Natural disturbances were categorised based on regional climatic factors and previous literature (AbdelMaksoud et al., 2019). Table 5.3 summarises the categories of disturbances considered. To evaluate the likelihood and severity of natural disturbances, projections and hazard maps were used along with the satellite imageries. For inland flooding, a MENA-scale hazard map (WHO, 2007) and a worldwide hazard map (Dottori et al., 2016) were consulted. For coastal flooding, projections of sea-level rise and annual flooding by 2030 and 2050 (Kulp & Strauss, 2019) were used.

Table 5.3 Types of disturbances towards QP sites considered in this study.

Category	Disturbance Type	Likelihood Criteria
Anthropogenic Disturbance	Agricultural/Pastoral	Null: No recent activity/development observable around the site in the past 5 years Potential: Activity/development within 50m of the site or rapid expansion of activity/development within 200m of the site in the past 5 years Ascertained: Activity/development in the immediate vicinity of the site in the past 3 years
	Infrastructure/Transport	
	Industrial/Productive	
	Development (Construction, Urban Sprawl)	
	Quarrying	
Natural Disturbance	Dune Movement	Null: No signs of dunes moving towards the site Potential: Dune movement towards the site is visible Ascertained: Dune movement visible over the site
	Inland Flooding	Null: Site not located in flooding zone in either hazard map Potential: Site located in flooding zone for one hazard map Ascertained: Site located in immediate vicinity of a wadi or in flooding zone of both hazard maps
	Coastal Flooding	Null: Site not located in flooding projections Potential: Site located in annual flooding zone for 2030 or located in flooded zone for 2050 Ascertained: Site located in flooded zone for 2030

Severity is included to account for the differences in the gravity of disturbance based on its consequences. It is categorised into reversible, irreversible, and cumulative. If the outcome of the disturbance can easily be reversed (e.g., site being fenced off and used for pasture, without removal of the original Quaternary sediment), it is considered reversible. On the other hand, if the disturbance leads to permanent damage, or damage that would require considerable effort to reverse (e.g., site becoming a housing complex), it is considered irreversible. Cumulative disturbance refers to disturbance that occurs continuously or intermittently (Pedersoli Jr et al., 2016), and it is relevant for natural disturbances, such as dune movement and annual flooding, in this study. Irreversible threats are considered the most severe threat, but the threat levels of reversible and cumulative threats are not ranked at the categorical level.

The likelihood considers the probability of the disturbance occurring. It is categorised as null, ascertained, or potential, following the assessment of World Heritage in Danger

(UNESCO, 2021a). Each category of disturbance is listed with the criteria of likelihood, which is split into three categories, null, potential, and ascertained. Firstly, if a site meets the null criterion, it is considered that there is no evidence of that type of disturbance towards that site. Secondly, if a site meets the potential criterion, it means that a possibility for disturbance towards a site is detected, but at a lower certainty or in a longer timeframe. Finally, if a site meets the ascertained criteria, disturbance to the site is expected. For anthropogenic threat, a site would be placed into this category when the disturbance is likely to occur in the next 3–5 years based on its trajectory of development. This judgement will be made by analysing satellite imagery from previous years. The 3-to-5-year span is based on the definition of threat in the EAMENA database (Flohr, 2017).

Each disturbance is summarised by combining its severity and its likelihood (e.g. irreversible ascertained, cumulative potential). The most severe level of the disturbance towards a site is used as its overall endangerment level unless it faces no observable disturbance or is already destroyed. For example, if a site faces irreversible ascertained danger due to development and cumulative potential danger due to coastal flooding, the overall endangerment level of the site will be represented as irreversible ascertained danger.

5.4.3 Geocultural Database of Southeast Arabia

5.4.3.1 Compiling the database

The collected data were compiled into an open-source database which is hosted at a free internet Cloud service for PostgreSQL databases. Instructions on how to access the database are included in Appendix C. It is most easily accessed via QGIS, which is a free

GIS software, and it has been designed for use by anyone with basic skills in GIS software. GDSA was compiled to serve two purposes:

To provide a publicly available catalogue of palaeoenvironmental archives of South-east Arabia and their endangerment status.

To provide a search engine that enables researchers to efficiently find relevant palaeoenvironmental and archaeological data from past research.

To serve these purposes, PostGIS was selected as the platform for this database. PostGIS is an extension of the PostgreSQL system, designed to process and analyse geospatial data (Hsu & Obe, 2021). PostGIS was deemed appropriate for this project as it can retrieve specified subsets of data chronologically and geographically using queries written with simple SQL code and can be disseminated easily without cost. The use of Arches Heritage Inventory and Management System, an open-source software platform designed for creating inventories of cultural heritage, used in many endangered archaeology databases was also considered (Myers et al., 2016). However, its enterprise-level requirement for upkeep and maintenance was considered inappropriate for this stage of the project.

5.4.3.2 Search functions

To facilitate the use of the query function of the database, template queries for anticipated uses of the database by researchers were created using the PostgreSQL coding language and included in Appendix A. With these template functions, users without knowledge of the PostgreSQL coding language can take advantage of the query functions, just by specifying the details (e.g., chronological range, MIS,

palaeoenvironmental/archaeological site of interest, radius, etc.), as guided by the instruction. Additional queries can be added to respond to the users' demands.

5.4.3.3 Additional analysis

To analyse the geographical distribution of sites and records in the database, spatial data that are not included in the GDSA have been used. First, Woor et al.'s map (2022) of the geomorphological sub-regions of Arabia (modified to include an Arabian Gulf Coast region) was added to analyse geographical distribution trends beyond legislative regions. This map enables a broad geomorphological and physiographic categorisation of the region and includes sub-regions such as the Arabian Sea Coast, the Arabian Gulf Coast, the Hajar Mountains, Northern Rub'al Khali (sub-coastal dune fields), Rub'al Khali (interior dune fields), and South Arabia (around the Hadramawt Plateau). In addition, shapefiles on roads in the region, from the open database provided by Humanitarian OpenStreetMaps were used to conduct an analysis of the accessibility of QP sites. The proximity of QP sites to roads was analysed using buffers from roads. Finally, the location of potential geoparks in Oman, proposed by (Searle, 2014), was used to consider the development of regional geoparks that combine QP sites with other geoheritage sites.

5.5 Results

5.5.1 Overview of the database

One thousand seventy-three chronological dates from 234 QP sites and 743 archaeological sites (44 with radiocarbon dated artefacts) currently form the GDSA, as shown in Figures 5.3 and 5.4. The publication years of QP studies range from 1988 to 2022, with a rapid increase in the number of publications after 2001, whereas

archaeological studies were published between 1994 and 2022, without a clear trend of increase or decrease. Eleven QP sites are located within protected natural areas.

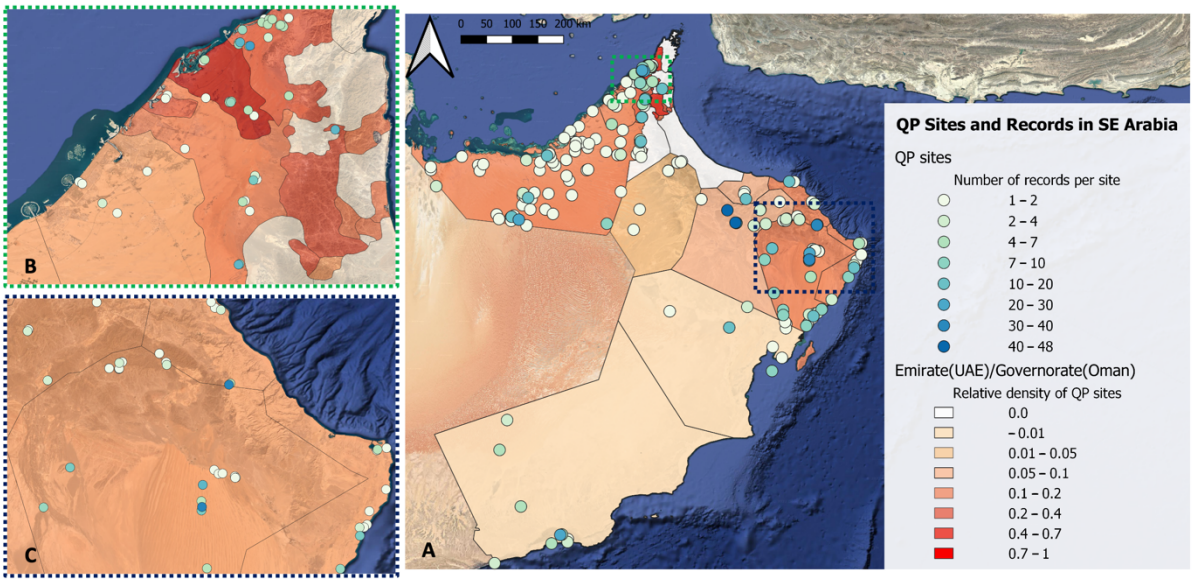


*Figure 5.3 (**A**) QP sites in southeast Arabia with an indication of the number of chronological records per site. The shaded background represents the relative density of QP sites per emirate/governorate. (**B**) An insert of northeast UAE, an area with a high concentration of endangered QP sites. (**C**) An insert of northeast Oman, an area with a high concentration of endangered QP sites.*

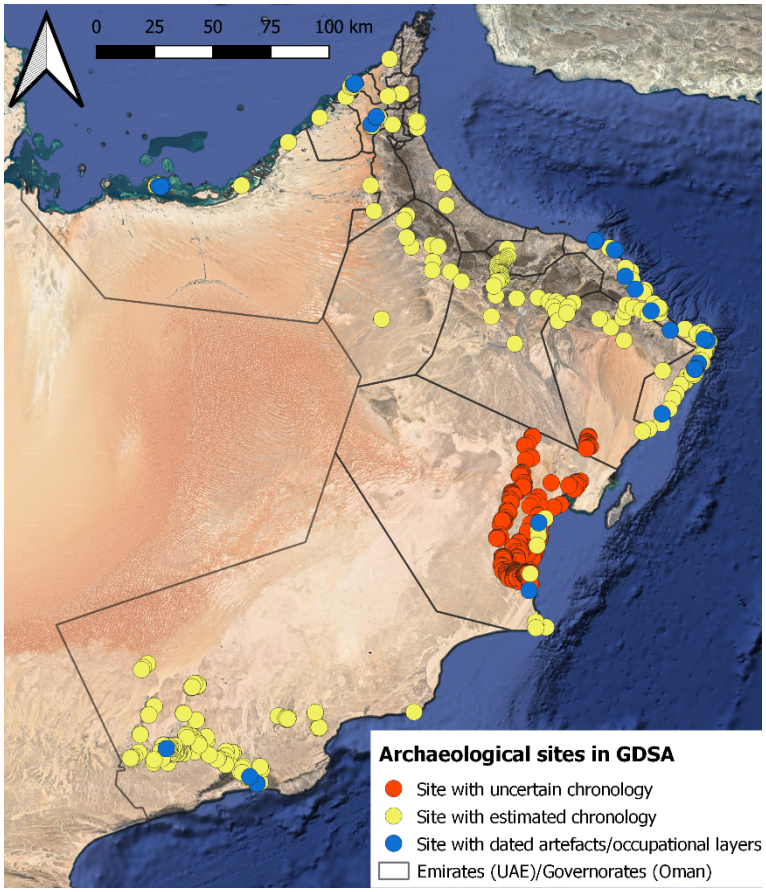


Figure 5.4 Archaeological sites included in the GDSA and the precision of the chronology at each site.

5.5.2 Endangerment assessment

Analysis of satellite imagery enabled an analysis of the overall conditions of QP sites in southeast Arabia. Of the QP sites, 31 (13%) have been found to be destroyed, and 34 sites (15%) have been marked as under ascertained danger of destruction. Of the 31 destroyed sites, 3 are in Oman, whereas 28 are in the UAE. Conversely, no signs of threat were observed at 103 (47%) sites, and five sites were located within protected areas. In many cases, destroyed sites demonstrate clear signs of destruction, as shown in Figure 5.5.

As detailed in Figure 5.6, urban development and infrastructure development are the most prevalent causes of destruction for QP sites in southeast Arabia, as these two threats are the causes for 13 and 8 sites being destroyed, respectively. Other causes of destroyed sites

include quarrying (five sites), agriculture (four sites), and industrial productive activities (one site).

Of the sites under ascertained danger, 11 sites are under irreversible threat, 1 site is under reversible threat, and 25 sites are under continuous threat. Three sites face both irreversible and continuous ascertained danger. Of the 11 sites under irreversible ascertained danger, 9 are in the UAE and 2 are in Oman, with the most prevalent causes being development and quarrying, with 4 sites each.

For potential danger, sea level rise is the most prevalent cause, with 15 sites under irreversible threat, meaning they are projected to be under water permanently by 2050, while 12 sites are under continuous threat, meaning they may be in danger of being underwater during seasonal floods. It is closely followed by inland flooding, with 20 sites under ascertained danger and 6 sites under potential danger. Sea level rise and inland flooding are two of the most common types of disturbance in the database.

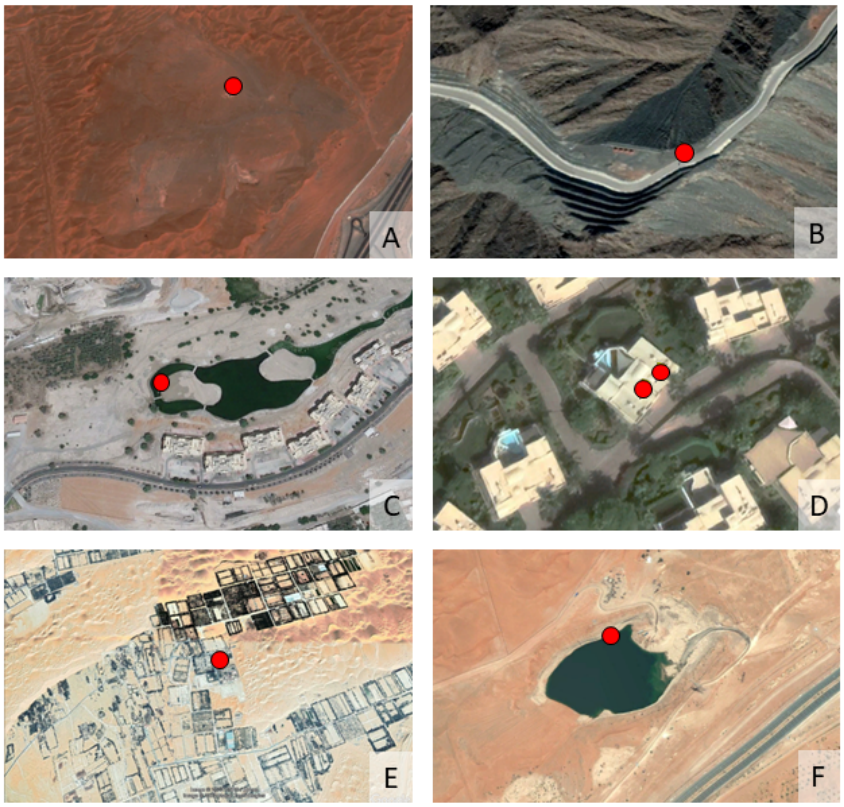


*Figure 5.5 A composite of destroyed QP sites in Oman and the UAE (images from Google Earth): (**A**) outcrop from Atkinson et al. (2011) destroyed by quarrying activities; (**B**) travertine site from Kelemen et al. (2008) destroyed by the development of a road; (**C**) Hili Formation gravel site from Stokes et al. (nd). destroyed by construction of an artificial water body; (**D**) coastal dune sites from Stokes et al. (nd) destroyed by housing development; (**E**) sub-sabkha dune site from Juyal et al. (1998) destroyed by agricultural development; (**F**) aeolian and fluvial site from Parton et al. (2015) turned into wastewater disposal site.*

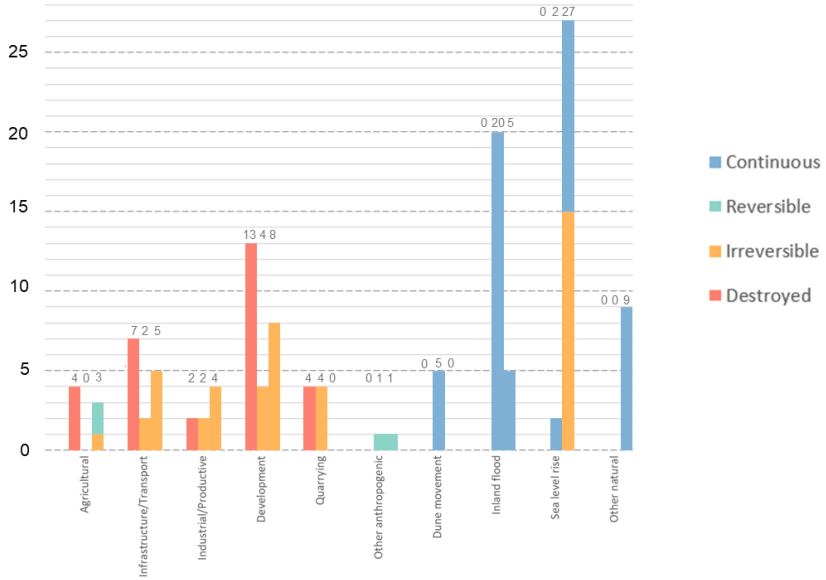


Figure 5.6 Types and gravity of threat towards QP sites in southeast Arabia. The three bars for each type of threat represent different levels of its likelihood: the left bar indicates sites already destroyed, the centre bar indicates sites under ascertained danger, and the right bar indicates sites under potential danger. The colour of the bar indicates the severity of the threat, as shown in the legend. Numbers on top of each stacked bar demonstrate the total number of sites in each threat type and likelihood category.

5.6 Discussion

5.6.1 Threats towards QP sites

Compared to archaeological sites in the MENA region, as recorded by the EAMENA project, QP sites southeast Arabia demonstrate a greater proportion of disturbance and a different distribution in the type of threats. As of 2016, of the 180,000 sites registered in the EAMENA database, about 10% of them have been recorded as disturbed (Bewley et al., 2016), which is less than the proportion of QP sites recorded as destroyed in the GDSA, which is at 13%. Although sites in the two databases cannot be compared directly, due to differences in the methodology and the sample size, it could be said that QP sites studied in southeast Arabia are under at least as high a level of threat as archaeological sites in the MENA region.

In the EAMENA database, the five primary disturbance types are agricultural/pastoral, natural, infrastructure, looting, and industrial, with agricultural/pastoral threat affecting more than twice the number of sites disturbed by any single other type (Flohr, 2017). On the other hand, natural threat (i.e., dune movement, inland flood, and sea level rise), development, infrastructure/transport, quarrying, and industrial/productive are the five most common threat types in the GDSA. The relative abundance of sites under natural threat in the GDSA is most likely due to a combination of the coastal setting of sites, focus on water-related landscapes of QP research (e.g. wetlands, lakes, alluvial/fluvial systems), and the longer-term projection used for assessing natural threats. For anthropogenic threats, QP sites demonstrate a much higher level of endangerment due to development, infrastructure/transport, and quarrying, while demonstrating a lower level of impact from agriculture/pastoral activities. A possible reason for this difference

could be the faster pace of economic development in southeast Arabia compared to the rest of the MENA region, leading to more disturbances related to the secondary sector of the economy. Furthermore, the impact of quarrying must be noted and considered as a prevalent threat specific to QP sites. For QP sites, quarrying is the third most frequent anthropogenic cause for both destroyed and threatened statuses, whereas for archaeological sites in the EAMENA database, it is only the 11th most common cause of disturbance (Bewley et al., 2016).

5.6.2 Geographical and disturbance type trends

As can be seen in Figure 5.3, there is a similar number of QP sites in the UAE (119 sites, 51%) and in Oman (115 sites, 40%). Despite the slightly lower number of sites, the number of chronological records from Oman (618 records, 58%) exceeds that from the UAE (455 records, 42%). For archaeological sites, 94% of registered sites are in Oman. This is mostly due to the publication of large-scale surveys in Oman such as the Central Oman Palaeolithic Survey (Pümpin, 2010). As archaeological sites without clear published indications of their location are currently not included in the database, the addition of such sites could change this distribution trend.

QP sites are concentrated in certain legislative regions (i.e., in the UAE, individual emirates; in Oman, regional governates). In the UAE, Abu Dhabi, the largest emirate with mostly Quaternary surface geology, hosts the highest number of recorded QP sites (n=71), although the highest concentration of recorded QP sites per square kilometre is in Umm Al Quwain. In Oman, the highest number of recorded sites is in Ash Sharqiyah North (n=40), while the highest concentration was found in Muscat, although the concentration is less than one-fifth of that of Umm Al Quwain, demonstrating that the studied QP sites in Oman are more widely dispersed. On the other hand, no QP sites have

been studied or recorded in Fujairah (UAE), Al Batinah North, Al Buraymi, or Musandam (Oman). The distribution of sites does not seem to depend on the rural–urban classification, as 60% of the sites are located more than 50 km away from the centre of the 10 largest cities in either country, and 35% of sites are more than 100 km away.

On the other hand, proximity to roads has been identified as a strong influencing factor for the location of sites. Eighty-one sites (35%) are located within 200 m of major roads, along with 135 sites (58%) within 500 m, and 189 sites (81%) within 2 km, demonstrating that accessibility by car is a major factor in the location of QP research in southeast Arabia. Proximity to roads also helps us understand the characteristics of QP sites under threat, as a much higher proportion of destroyed sites are in proximity to major roads (and, therefore, an increased likelihood of development), with 55% within 200 m, 87% within 500 m and 94% within 2 km.

Another trend for sites under threat can be found when considering their geomorphological regions. As shown in Figure 5.7, destroyed sites are concentrated in three of the eight geomorphological regions: Northern Rub'al Khali (n=13), Arabian Gulf Coast (n=11), and Hajar Mountains (n=7). The ratio of the number of QP sites in the Hajar Mountains region (n = 66, 28%) is proportionate with the ratio of destroyed sites (n = 7, 23%). On the other hand, although the sites in Northern Rub'al Khali (n=67) and Arabian Gulf Coast (n=41) make up 46% of all sites, these two regions host 77% of all destroyed sites. In addition, these two regions host 9 of the 11 sites (82%) under irreversible ascertained danger, demonstrating the highest need for conservation efforts. The endangerment of QP sites in the Arabian Gulf Coast is especially noticeable, with 71% of the sites in this geomorphological region considered to be under some level of endangerment.

Furthermore, an analysis of the cause of endangerment reveals that QP sites in each of these three geomorphological regions demonstrate distinct patterns. In the Arabian Gulf Coast, development and expansion of cities endanger QP sites, with development and infrastructure causing the destruction of nine sites and two sites, respectively. Descriptions of the cause of destruction include the construction of housing and the construction of man-made water features. In fact, all 11 destroyed sites are located within 25 km from the centre of the 10 largest cities in the UAE, such as Abu Dhabi, Sharjah, and Dubai, and 8 of them are within 10 km.

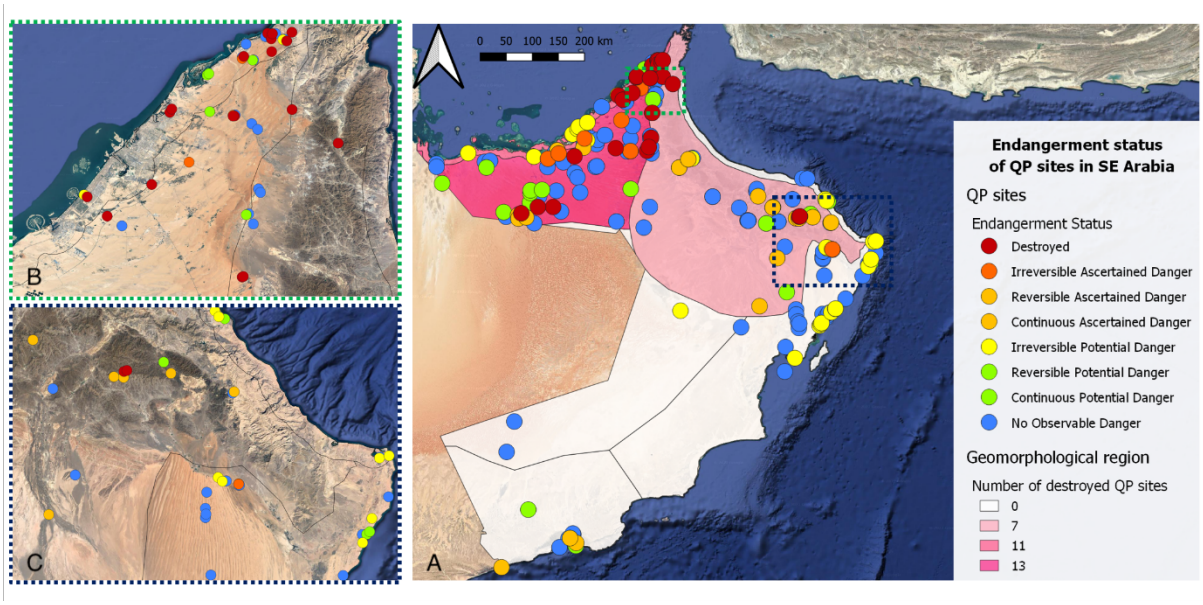


*Figure 5.7 **(A)**: The endangerment status of QP sites in southeast Arabia. The base layer represents the number of destroyed sites in each geomorphological region. (**B**): Insert of an area in northeast UAE with a high concentration of endangered sites. (**C**): Insert of an area in northeast Oman with a high concentration of endangered sites.*

In the Hajar Mountains region, destruction of QP sites has mostly been due to the development of roads (n=5) with some housing development (n=2). With only two sites within 50 km from the centre of the 10 largest cities in either UAE or Oman, urban development does not explain the destruction of QP sites in this region. Beyond destroyed sites, there are no sites with irreversible ascertained danger in the Hajar

Mountains region, but this region has the highest number of continuous ascertained danger (n=13), due to the number of sites located within fluvial settings to study the chronology of hydrological processes in the area.

Finally, QP sites in the Northern Rub'al Khali region face the widest variety of threats. The two primary causes of destroyed QP sites in this region are quarrying (n=5) and agriculture (n=4). These two types of threats are almost exclusive to this geomorphological region at all levels of endangerment. All eight sites under threat or destroyed by quarrying are in this region, as well six out of seven sites endangered due to agriculture. In this region, quarrying activities provide materials such as rocks for land reclamation and aggregate for construction. Geographically, four of the five sites destroyed by quarrying are located within 20 km of the Arabian Gulf coast, where the largest cities are concentrated. Sites under irreversible ascertained threat due to quarrying are located further away from the coast, but with further economic development without conservation efforts, they will most likely be disturbed and lost. On the other hand, sites destroyed due to agriculture are located either in the Liwa Oasis (n=3) or the Al Ain Oasis (n=1), where arable land is limited.

Overall, although the location of the QP sites in southeast Arabia does not seem to depend on the proximity to large urban areas, QP sites that are destroyed or are under irreversible threat are concentrated in urban areas or are related to industrial activities related to urban development (e.g. quarrying).

5.6.3 Landform trends

The number of QP sites recorded from each type of landform is outlined in Figure 5.8 (some sites include records from more than one landform). With 108 sites (43%), aeolian records are the most common type of landform features represented in the database

followed by springs (n=46, 18%) and fluvial (n=40, 16%) records. Sites with aeolian records have been destroyed the most, at 16 sites. This could be because aeolian sites are also the most common type of chronological records in the database. Aeolian QP sites, however, are prone to quarrying. All eight QP sites in the database disturbed by quarrying contain aeolian records of which four have been destroyed. At the sites destroyed by quarrying, satellite imagery shows the presence of cross sections suitable for palaeoenvironmental studies at some point over the last 20 years. In these cases, it is likely that the cause of the destruction of the site was the intervention that enabled the data to be collected in the first place. A similar trend can be observed in analysing the cause of destruction for QP sites with fluvial records. QP sites with fluvial records represent 24% of destroyed sites, although they are only found in 16% of sites in the database. This relatively high representation indicates that fluvial QP sites are more prone to disturbance than other types of sites. This could be attributed to the fact that sand and gravel present at fluvial QP sites are often quarried for aggregates and is evidenced by the fact that 4 out of 10 destroyed fluvial QP sites were destroyed due to quarrying.

Conversely, spring sites and mangrove sites in the database are less prone to disturbance. For spring sites, only 3 out of 46 sites have been destroyed and most ascertained and potential dangers are natural threats due to proximity to water sources. The relative lack of anthropogenic threat towards these sites is likely because most of these sites are located in the Hajar Mountains, away from large urban areas, and because they are often too small for economic activities such as mineral extraction. For mangrove sites, 1 out of 16 sites has been destroyed, and none face irreversible ascertained danger. As 4 of these 16 sites are designated under protection, this result could be considered as

an outcome of nature conservation efforts in this region since mangroves often benefit from ecological/biodiversity protective measures (Al-Afifi, 2018; Alsumaiti et al., 2017).

On the other hand, for coastal sabkha sites, although none of the nine sites are destroyed or under irreversible ascertained danger according to the criteria of this study, it has been reported that in the UAE, only 36% of the Abu Dhabi Sabkha has remained undisturbed since the 1960s (Lokier, 2013). This discrepancy demonstrates the limitation of the GDSA, as the sites recorded in this database are only sites documented by published sources and analyses of the changes only cover the last 20 years. To analyse larger areas or a longer timescale, it is necessary to combine the GDSA with other sources and/or field observations.

Of the less common types of landforms, some, such as palaeosols (two out of four), shorelines (two out of four), and wetlands (two out of six), have been destroyed proportionately more than others. However, due to the small sample size and the lack of a clear trend in the destruction cause or geographical location, it is unclear whether these sites face (or have faced) a greater level of threat than other types of sites.

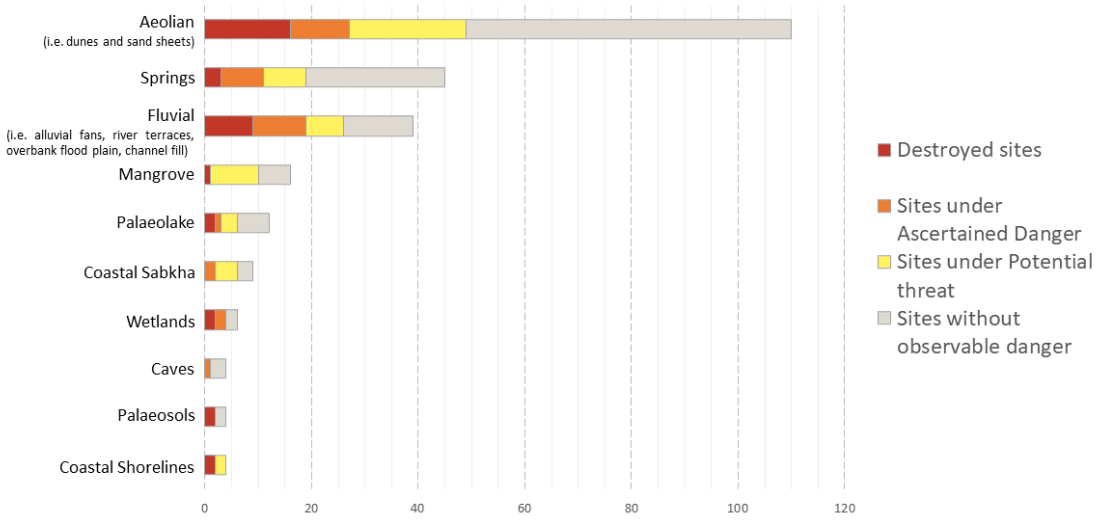


Figure 5.8 Endangerment status of QP sites in southeast Arabia per landform type

5.7 Applications

5.7.1 Use of the database for archaeologists and palaeoenvironmental scientists

The strength of the GDSA database is that it is publicly available, and it allows both chronological and geographical analysis of QP data simultaneously. Furthermore, it allows an analysis not only of QP sites, but also of regional archaeological sites. Archaeologists, on the other side, can use the database to analyse the relationship between their archaeological site of interest and the regional palaeoenvironment. Furthermore, this database can be used in secondary or tertiary education for students studying geography, Earth sciences, and archaeology. The database will be updated on demand when provided with new data, and annually to include newly published data.

As shown in Figure 5.9, the database can demonstrate regional climatic transitions among marine isotope stages using data obtained from QP sites and the corresponding archaeological sites. Although Figure 5.9A shows MISs that are considered “wet”, and

Figure 5.9B shows MISs that are considered “dry” at the scale of the entire Arabian Peninsula, the palaeoenvironmental from this region do not always correspond with this general trend. Instead, they demonstrate the spatio-temporal variability of climatic conditions within the region, reiterating the results of recent studies (e.g. Bretzke et al., 2022; Woor et al., 2022) that show evidence of increased sub-regional scale precipitation, humidity, or water resources even in the supposedly dry periods. Furthermore, the database also provides a useful synthesis of a site’s scientific attributes. As shown in Figure 5.10, all information regarding the record, such as the source, chronology, and data type, can be included in the attribute table of the maps, and be accessed with a few clicks. Researchers can use this database as a starting point to analyse their new data, to gain an overview of the regional palaeoenvironment, or to prioritise sites and/or regions on which to focus research.

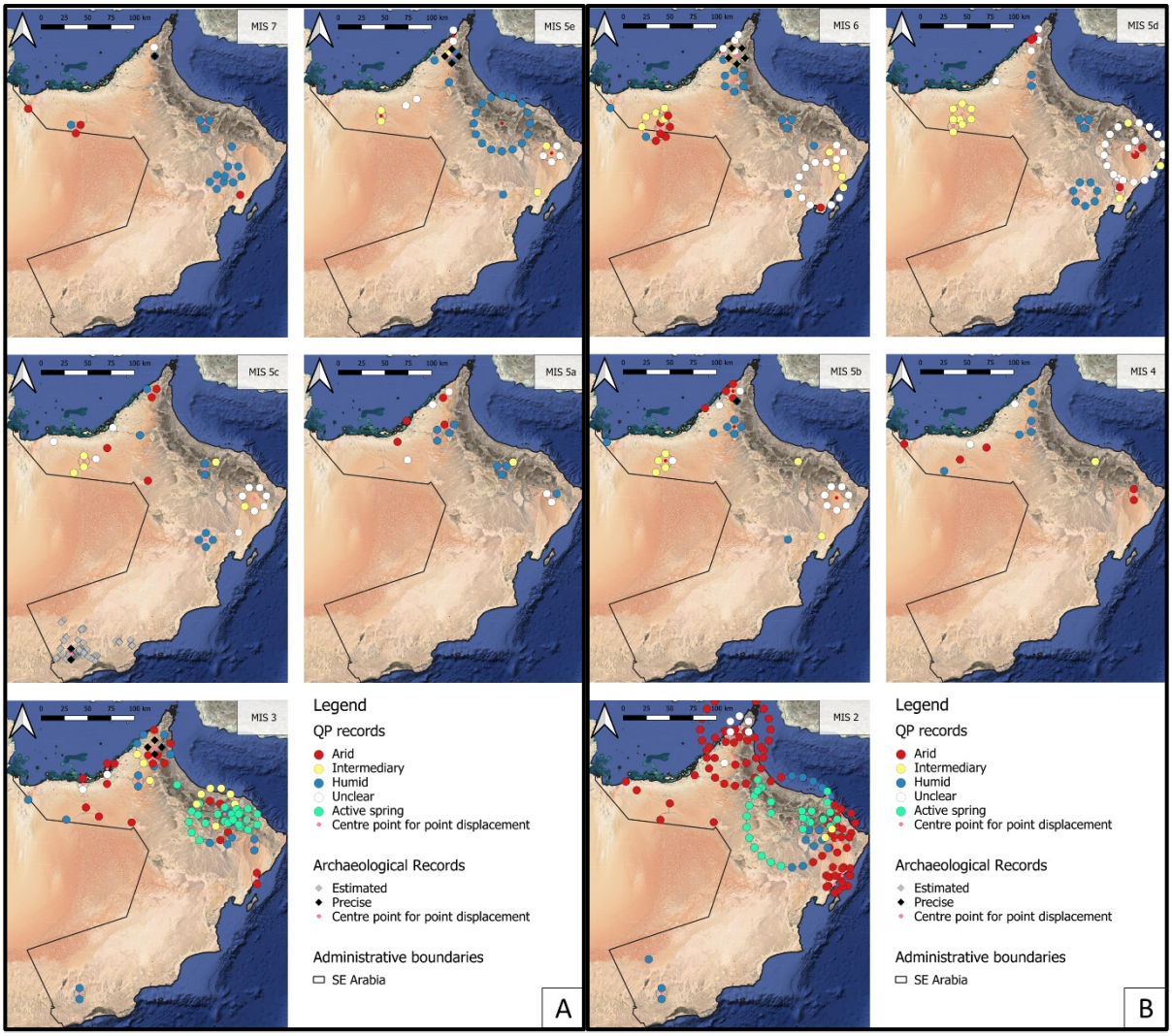


*Figure 5.9 Maps demonstrating QP sites and archaeological sites in southeast Arabia dated to MIS 7 to MIS 2. Point displacement is applied on the map to demonstrate multiple records from the same site. (**A**) MISs that are generally considered "wet"; (**B**): MISs that are generally considered "dry".*

	recordid	source_summary	type	agebp	igma_sta	igma_en	osl_error	climatic_implications	landform_type	record_information	mis	easting	northing
1	140	Blechschmidt et al. (2009)	OSL	233000	NULL	NULL	26000	Humid	Fluvial	Alluvial Fan sands	MIS7	57.718457	21.330856
2	141	Blechschmidt et al. (2009)	OSL	232000	NULL	NULL	21000	Humid	Fluvial	Alluvial Fan sands	MIS7	57.718457	21.330856
3	142	Blechschmidt et al. (2009)	OSL	225000	NULL	NULL	22000	Humid	Fluvial	Alluvial Fan sands	MIS7	57.718457	21.330856
4	143	Blechschmidt et al. (2009)	OSL	214000	NULL	NULL	19000	Humid	Fluvial	Alluvial Fan sands	MIS7	57.718457	21.330856
5	157	Blechschmidt et al. (2009)	OSL	229000	NULL	NULL	37000	Humid	Fluvial	Alluvial Fan sands	MIS7	58.206772	21.582674
6	158	Blechschmidt et al. (2009)	OSL	227000	NULL	NULL	27000	Humid	Fluvial	Alluvial Fan sands	MIS7	58.206772	21.582674
7	159	Blechschmidt et al. (2009)	OSL	220000	NULL	NULL	24000	Humid	Fluvial	Alluvial Fan sands	MIS7	58.206772	21.582674
8	160	Blechschmidt et al. (2009)	OSL	213000	NULL	NULL	46000	Humid	Fluvial	Alluvial Fan sands	MIS7	58.206772	21.582674
9	161	Blechschmidt et al. (2009)	OSL	194000	NULL	NULL	18000	Humid	Fluvial	Alluvial Fan sands	MIS7	58.206772	21.582674
10	976	Bretzke et al. (2022)	OSL	212000	NULL	NULL	19000	Humid	NULL	Occupational layer	MIS7	55.847519	25.118808
11	412	Goodall (1995) in Glennie a...	OSL	208000	NULL	NULL	21000	Arid	Aeolian	Aeolian beneath duricrust	MIS7	52.033333	23.533333
12	449	Immenhauser et al. (2007)	U-Th	212402	NULL	NULL	NULL	Humid	Caves	NULL	MIS7	58.171986	22.397347
13	467	Juyal et al. (1998) in Glenni...	IRSL	229000	NULL	NULL	19000	Arid	Aeolian	Aeolianite (miliolite)	MIS7	58.423181	20.940241
14	881	Stokes and Bray (2005)	OSL	209000	NULL	NULL	16000	Arid	Aeolian	Madinat Zayed Fm (Megabarchan)	MIS7	53.411389	22.976944
15	894	Stokes and Bray (2005)	OSL	188000	NULL	NULL	18000	Arid	Aeolian	Madinat Zayed Fm (Megabarchan)	MIS7	53.542222	22.922778
16	944	Stokes et al. unpubl.	OSL	193110	NULL	NULL	30750	Unclear	Palaeosols	Hili Fm	MIS7	55.827234	25.388445
17	966	Wood et al. (2003)	OSL	195000	NULL	NULL	27000	Humid	Fluvial	Palaeo interdunal sabkha - HUMID?	MIS7	53.453791	22.996758

Figure 5.10 Attribute table of QP records in southeast Arabia from MIS 7 obtained from the GDSA. All mentioned references are Blechschmidt et al. (2009), Goodall (1995) in Glennie and Sighvi (2002), Immenhauser et al. (2007), Juyal et al. (1998) in Glennie and Singhvi (2002), Stoke and Bray (2005), Stokes et al. (nd), Wood et al. (2003), Bretzke et al. (2022), and Fleitmann et al. (2003).

5.7.2 Case study: relating archaeological records and QP records at Jebel Faya, UAE

Jebel Faya, a site with the oldest evidence of human occupation beyond the Levant, is a rockshelter site located in the interior of the Emirate of Sharjah, with evidence of human occupation at around 210 ka (MIS 7), 170 ka (MIS 6), 135–120 ka (MIS 5e), 95 ka (MIS 5b), and 10–6 ka (MIS 1) (Armitage et al., 2011; Bretzke et al., 2022). This site has been occupied by humans due to its favourable geographical setting within a large alluvial plain situated between the mountains and the coast. The evidence of settlement at the site, however, indicates intermittent occupation. A hiatus in occupation from ca. 38 to 10 ka BP and possibly for a period after ca. 90 ka BP is evidenced by cultural discontinuities in the finds from each assemblage (Bretzke et al., 2013; Bretzke et al., 2014).

With queries set up alongside the database (see Appendix B for instructions), users can connect chronological data, their geographical location, and attributes such as climatic implications to archaeological records from this site, as shown in Figure 5.11. This figure shows all QP records in the database for which the error range of the chronology overlaps with the chronology archaeological records from Jebel Faya. Each map represents an MIS in which archaeological records from Jebel Fayahave been found. The distribution of QP sites for MIS 7 to MIS 5 is very similar to that of Figure 9 except for the speleothem data from Dominik Fleitmann et al. (2003). This is most likely due to the fact that the resolution of U-Th records in this region (e.g. those from Fleitmann et al. (2003)) is relatively higher than the resolution of OSL records, especially when they are of older periods. Nevertheless, it shows the need for further palaeoenvironmental data from around the archaeological site (particularly for MIS 7) to better understand how the regional climatic setting may have facilitated the occupation of Jebel Faya. For MISs 1 and 3, the map allows a focused analysis of the palaeoenvironmental records related to the Jebel Faya

site, showing a great variability in the regional climate, at periods in which evidence for human occupation is found.

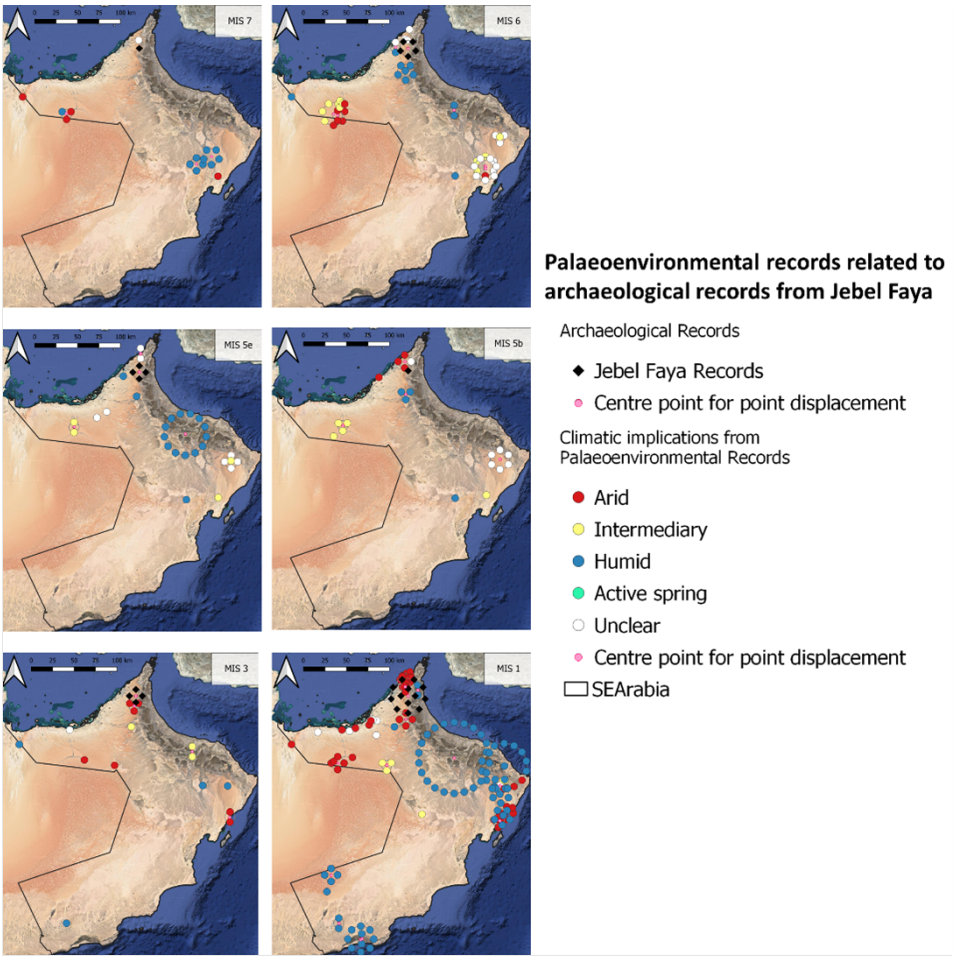


Figure 5.11 Map demonstrating archaeological records from Jebel Faya, UAE, per MIS, with chronologically corresponding QP records. Point displacement is applied to demonstrate multiple records from the same site.

Users can generate these maps and tables for any archaeological site by changing the archaeological area and the timeframe (available in year BP or MIS) of interest. With the queries, users can further filter the data based on attributes such as landform type, geomorphological region, climatic implications, distance from the archaeological site, a and the robustness of the chronology (for QP sites with ages younger than 20,000 BP). These queries facilitate the review of the connections between QP sites and archaeological sites. Similarly, palaeoenvironmental data can be compared to other

palaeoenvironmental records in the database. Instructions for using these functions in the database are available as Appendix B.

5.7.3 Use of the database for geocultural conservation

The catalogue and endangerment status for each QP site in this database provide a baseline for initiating the conservation of QP sites in southeast Arabia. The database can be used as a communication tool with local stakeholders to monitor and flag the destruction of sites, especially those that are under ascertained threat. In this regard, the endangerment status for registered QP sites is planned to be updated next year to remotely track changes in potential threats.

In promoting the conservation of QP sites, those located in quarries present a unique issue. Quarrying activities have provided opportunities for many QP studies (e.g. Atkinson et al., 2011; Parton et al., 2013) by providing human-made cross sections (e.g., through quarry face outcrops) suitable for investigation. For some former mining/quarrying geoheritage sites, such as the Mesel Pit Fossil Site in Germany, extraction activities have been stopped after the discovery of scientific findings (i.e., fossils) (IUCN, 1995), but given the current lack of conservation measures for QP sites, such large interventions could be difficult in the near future. Nevertheless, with an inventory such as this database, a system of reporting similar to one employed in the UK (Burek, 2012), could be created to inform scientists and other stakeholders before destruction takes place, and to enable additional data collection if necessary.

In addition, the database facilitates a geocultural approach in promoting QP sites and other geoheritage sites in the region. By browsing and querying the database, users can easily find locations where archaeological sites and QP sites are concentrated in proximity and analyse the chronological relationship between the two types of sites.

These data, combined with information on other types of regional geoheritage sites such as suggestions for geoparks by (Searle, 2014) can be used to propose potential geoparks in the region, such as the one demonstrated in Figure 5.12. This demarcated area, in the north of Oman in the Hajar Mountains includes archaeological findings from the Late Bronze Age,palaeoenvironmental data from springs between MIS 1 and early MIS 3 and speleothem data ranging from MIS 1 to MIS 11 that can be used to build a story of how the natural environment of the region changed throughout the Late Quaternary. The speleothem data from Al Hoota (or Hoti) Cave (Dominik Fleitmann et al., 2003) are especially important as they provide a continuous high-resolution record of humid periods in this region. As Al Hoota Cave is already protected and developed as a tourist destination (Dowling, 2012) with a museum, it could serve as the central area to explain the entire geopark. Beyond the Quaternary, three geoheritage sites highlighted by (Searle, 2014), Jebel al Akhdar, Jebel Shams, and Jebel Misht with features from the Permian to the Cretacious periods are located within the proposed geopark area. Jebel al Akhdar, in particular, is an important site for the study of Late Cretaceous thrust sheets and Permian–Cretaceous shelf carbonates, and it is suggested as a potential world heritage site by (Searle, 2014). Although primarily focused on the conservation of QP sites, this database can potentially contribute to the advancement of geoheritage conservation as well as archaeological conservation in this region.

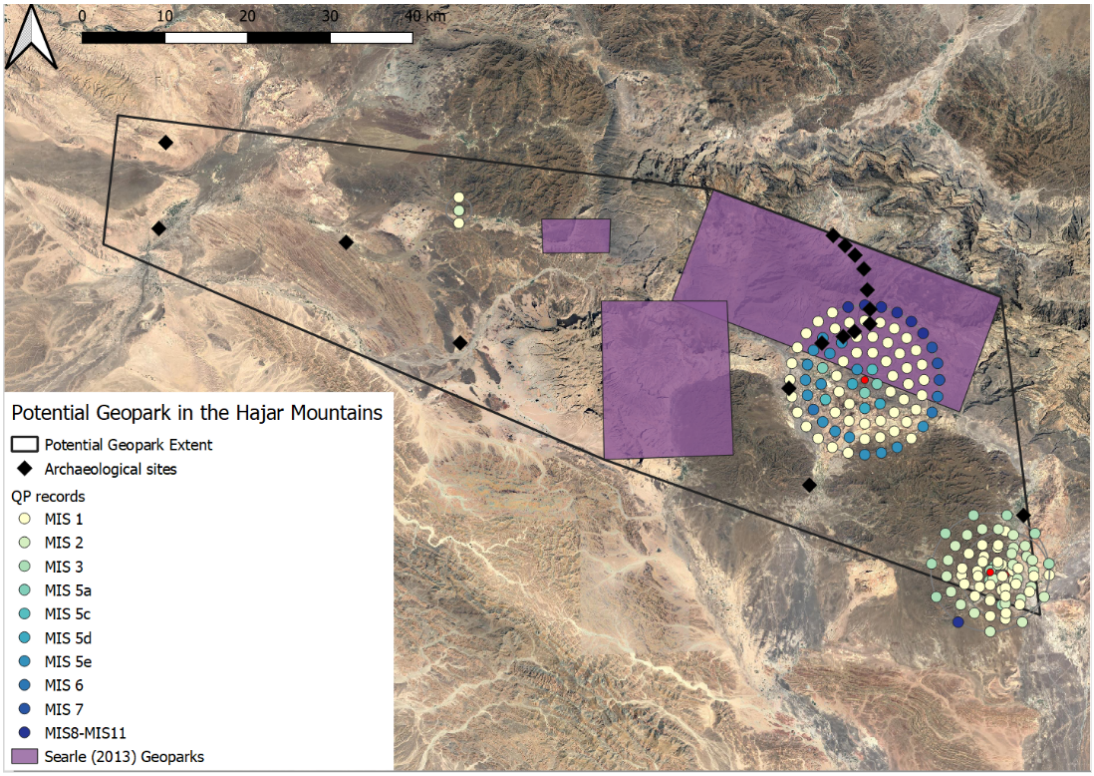


Figure 5.12 Potential area for a future geopark in Oman, in the Hajar Mountains. Point displacement is applied to demonstrate multiple records from the same site.

5.8 Conclusion

Geoconservation is a budding initiative in southeast Arabia and the broader MENA region, but the protection of Quaternary sites has not been a priority in most cases. The GDSA serves as the first step towards a systematic and scientific conservation of QP sites in southeast Arabia. This study showed that an analysis of satellite imagery can provide an adequate assessment of the overall conditions of QP sites, using a methodology adopted from projects targeting archaeological sites in the MENA region (Bewley et al., 2016). A need for protection of these sites is evident, with 13% of QP sites registered in the database found to be destroyed in the last two decades, along with more than 15% of sites considered to be under ascertained danger. Anthropogenic activities related to economic development are the main causes of endangerment for QP sites in this region,

and sites in coastal areas and sites with fluvial landscape-related records face the highest level of endangerment. As economic development continues in this region at a fast pace, monitoring of sites in these higher risk settings should be considered a priority at this stage. Nonetheless, an evaluation of the values of QP sites from different perspectives, such as scientific values, touristic values, and educational values, is required to conduct a rigorous assessment to determine sites that should be prioritised for conservation or sites that are suitable for geotourism development.

The GDSA also functions as an open-access platform for researchers and other interested parties to obtain data on the palaeoenvironment of this region, along with studying their relevance for the regional archaeology. Its unique capability to conduct spatial and chronological analysis simultaneously should facilitate future research in this field, especially when comparing palaeoenvironmental data with archaeological data. The close relationship between the two disciplines, or the geocultural connection, should be explored as a strategy to protect both types of heritage sites.

Section C: Interpretation and Promotion

Chapter 6 Including Cultural Context Improves Communication Outcomes for Quaternary Geoheritage: Evidence from Southeast Arabia*

Submitted as: Sayama, K., Al Rawahi, H., Fahey, R. A., Parker, A. G., Viles, H. Including Cultural Context Improves Communication Outcomes for Quaternary Geoheritage: Evidence from Southeast Arabia

To *Quaternary Science Reviews in July 2024*

Abstract

Effective science communication plays a crucial role in enhancing public understanding of Quaternary science. One potential strategy for advancing public engagement involves highlighting the interconnectedness of Quaternary sites, archaeology, and human culture. Despite the recent increased focus on science communication within the geosciences, the significance and effectiveness of emphasising such geocultural connections in communicating about Quaternary geoheritage sites have rarely been explored in experimental settings.

This study investigates the efficacy of educational videos in communicating the significance of Quaternary geoheritage sites in southeast Arabia. Specifically, it examines the impact of including geocultural context information as a communication strategy. An online experiment was conducted to evaluate the effects of videos produced with input from academics from the region, museum professionals, and heritage officials. The study compares the impact of two different 9-minute videos— one emphasising the geocultural

* Minor changes have been made to this manuscript to aid the readability and continuity within the thesis. For example, the number of the figures and tables have been changed.

context, and the other focusing solely on Quaternary science —on participants' knowledge, interest, and perception of Quaternary geoheritage sites.

In an experiment conducted towards a sample population that is representative of likely targets for geotourism, both videos were found to be effective overall in enhancing participants' self-reported knowledge of Quaternary geoheritage sites and increasing their overall interest. However, the inclusion of geocultural information resulted in improved long-term retention of information and heightened levels of interest, particularly among respondents without a specialist background in this field. Although the geocultural video was less effective as an immediate teaching tool compared to the Quaternary science-focused video, participants exposed to it also reported a stronger sense of the need to protect Quaternary geoheritage sites.

This study advances our understanding of the role of geocultural connections in communicating the importance of Quaternary science and raising awareness of Quaternary geoheritage. By demonstrating the benefits of incorporating information on cultural relevance into communication strategies, the study illustrates how Quaternary scientists and geoheritage practitioners can enhance audience engagement, deepen understanding, and inspire lasting changes in attitudes. These positive findings underscore the necessity for future research to explore the applicability of this concept in various social, cultural, and/or geographical settings.

6.1 Introduction

Quaternary science holds significant relevance for society, with implications for climate change, sea level oscillations, coastal erosion, geohazards, historical biodiversity, and human evolution (Elias, 2007). Furthermore, Quaternary processes have shaped numerous distinctive landscapes, some of which have been protected internationally. According to Boylan (2008), 17% of all World Heritage Sites characterised by geological features predominantly represent Quaternary features, including karstic landscapes (e.g. Plitvice, Croatia), deserts (Lut Desert, Iran), or volcanoes (Hawaii Volcanoes National Park, USA), despite this period only represents 0.057% of Earth's history. However, many geological heritage sites, or geoheritage sites, have been protected (Chylińska, 2019) and visited (Štrba, 2019) for their aesthetic appeal rather than their scientific significance or appreciation, with Quaternary sites being no exception.

In both the World Heritage List (Boylan, 2008) and the Global Geopark Network (Brilha, 2018a), Quaternary sites predominantly feature glacial, karstic, or volcanic formations, aligning the classic definition of natural beauty (Churchward et al., 2013; Mitchell, 2013). Consequently, the communication and promotion of geoheritage sites, particularly concerning their scientific and societal importance, have emerged as crucial agendas (Gordon et al., 2018; Stewart & Nield, 2013).

Recognising the cultural significance of Quaternary sites presents a potential avenue to enhance their appreciation among the general public. This concept, known as geocultural heritage (Kubalíková et al., 2020; Reynard & Giusti, 2018; Sayama et al., 2022), offers alternative pathways for non-experts to connect with these sites. Various studies have explored how specific sites embody interdisciplinary heritage values (Coratza et al., 2016;

Gravis et al., 2017; Kazancı & Lopes, 2022; Mariani & Melis, 2022). However, the practical efficacy of this concept in interpreting and promoting Quaternary geoheritage sites has received limited attention, particularly in terms of input from the relevant publics. By using educational documentary-style videos to introduce Quaternary geoheritage sites to the public in Southeast Arabia (i.e. the UAE and Oman), this study aims to provide data to help advance effective science communication of Quaternary geoheritage and evaluate the utility of the geocultural concept in this process.

6.1.1 Quaternary geoheritage and its cultural dimension

Quaternary geoheritage sites encompass all geological/geomorphological sites whose primary heritage values originate in the Quaternary period (Sayama, 2024). This concept represents a broader interpretation of geomorphosites (sensu Reynard et al., 2009), which confines its definition to sites with aesthetic characteristics. In general, Quaternary geoheritage sites demonstrate three main characteristics (Reynard, 2009; Sayama, 2024). Firstly, Quaternary geoheritage sites are dynamic, as they are strongly influenced by ongoing earth surface processes. These sites offer opportunities for observing current earth dynamics and are relatively susceptible to changes through weathering and other natural processes. Consequently, Quaternary geoheritage sites may undergo transformations in their form, which may not always align with their aesthetic value. Secondly, these sites can exist at various scales, ranging from those covering entire landscapes, such as alluvial plains, to smaller individual features. Finally, many Quaternary geoheritage sites exhibit strong connections with human culture, encompassing archaeological, historical, architectural, and other dimensions. These sites were formed, are forming, or will be formed, concurrently with human history. Given

this synchronicity, Quaternary geoheritage sites can provide geoarchaeological records of the human-environment interactions over time and document the impact of humans on this nature-culture relationship. Moreover, Quaternary geoheritage sites have inspired creative ingenuity in art and cultural traditions, as exemplified by the religious and artistic significance of Mount Fuji, Japan (Chakraborty & Jones, 2018; Oguchi & Oguchi, 2010), or the importance of Holocene meteorite impact craters in Australia for Aboriginal dreamtime stories, some with an oral history dating back approximately 4500 years (Hamacher & Goldsmith, 2013).

Given these distinctions, many geoheritage studies (Erhartič, 2010; Moradi et al., 2021; Pereira & Pereira, 2010; Pereira et al., 2007) have treated Quaternary sites (or geomorphosites) separately from the rest of geoheritage sites. This differentiation is particularly evident in site evaluations, which place added emphasis on encompassing cultural and aesthetic dimensions of Quaternary sites. However, the necessity of such a differentiation is still debated with contradicting outcomes depending on the study. On one hand, Santos et al. (2020) found notable differences in evaluating sites in Brazil and Switzerland between methods for general geoheritage sites and specialised methods for geomorphosites. However, in a similar analysis, Mucivuna et al. (2022) found no significant differences between general and specialised methods, concluding that existing general methods should be used in the future to maintain consistency amongst various studies. In arid environments, Sayama (2024) identified distinctive features when developing a method for the scientific evaluation of Quaternary geoheritage sites, including the consideration of connections with archaeology/anthropology, with greater importance placed on scientific knowledge. Nevertheless, the geocultural dimension of Quaternary sites has not been studied in detail from the perspective of science

communication. Therefore, further investigation is required to understand the importance and utility of different strategies, including the incorporation of the cultural dimension of Quaternary geoheritage sites.

6.1.2 Quaternary geoheritage sites in southeast Arabia

Southeast Arabia is a region with a diverse array of Quaternary landscapes, including alluvial fans (Blechschmidt et al., 2009; Parton, Farrant, et al., 2015a), caves (D. Fleitmann et al., 2003; Immenhauser et al., 2007), palaeolakes (Rosenberg et al., 2012)), sabkhas (Heathcote & King, 1998; Matter et al., 2015), and sand dunes (Atkinson et al., 2013; Goudie et al., 2000; Leighton et al., 2014; Radies et al., 2005). Research conducted at these sites has significantly advanced our understanding of environmental variability during the Quaternary, and its impact on human demographics. Throughout the Quaternary, the landscape of southeast Arabia experienced alternating wetter and drier conditions, corresponding to 100k-year eccentricity (Parker et al., 2004; Rose et al., 2019) and 23k-year precessional cycles (Parton, Farrant, et al., 2015b; Preston et al., 2015). By integrating archaeological and palaeoclimatic data, researchers such as Parker (2009) and Parton, White, et al. (2015) have highlighted the close correspondence between early human settlement and environmental variability in this region. This connection underscores the importance of Quaternary palaeoenvironmental sites not only important as climatic archives but also as geocultural sites with relevance for regional archaeology and culture. This academic recognition of the connection has been acknowledged by various Quaternary scientists (Atkinson et al., 2013; Farrant et al., 2015; Nicholson et al., 2020; Preston et al., 2015; Rosenberg et al., 2012; Zerboni et al., 2020) who cite

archaeological relevance as a primary motivation for conducting their palaeoenvironmental research.

However, only a limited number of studies have considered these Quaternary sites as heritage sites requiring and/or deserving conservation, despite various reports of their loss. A recent inventory of Quaternary palaeoenvironmental sites in this region identified the destruction of 31 out of 234 sites (13%) along with endangerment of 34 sites (15%) (Sayama et al., 2022), primarily due to urban development and quarrying. On the scale of individual sites, Lokier (2013) and Kirkham and Evans (2019) have emphasised the endangerment of the Abu Dhabi Sabkha, UAE, illustrating how recent developments in petroleum and civil engineering activities have damaged over 60% of this landscape with unique heritage values. The loss of Quaternary sites has also been documented in palaeoenvironmental studies, such as those by Atkinson et al. (2011), where sites were destroyed by industrial development (Preston et al., 2015).

6.1.3 Science communication on geoheritage and geosciences

The lack of appreciation of geosciences and geoheritage has been extensively documented from various perspectives. Although recent global initiatives such as the Global Geoparks Network have aimed to promote and protect geoheritage sites, visitors to geoparks often prioritise natural beauty (Štrba, 2019; Zgłobicki & Baran-Zgłobicka, 2013) or the curiosity of exploring new places (Allan et al., 2015; Chrobak et al., 2020; Farsani et al., 2019). On social media, the hashtag “geology” has been used approximately 80% less (617.6 million times) than “physics”, “biology”, or “chemistry” (Zawacki et al., 2022). Even when the media features geosciences, Stewart and Nield (2013) found that topics broadcast on British television were largely limited to a few

popular domains, including palaeontology, volcanology, and seismology, with a range of featured Quaternary topics mainly related to geohazards or archaeology. These findings highlight the clear need for improvement in the public recognition of geosciences, including Quaternary science.

Effective communication strategies have garnered attention and recognition as potential solutions to this apparent "detachment" (Stewart & Nield, 2013, p. 699) from geosciences. As described by Illingworth et al. (2018) and Rodrigues, Castro, et al. (2023), geoscience communication is still at its infancy as an academic field with further need for formalisation and identification of its discipline-specific challenges. Nevertheless, key issues such as the difficulty of understanding deep time (Bowring, 2014; Trend, 2001; Warmold, 2017), unfamiliarity with technical jargon (Kortz et al., 2017; Ren et al., 2013), and the global lack of geosciences education in schools (Melendez et al., 2007; Reis et al., 2014; Subedi et al., 2020), have been identified as hurdles to wider appreciation and understanding of geoheritage sites and geosciences.

Over the last 10–15 years, various creative approaches have been developed to enhance geoscience communication, including information panels (Bruno & Wallace, 2019; Pasquaré Mariotto & Venturini, 2017), 3D models/virtual site visits (Dolphin et al., 2019; Hoblea et al., 2014), animations (Lansigu et al., 2014), poetry (Illingworth, 2023), mobile applications (Cayla, 2014), and dance (Matias et al., 2020). Regardless of the approach, many studies share the common theme of storytelling (Illingworth, 2023; Matias et al., 2020; Migoń & Pijet-Migoń, 2017; Stewart & Nield, 2013; Van Loon et al., 2020), praising its utility in delivering information in ways that connects with the audience cognitively and emotionally (Dahlstrom & Scheufele, 2018).

However, in analysing these initiatives, only a few studies have conducted qualitative or mixed-method assessments of the impacts of interventions. Matias et al. (2020) conducted such an analysis to evaluate the impact of a creative dance programme for elementary school education on coastal geomorphology and hydrology. In this study, more than 60% of the 112 participating students preferred learning science through movement, rather than in conventional settings. Another study by Mani et al. (2016) found a 12–17% improvement in participants' knowledge on volcanic hazard after playing a video game on the topic. These impact assessments demonstrate the potential of geoscience communication but have mostly been limited to evaluating the short-term, immediate effects of the interventions, with no data beyond those collected immediately after the experience. Given the goal of geoscience communication to increase public discussion and attention to geosciences (Illingworth et al., 2018), longer-term assessments are required to capture a more comprehensive picture of the impact of interventions.

6.1.4 Science communication studies using online video

Videos have been used in scientific communication studies across various fields, including ecology (Ruzi et al., 2021), climate science (Ettinger et al., 2021), and medical sciences (Dudley et al., 2023). The preference for using videos stems from several advantages they offer. Firstly, delivering information in person or through videos and other visual media has been found to outperform written text in 15 studies (Dudley et al., 2023). Secondly, videos facilitate enhanced emotional engagement of the audience (Yadav et al., 2011) and easier comprehension through the combination of narration and images (Moreno & Mayer, 1999). For example, in discussing climate science, videos were found

more effective than written text in communicating the consensus amongst scientists that current climate change issues are triggered by anthropogenic activities (Goldberg et al., 2019). Finally, as a method, videos offer the advantage of "making communication visible" (Goldman & McDermott, 2007, p. 112) by capturing and enabling the analysis of the effect of a specific content in a controlled manner, unlike personal communication, which can vary in its delivery.

Recognising the importance of videos in science communication, studies have provided guidelines for developing effective videos. Desired features included visual attractiveness, brevity, engaging content, and consideration of the audience needs and expectations (León & Bourk, 2018). Regarding the length of educational videos, multiple studies (Guo et al., 2014; Kaim et al., 2020; Manasrah et al., 2021) have found the optimum length of videos to be around 6–9 minutes. In Guo et al. (2014), eye-tracking of participants showed that viewers lost attention when videos exceeded nine minutes, with engagement lasting less than 50% of the video's duration. To create an engaging video, Brame (2016) has demonstrated the need for enthusiasm from the narrator, the use of conversational language, and an emphasis on the relevance of the content.

Academically, videos can be used to analyse changes in opinions or knowledge after viewing (Dunn et al., 2020; Kaim et al., 2020), or to compare different communication methods, such as the relative effectiveness of various strategies in communicating a topic to the public. For example, Ettinger et al. (2021) used short videos to compare differences in viewers' reactions to videos with a pessimistic or an optimistic outlook on the trajectory of climate change. In geoscience communication, however, the utility of educational videos has seldom been studied quantitatively. One of the notable exception

is Zawacki et al. (2022), who analysed the relative success of 48 geoscientific Tik Tok videos. This study found that while the most viewed videos were short clips related to news events, longer videos, which received fewer views, garnered the most user engagement. Given the demonstrated efficacy of videos in communicating science and technology, there are further opportunities to test their applicability for geoscientific topics.

6.1.5 Aim of the study

As outlined above, there is a need for further investigation into science communication regarding Quaternary science and Quaternary geoheritage. This study addresses this knowledge gap by analysing reactions to two videos: one that describes Quaternary geoheritage sites of southeast Arabia with their geocultural context, and another that describes the same sites through a solely geoscientific lens. The study aims to explore the effectiveness of using educational videos and incorporating geocultural context in communicating the value of Quaternary geoheritage sites in southeast Arabia, a region where reports of destruction of Quaternary sites have been documented. The study is designed to address three primary objectives. First, it seeks to determine if videos can enhance science communication of Quaternary geoheritage sites in southeast Arabia. Second, it aims to assess how effectively the connections between Quaternary geoheritage sites and local culture (i.e. history and archaeology) can be communicated to the public in this region. Lastly, it aims to investigate whether and to what extent the inclusion of these geocultural connections improves awareness of these sites in terms of knowledge and interest, as well as fostering willingness to protect them.

6.2 Regional setting

Southeast Arabia (Figure 6.1) is situated within the arid subtropical climate belt, spanning approximately 16°4′ N and 26°4′ N, with the Rub'al Khali Desert to the west and the Hajar Mountains to the east. Presently, the climate of this region is hyper-arid, characterised by an annual rainfall of less than 100 mm in most areas, except for the area around the Hajar Mountains, where it can reach up to 400 mm (Kwarteng et al., 2009). Rainfall primarily occurs during the winter across much of the region, facilitated by mechanisms such as convective rainstorms, tropical cyclones, cold frontal troughs, and southwesterly monsoons. In southern Oman, however, precipitation occurs as monsoon rainfall during the summer months (Hoffmann et al., 2016). Geologically, Quaternary deposits cover approximately 44% of the land surface (Figure 6.1). The types of Quaternary landscapes in the region include aeolian (57%), alluvium and gravel (24%), fluvial (14%), sabkha (5%), and others (>0.1%). The Rub'al Khali and the Wahiba sands are the primary areas covered by aeolian sediments in this region.

Socioeconomically, both UAE and Oman have undergone significant major economic development over the past two decades, with GDP growth exceeding 300%, driven by the expansion of the oil industry (Pirlea, 2023a, 2023b). The economy of the region is supported by a high percentage of migrant population, standing at 41.1% in Oman and 88.4% in the UAE as of 2015 (United Nations Population Division, 2024). This economic growth has led to an improvement in educational standards in the region, with 19.1% and 47.2% of the population above age 25 attaining a Bachelor's degree in Oman (2022) and the UAE (2021), respectively (World Bank, 2023). However, opportunities for geosciences education are rather limited. In the UAE, Earth and Space Sciences are taught up to the

8th grade (13-year-old) (Al Ghfeli, 2016), but are not offered as a science elective beyond the 11th grade (16-year-old) (Ministry of Education, 2023). At the tertiary level, only three universities offer courses in geosciences. Similarly, in Oman, while environmental and natural resources are included in science education goals, geosciences are not taught at the primary or secondary levels (Ambusaidi & Al-Balushi, 2015), and only two universities offer related courses at the tertiary level.

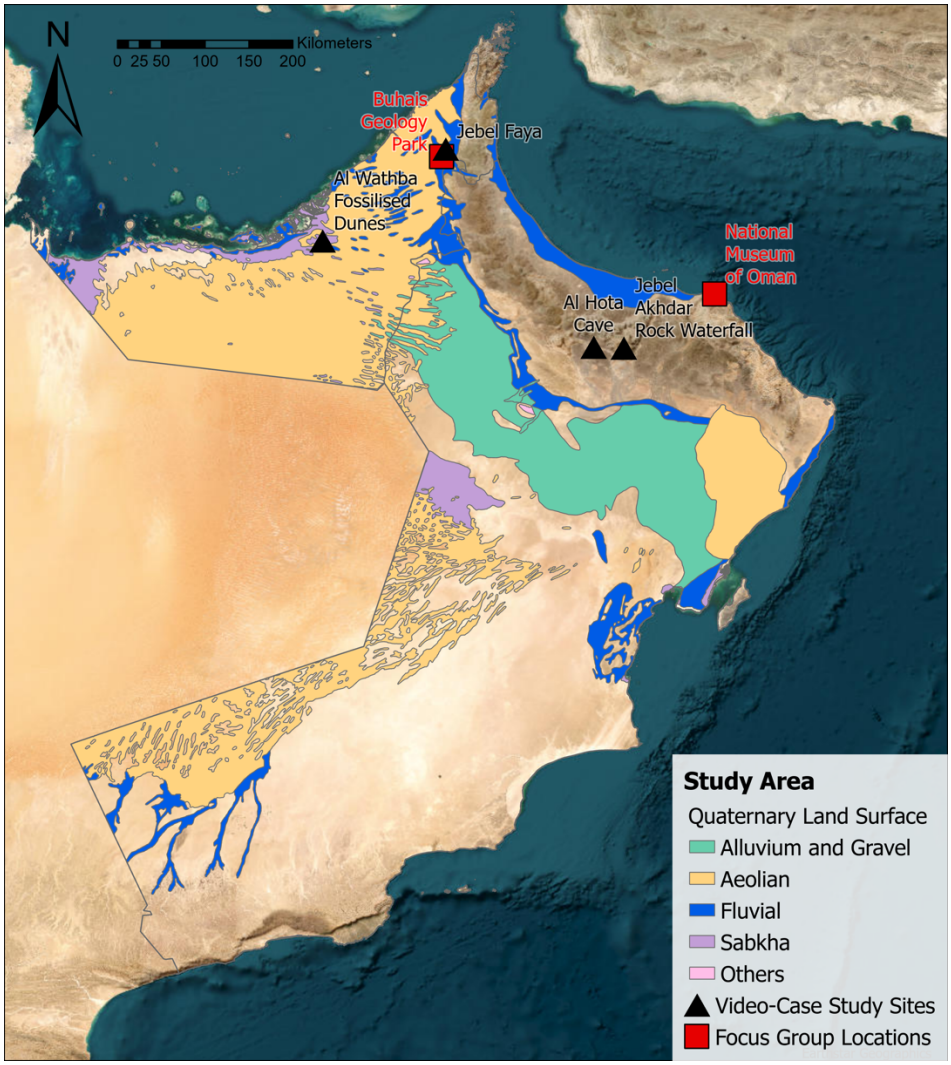


Figure 6.1 A map of southeast Arabia with Quaternary land surface characteristics, locations for case study sites on the videos, and locations where focus groups were conducted. Geological data derived from Pollastro et al. (1999).

6.3 Methodology

To conduct a study on Quaternary geoheritage sites in southeast Arabia using carefully produced videos that align with the audience's needs and expectations, a three-phase approach was formulated and executed between November 2022 to January 2024, as illustrated in Figure 6.2.

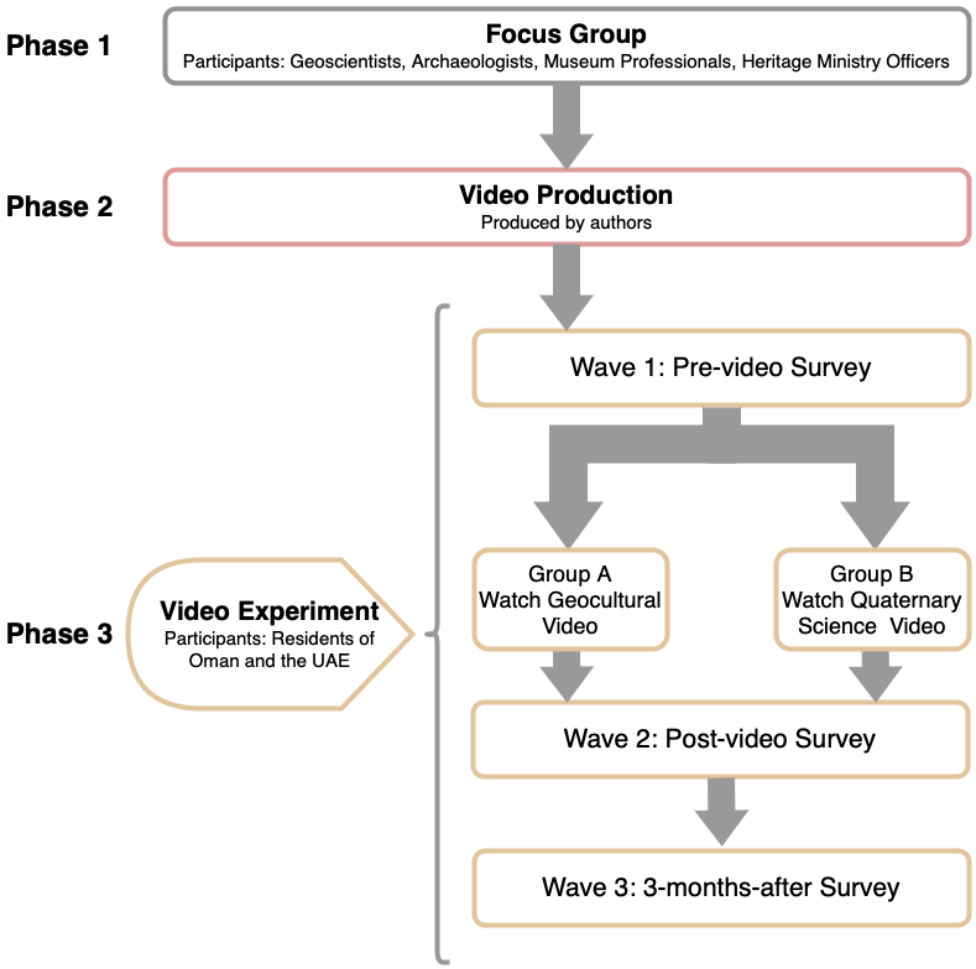


Figure 6.2 Flow chart describing the phases of the study

6.3.1 Phase 1: planning video contents

To determine the content of the videos, including the optimal use of the geocultural connections, two focus group meetings were conducted, once in the UAE and once in

Oman. Key partners and decision makers involved in the protection and communication of Quaternary sites, including museum professionals, geoscientists, archaeologists, and officials from the Ministry of Heritage, were invited to participate. The participants were provided with a brief presentation on the relationship between archaeology, culture, and the palaeoenvironment by the authors, followed by a discussion on three main topics: their reaction to the presentation, recommendations based on past experiences, and identification of the main factors to be emphasised in the videos. The focus groups were designed to last approximately one hour and half to two hours each. Considering the linguistic abilities of the participants, the focus group in Oman was conducted in English with Arabic interpretation available upon request, while the focus group in the UAE was conducted in both English and Arabic, facilitated by an interpreter. The discussions in the focus groups were recorded, transcribed, coded, and analysed qualitatively using a combination of deductive and inductive content analysis (Bengtsson, 2016) via NVivo to categories and themes related to the research questions.

6.3.2 Phase 2: video production

Based on the insights gained from the focus group discussions, two videos were developed by the authors in collaboration with partners. The videos incorporated footage filmed by the authors, as well as videos and photographs provided by collaborators, along with Creative Commons licensed visuals and music. Each video featured voice narration in English, complemented by dialogues with experts conducted in Arabic, with corresponding translation provided as subtitles in Arabic or in English. The videos were carefully crafted to maintain a similar length, with the primary distinction between the two being an emphasis on the geocultural context in one (referred to as the geocultural

video), and the exclusion of the geocultural context in favour of a more detailed description of the Quaternary science in the other (Quaternary science video).

6.3.3 Phase 3: video experiment

An online experiment was conducted using the videos produced in the second phase of the study. Participants were recruited based on the inclusion criterion of being residents of the UAE or Oman. Recruitment efforts included calls at universities, as well as emails and posts through nature societies, museums, and social media platforms. The experiment consisted of a registration process and three waves of surveys, including a questionnaire administered before, immediately after, and three months after watching the video. Upon completion of the pre-video questionnaire, participants were randomly assigned to either the treatment group, which received and watched the geocultural video, or the control group, which received and watched the Quaternary science video. All procedures of the experiment were conducted using online questionnaires, and instructions were provided in both Arabic and English.

The three questionnaires aimed to assess the participants' knowledge and interest in geoheritage sites, Quaternary geoheritage sites, archaeological sites, and the relationship between Quaternary geoheritage sites and archaeological sites. The Quaternary geoheritage sites section included a quiz where participants were required to select photos of Quaternary geoheritage sites, while the geocultural connection included questions to identify the correct relationship described between the two disciplines. Both quiz questions were presented as multiple-choice questions with multiple correct and incorrect answers. Wave 1 additionally included questions about participants' level of knowledge and interest in natural heritage sites to gauge their predisposition towards

nature and nature conservation. In Wave 3, additional questions were included to assess participants' impressions of the video and the impact, aiming to understand memorable features of the video and whether watching it led to further engagement and/or action by the viewers.

Each questionnaire was designed to take between 5–10 minutes to complete. Most questions utilised a five-point Likert-like scale, with exceptions including Yes/No questions, text-entry questions (mostly in Wave 3 regarding impressions and impact of videos), multiple-answer questions (including quizzes), and questions on the importance of protecting certain types of sites, which were presented as a 10-point slider-scale. Text-entry questions on naming Quaternary geoheritage sites were included to avoid revealing which sites are considered Quaternary sites through multiple-choice questions. The full questionnaires are available in Appendix D.

6.3.4 Data analysis

The data collected from the questionnaires underwent quantitative and qualitative analysis, based on the nature of the questions. Descriptive and statistical analyses, including hypothesis testing where applicable, were employed. The statistical analyses were conducted using paired t-tests and difference in differences analysis. Although some discussion continues on the treatment of aggregated Likert-type data as an ordinal scale rather than discrete categories (Bishop & Herron, 2015), this study employed parametric methods to analyse this data in line with other studies such as De Winter and Dodou (2010).

Quantitative methods were applied to Likert scale items and quiz scores, while a qualitative assessment was conducted for responses to text-entry questions. The

qualitative analysis involved deductive and inductive content analysis using NVivo to categorise themes related to the research questions and emerging themes from the responses. The predetermined themes included those related to the key points mentioned in the focus groups, and options indicated in the questionnaire as multiple-choice questions.

Statistical analyses followed methods commonly used in Randomly Controlled Trial (RCT) experiments, where both treatment and control groups are present. In this study, both groups viewed a video about Quaternary geoheritage sites, with the control group watching a video focused solely on Quaternary science and the treatment group watched a video with geocultural information included. While a third control group watching an unrelated video would have been ideal, practical constraints limited this option. However, the absence of a true "baseline" control group did not hinder the effects of the treatment – i.e., the inclusion of geocultural information in the video. Since the members of the control group had also watched a relevant video and we would expect it to have an effect on their responses in the post-treatment (Wave 2) and follow-up (Wave 3) surveys, it was determined that the most appropriate method for analysing this data would be a difference-in-differences analysis with fixed effects for the treatment group and the survey wave. Difference-in-differences analysis is a specific type of fixed effect analysis that is commonly used to evaluate treatment effects in natural experiments (see Abadie (2005) for a detailed discussion). It allows for the assessment of treatment effects over time, even when there are underlying differences between observed groups and timeframes. The strong assumption of difference-in-differences is that of parallel trends, which posits that changes over time would have been similar between groups if not for the treatment effect. In other words, while the groups may have started differently and

experienced changes over time, these changes would have followed parallel trajectories in the absence of treatment. Given the design of this experiment, we found no cause to believe that the parallel trends assumption would be violated in this case. Statistical analyses were performed using R Statistical Software (v4.4.0; R Core Team 2024) and the *tidyverse* environment (v2.0.0, Wickham et al 2019). Fixed effects and difference-in-differences modelling were performed using the *fixest* R package (v0.12.1; Berge 2018). The full reporting of the results of differences-in-differences analyses is provided separately in Appendix E.

For each survey item, the responses in each wave of the survey were initially compared to the Wave 1 responses using a t-test to determine if there was a statistically significant difference between waves. Subsequently, difference-in-differences was conducted to assess the effects of the treatment. It is important to note that even in cases where the t-test for the overall dataset showed no statistical significance, the difference-in-differences analysis could reveal a significant difference between treatment and control groups. This is because the treatment group may have a positive effect while the control group has a negative effect, potentially cancelling each other out in the overall population analysis.

Finally, the data were subdivided into specialist and non-specialist respondents. The specialist group comprised of respondents who were either geology students or professionals in a geology-related field, while the non-specialist group comprised all other respondents. This division aimed to examine whether the treatment effect varied based on the respondent's level of expertise or prior subject knowledge. The difference-in-differences analysis was then re-run for both groups, and the results were used to

conduct direct comparisons of the treatment effect between specialist and non-specialist respondents.

6.4 Results and discussion

6.4.1 Phase 1

The focus group in the UAE took place in November 2022 at Buhais Geology Park, and the focus group in Oman was conducted in December 2022 at the Oman National Museum. As demonstrated in Table 6.1, in the UAE, participants included an archaeologist, two staff from a geology museum and two staff from an archaeology museum. In Oman, the focus group was attended by two archaeologists, two staff from the National Museum, an officer from the Ministry of Heritage, and two geologists. Both genders and nationals and non-nationals were intentionally selected to ensure diversity among participants.

Table 6.1 Participant profile for the focus groups conducted in this study.

	Participants	Number	Non-nationals
UAE	Archaeologist	1	1
	Staff from Buhais Geology Park	2	0
	Staff from Mleiha Archaeology Center	2	2
Oman	Archaeologist	2	1
	Geologist	2	0
	Staff from the National Museum of Oman	2	0
	Staff from Ministry of Heritage	1	0

The focus group discussions lasted approximately two hours and seven minutes in the UAE and one hour and 38 minutes in Oman. From the coded transcripts, seven main

themes emerged, summarising the key points discussed. Overall, the focus groups highlighted the importance of striking a delicate balance between aesthetic appeal, scientific rigor, and cultural resonance in creating an effective video for communicating Quaternary geoheritage sites. It was also emphasised that the narrative should be designed with care to engage and enhance audience understanding.

6.4.1.1 Visual preference

The focus groups included in-depth discussions about the most suitable visuals to include in the video. The consensus view favoured aesthetic images over detailed scientific visuals to engage audiences with Quaternary geoheritage sites. Additionally, in the UAE, there was widespread approval for selecting scientific images that also had aesthetic appeal. Participants highlighted the crucial role of captivating visuals in capturing initial interest, particularly among non-specialists. One participant aptly summarised this sentiment, stating “for me it's the image from the first glance, you can decide whether you will like it or not like it. You are interested, you will go further, or you withdraw.” However, participants also recognised the importance of incorporating scientific imagery strategically to explain key processes and explore the values of sites beyond their aesthetic beauty. This balanced approach was seen as essential for providing a comprehensive understanding of Quaternary geoheritage sites.

6.4.1.2 Financial matters

The discussion on whether to include the economic potential and benefit of protecting Quaternary sites generated varied opinions within the focus groups. In the UAE, participants unanimously advised against emphasising economic benefits in a video targeting non-specialists, despite a shared recognition of its importance. Conversely, in Oman, the participants overall supported the inclusion of the economic relevance,

although two participants highlighted the importance of not making this element the video's main message. In summary, there was a recognition of the importance of financial aspects to make the topic more relatable to the audience, especially for ones living near the sites. However, there was an agreement that economic considerations should be introduced sporadically in the video without overshadowing other content.

6.4.1.3 Need to raise awareness

The importance of raising awareness about Quaternary geoheritage sites received unanimous support in both focus groups, with no negative opinions. Participants underscored the prevalent lack of awareness among the local people and communities regarding the importance and significance of the regional Quaternary sites and advocated for clear, accessible communication with little to no technical jargon. However, discussions also emphasised the need to consider the underlying motivations and objectives of any awareness-raising efforts. One participant highlighted this by commenting: “the question that we always forget is, why do we want people to be aware of those sites, maybe it's actually good for them not to be aware of this kind of stuff.” A clear message describing why the topic is relevant for the audience was identified as an essential component in the video.

6.4.1.4 Narrative

Participants unanimously endorsed the need to include a compelling narrative to engage audiences. Two distinct concepts emerged in this regard. First, participants highlighted the potential of narratives that stimulate the audience's imagination and allow them to envision the past. Second, the participants agreed that the use of the geocultural context can be an effective way for viewers to create personal ties with the subject. Notably, suggestions were made to incorporate culturally relevant anecdotes, such as verses from

the Quran with resonance to historical climate change in Arabia, to enhance viewer engagement and comprehension.

6.4.1.5 Local people, culture, and knowledge

In both focus groups, the idea of involving older/respected figures to narrate the cultural relationship between humans and the regional landscape was discussed as a potentially effective strategy for introducing Quaternary geoheritage sites. The concept of cultural identity was highly emphasised and supported in these discussions. Four participants shared anecdotes in which a site's relevance to the local community significantly influenced how people perceived its importance. Positive responses to this idea were not limited to participants who were nationals of the UAE or Oman but were emphasised more by non-national participants.

In Oman, there was a discussion on the importance of the storyteller's identity, with an agreement that a foreign researcher presenting this idea is not negative, but having a local person telling the story would be preferable whenever possible.

Although the introduction of the geocultural context by local figures was supported, the use of interviews in the videos evoked mixed views. Four participants in the focus group in Oman were enthusiastically supportive of using interviews, noting that they lend scientific information with more authority in delivering the message. Additionally, proponents of interviews mentioned how voices of respected (widely supported) or locally based figures can make the subject more personal and relatable. However, in the group in the UAE, participants unanimously spoke against the idea of interviews, expressing concerns that they could make the video resemble a "lecture" or a "documentary", which people might find "boring". Even in Oman, one of the participants

was wary of the use of interviews, suggesting they should be very brief and scattered even if used at all. A similar sentiment was expressed by the supporters of the interview, leading to the conclusion that the interviews, if included, should be few and short.

6.4.1.6 Scientific information

In each of the focus groups, some participants (three in the UAE, one in Oman) initially considered scientific information the most important factor to introduce in the video. Overall, there was no disagreement about the importance of conveying the general idea of what makes each site scientifically significant. However, during the discussions, different ideas emerged regarding the depth to which the video should engage with scientific information. While there was overall agreement on the value of the scientific information in introducing the main features of the site and justifying why it is worthy of protection, opinions diverged on the level of detail that should be included. While two participants supported providing detailed scientific information, others were more supportive of presenting simple, general ideas rather than delving into the specifics.

6.4.1.7 Sequence of presentation

At the end of the focus groups, strategic discussions revolved around the optimal sequencing of elements in the video. Participants generally favoured starting with aesthetically pleasing images to captivate the audience, particularly those who are not inherently interested in geology. Nearly all participants, with the exception of one who did not express an opinion, agreed that if interviews were to be included, they should not be placed at the beginning of the video to avoid giving it a lecture-like feel.

There was also a consensus on the need for a simple description of the general concept of geoheritage. As one participant mentioned, “images without information would not mean anything to the viewers”, highlighting the importance of providing a straightforward

explanation of the general concept without using technical jargon. In Oman, the focus group proposed the idea of introducing the superiority of the region's Quaternary geoheritage by describing what makes it special or unique. Additionally, participants widely supported the idea of creating a connection (e.g. cultural, economic) between the audience and the subject matter. However, there was agreement that the economic aspect should be introduced after the general idea, so as not to overshadow other aspects of the video's message.

Discussions also favoured the idea of introducing deeper details of the relevance of Quaternary geoheritage sites (cultural, economic, scientific, etc.) later in the video, once the viewers gain a general understanding and developed a connection with the subject. The use of case studies was supported by many participants, although two participants in the UAE opposed to this idea, identifying case studies as the least important element.

6.4.2 Phase 2

Two videos were produced based on the best practices from science communication research and the insights gained from the focus groups. The videos are available via the links https://ora.ox.ac.uk/objects/uuid:e14384cb-68fa-45f1-914d-3204e05bb3ea (Control Video) and https://ora.ox.ac.uk/objects/uuid:ee8c3f2a-1888-4967-a104-b5799ba68d8d (Treatment Video). Table 6.1 outlines the contents and duration of the two videos.

Table 6.2 Contents and duration of the two videos produced for the study. The asterisk indicates contents with different narration/dialogue between the two videos.

	Geocultural video (s)	Quaternary science video (s)
Introduction	30	36
Introduction of narrator and title	22	22
Geoheritage sites–global	17	17
Geoheritage sites–SE Arabia	29	31
History–Earth's geology	12	14
Introduction to Quaternary geoheritage (scenery)	16	18
Introduction to Quaternary period (scientific)	11	15
Examples of Quaternary sites in SE Arabia	15	15
Social relevance of Quaternary sites for geohazards	14	16
Quaternary climate change*	39	47
Implications for the Quran	30	0
Archaeological relevance	38	0
Example 1, travertine–non-cultural* (dialogue in Arabic)	31	52
Example 1, travertine–cultural (dialogue in Arabic)	8	0
Geoheritage conservation frameworks and geotourism (economic relevance)	30	34
Example 2, fossilised dunes* (dialogue in Arabic)	31	46
Example 3, Al Hoota Cave	32	36
Example 4, Jebel Faya–non-cultural*	18	77
Example 4, Jebel Faya–cultural	64	0
Endangerment of Quaternary sites	19	19
Summary	33	35
End credit	6	6
Total duration	545	536

The duration of the two videos is different by 9 seconds at 9 minutes 5 seconds for the geocultural video and 8 minutes 56 seconds for the Quaternary science video. The length of the videos falls at the longer limit of the 6–9 minute length range suggested in the literature for optimal engagement. After producing the videos with distinctive elements for each, the difference in the length of the video was minimised by elongating the transition elements in the Quaternary science video, which included 153 words (in English translation) less of dialogue than the geocultural video. The total length of sections introducing the geocultural context in the geocultural video was 140 seconds, accounting for ≈26% of the entire video. The geocultural elements included the description of the relationship between findings from Quaternary science (palaeoenvironmental records) and a verse in the Quran, an introduction to the relevance of Quaternary science for archaeology, and cultural connections at example sites 1 and 4, through agriculture and archaeology, respectively. The distinctive elements of the Quaternary science video included additional scientific information related to example sites 1, 2, and 4, related to the formation of the sites and descriptions of a sediment cross section. The videos did not include a formal interview but included a dialogue with local geologists from a site each in Oman (example 1) and the UAE (example 2), who explained the significance of the respective site.

The videos were piloted and approved by the participants of the focus group on cultural/social content and scientific accuracy before being distributed to the study participants.

6.4.3 Phase 3

6.4.3.1 Participant profile

After excluding blank responses and responses from participants who do not meet the study inclusion criterion, the study gathered 211 registrations, 160 responses to Wave 1 (pre-video), 104 responses to Wave 2 (post-video), and 82 responses to Wave 3 (3-months-after). The breakdown of participants is demonstrated in Table 6.3. The drop-out rate of these surveys is within or better than the expected range of around 30–40% (Grønmo, 2019), with an especially low rate between Waves 2 and 3 at 21%. The results and analyses below consist of findings from the data of 104 participants who completed the questionnaires at least up to Wave 2. The term "participants" will refer to these 104 participants hereafter. Given the total population of southeast Arabia at 14.1 million, according to Yamane's formula for sample size (Yamane, 1967), 104 participants are able to represent the population of this region at a margin of error at ±9.8%. For reference, to achieve an error margin of ±5%, a sample size of about 400 would have been required.

Table 6.3 Breakdown of video study participants. All questions in the survey were optional, leading to some missing responses.

		Total	Specialist	Non specialist	Student	Non student	UAE resident	Oman resident	National	Non national
Wave 1		160	73	87	109	51	64	94	128	31
Wave 2	Control	49	26	23	40	9	16	33	39	10
	Treatment	55	22	33	39	16	24	31	43	12
Wave 3	Control	38	22	16	33	5	27	11	31	7
	Treatment	44	19	25	33	11	18	26	33	11

The responses were collected from 55 participants in the treatment group and 49 participants in the control group for Wave 2, and 44 participants in the former and 38 participants in the latter for Wave 3. The residence of the participants was split 64 in Oman and 40 in the UAE, and their nationality consisted of 61 Omanis, 21 Emiratis, and 22 others. The ratio of nationals over non-nationals in each country is higher than the demographics of either country, but the ratio of non-nationals was higher in the UAE group, in correspondence with the country's higher ratio of non-nationals within the overall population.

The profession of the participants included 78 university students, of whom 47 study geosciences and 31 study other subjects. Of the 23 employed participants, only one worked in geology related fields. There were two unemployed and one retired participant. In analysing the data, geosciences students and professionals were considered domain specialists (n=48), and the others were considered non-specialists (n=56), to distinguish results based on the participants' familiarity with geology. Between the specialists and the non-specialists, there was a statistically significant difference in their pre-treatment self-reporting of knowing any geoheritage sites (t-test p <0.001) or Quaternary geoheritage sites (t-test p=0.051 in Chi-squared test and p-value=0.035 in Fisher's exact test). However, there was a difference in the number of specialists who knew some geoheritage sites (95%) compared to those who knew Quaternary geoheritage sites (50%), showing that the recognition of Quaternary sites in southeast Arabia was relatively low, even amongst the specialist population.

Regardless of their familiarity with geoheritage sites or Quaternary geoheritage sites, the respondents had a very high predisposition to nature conservation in general, with a mean

of 9.2 (out of 10, SD=1.4) in rating the importance of protecting natural heritage sites. Similarly, even before watching the video, the respondents reported a high level of support for protecting geoheritage sites (mean=9.0, SD=1.7) and Quaternary geoheritage sites (mean=8.6, SD=2.0), despite a consistent decrease in the mean and increase in the standard deviation as the category became more specific.

Although this study originally aimed to target the general public, the participant profile is limited to a highly educated, nature-loving, and young portion of the general population. This restricted sample demographic, however, fits well with the common description of potential targets for geotourism identified through studies conducted in various geographic and cultural settings around the world (Dowling & Allan, 2018; Kim et al., 2008; Štrba, 2019).

6.4.3.2 Impressions and impact of the video after 3-months

The questions asked exclusively in the Wave 3 revealed different impressions and interactions that the participants had toward/with the video and its contents, based on the video assigned. In terms of the number of times that the participants watched the video, the two groups did not differ much with a little less than half of both groups (T: 48%, C: 47%) watching the video more than twice. However, the self-reported memory of the contents of the video was higher for the treatment group, with 25% of the participants reporting that they remember the video well, as opposed to 16% in the control group. For the video length, the overall impression is that the length was just right, supported by 80% of all Wave 3 participants. However, 17% (14) mentioned that the video was a little too long. Of the participants who gave this answer, 64% were from the control group. In ratio, compared to the overall size of each group, those who thought the video was a bit too long

in the control group was 11% higher (24%), compared to those in the treatment group (13%).

For the impact of the video, a curious result was found in the aspect of video that left the strongest impression on the participants. The “importance of protecting geoheritage sites” was the most selected by the treatment group (13), but the “Connections between Quaternary geology and culture/archaeology” (10) was favoured the most by the control group, despite the lack of any explanation about these connections in the video. As seven of these 10 participants who gave this answer indicated that they conducted further research into the contents of the video, this result could be due to the independent knowledge gained beyond the video. At the same time, it could be the case that the participants found cultural and archaeological connotations in the video, even without having it introduced explicitly. In turn, for the treatment group, the geocultural connections was joint third (8), which could be showing that the message of the video steered the audience more towards thinking about the protection of sites overall, rather than focusing on particular elements. Finally, when asked the effect of the video towards their level of interest in Quaternary geoheritage sites, 91% of the respondents (72) reported that it made them either “a little more interested” (16, 20%) or “more interested” (56, 71%). The ratio of those who answered positively was 4% higher for the treatment group. It should be noted, however, that none of the differences described in this section were statistically significant. Qualitative analyses toward open-answer questions and statistical analyses on other questions have been used to provide additional context to these results.

6.4.3.3 Qualitative analysis on impressions towards the video

Of the 82 respondents to the 3-months-after questionnaire, 46 provided open-ended answers on things they liked or learned from the video. The responses consisted of 20 answers from the treatment group and 26 from the control group. The answers were split into 19 that included comments only on their learning experience, eight only on things they liked, and 19 that provided both aspects. For the parts liked by the audience, the learning experience (13), clarity of the contents (8), and the beautiful scenery (8) were mentioned most frequently. The clarity of the video was praised by multiple participants as “accessible”, “easy”, or “enjoyable”. Moreover, although mentioned only by four participants, the dialogue with the local geologists received enthusiastic support with a sense of appreciation for the engagement. In terms of the learning experience, a notable tendency was the relative lack of mentions related to Quaternary geoheritage sites (6), as opposed to general geoheritage sites (19). This may indicate that the video was effective in communicating on geoheritage sites in general, but did not leave as much of an impression about Quaternary sites in particular.

Similarly, 33 open-ended answers were collected on points that the video could improve on, of which 13 did not include any suggestions. The 20 answers with points for improvement consisted of eight from the treatment group and 12 from the control group. The most frequently indicated suggestion was related to reducing the length of the video, which was mentioned by eight participants. These comments were provided by seven participants who watched the Quaternary Science video, with only one participant from the treatment group suggesting this point. On the contrary, three comments, all from the treatment group, suggested the benefits of providing more information. Other themes of the comments included points related to the production value, including the adding of a

short animation (2), improving the narration (2), and improving the overall quality (3) as well as the delivery of the contents by providing less complexity (3), and making the content more interesting (5).

In general, the qualitative analysis of responses to open-ended questions indicates a positive reception of the videos among participants. A notable trend emerges from the control group's feedback, which emphasises the desire for a shorter video length. This observation aligns with the earlier quantitative findings, wherein a higher percentage of the control group expressed a perception of the video being slightly lengthy, thereby reinforcing the notion that the treatment video effectively maintained audience engagement. Moreover, these insights underscore the value of engaging relevant stakeholders in video production process. Key themes identified as significant in the focus group discussions, including the importance of employing clear language, of the use of aesthetic imagery and strategic incorporation of dialogues with locals, were highlighted as positive aspects by participants across both groups.

6.4.3.4 Statistical analysis: Quaternary geoheritage

6.4.3.4.1 Self-reported interest in Quaternary geoheritage

This question measured participants' interest in learning about Quaternary geoheritage sites using a five-point scale, from 0 to 4. As shown in Figure 6.3, the study showed a statistically significant (t-test p = 0.0011) increase in self-reported interest in the post-treatment wave. However, this effect disappeared by the follow-up survey, with no statistically significant difference found in the distributions of the pre-treatment and follow-up waves (t-test p = 0.55). Difference-in-differences analysis revealed that subjects in the treatment group reported higher increases in their post-treatment interest levels than those in the control group (DiD coefficient = 0.067, p < 0.001). Although the

effect was small, it appears to have been sustained over time, remaining statistically significant in the 3-months-after survey (DiD coefficient = 0.073, $p < 0.001$). This finding contrasts somewhat with the self-reported gain in interest in Quaternary geoheritage sites observed in Wave 3, as discussed in the previous section. One plausible explanation for this discrepancy could be the difference in the disparity could stem from a distinction between overall interest in the topic and the interest in learning about the Quaternary geoheritage sites. While participants may have experienced a general uptick in interest, it may not necessarily have translated into a desire to delve deeper into Quaternary geoheritage sites.

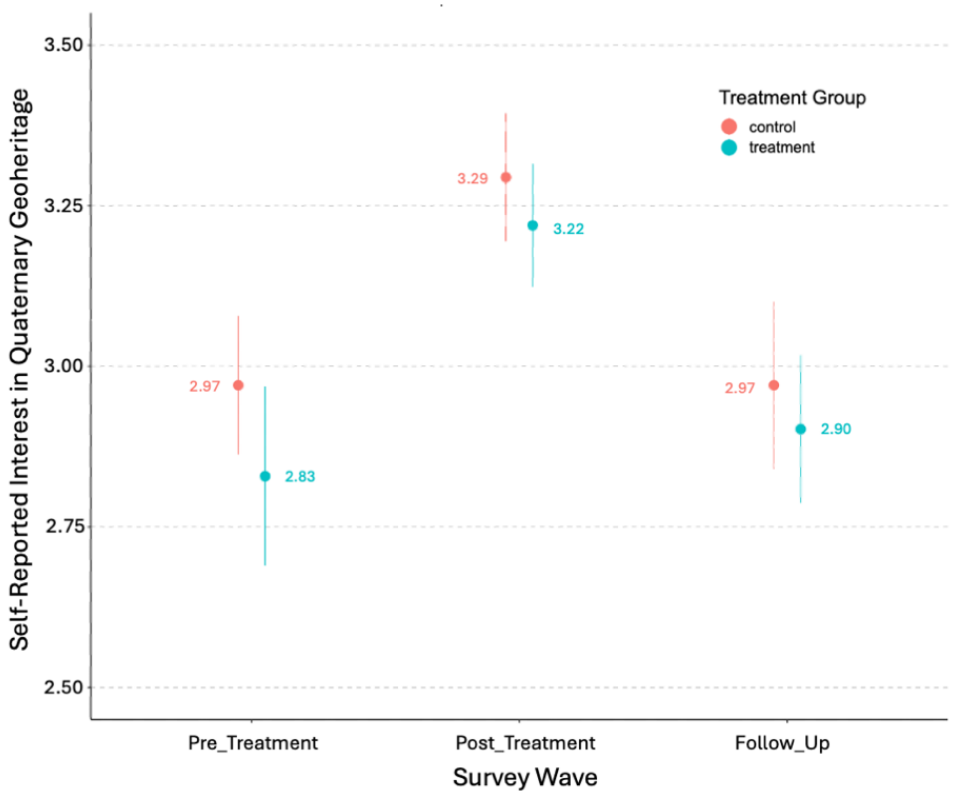


Figure 6.3 Interest in Quaternary geoheritage: score

Nevertheless, the treatment effect displayed inconsistency across the specialist and non-specialist respondents. Among specialists, the treatment group reported a marginally higher increase in interest post-video (DiD coefficient = 0.056, $p < 0.001$),

accompanied by a slightly lower increase in the follow-up survey (DiD coefficient = -0.056, p < 0.001). Conversely, among non-specialists, the treatment group demonstrated a very small increase in interest compared to the control group in the post-treatment survey (DiD coefficient = 0.003, $p < 0.001$), followed by a notably larger increase by the time of the follow-up survey (DiD coefficient = 0.155, $p < 0.001$). This discrepancy implies that the treatment material may have been effective in not only initially piquing the interest of non-specialists but also in sustaining their curiosity over the longer term. This outcome suggests that the inclusion of the geocultural context in the treatment aided the audience, particularly non-specialists, in maintaining their engagement and fostering a sense that there is more to explore regarding Quaternary geoheritage sites.

6.4.3.4.2 Self-reported knowledge about Quaternary geoheritage

This question asked the participants how much they know about Quaternary geoheritage sites, on a five-point scale from 1 to 5. The study found a statistically significant increase in respondents' self-reported knowledge in the post-treatment survey (t-test $p < 0.001$). While some degree of mean reversion was seen in the follow-up survey, the uplift remained significant (t-test $p < 0.001$) at this point (Figure 6.4).

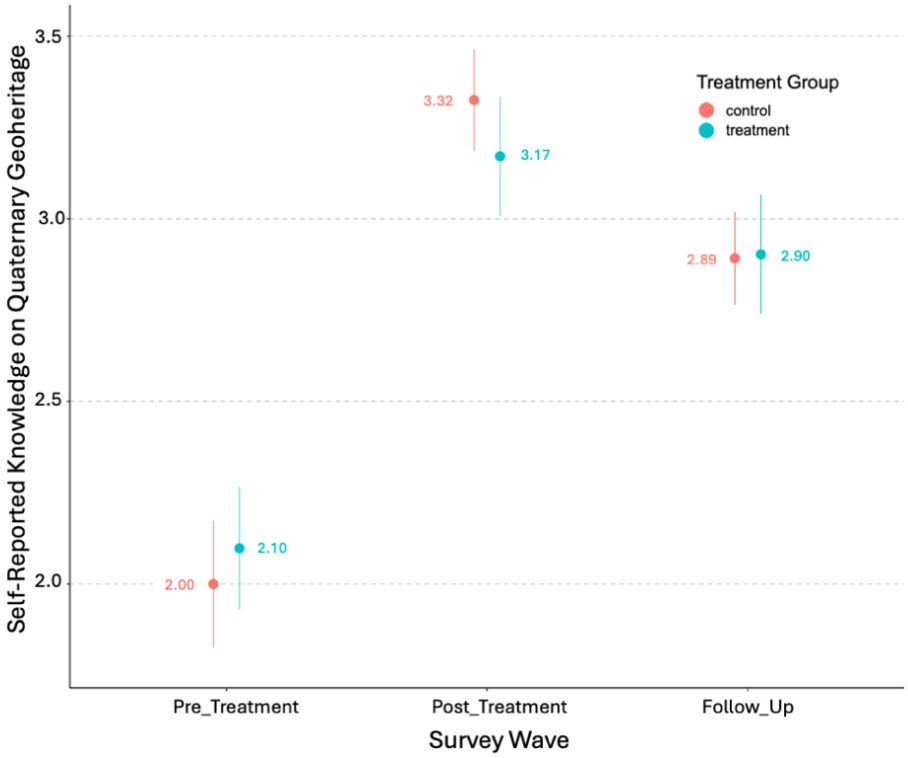


Figure 6.4 Knowledge about Quaternary geoheritage: score

Difference-in-differences analysis conducted on the two groups revealed a statistically significant and negative effect associated with being in the treatment group (DiD coefficient = -0.160, $p < 0.001$). In essence, participants in the control group reported larger increases in their knowledge compared to those in the treatment group. This effect was strongest in the post-treatment survey (DiD coefficient = -0.251, $p < 0.001$)., but also persisted at a lesser extent in the follow-up survey (DiD coefficient = -0.087, $p < 0.001$). The difference in self-reported knowledge increase may be explained by the diversified focus of the treatment video, which introduced viewers to a wider range of topics and made them feel less informed about Quaternary geoheritage specifically than those who watched the more focused control video. In self-assessing the knowledge gained from the video, the in-depth scientific information (e.g. explanation of a cross section) led to an enhanced perception of the participants on the extent to which they know about Quaternary geoheritage sites. Nevertheless, the overarching findings suggest that the

video effectively heightened awareness of Quaternary geoheritage sites, at least at a superficial level.

The negative results among treatment group members were found in both specialist and non-specialist respondents (Table 6.4). Specialists reported a higher uplift in knowledge after viewing the video than non-specialists, but this effect was consistently weaker in the treatment group than in the control group across both sets of subjects. The relative ease with which those with some degree of specialist knowledge could gain more knowledge about Quaternary geoheritage corresponds well with the findings in general geosciences communication literature, that many non-special people (including students) find geology and its deep time concept difficult to approach (Trend, 1998, 2001) and find a high barrier in starting to learn about the field (Rogers et al., 2024).

Table 6.4 Self-reported knowledge on Quaternary geoheritage: DiD analysis by expertise level

	Specialist	**Non-Specialist**
DiD coefficient: Post-Video Survey	-0.302	-0.106
(p-value)	(<0.001)	(<0.001)
DiD coefficient: Three-months-after Survey	-0.222	-0.101
(p-value)	(<0.001)	(<0.001)

6.4.3.4.3 Photo quiz scores for Quaternary geoheritage sites

In this quiz, participants were tasked with identifying photos of sites they believed to be Quaternary geoheritage sites. The photos used for this quiz is shown on Figure 6.5. Among the five options provided, three were correct while two were incorrect. The quiz score was

calculated by subtracting the number of incorrect answers from the number of correct answers. This method was chosen to mitigate potential bias from participants selecting numerous answers, which could skew data collection if only correct answers were counted. Analysis of the resulting variable revealed a very significant (t-test $p < 0.001$) increase in respondents' scores in the photo quiz immediately after viewing the post-video (Figure 6.6). As expected, there was a high degree of mean reversion observed by the time of the follow-up survey. However, the scores remained significantly higher than those recorded in the pre-video quiz (t-test $p = 0.013$), indicating that respondents retained knowledge acquired from the video for several months.

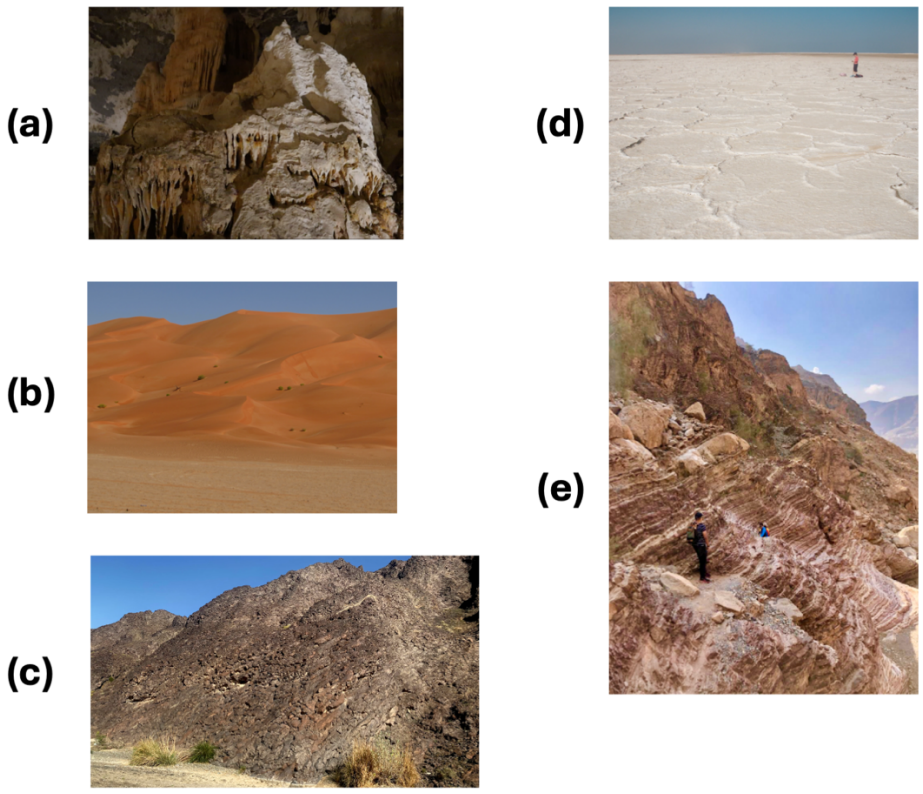


Figure 6.5 Photos used in the quiz to identify Quaternary geoheritage sites. The correct answers are (a) [cave features], (b) [sand dunes] and (d) [sabkha]

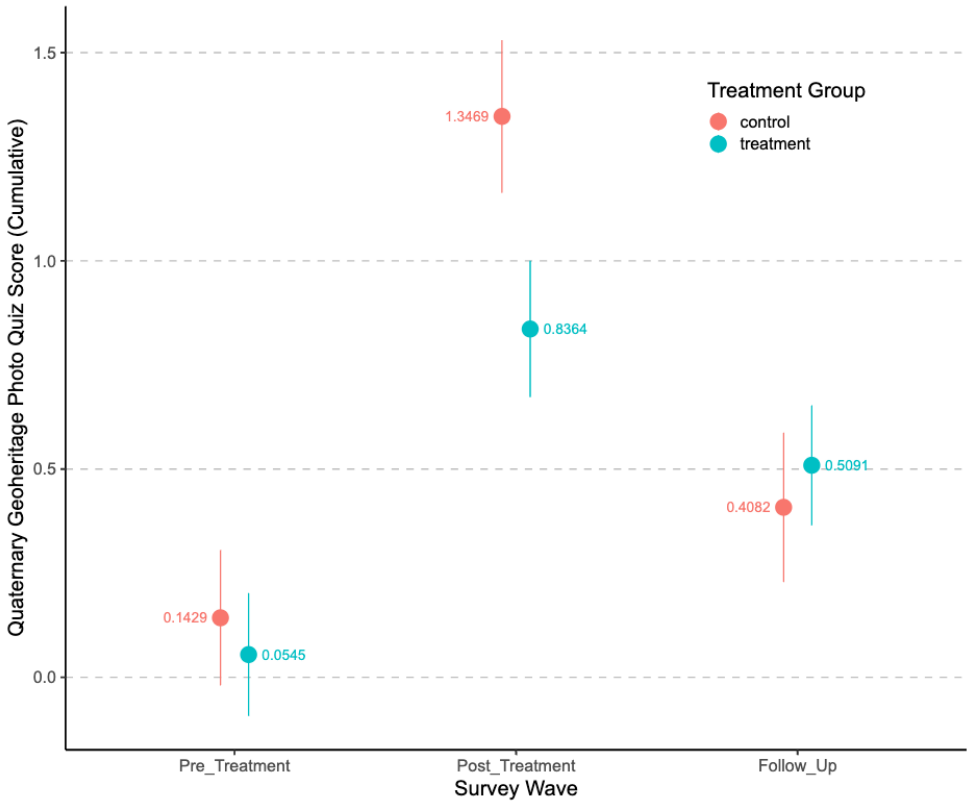


Figure 6.6 Quaternary geoheritage photo quiz: score

The difference-in-differences analysis conducted on this data corroborated the observations made from the visual examination of Figure 5. It revealed that the treatment group had markedly less improvement than the control group in the photo quiz immediately after the video (DiD coefficient = -0.422, $p < 0.001$), but by the time of the follow-up survey, these differences had been erased and even partially reversed (DiD coefficient = 0.189, $p < 0.001$). Subjects who viewed the treatment video showed greater knowledge retention in the follow-up survey than those who viewed the control video, despite the control group's significantly better performance in the immediate post-video quiz. This could be attributed to the different focus of the treatment video making its content more memorable at the expense of giving more in-depth information. Given the focused and in-depth information about Quaternary geoheritage sites in the control video, those who viewed this material were more effective at identifying Quaternary geoheritage

sites immediately after viewing the material. However, after three months, the seemingly more memorable nature of the treatment video levelled out the performance of both groups, with the treatment group even pulling marginally ahead in the quiz task at this point.

The above-mentioned result, however, appears to have been primarily influenced by the responses of the specialist respondents in the survey, as indicated by the distinct outcomes observed in the separate difference-in-differences analyses for specialists and non-specialists presented in Table 6.5. While the effect in the immediate post-video quiz scores was largely consistent across both specialist and non-specialist respondents – with the treatment group performing less favourably than the control group in both cases – their performance in the follow-up survey diverges significantly. Among specialists, those who viewed the treatment video retained significantly more knowledge by the follow-up quiz compared to those who viewed the control, whereas among non-specialists, those who viewed the treatment video continued to underperform those who viewed the control video (albeit by a very small margin in the follow-up). This outcome suggests that while the treatment video may not have been as effective in imparting knowledge about Quaternary geoheritage sites, it did contribute to better memory retention among individuals who already possessed a foundational level of domain specific knowledge. For participants without a background in geology within the treatment group, a similar rationale may account for the result.

Table 6.5 Photo quiz score: DiD analysis by expertise level

	Specialist	Non-Specialist
DiD coefficient: Post-Video Survey	-0.458	-0.386
(p-value)	(<0.001)	(<0.001)
DiD coefficient: Three-months-after Survey	0.490	-0.045
(p-value)	(<0.001)	(<0.001)

6.4.3.4.4 Protection priority for Quaternary geoheritage sites

This question asked participants to answer how important it is to protect Quaternary geoheritage sites on a 10-point scale, ranging from not important at all to top priority. There was a significant (t-test $p < 0.001$) increase in respondents' rating of how much protection of Quaternary geoheritage sites should be prioritised in the post-video survey (Figure 6.7). However, these scores saw a high degree of regression to the mean by the time the follow-up was conducted three months later. While the priority scores in the follow-up did have higher means than in the pre-video survey, the overall difference was not statistically significant (t-test $p = 0.142$). It is worth reiterating that the initial scores were quite high, with means of around 8.5 (the highest possible rating being 10) and very few respondents rated these sites as a low priority for protection.

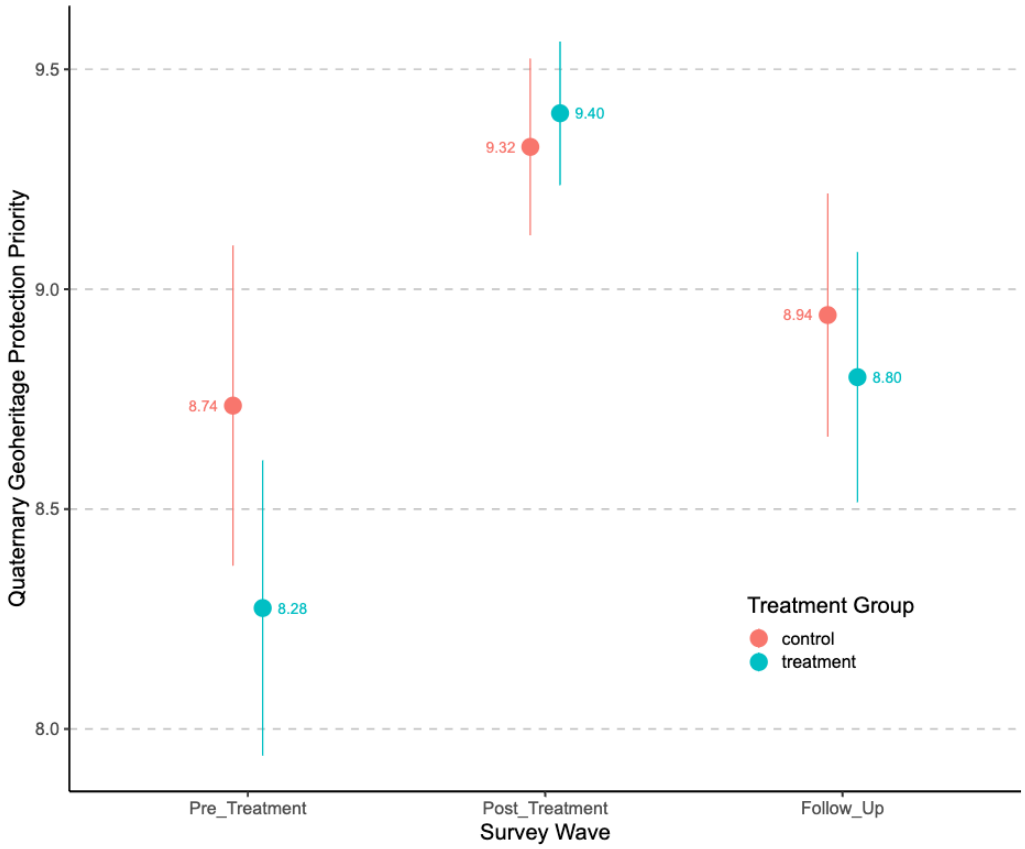


Figure 6.7 Quaternary geoheritage protection priority: scores

The difference-in-differences analysis reveals that subjects who viewed the treatment video were significantly more likely than those who viewed the control video to increase the score they gave for protection priority for Quaternary geoheritage sites (DiD coefficient = 0.428, $p < 0.001$). This effect is not only apparent immediately after watching the video (DiD coefficient = 0.537, $p < 0.001$), but persists strongly in the follow-up survey (DiD coefficient = 0.319, $p < 0.001$), suggesting that the treatment material was effective at convincing viewers of the importance of protecting these sites, with that updated belief being carried through for at least three months. This is consistent with the finding that "importance of protecting geoheritage sites" was the video theme which left the biggest impression on the largest number of participants in the treatment group.

The effect mentioned above is replicated across both specialist and non-specialist respondents in the survey (Table 6.6) – in both cases, the treatment group had a larger

increase in their protection priority score than the control group, both in the post-video and follow-up surveys. The effect size, however, is notably larger for the non-specialist respondents, being almost double the effect size for specialists. This may suggest that the treatment material is especially effective at convincing non-specialist audiences of the value of protecting quaternary geoheritage sites. However, it should also be noted that specialist respondents on average gave a higher score for protection priority in the pre-video survey (their mean score being 9.13, versus 8.23 for non-specialists), which may serve to reduce the effect size in this group as many respondents were already at or near the ceiling for the highest possible score. Nonetheless, overall, the result supports the idea that the geocultural connection fostered a stronger sense of importance for Quaternary geoheritage sites, to the extent that they deserve protection.

Table 6.6 Quaternary geoheritage conservation priority: DiD analysis by expertise level

	Specialist	**Non-Specialist**
DiD coefficient: Post-Video Survey	0.227	0.517
(p-value)	(<0.001)	(<0.001)
DiD coefficient: Three-months-after Survey	0.197	0.308
(p-value)	(<0.001)	(<0.001)

6.4.3.4.5 Overall implications: Quaternary geoheritage

These results demonstrate the overall success of using videos to communicate information about Quaternary geoheritage sites, as they effectively enhanced viewers' perceived knowledge of Quaternary science and fostered a heightened sense of the sites' significance for conservation. This result, however, should be tested in the future with

participants with a lower interest in nature conservation. At the population level, the study revealed limited increases in interest in learning about Quaternary geoheritage sites, particularly over the long term, despite an overall reported improvement in interest toward these sites. The degree of interest generated by the video may not have been substantial enough to translate into sustained motivation for further learning.

When comparing the two videos, the treatment video emerged as more effective in impacting its audience in the longer-term. With a singular focus, the control video served as a better education resource immediately after watching, with larger gains in the audiences' sense of knowledge on the subject and score in the quiz. The sense of knowledge was continuously better for the control group, even in the follow up survey. However, in all other aspects, the treatment video provided markedly better outcomes in the longer-term. For specialists, it served as a better tool to identify Quaternary sites, and for non-specialists to raise their interest and sense of need for the protection of these sites. These results, combined with the findings from the previous sections may suggest that the geocultural context in the treatment video enable the audience to better engage with the materials and retain memory of its content. Consequently, the geocultural context provided a positive influence on interpreting and promoting Quaternary geoheritage sites among the study participants.

6.4.3.5 Statistical analysis: geocultural relationship

6.4.3.5.1 Self-reported interest in relationship between Quaternary geology and archaeology

Similar to the self-reported level of interest in Quaternary geoheritage (see Chapter 6.4.3.4.1 above), this question asked how interested the participants are to learn about Quaternary geoheritage sites on a 5-point scale from 0 to 4. The level of interest

participants reported in the geocultural relationship between Quaternary geology and archaeology saw a small but statistically significant (t-test $p = 0.028$) increase in the post-video wave, followed by mean reversion which returned the results for the respondents overall to a baseline statistically indistinguishable from the first wave results (t-test $p = 0.230$) (Figure 6.8).

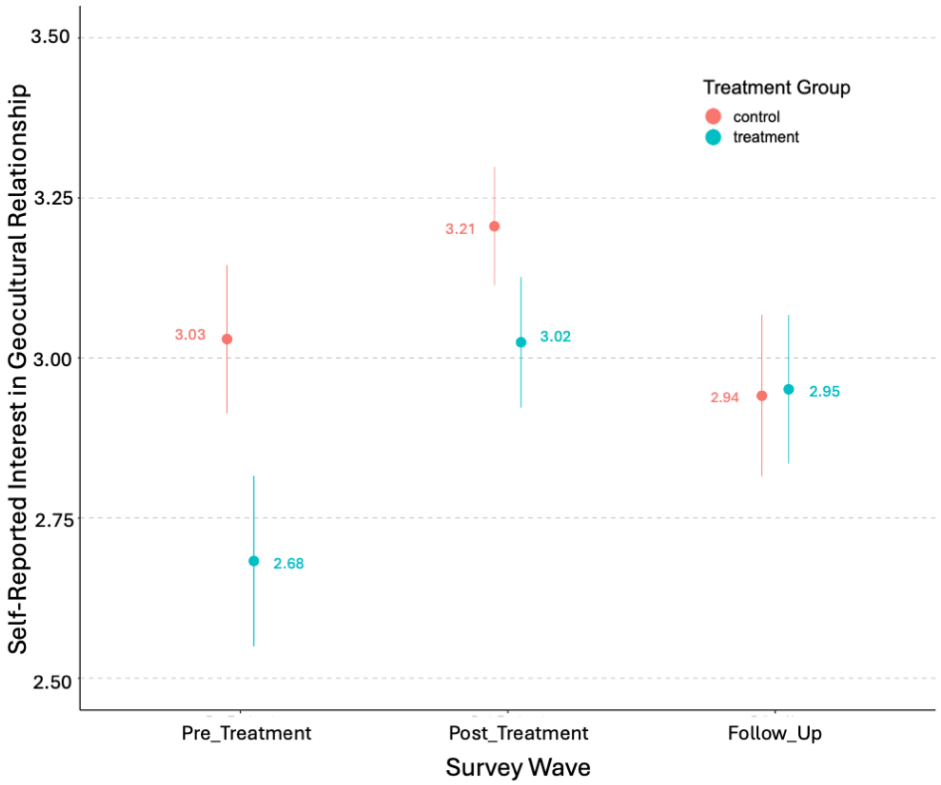


Figure 6.8 Geocultural relationship interest: scores

Difference-in-differences analysis, however, revealed that the treatment group had significantly different results from the control group for this question – reporting significantly higher increases in their levels of interest than the control group both in the post-video (DiD coefficient = 0.165, $p < 0.001$) and in the follow-up survey (DiD coefficient = 0.357, $p < 0.001$). This effect was stronger in the follow-up survey, with those in the treatment group sustaining their increased level of interest at the three-month point to a notably higher degree than those in the control group. This corresponds well with the fact

that the mean of the control group in the follow-up survey was lower than that reported pre-treatment. Moreover, this result suggests that the treatment material was effective in increasing respondents' interest in the geocultural relationship both in the short- and the medium-term.

Dividing the respondents into specialists and non-specialists and carrying out difference-in-differences analyses on both groups (Table 6.7) showed that the difference in effect size between treatment and control groups was significantly larger among non-specialists than among specialists. This was sustained in both the post-video and follow-up surveys, with the positive relative effect for the treatment group being seen in all groups but being at its strongest in non-specialist respondents in the follow-up wave. This finding supports the idea that the geocultural context in the treatment material was effective in raising respondents' interest in the geocultural relationship over a longer term. The gain in the interest, especially of the non-specialist population, in this relationship helps substantiate the claims made in the literature that the geocultural context helps expand the reach of Quaternary geoheritage sites.

Table 6.7 Geocultural relationship interest: DiD analysis by expertise level

	Specialist	**Non-Specialist**
DiD coefficient: Post-Video Survey	0.067	0.193
(p-value)	(<0.001)	(<0.001)
DiD coefficient: Three-months-after Survey	0.167	0.562
(p-value)	(<0.001)	(<0.001)

6.4.3.5.2 Self-reported knowledge in relationship between Quaternary geology and archaeology

This question asked the participants how much they know about the relationship between Quaternary geology and archaeology, on a five-point scale. The study found a statistically significant increase in respondents' self-reported knowledge in the post-video survey (t-test $p < 0.001$). Surprisingly, the mean difference was larger in the follow-up survey, with statistically significant (t-test $p < 0.001$) outcome, indicating that the participants' sense of understanding improved three months after watching the video, more so than immediately after watching the video (Figure 6.9). However, it should be noted that the reported scores are generally very low here, with the mean not going over 2, which is the option that describes the extent of knowledge as "Not very much".

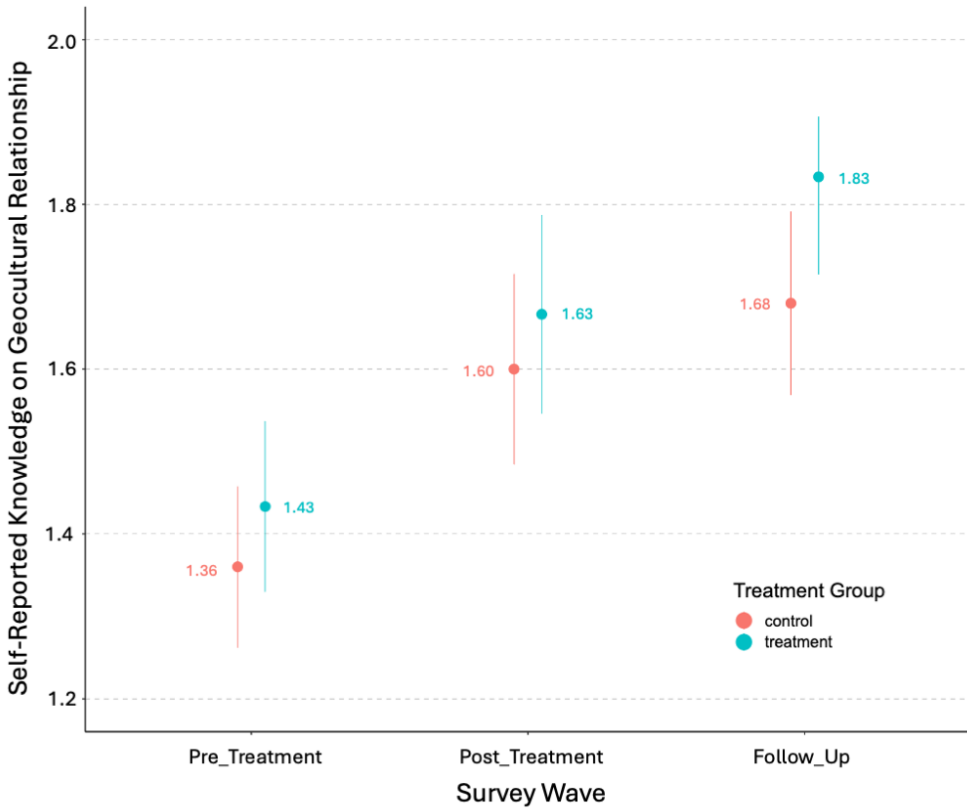


Figure 6.9 Geocultural knowledge: scores

Difference-in-differences analysis of the two treatment groups revealed a marginal, yet statistically significant negative effect to being in the treatment group, immediately after watching the video (DiD coefficient = -0.007, $p < 0.001$). This effect was reversed in the follow-up survey, in which the treatment group showed larger effects (DiD coefficient = 0.080, $p < 0.001$). Overall, this result shows a rather limited level of success in the extent to which the video could make the participants feel more knowledgeable about the geocultural connections (DiD coefficient = 0.037, $p < 0.001$). The larger positive long-term effect towards the treatment group, however, indicate that the direct mention of such connections did enable the participants to remember about them in the longer-term.

The negative results among treatment group members in the post-video survey were led primarily by specialist respondents (Table 6.8). In the post-video survey, while the non-specialists in the treatment group reported a gain in their knowledge on the geocultural connections than the control group, the divided analysis shows that the lower comparative uplift by the specialists led to the overall worse performance by the treatment group. On the other hand, the better performance of the treatment group is derived entirely by the degree of knowledge retained by the non-specialists. These contrasting results may indicate that the geocultural context included in the treatment video had different effects for the specialists and the non-specialists. For the non-specialists, the geocultural context seems to have been comprehensible, and memorable enough to retain the knowledge after 3-months. For specialists however, the inclusion of this content did not seem to help their knowledge, perhaps as they could recognise its complexity.

Table 6.8 Geocultural knowledge: DiD analysis by expertise level

	Specialist	Non-Specialist
DiD coefficient: Post Video Survey	-0.091	0.011
(p-value)	(<0.001)	(<0.001)
DiD coefficient: Three-months-after Survey	0	0.135
(p-value)	(<0.001)	(<0.001)

6.4.3.5.3 Quiz scores on relationship between Quaternary geology and archaeology

This question was asked to test the subject's understanding of the geocultural connections by making them select correct examples of relationships between Quaternary geology and archaeology in southeast Arabia. Of the seven choices given, three were correct and four were incorrect. As with the photo identification quiz on Quaternary geoheritage sites shown in Chapter 6.4.3.4.3, the results for this quiz were calculated by subtracting the number of wrong answers selected by each respondent from the number of correct answers they selected, in order to avoid the figures being skewed by respondents who selected a large number of answers. In this case, it is important to note that the resulting scores were extremely low overall, with the means in all waves hovering around zero (Figure 6.10). The responses seem to suggest that either the question was too difficult, or most respondents did not understand this aspect of the material presented. Despite the low overall scores, however, there was a statistically significant improvement in the post-video survey (t-test p = 0.0014). The mean scores in the follow-up survey were also improved from the original quiz, but this is not statistically significant at the 95% confidence level (t-test p = 0.1086). The improvement by the control

group in this quiz was rather surprising, but it may indicate how the audience could connect the scientific contents of the video with their implications for the regional archaeology, when prompted to do so. This ability, as well as the fact that they were asked questions about these connections in each survey could be an explanation for the control group answering "connection between Quaternary geoheritage and culture/archaeology" as the part of the video that left an impression for them.



Figure 6.10 Geocultural quiz: scores

The difference-in-differences analysis suggests that overall, the treatment group saw a marginally smaller improvement than the control group in this quiz (DiD coefficient = -0.008, $p < 0.001$). Compared to the control group, the treatment group had slightly more improvement in the post-video survey (DiD coefficient = 0.026, $p < 0.001$), and slightly less

improvement in the follow-up survey (DiD coefficient = -0.043, $p < 0.001$). However, these effect sizes are extremely small and while they are statistically significant, the actual degree of difference they represent does not seem meaningful.

Dividing respondents into specialists and non-specialists (Table 6.9) enables an observation of quite different results for the two groups. Among specialists, the treatment group had slightly worse performance in the quiz compared to the control group, while among non-specialists, the treatment group had slightly better performance (although the difference between treatment and control groups largely disappeared by the follow-up survey among non-specialists). This is the opposite of the outcome of the result of the quiz on detecting Quaternary geoheritage sites, in which the specialists in the treatment group led the overall improvement of the treatment group over the control group in the follow-up survey. On one hand, it could be an indication that the elements remembered by the specialists and non-specialists were slightly different after watching the treatment video. Perhaps the non-specialists remembered more about the geocultural relationship, a topic that they are more familiar with, rather than the Quaternary science elements of the video. On the other hand, it may be the case that this aspect of the video was rather confusing for specialists with previous knowledge. However, it remains unclear why the specialists in the treatment group performed worse in answering these questions, given the information provided in the video and their previous knowledge on geosciences.

Table 6.9 Geocultural quiz: DiD analysis by expertise level

	Specialist	Non-Specialist
DiD coefficient: Post Video Survey	-0.098	0.124
(p-value)	(<0.001)	(<0.001)
DiD coefficient: Three-months-after Survey	-0.133	0.038
(p-value)	(<0.001)	(<0.001)

6.4.3.5.4 Overall implications: geocultural relationship

Overall, these findings highlight that communicating about Quaternary geoheritage sites primarily enhances the audience's recognition of the geocultural relationship, rather than fostering a sustained interest in the topic, particularly in the longer-term. Additionally, despite the perceived increase in knowledge post-viewing, participants reported a relatively low level of understanding even after watching the videos. Assessing the impact on knowledge improvement via the quiz was challenging due to the overall low scores, potentially stemming from factors such as confusion or the complexity of the question.

Comparing the two videos, the treatment video, with its emphasis on the geocultural aspect, appeared to stimulate greater interest in the subject, particularly among non-specialists, suggesting that the geocultural context effectively engages audiences in communicating Quaternary geoheritage sites. On the other hand, this gain in interest by the treatment group did not translate to a better improvement in the quiz. The treatment group, particularly the specialists, fared worse than the control group in all three waves, as well as in terms of overall improvement in the score. Given the treatment group's

enhanced memory retention observed in other parts of the study, it seems likely that the geocultural context stimulated curiosity of its viewers. However, this curiosity did not directly lead to enhancing participants' factual understanding. As an outreach tool, however, these findings underscore the effectiveness of incorporating geocultural context as a tool in introducing Quaternary geoheritage sites to the general public.

6.5 Conclusions

This study aimed to investigate the effectiveness of using educational videos and the geocultural context to introduce the significance of Quaternary geoheritage sites in southeast Arabia. Through a comprehensive three-phase approach involving focus groups to determine the video contents, video production, and an online experiment, the study assessed the impact of two distinct videos—one highlighting the geocultural context and the other focusing solely on Quaternary science—on participants' knowledge, interest, and perception of Quaternary geoheritage sites.

The findings reveal several key insights into effective science communication strategies and the role of geocultural connections in fostering audience engagement with Quaternary geoheritage. The input gathered from relevant local specialists during focus group discussions emphasised the significance of visual appeal, narrative coherence, and culturally relevant storytelling in capturing audience interest and establishing a meaningful connection with the subject matter. These insights informed the development of clear and easily comprehensible videos.

The experimental comparison of the two videos provided valuable insights into their effectiveness in conveying key messages and engaging the audience. Both videos resulted in significant improvements in participants' knowledge and attitude towards protecting Quaternary geoheritage sites. The benefit of incorporating geocultural connections could be seen in improved longer-term scores for the quiz and levels of interest. The geocultural video also enhanced participants' interest and understanding of the cultural significance of Quaternary geoheritage, particularly among non-specialists. Methodologically, this study showed the importance of considering longer-term effects of interventions in geoscience communication studies and demonstrated marked differences in learning experiences between those with and without previous knowledge in the field.

The study identifies two primary advantages of integrating geocultural context into science communication efforts for Quaternary geoheritage sites in southeast Arabia. First, the inclusion of geocultural context enhanced the videos' engagement and appeal, particularly for non-specialist audiences. Second, while not as immediately effective as a teaching resource, the geocultural context appeared to improve viewers' retention of the video contents and fostered a greater need to protect Quaternary geoheritage sites.

Limitations of this study includes the rather small sample size, and the limited demographic of the participants, as well as their pro-nature conservation propensities. Future studies in different contexts could help understand whether these benefits are applicable in different social, cultural, and/or geographical context. Furthermore, exploring the applicability of geocultural connections to promote awareness and

conservation of geoheritage sites more broadly represents an important avenue for future investigation.

In conclusion, this study advances understanding of how integrating geocultural connections can enhance science communication efforts aimed at promoting awareness and conservation of Quaternary geoheritage. By leveraging the cultural relevance of these sites in communication strategies, Quaternary scientists and geoheritage practitioners can enhance audience engagement, deepen understanding, and inspire longer-term changes in the attitude towards the protection of Quaternary geoheritage sites. These insights offer valuable guidance for refining communication strategies for complex scientific concepts and fostering public engagement with Quaternary science initiatives.

Section D: Quantitative Assessment

Chapter 7 Promoting diversity in geoheritage evaluation: Creating an evaluation method for the scientific value of Quaternary sites in arid environments*

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Abstract

A rigorous assessment is an essential part of geoconservation, and choosing an appropriate evaluation method is essential for this process. Globally, an increasing number of sites are being assessed for their geoheritage values, but the most popular methods have been created by researchers with experiences centred in Europe, without considerations of regional differences. To understand whether regional perspectives are required in the evaluation process, this study developed a new method targeting the scientific value of Quaternary geoheritage sites in arid environments, using input from 49 researchers in geosciences and related disciplines with interests in arid landscapes. The results demonstrated the need for a new or modified method, given the different preferences in the weighting system and the necessity to include additional criteria specific to the type of sites targeted by the study. The strong preference to include a new criterion on connections with archaeology/anthropology highlighted the significance of

* Minor changes have been made to this manuscript to aid the readability and continuity within the thesis. For example, the number of figures and tables have been changed.

the interdisciplinary scientific values of Quaternary geoheritage sites in arid environments. These findings imply the need for regional diversity or adjustments in geoheritage evaluation. Future research is required to consider such differences for geoheritage values beyond the scientific dimension, such as educational values and touristic values in diverse geographical settings.

7.1 Introduction

To protect and celebrate geoheritage sites in a world with limited resources, their evaluation is essential to select those with the highest need for conservation. Evaluation is identified as one of the primary tasks for geoheritage researchers (Reynard, 2009), as it requires a delicate consideration of combining intrinsic values as well as human focused values (economic/touristic, educational, scientific, etc.). Objectivity and transparency are desired traits in a robust evaluation process (Brilha, 2018b; Reynard, 2009), although a level of subjectivity is inevitable for any evaluation. The need for an effective evaluation is evident from the number of methods proposed in the last few decades (Brilha, 2016; Coratza & Giusti, 2005; De Lima et al., 2010; Knapik et al., 2009; Panizza, 2001; Reynard et al., 2007; Ruban, 2010; Vujičić et al., 2011), corresponding to the growth of global interest in geoconservation. Of these methods, several popular “schools” have been identified (Siuki & Kowalczyk, 2012), and the most popular methods have been applied to geoheritage sites around the world. In the process of this development, specialised methods for different types of geoheritage sites have been considered, but very few methods have been created for assessing geoheritage sites from specific environmental regions. Focusing on Quaternary geoheritage sites in arid environments, this study

presents an exploratory analysis of the necessity of environment-specific methods for geoheritage evaluation and present a potential model for creating such methods.

7.1.1 History of geoheritage evaluation

In this paper, the definition of the term geoheritage by Brocx and Semeniuk (2007, p.62), "[g]lobally, 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" will be used. Some researchers such as Brilha (2016) advocate for a restricted use of the term geoheritage to sites that present significant science value, and have promoted the use of the term geosites for sites without scientific significance. A more focused definition has its advantages, such as promoting geological sites for values beyond aesthetics. This approach, however, limits the scope of geological heritage in ways contrary to international frameworks of natural heritage, such as the World Heritage Convention (UNESCO, 2021a). In the World Heritage Convention, natural heritage sites are valued not only from a scientific perspective, but also from aesthetic (natural beauty), and conservation perspectives. Moreover, with the recognition of cultural landscapes, the cultural values of natural heritage sites are acknowledged. With a wider scope of heritage values in mind, an inclusive definition of geoheritage will be used in this paper.

The first systematic evaluation of geoheritage sites was conducted in 1977 by the British Nature Conservancy Council (Nature Conservancy Council, 1990). Although this was a

noble effort to provide clarity to the process of selecting geological sites worthy of protection, the lack of a rubric that describes how a site is evaluated meant that the evaluation was dependent on the evaluator's opinion, resulting in a high level of subjectivity. Similarly, the earliest evaluation methods relied solely on the knowledge of the evaluator, leaving the process more or less a "black box" (Bruschi et al., 2011).

Since the late 1990s, many geoheritage evaluation methods have been developed. One category of these methods is qualitative methods like that of Brocx and Semeniuk (2015b), which have advantages of being more descriptive and for assessing sites that require highly nuanced assessments, such as when the site possesses little scientific value, but very high cultural value (Brocx & Semeniuk, 2007). On the other hand, many other methods have employed a quantitative and/or semi-quantitative approach in the assessment with an accompanying rubric that identifies how to evaluate each criterion (or indicator) clearly with a numerical outcome that enables comparisons between assessed sites (Brilha, 2018b; Bruschi & Cendrero, 2009). These methods are not devoid of subjectivity, as many criteria (e.g. aesthetics, rarity, historical significance, cultural significance) used in the evaluation cannot be applied purely on a numerical basis (Brilha, 2016). Nevertheless, quantitative methods have been used more often in geoheritage studies, as they offer relatively higher levels of transparency, comparability, and reproducibility (Mucivuna et al., 2022). These benefits are especially important as they make the outcomes more straightforward and credible for the interpretation and understanding by non-specialists such as local stakeholders and government officials. Following this recent trend in the development of the scholarship, this paper will focus on quantitative and/or semi-quantitative methods for evaluating geoheritage sites.

Along with the development of overall evaluations of geoheritage sites, many methods have been developed for the evaluation of geotourism potential/value (e.g. Kubalíková, 2013; Pralong, 2005b) and geodiversity (e.g. Ruban, 2010; Zwoliński et al., 2018). A more detailed discussion on this topic can be found in papers such as Bruschi and Cendrero (2009) (geoheritage evaluation), Kubalíková (2013) (geotourism), and Zwoliński et al. (2018) (geodiversity assessment). In many of these methods, various dimensions (large categories) of geoheritage values are considered. Dimensions of geoheritage values include: scientific value, educational value, touristic value, endangerment status, aesthetic value, and cultural value. A number of researchers (Brilha, 2016; Kubalíková, 2013; Reynard, 2009) consider the scientific value as the central aspect of geoheritage evaluation, as it provides a relatively objective and transparent description of the intrinsic quality of the site. The scientific value is important, as it is the geoscientific elements of sites that distinguishes geoheritage sites from other types of heritage sites. In fact, as mentioned by Erhartič (2010), many of the early assessment methods focused primarily on the scientific value. Hence, although it is true that the consideration of other aspects of geoheritage sites is essential, the scope of this study will focus on the scientific value.

To assess the scientific value quantitatively, various relevant criteria (factors used to evaluate each dimension) are considered. Table 7.1 summarises the criteria used in previous literature to evaluate the scientific value of geoheritage sites. As shown in Table 7.1, many criteria are shared among different methods. Although the criteria used in these methods tend to overlap, their weighting strategy varies. In a quantitative assessment, the weighting is an important consideration, as it determines two things: the relative importance of different criteria towards a specific value dimension of a site and the relative importance of each value dimension towards the overall geoheritage value of a

site. However, as mentioned by Zorlu and Dede (2023), strategies for weighting have not often been studied in the geoheritage literature. Although it is an essential component of a quantitative assessment to provide a robust outcome, weighting in most methods (Brilha, 2016; Pereira & Pereira, 2010; Reynard et al., 2007; Ruban et al., 2021) has simply been created by the professional experience of the researcher(s), which by nature tend to be subjective. This *status quo* contradicts with the need for subjectivity in the assessment process. Other than the researcher's experience, methods for weighting include, equal weighting (Pereira et al., 2007; Reynard et al., 2007) or using the mean value obtained from a survey conducted towards a larger group of relevant regional experts (Bruschi et al., 2011). Of these three methods, the last option, as used by Bruschi et al. (2011) offers the least subjectivity, by reflecting the opinions of various professionals. When speedy decisions are required, or only a few relevant experts are available for consultation, the use of other methods could be justifiable, but a weighting system derived from the experience of a single or a few researchers inevitably includes inherent subjectivity, which should be minimised in the process of evaluation.

For the weighting method to combine assessments of different value dimensions into one overall metric, strategies from previous studies include: no categorisation of different value dimensions (Bruschi et al., 2011), the sum of all value dimension (Knapik et al., 2009; Solarska & Jary, 2010; Vujičić et al., 2011), or the use of a matrix (Pereira & Pereira, 2010).

Table 7.1 Summary of criteria used in previous methods for the evaluation of scientific value for geoheritage sites, with criteria developed for this study. The list includes all criteria included in the questionnaire.

Criteria	Methods in which the criterion was used
Representativeness: whether the site demonstrates exemplary characteristics of the geological/geomorphological elements or processes.	Panizza (2001), Coratza and Giusti (2005), Reynard et al. (2007), Pereira and Pereira (2010), De Lima et al. (2010), Bruschi et al. (2011), Brilha (2016)
Integrity: Current state of conservation of the main geological/geomorphological elements of the site.	Reynard et al. (2007), Pereira and Pereira (2010), Kubalíková (2013), Brilha (2016), Ruban et al. (2021)
Geological diversity: Whether the site and its surrounding area covers a diverse array of geological/geomorphological features of scientific interest.	De Lima et al. (2010), Pereira and Pereira (2010), Kubalíková (2013), Brilha (2016), Ruban et al. (2021)
Rarity: Whether the feature is rare or unique in the region, the country, or the world.	Coratza and Giusti (2005), Reynard et al. (2007), P Pereira and Pereira (2010),. Bruschi et al. (2011), Kubalíková (2013), Brilha (2016), Ruban et al. (2021)
Historical value: Importance of the site for the development of the field.	Coratza and Giusti Coratza and Giusti (2005), Reynard *et al.* Reynard et al. (2007)
Scientific knowledge: The extent of scientific knowledge gained from the site.	Coratza and Giusti (2005), Pereira and Pereira (2010), Bruschi et al. (2011), Kubalíková (2013), Brilha (2016), Ruban et al. (2021)
Potential for future research: 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)
Connection with other disciplines: Whether the site has connections with disciplines other than archaeology/evolutionary anthropology (flood management, natural disaster management, current land use, etc.).	Bruschi et al. (2011)
Chronological resolution: How far back the chronology from the site extends and at what resolution (intervals).	Developed by author for this study
Connection with the regional archaeology/anthropology: Whether the site has significant meaning towards the regional archaeology/anthropology.	Developed by author for this study

On the other hand, some methods (Brilha, 2016; García-Cortés et al., 2019; Reynard et al., 2007) refrain from calculating an overall value and opt to produce separate outputs for each value dimension as the final outcome. This approach takes into consideration of the idea that the objective of the conservation of the site and the plan for its use would change the way different value dimensions are prioritised. For example, if a site or an area

is to become protected for solely touristic use, incorporating educational values in its overall assessment is unnecessary. While the single output approaches provide simplicity in ranking sites, the multi-output methods offer better flexibility in their application, accounting for different objectives for protecting geoheritage sites.

7.1.2 Geographical perspectives on geoheritage evaluation

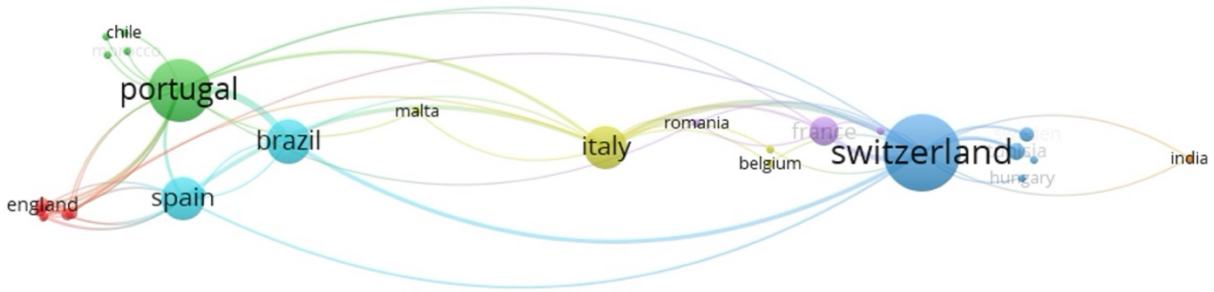
In adopting methodologies for geoheritage evaluation, an important consideration is the applicability of the method to different geoheritage sites. Geographical region is an important factor to consider in this regard. Evaluation methods have been developed around the world, such as in Australia by Brocx and Semeniuk (2009, 2015) , in Turkey by Zorlu and Dede (2023), in Japan by Suzuki and Takagi (2018), in Korea by Woo and Kim (2018), and in Brazil by Santos et al. (2020). The geographical diversity of assessment methods has increased considerably in the last five years. Most commonly used methods, however, have been developed in Europe, such as the three methods from Switzerland (Reynard et al., 2007), Spain (Bruschi & Cendrero, 2005; Bruschi et al., 2011), and Portugal (Pereira et al., 2007) identified as the popular schools of geoheritage evaluation by Erhartič (2010). These methods were developed for use at various settings based on the experiences of researchers from some of the pioneering countries for geoheritage research. Furthermore, the method by Brilha (2016) has become one of the most cited and applied methods recently, most likely due to its development through a rigorous review of previous methods. In terms of geographical representativeness, these four popular methods for geoheritage evaluation have been developed with experiences predominantly in Europe. As shown in Figure 7.1, creators of these methods not only work in European institutions, but also, most of their collaborators are concentrated in Europe,

apart from a cluster in Brazil. This is not to say that they have not conducted work in other regions or lack knowledge on other regions, but it provides an indicator of the Euro-centric foundation of the methods used commonly around the world.

These methods may provide a useful base for conducting geoheritage evaluation around the world. However, they may not be as effective in non-European settings, not only because different regions present different types of sites, but also because the assessment of heritage values requires a human perspective, as can be seen from the inclusion of the cultural value and potential threats/degradation risk in the assessment. Even for the scientific value, the evaluation cannot be based solely on scientific observations, especially when traditional and/or indigenous perspectives towards science or knowledges are considered. As Sillitoe (2009) and Whyte et al. (2016) explains in the context of international development and sustainability science, respectively, respecting, learning, and incorporating ideas from different knowledge systems produce better results when working with indigenous peoples.

Zorlu and Dede's assessment (2023) of the geoheritage values of palaeoglacial sites in Northern Turkey exemplifies the need for such a regional adjustment. By using of opinions by three experts and a suite of statistical techniques, this study considered the need to modify the weighting system of the evaluation method proposed by Ruban et al. (2021) for application in the study's targeted area. The resulting system diverges significantly from that of the original method in ways such as a lower weight for rarity (66.7% to 30.8%), and higher weights for scientific importance (3.3% to 17.8%) and educational importance (3.3% to 14.6%). The modified weight system helped differentiate the ranking of three sites with identical score in the original method, showing the benefits of a specialised

method and potential limitations of evaluation methods designed for global application. Although a universal method for evaluation may be ideal for consistency, adjustments towards these methods should be considered to account for region-specific conditions, such as different climate, geological/geomorphological processes, and cultural conditions, when using them in different regions.



Country	Number of Documents	Total Link Strength	Country	Number of Documents	Total Link Strength
Switzerland	73	50	Finland	1	7
Portugal	50	43	Romania	1	4
Brazil	25	27	Belgium	1	2
Italy	24	35	India	1	2
Spain	24	23	Malaysia	1	2
France	11	16	Malta	1	2
Tunisia	4	4	Nepal	1	2
England	3	10	Poland	1	2
Sweden	3	3	Chile	1	1
Netherlands	2	9	Denmark	1	1
Scotland	2	9	Ethiopia	1	1
USA	2	8	Hungary	1	1
Argentina	2	3	Morocco	1	1
Australia	1	7	Wales	1	1

Figure 7.1 The network of countries where researchers who have co-authored with the first authors of Brilha (2016), Bruschi et al. (2011), Pereira et al. (2007), and Reynard et al. (2007) are based (Visualisation created using VOSviewer with citation data from Web of Science), with a table providing the breakdown of countries included in the network (European countries highlighted in blue). The network includes home countries of the researchers (Portugal, Spain, and Switzerland).

7.1.3 Geoheritage evaluation in arid environments

Arid environments encompass a significant portion of the Earth's land surface, constituting approximately 41% of its total area (Mortimore et al., 2009). Within arid environments, there are diverse geomorphological characteristics and climatic heterogeneity, but the relative importance of processes and their magnitude and

frequency are distinct from other regions, which justifies such a regional categorisation from a geoscientific perspective (Thomas, 2011). These distinct processes create characteristic landforms such sand dunes, mesas, sabkhas, and palaeolakes/rivers (see Figure 7.2 for examples), many of which demonstrate high geoheritage values.

Over the past decade, there has been a notable increase in the number of studies focused on geoheritage evaluation in arid environments, particularly in the MENA (Middle East-North Africa) region. This surge is especially evident in countries such as Iran (Farsani et al., 2019; Habibi et al., 2018; Khoshraftar & Farsani, 2022; Mehdipour Ghazi & Audra, 2022; Mehdipour Ghazi et al., 2021; Molchanova & Ruban, 2019; Moradi et al., 2021; Moradipour et al., 2020; Pourahmad et al., 2018; Sadry et al., 2021; Salamzadeh et al., 2021; Siuki & Kowalczyk, 2012; Soltan, 2021; Tomić et al., 2021), Egypt (AbdelMaksoud et al., 2018, 2019; Khalaf, 2022; Kharbish et al., 2020; Plyusnina et al., 2016; Ruban et al., 2021; Sallam, Abd El-Aal, et al., 2018; Sallam, Abd El-Samee, et al., 2020; Sallam, Fathy, et al., 2018; Sallam, Ruban, et al., 2020), and Morocco (Arrad et al., 2018; Arrad et al., 2020; Beraaouz et al., 2019; Berred et al., 2019; Bouzekraoui, Barakat, El Youssi, et al., 2018; Bouzekraoui, Barakat, Mouaddine, et al., 2018; Mehdioui et al., 2020; Mehdioui et al., 2022). The majority of these investigations involve inventories or inventory-based evaluations, which correspond to the initial stages of geoheritage conservation proposed by Brilha (2016). The evaluation methods used in these studies primarily adopt approaches developed by European researchers, including Brilha (2016), Vujičić *et al.* (2011), and Ruban *et al.* (2021) directly, or use simple original methods with qualitative evaluations . Moreover, some studies have focused specifically on evaluating the endangerment status of geoheritage sites in arid environments (AbdelMaksoud et al., 2018, 2019). In Oman and the UAE, Sayama *et al.* (2022) found that 14% of Quaternary

geoheritage sites were already destroyed, mainly due to quarrying and economic development.

Of studies from the MENA region, Siuki et al.'s study (2012) on the evaluation of geosites in the Razavi Khorasan region in eastern Iran stands out as an exception. By using input from tourist and scientific specialists, this study developed an evaluation method focused on the touristic potential of geoheritage sites and used it to rank sites in Razavi Khorasan. Developed using input from multiple stakeholder groups, this method provides a high level of objectivity. On the other hand, the study offers limited instructions on how to apply the resulting method, most likely as it was designed for use at a local scale. Moreover, the criteria considered in this study differs significantly from any other methods. This may mean that the required criteria are different for different regions, but it makes comparison with other existing methods difficult. Given these considerations, further studies are required to examine the specificity of geoheritage evaluation in arid environments, in terms of weighting and criteria required.

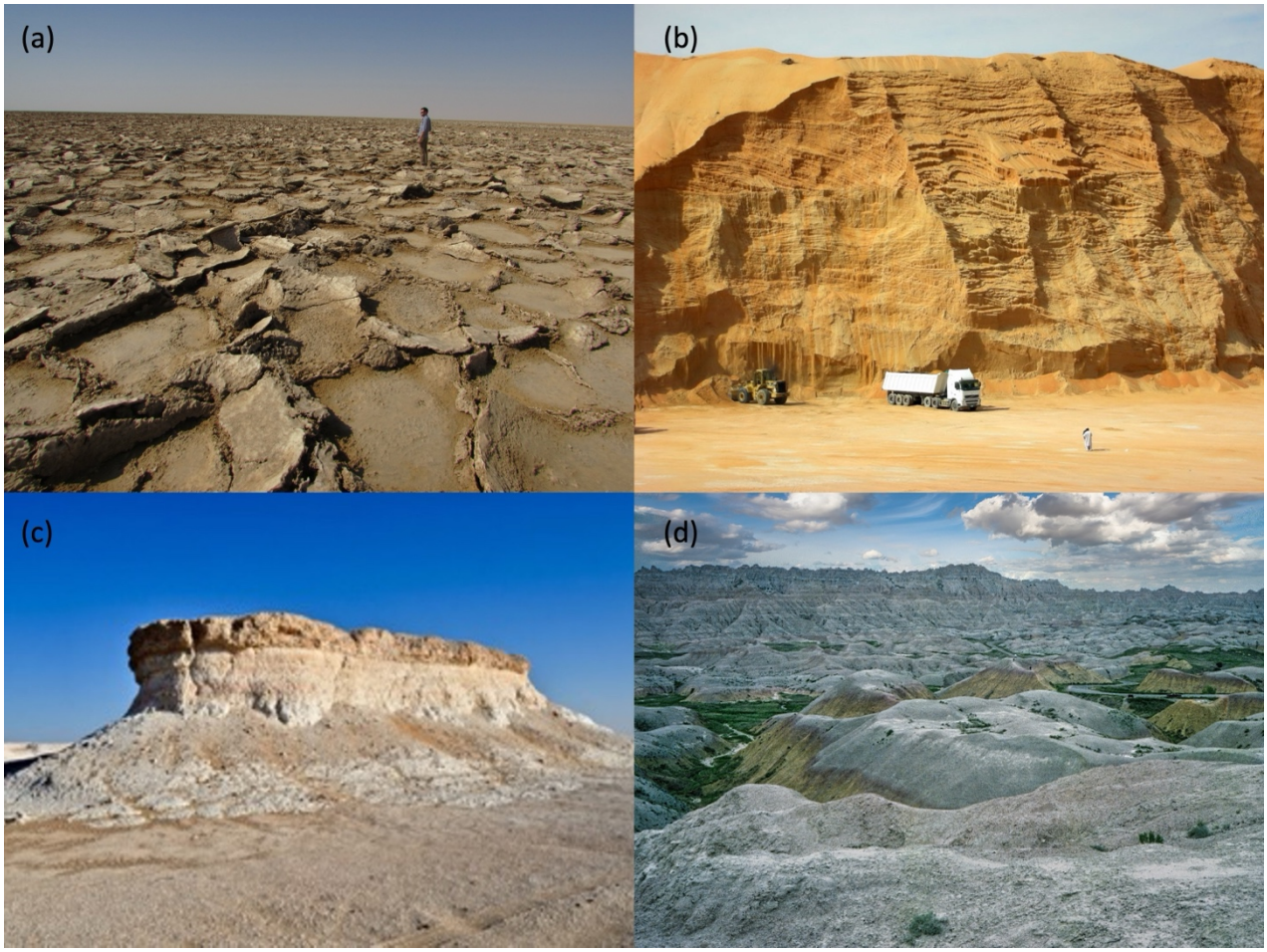


Figure 7.2 Examples of Quaternary geoheritage from arid environments: (a) inland sabkha from Oman, (b) section of a mega sand dune in the UAE, (c) wind-eroded sandstone from a palaeolake in the UAE, (d) badland landscape in southewest United States (Photos courtesy of Professor Andrew Goudie, Dr Ash Parton, and Tom Fink).

7.1.4 Temporal/typological subdivision of geoheritage evaluation

Geoheritage includes many types of sites with a wide range of sizes, ages, and processes. Habibi et al. (2018) provides a list of 21 geoheritage types, such as stratigraphical, geomorphological, paleontological, igneous, and palaeogeographical sites. Most methods for geoheritage evaluation target all types of geoheritage sites (Brilha, 2016; De Lima et al., 2010; Knapik et al., 2009; Ruban, 2010; Vujičić et al., 2011). Comparatively, not many specialised methods have been developed for certain types of geoheritage sites, other than a few methods, such as method for dinosaur track sites.

An exception to this trend is geomorphological heritage sites, or geomorphosites. Geomorphosites are defined as “qualifying geomorphological sites that are part of the geomorphological heritage” (Reynard, 2009, p.14). Three main distinctions between general geoheritage sites and geomorphosites are made by Reynard (2009), which are as follows:

1. Aesthetic character: they are often defined by their beauty more so than other types of geoheritage sites, with many of them being considered natural monuments.
2. Dynamic nature: they are experiencing ongoing earth surface processes and current earth dynamics can be observed with these sites. The current state of these sites may be prone to change through natural processes such as weathering. Although geomorphosites may be damaged by these natural processes, they should not be interrupted to protect the current state of the sites.
3. Scale: they can be very large scale which can encompass entire landscapes, such as alluvial plains, or they can be smaller individual features.

In addition, as can be seen from the proposed use of the cultural geomorphology concept by Panizza and Piacente (2003), geomorphological sites demonstrate a strong connection with human culture, whether it be archaeological, historical, architectural, or beyond. Geomorphosites were formed, are forming, or will be formed, contemporaneously with the history of humans. This synchronicity provides geomorphosites the uniqueness as sites that provide records of the interactions of humans and the abiotic environment through time and document the impact of humans in this relationship. In arid

environments, the use of this connection has helped many archaeological studies, to better understand topics such as human migration out of Africa (Nicholson et al., 2021), ancient-human responses to arid events in the Cusco region, Peru (Chepstow‐Lusty et al., 2003), and human settlement patterns in Australia (Williams et al., 2015). Furthermore, some of these sites and/or records have evoked human creativity, in the sense of art, technology, or cultural traditions, as exemplified by the religious and artistic significance of Mount Fuji in Japan (Chakraborty & Jones, 2018; Oguchi & Oguchi, 2010).

In different parts of the world such as arid environments, however, the defining features of geomorphosites do not always hold true for all Quaternary geological or geomorphological sites, especially as these sites are not made distinct by their aesthetic character. As can be seen from Figure 7.2, characteristic geomorphological sites in arid environments are not always majestic sites that could be considered natural monuments. This distinction is important, as many geoheritage sites are protected due to their aesthetic values, especially for the purpose of tourism (Chylińska, 2019), but that is not the primary criterion for the conservation of many others (Brilha, 2018b). To make this distinction, this study will use the term Quaternary geoheritage, to refer to all geological/geomorphological sites from the Quaternary period, including geomorphosites.

Various evaluation methods have been developed targeting geomorphosites (Coratza & Giusti, 2005; Kubalíková, 2013), including two of the four aforementioned popular methods (Pereira & Pereira, 2010; Reynard et al., 2007) of geoheritage evaluation. Some distinguishing features of these methods are the inclusion of the aesthetic value and the cultural value as separate dimensions in the evaluation, which reflects the distinctive

features of geomorphosites. In fact, Santos et al. (2019), with a case study that compares a coastal temperate region of Brazil and the alpine region of the Alps, found significant differences in the evaluation outcomes between methods developed for general geoheritage sites and methods developed for geomorphosites. In the case of scientific values, the study pointed out the differences in the criteria considered, as the main reason for the differences in the evaluation outcomes. On the other hand, in a similar study in a temperate region of Brazil, Mucivuna et al. (2022) found no significant differences in the outcomes between the general and specialised evaluation methods. This study suggested the use of existing evaluation methods in future research and advised to limit the use of specialised methods for only "specific features". These studies do not provide a conclusive guideline, but it is noteworthy that arid environments have not been considered in such a context. Given their distinctive characteristics, Quaternary geoheritage sites from arid environments may need to be considered as "specific features".

Overall, given the (a) lack of evaluation methods using input from a group of experts, (b) lack of evaluation methods targeting arid environments and (c) reported endangerment of Quaternary geoheritage sites identified in previous literature, this study aims to develop a new evaluation method for the scientific values of Quaternary geoheritage sites in arid environments by consulting a group of experts on the weighting strategy. In so doing, it also seeks to compare existing methods with this new method developed by the opinions of experts on arid environments.

7.2 Methods

To gather input required from experts on Quaternary geoscience of arid environments, an online questionnaire was created and distributed towards postgraduate students and academics in geosciences (i.e. geologists, geomorphologists, palaeontologists, physical geographers, and hydrologists) or related disciplines that use geoscientific data (i.e. archaeologists, evolutionary anthropologists), with research interest in arid environments. The recruitment was conducted through geosciences and geoheritage conferences, social media adverts, and direct emails (see Appendix F for the advert used in this study).

The survey asked researchers about:

1. Their profession
2. Their disciplinary expertise
3. Which criteria (out of the 10 as shown in Table 7.1) should be included to evaluate the scientific value
4. The relative importance of criteria that should be included to evaluate the scientific value
5. The appropriateness of various proxies to evaluate criteria that should be included in the evaluation
6. Comments and suggestions

A five-option scale, ranging from 1–5 was used for most of the questions with the following description for each value:

1. Should not be ignored, but comparatively it is not very important
2. Should be considered to some degree
3. Should be considered

4. Very important to determine the scientific value
5. Essential, most important to determine the scientific value

The full questionnaire is available as Appendix G. The purpose of the study was to ask the participants to decide the relative importance of criteria used evaluate the scientific value of Quaternary geoheritage sites in arid environments. The criteria considered in the questionnaire were selected based on those used in past literature, with a couple of additions to reflect the characteristics of Quaternary geoheritage sites in arid environments. Most criteria used in past literature were selected, except for ones that overlap in its scope with other criteria. A criterion on the connection with the regional archaeology/evolutionary anthropology and another on the chronological resolution were added, as Quaternary geoscience research has made large contributions to these disciplines in arid regions around the world (Chepstow‐Lusty et al., 2003; Clarke et al., 2016; Field et al., 2002; Goebel et al., 2021; Madella & Fuller, 2006; Migowski et al., 2006; Morgan et al., 2022; Williams et al., 2015). Table 7.1 describes the 10 criteria selected and outlines the criteria included in popular methods for geoheritage evaluation.

For the proxies, as many past evaluation systems rely on “expert opinions”, they do not provide clear proxies to quantify each factor. In order to understand which proxies are most suitable, the questionnaire asked participants to rate the most appropriate proxy from those used in the previous literature, such as the number of papers published on the site for scientific knowledge and the analysis of protection status for integrity, and potential proxies proposed by the author, such as the analysis of satellite imagery for integrity.

The weight for each criterion used to calculate the overall scientific value was determined using the mean of all responses. Numbers from the five-point scale were used directly, but to reflect the opinions of those who answered against including a criterion in the assessment, a numerical value of -4 was given for the answer: “the criterion should not be included in the evaluation”. The value -4 was selected as it allows the mean of two responses, when one respondent considers a criterion as the most important (indicated by a 5), and another considers it as it “should not be included”, to equal the lowest value possible, 1, for the relative importance of a criterion.

7.3 Results

The questionnaire was conducted between November 2021 and July 2022. It was answered by 49 researchers. The professions of participants include 6 PhD students, 42 academic researchers, and 1 professional geoscientist. Of the academic researchers, 2 are also professional geoscientists, and 1 is a heritage manager. Their fields of expertise are outlined in Figure 7.3. Of the 25 participants with archaeological expertise, 15 are also experts in Quaternary geoscience, and 3 are either experts in wider geoscience or environmental science. Of the 20 participants without expertise in Quaternary geoscience, 10 are experts in archaeology, 7 in geosciences, and 5 in heritage conservation.

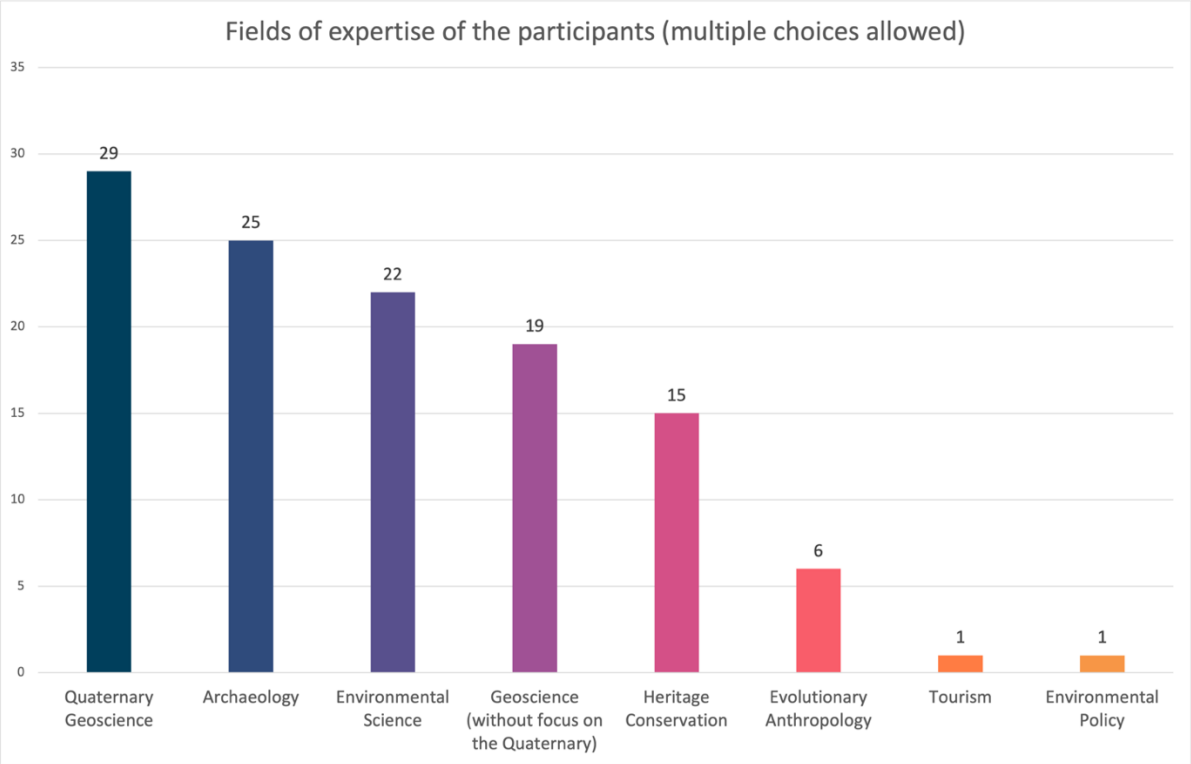


Figure 7.3 Fields of expertise of the participants of the questionnaire

The outcomes of the survey of the necessity and relative importance of each criterion are described in Figure 7.3 and Figure 7.4. For the necessity, none of the criteria were unanimously considered necessary, but representativeness and scientific knowledge were considered necessary by most participants with only one response against the inclusion of the criterion. This was followed by rarity and connection with archaeology/anthropology with two responses against their inclusion. Contrarily, chronological resolution, geological diversity, and potential for future research received the most responses against inclusion, with 12, 9, and 8 participants against their inclusion, respectively.

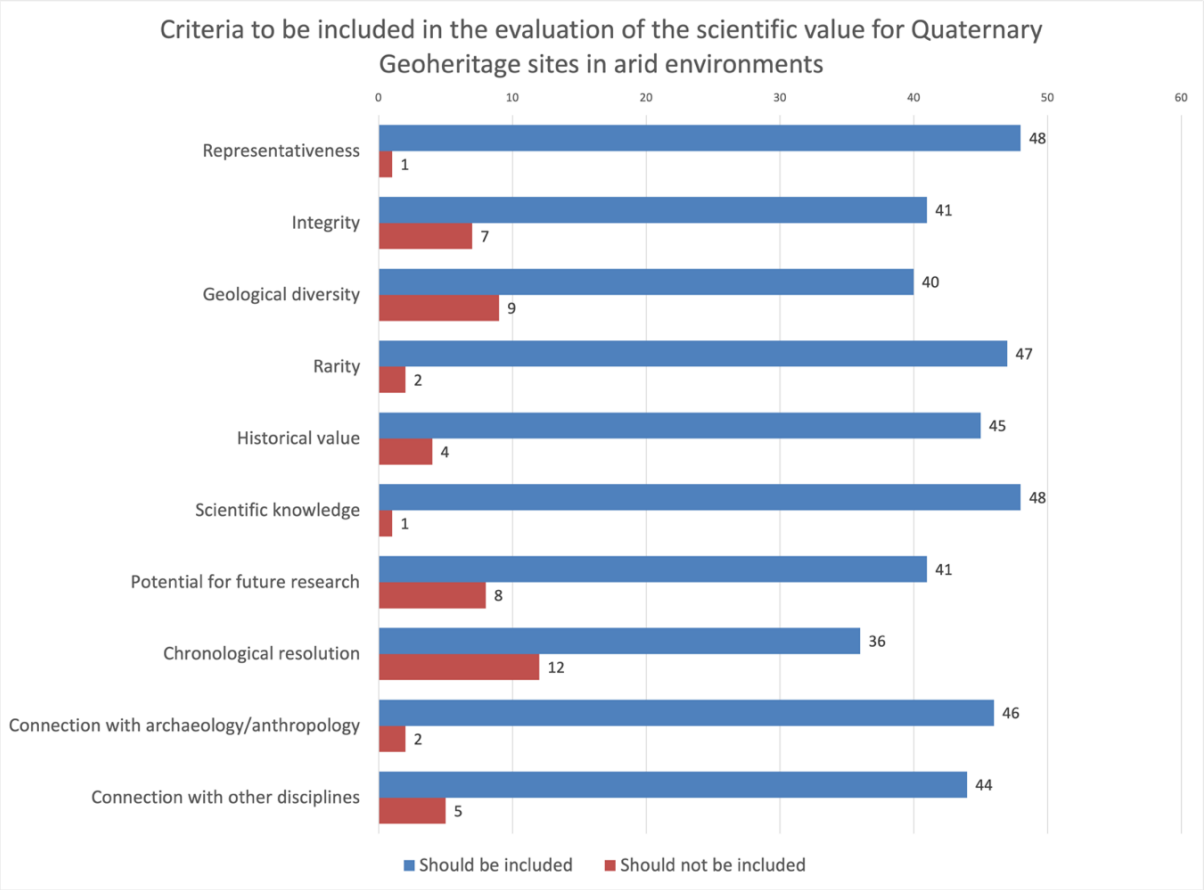


Figure 7.4 Number of responses to the questionnaire indicating the necessity of including each criterion in assessing the scientific value of Quaternary geoheritage sites in arid environments (n=49, with respondents given the option to opt out of answering).

As shown in Table 7.2, for the relative importance of criteria, rarity had both the highest mean and median, followed by representativeness and scientific knowledge. These three criteria stood out as the most important, with more than a 0.5 difference in the mean relative importance to the next highest criterion, archaeological/anthropological connections. On the other end, chronological resolution had the lowest relative importance with a mean value of 1.65, about 0.47 lower than the second lowest criterion, geological diversity. In order to calculate the scientific value reflecting the relative importance of each criterion, a weighting system out of 100 was developed, as shown in Table 7.2.

Finally, the suitability of proxies for use as parameters for each criterion, are listed in Table 7.3. Overall, site visits and expert judgement are consistently considered as one of the most appropriate proxies for the evaluation of the scientific value. Literature review and analysis scored relatively highly, especially for representativeness, rarity, and historical significance. On the other hand, proxies related to publication (i.e. number of citations and number of publications) are considered as poor metrics, with a low relative importance value, especially those related to the number of citations. Beyond "discussions with experts", the highest rated proxy is generally those that have been used in previous methods. Proxies proposed by the author such as "comparative analysis of images of the site" for representativeness and the "analysis of satellite imagery" for integrity were not considered very appropriate.

Table 7.2 Summary of the responses to the questionnaire on the relative importance of each criterion for the scientific evaluation of Quaternary geoheritage sites in arid environments (number in parentheses represent the number of answers).

	Represent-ativeness (49)	Integrity (48)	Geological Diversity (49)	Rarity (49)	Historical importance (49)	Scientific knowledge (49)	Potential for future research (49)	Chronological resolution (48)	archaeo/anthro connection (48)	connection with other disciplines (49)
Mean	3.96	2.57	2.12	3.98	2.98	3.92	2.53	1.65	3.45	2.80
Median	4	4	3	5	4	4	4	3	4	4
Weight out of 100	13.22	8.60	7.09	13.29	9.95	13.08	8.45	5.50	11.51	9.33

Table 7.3 Summary of the responses to the questionnaire towards the suitability of proxies for the scientific evaluation of Quaternary geoheritage sites in arid environments (number in parentheses represent the number of answers).

	Representativeness			**Integrity**			**Geological diversity**			**Rarity**		**Historical significance**	
	Comparative analysis of literature (47)	Comparative analysis of images of the site (44)	Number of articles published on the site (45)	Analysis of satellite imagery (41)	Analysis of the protection status (40)	Site visits (37)	Literature review (38)	Discussions with experts (32)	Site visits (34)	Literature review (46)	Discussions with experts (41)	Literature analysis (44)	Discussions with experts (39)
mean	3.80	3.56	2.32	3.41	3.53	4.70	3.61	3.88	4.53	4.11	4.22	4.09	4.15

	Scientific knowledge			**Future research**			**Chronological resolution**		**Connections with archaeology/anthropology**				**Connections with other disciplines**		
	Number of citations (47)	Publication in high-impact journals (48)	Number of articles published on the site (48)	Literature analysis and search for ongoing projects (41)	Mentions of need for future research in academic literature (41)	Discussions with experts (37)	Depth of the sequence (34)	Number of chronological records collected from the site (36)	Chronological proximity or relationship with regional archaeological sites (46)	Discussions with experts (44)	Citation by archaeology or evolutionary anthropology articles (41)	Citation in high-impact journal articles on archaeology or evolutionary anthropology (39)	Citation by non-geoscience, archaeology, or anthropology, articles (43)	Citation in high impact journals (42)	Discussions with experts (39)
mean	2.94	2.73	3.44	3.66	3.63	4.24	3.62	3.92	4.20	4.23	3.43	2.86	3.42	2.52	4.23

7.4 Discussion

The number of participants in this study, 49, is the highest for a study focused on developing an evaluation method for geoheritage sites. The number of participants, as well as their academic background focused on disciplines related to Quaternary geosciences, provide appropriate representation for the purpose of this study. Overall, the study has been able to reflect the opinion of a breadth of regional experts, but a limitation of approaching researchers as participants is the lack of representation of indigenous knowledges, which should be addressed in future studies.

To finalise the criteria and weighting system used to evaluate Quaternary geoheritage sites in arid environments, the necessity of each criterion must be considered. The criterion that stands out as unimportant in the result of this study is chronological resolution, the only criterion with a mean value below 2. This result is mostly because this criterion has been considered unnecessary by 25% of all participants. The relatively low importance of this criterion is apparent in the categorised data, as shown in Table 2. Interesting, even when excluding the “should not include” answers, chronological resolution is the criterion with the second lowest relative importance. The chronological resolution criterion gained relatively high support from archaeologists and anthropologists both with and without expertise in Quaternary geoscience, most likely as they use the chronological data for their research or due to differences in semantic views between disciplines. Nevertheless, even in this case, chronological resolution was within the three lowest ranked criteria. Additionally, as noted by one of the participants, the chronological resolution criterion could possibly be considered within the scientific knowledge criterion. As mentioned in previous studies (Bruschi et al., 2011; Mucivuna et

al., 2019), overlapping criteria should be combined, when possible, to simplify the evaluation. Therefore, the chronological resolution criterion was removed entirely from the final evaluation method.

The final weighting system developed by this study is compared to other methods in Table 7.5. The main characteristics of the method developed in this study include the relatively high number of criteria, lower importance of representativeness and historical value, higher importance of scientific knowledge, and the inclusion of criteria on connections with archaeology/anthropology and with other elements. The higher number of criteria can be explained by the study's approach to include most criteria used in previously developed methods, and the outcome of the questionnaire that indicated most criteria as necessary for the evaluation. As discussed previously, having many criteria can lead to complexity in analysis and overlap in assessment. Potential overlaps for this method include scientific knowledge and historical value, as seen by the fact that only Brilha (2016) uses these two criteria together in the assessment. When implementing this method, statistical analyses, like those conducted by Bruschi et al. (2011) may be necessary to reduce the number of criteria used to ensure that there is no redundancy in the assessment.

Among the weight of the criteria, the high relative importance of archaeological/anthropological connections is noteworthy, as it is a criterion that has not been discussed in previous evaluation methods. As can be seen from comparing the results from all responses to the results from only Quaternary geoscientists in Table 7.4, this criterion was (rather predictably) considered more important by archaeologists and anthropologists. Nevertheless, in all categories of participants considered in Table 6.4, its

relative importance is ranked either fourth or fifth and only 2 participants considered it unnecessary in assessing the overall scientific value. The importance of this connection is emphasised by the relatively lower evaluation of the importance of the connections with other disciplines as well. These outcomes help justify the use of a specialised evaluation method for the scientific values of Quaternary geoheritage sites in arid environments.

Table 7.4 Differences in the weighting for the scientific value assessment in different scenarios.

		Representativeness	Integrity	Geological Diversity	Rarity	Historical importance	Scientific knowledge	Potential for future research	Chronological Resolution	archaeo/anthro connection	connection with other disciplines
All responses	Mean (all criteria)	3.96	2.57	2.12	3.98	2.98	3.92	2.53	1.65	3.45	2.80
	Weight (all criteria)	13.2	8.6	7.1	13.3	9.9	13.1	8.4	5.5	11.5	9.3
	Weight (without chronological resolution)	14.0	9.1	7.5	14.1	10.5	13.8	8.9	-	12.2	9.9
Without "shouldn't include"	Mean (all criteria)	4.13	3.73	3.50	4.32	3.60	4.09	3.80	3.53	3.78	3.57
	Weight (all criteria)	10.8	9.8	9.2	11.4	9.5	10.7	10.0	9.3	9.9	9.4
	Weight (without chronological resolution)	12.0	10.8	10.1	12.5	10.4	11.8	11.0	-	10.9	10.3
Without archaeologists and anthropologists with no expertise in Quaternary Geosciences	Mean (all criteria)	4.08	2.15	2.08	3.85	2.85	3.62	2.38	1.44	2.95	2.67
	Weight (all criteria)	14.5	7.7	7.4	13.7	10.1	12.9	8.5	5.1	10.5	9.5
	Weight (without chronological resolution)	15.3	8.1	7.8	14.5	10.7	13.6	9.0	-	11.1	10.0
Only Quaternary Geoscientists	Mean (all criteria)	4.03	1.59	1.45	3.72	2.66	3.83	2.28	2.24	2.90	2.59
	Weight (all criteria)	14.8	5.8	5.3	13.7	9.7	14.0	8.3	8.2	10.6	9.5
	Weight (without chronological resolution)	16.1	6.3	5.8	14.9	10.6	15.3	9.1	-	11.6	10.3

Another strength of the outcome of this study is its compatibility with other methods. As the criteria considered in this study encompass most criteria from previous studies, it can easily be adapted to create a derivative method that reflects the criteria used in a certain study, but with a weight system that reflects regional experts. For example, if a researcher wishes to use only the four criteria used by Reynard et al. (2007) in the assessment, the relative importance of those criteria from this study could be selected to create a new weighting system, as presented in Table 6.5. The resulting weighting system includes a 7.6% difference between the most important and the least important criterion, reflecting the regional experts' preferences towards a method that originally uses equal weight for all criteria. As this study reflects the preferences of many regional experts, such a partial application may be useful to reduce subjectivity in existing methods.

Table 7.5 Comparison of percentage for each criterion used in weighting methods for the assessment of scientific values for geoheritage sites

	Brilha (2016)	Bruschi et al. (2011) (Weight for criteria related to scientific value)	Pereira and Pereira (2010)	Reynard et al. (2007)	Current Study	Current study adapted to Reynard et al. (2007)
Representativeness (%)	30	21.6 (Good example of process)	18.2	25	14	27.8
Integrity (%)	15	17.0 (Fragility)	18.2	25	9.1	20.9
Geological Diversity (%)	5	NA	18.2	NA	7.5	NA
Rarity (%)	15	21.2	27.3 (rarity at national level + rarity at regional level)	25	14.1	28.5
Historical Value (%)	20 (Key locality)	NA	NA	25 (Palaeogeographical value)	10.5	22.8
Scientific knowledge (%)	5	12.6 (Degree of knowledge)	9.1	NA	13.8	NA
Potential for future research (%)	NA	NA	NA	NA	8.9	NA
Archaeo/anthro connection (%)	NA	16.4 (Cultural interest)	NA	NA	12.2	NA
Connection with other disciplines (%)	NA	12.2 (Related to human issues)	NA	NA	9.9	NA
Others (%)	10 (Use limitation)	NA	9.1 (Non-geomorphological geodiversity)	NA	NA	NA

Using the responses to the questionnaire, appropriate proxies used to assess each criterion was determined, as described in Table 7.6. The responses to the questionnaire highlighted the difficulty of assessing every criterion using purely quantitative parameters, with the “discussions with experts” proxy rated the highest for 5 out of 6 criteria for which it was an option. This proxy was considered more appropriate than proxies that can be assessed quantitatively, such as “number of publications”, “number of citations”, or

“literature analysis”. For the use of proxies related to the academic literature, three participants expressed their concerns as comments, pointing out shortfalls such as the prioritisation of older sites, the exclusion of information gained from grey literature, and the exclusion of sites that have not yet been studied. An expert judgement may be necessary to consider newer sites or sites that have been understudied or have never been started. Criteria that may require such an input from experts are highlighted with an asterisk in Table 7.6. In developing the list of appropriate proxies, as no new quantitative proxy gained strong support, for criteria that have been assessed previously using a parametric system, proxies suggested in previous literature (Brilha, 2016; García-Cortés et al., 2019; Pereira et al., 2007) were used. For criteria that have not been assessed with proxies in previous studies (i.e. future research, connections with archaeology/anthropology, connections with other disciplines), the highest ranked quantitative proxy was selected. For the evaluation of all criteria, the 4-point scale system (0, 1, 2, 4 points) developed by Brilha (2016) was adopted.

Table 7.6 List of proxies and points system to be used in evaluating each criterion.

	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
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
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
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 significance	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
Scientific knowledge*	There are no published studies, conference abstracts, or doctoral theses on the site	There are abstracts presented in international scientific events about this site, 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 research*	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 proposals to conduct research at the site	Project(s) ongoing currently at the site
Connections with archaeo/ anthro*	No data from the site, or no data that corresponds with archaeological or anthropological records	Data from site has been used in a single archaeological or anthropological study at the local level	Data from site has been used in multiple archaeological or anthropological studies at local level	Data from site has been used in archaeological or anthropological studies at the regional/global level
Connections with other disciplines*	No citation towards studies on the site by disciplines other than geosciences, archaeology, or anthropology	Single citation towards studies on the site by disciplines other than geosciences, archaeology, or anthropology	2 or 3 citations towards studies on the site by disciplines other than geosciences, archaeology, or anthropology	More than 3 citations towards studies on the site by disciplines other than geosciences, archaeology, or anthropology

[a]Criteria that may need expert input if the site is new, understudied or have never been studied (adapted from Brilha (2016) and García-Cortéz et al. (2019)).

Finally, this study highlights the necessity for future studies to assess the need for specialised methods in geoheritage values beyond the scientific value. Regional experts

in different additional values of geoheritage (touristic, educational, etc.) must be consulted to understand whether the previously developed methods require adjustments in different regions. A need for a modified method is likely, especially as this study identified connection with archaeology/anthropology, a criterion with strong cultural and human elements, as a highly necessary criterion in evaluating the scientific value. Similar cultural dimensions of geoheritage would likely influence the way that more human-centric values are assessed. In conducting future studies to develop new methods for these additional values, a more localised geographical focus may be necessary, as socioeconomic and cultural heterogeneity would likely lead to differences in preferences.

7.5 Conclusion

This study assessed the necessity of a specialised evaluation method for the scientific values of Quaternary geoheritage sites in arid environments by using input from scientific experts from Quaternary geosciences and related fields. The analysis of the responses from 49 researchers demonstrated differences in the preferences towards the relative importance of criteria used in the evaluation compared to those indicated in previously developed methods designed for application around the world.

The specialised method developed in this study addressed this issue by selecting the criteria and their respective weights based on the responses by regional experts. The resulting method includes key differences such as lower weight for representativeness, integrity, and historical value, higher weight for scientific knowledge, and the inclusion of two specialised criteria, connections with archaeology/anthropology and connections with other disciplines. This study also explored the appropriateness of proxies for

evaluating each criterion. The participants' responses highlighted the challenges of relying solely on quantitative parameters for assessment, with expert judgement consistently considered as highly appropriate.

In practical application, adjustments to this method may be necessary to reduce the relatively high number of criteria considered to reduce complexity and overlap in assessment. Nevertheless, the results of this study can be used not only as a fully new method, but flexibly as a tool to create versions of existing methods with a region-specific weighting system. By selecting the preferences of regional experts for the criteria required for the method of choice, a revised method with considerations for the arid environment can easily be created to help reduce subjectivity and improve applicability.

Overall, the result of this study suggests the need to consider the necessity of diversity in methods for geoheritage evaluation not only for Quaternary geoheritage sites in arid environments, but for other environments and regions as well. Consistency in evaluation methods is desirable, but if consistency hinges on the quality of the evaluation, it should not be the primary concern. Even for Quaternary geoheritage sites in arid environments, evaluation methods with a narrower focus may be necessary to capture subtle differences in the evaluation. The method presented in this study is the outcome of an effort to achieve the right balance between the regional and environmental differences and the need for comparability and consistency in evaluation methods. Such considerations are required for regional and environmental differences in geoheritage values beyond the scientific domain as well. Future research is encouraged to assess the need for specialised evaluation methods in different environments at different scales,

and for values not limited to the scientific value, such as educational value and touristic value, involving input from regional experts in respective fields.

Chapter 8 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.

8.1 Introduction

8.1.1 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 programme (UNESCO, 2015). Although there is still debate over the definition of some field-specific terms some consensus has emerged (Table 8.1), 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.

Table 8.1 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 & Dowling, 2018)
Geoeducation	The process to facilitate learning, or the acquisition of knowledge about Geology through the use of geological sites (Brocx & Semeniuk, 2019)

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 & 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 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 (2015b), 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 & Giusti, 2005; Erhartič, 2010; Fassoulas et al., 2012; Kubalíková, 2013; Pereira & Pereira, 2010; Pralong, 2005b; 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, 2018b; Bruschi et al., 2011; Derafshi & 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 30×2/4= 15 (%) towards 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.

8.1.2 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 & Evans, 2019; Lokier, 2013), compiled an inventory of Quaternary geoheritage sites (Sayama et al., 2022), and explored the geotouristic potential of selected sites (Afifi & 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.

8.1.3 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) (Figure 8.1). 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, 2019b). 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).

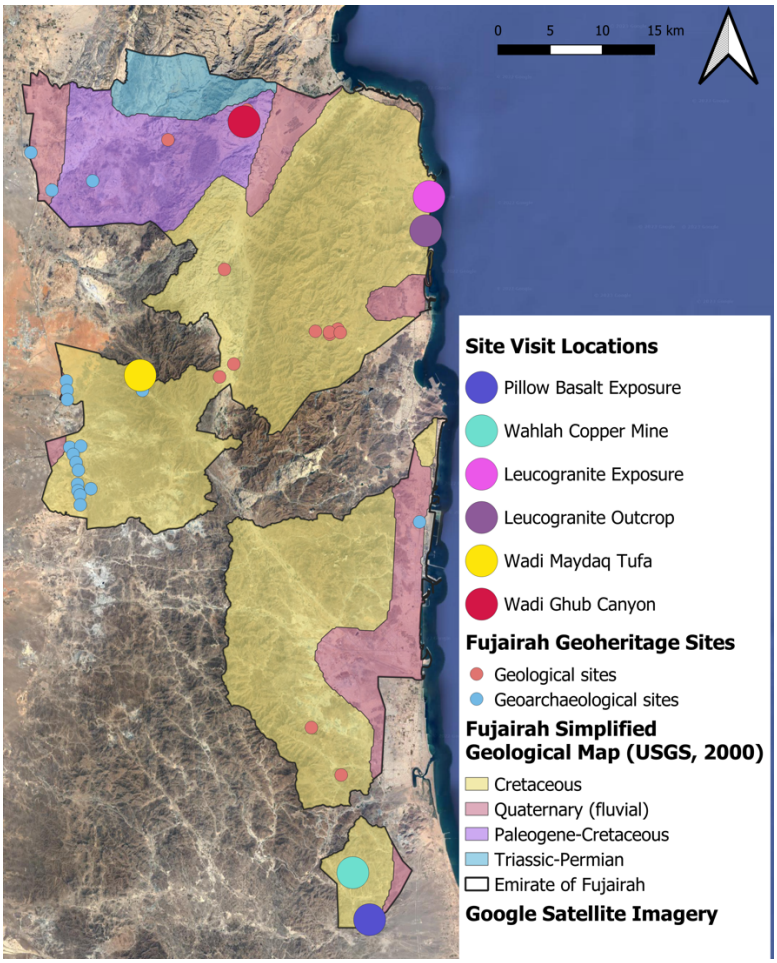


Figure 8.1 Map of Fujairah, UAE with sites visited by the participants, and sites included in the inventory (Parker and Bretzke, unpublished).

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 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.

8.2 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 organisations 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 Figure 8.2.

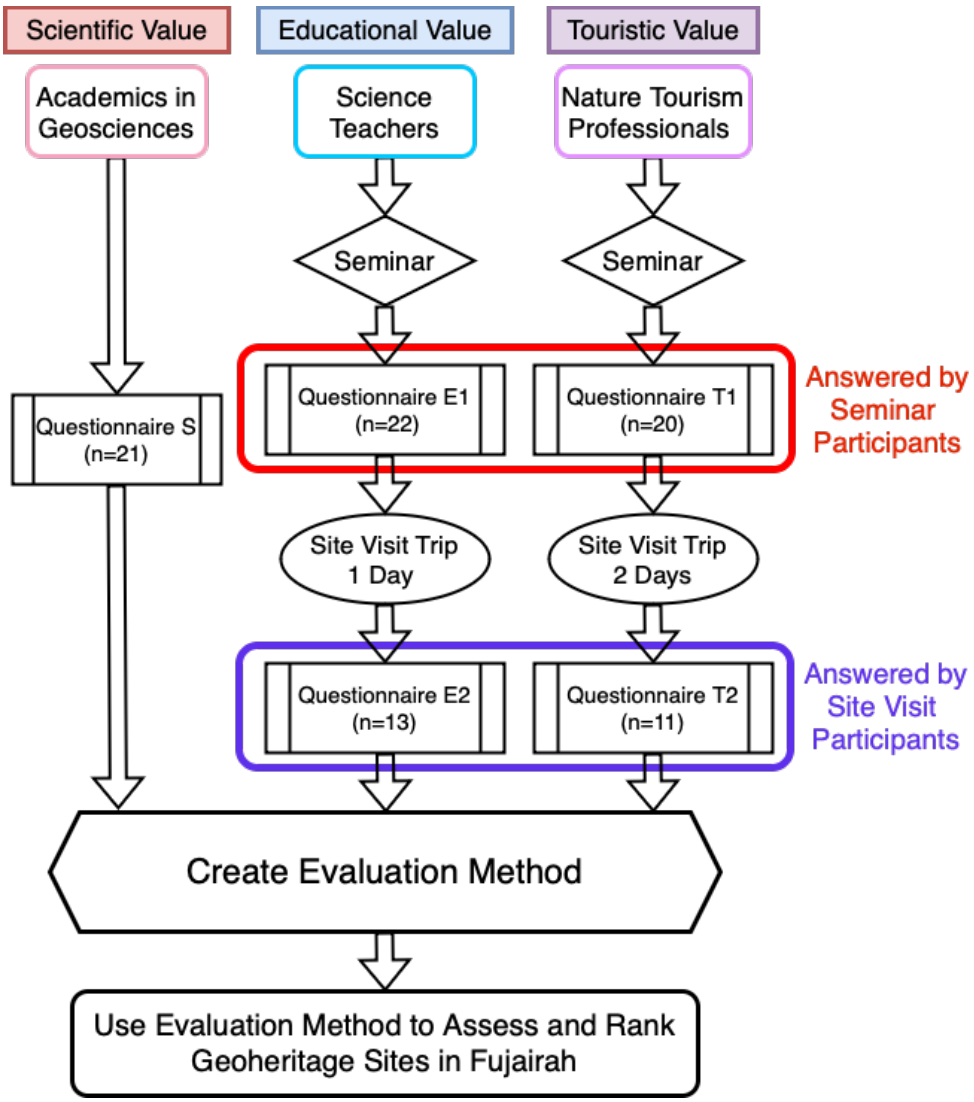


Figure 8.2 Flowchart outlining the overall study design.

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 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 8.2. The locations of the visited sites are shown in Figure 8.1.

Table 8.2 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 of the Moho Transition zone (MTZ), studied and published by geologists (Cox et al., 1999; Searle, 2019b). Easy access from a main road. Selected to consider the application of the roadside geotourism concept (Gates, 2006; Štrba 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

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, 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 8.3 and 8.4 summarise the criteria considered for the three value dimensions. Table 8.4 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), 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.

Table 8.3 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 and/or anthropology.	Developed by author for this study

Table 8.4 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

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 & 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 & 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 Appendix J.

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 towards 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 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 & 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.

8.3 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 & Li, 2016). The reliability of the questionnaires was all within the moderate range, with ICC values between 0.57–0.74. This moderate reliability indicates that the assessors had a rather diverse range of opinions in evaluating the criteria.

Figure 8.3 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

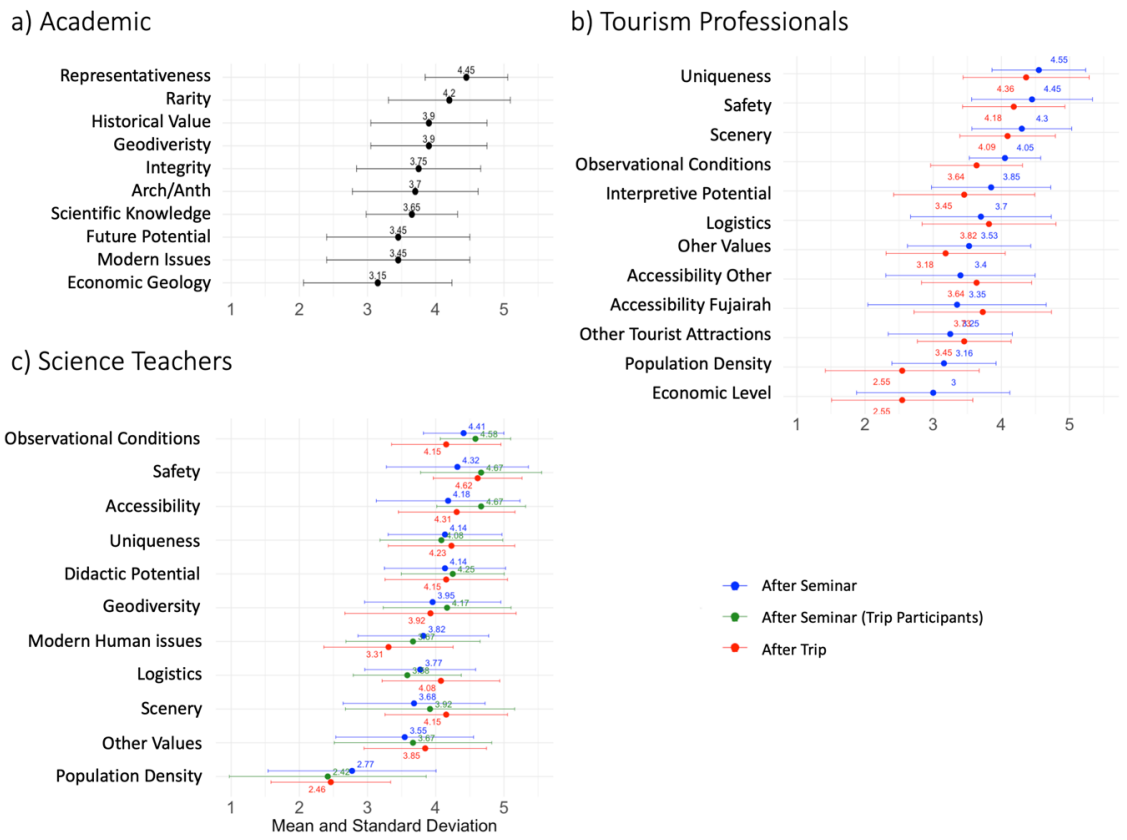


Figure 8.3 Means and standard deviations of the relative importance of each criterion for a) educational value, b) touristic value, and c), scientific value. For a) and b), the results from the questionnaire T1/E1 are colour coded in blue, and the results from the questionnaire T2/E2 is colour coded 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).

8.3.1 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 towards geoheritage evaluation from questionnaires E1, E2, T1, and T2 are shown in Figure 8.4 and Figure 8.5. Figure 8.4 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.

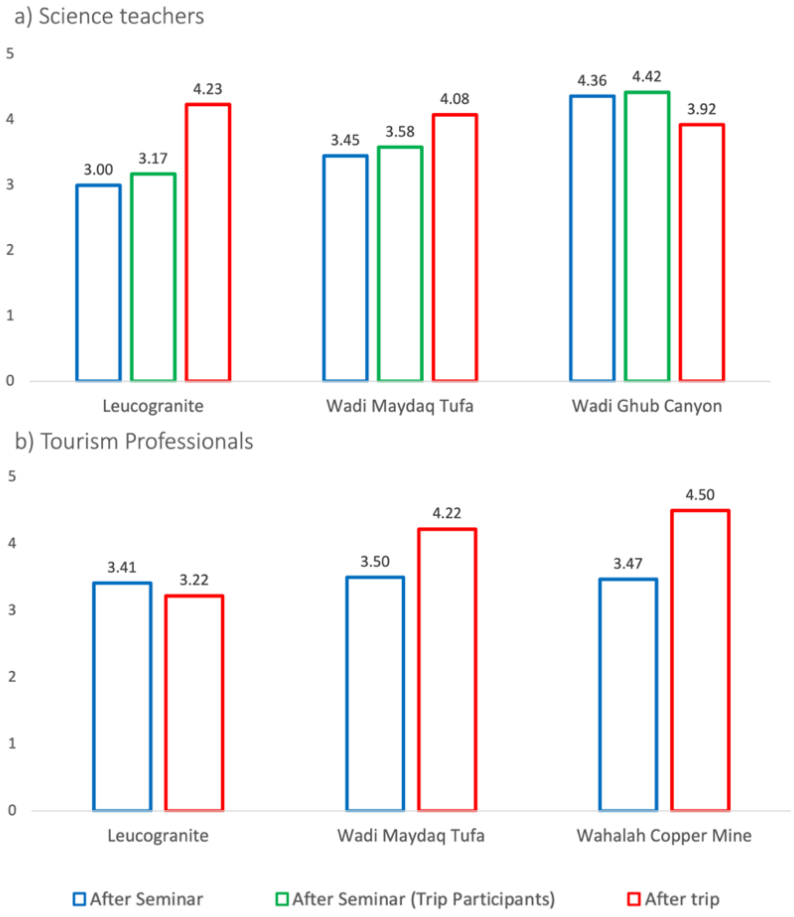


Figure 8.4 Bar graphs demonstrating the means of site evaluation values for education value and tourism value. After lecture and after site visit trip data are demonstrated for both values, with an additional bar for the educational value showing the answers of the trip participants after the seminar.

Figure 8.5 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.



Figure 8.5 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.

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 J 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.

8.3.2 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 & Williams, 2010). Data from questionnaires E2 and T2 did not meet the threshold for BS test either.

Table 8.5 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).

Table 8.5 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	**0.59**	0.63	0.19	0.01
	Integrity	0.53	0.39	-0.39	0.19	**0.47**
	Geodiversity	0.33	-0.23	**0.81**	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	**0.59**	-0.46
	Economic geology	**0.80**	-0.24	0.18	0.02	-0.08
	Archaeology/ Anthropology	0.63	0.51	-0.03	-0.18	-0.40

For the correlation matrix, as shown in Table 8.6, 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 K for the complete correlation matrices and the corresponding p-values for each dataset.)

Table 8.6 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

8.4 Discussion

8.4.1 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 towards 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 & 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.

8.4.2 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 Figure 8.3), 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 & 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.

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.

8.4.3 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). 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.

Table 8.7 and 8.8 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)

Table 8.7 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 8.8 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 cars 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 <100m 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 minutes away from emergency services	Site with no safety facilities and not so easy environment but with mobile phone coverage and located less than 30 minutes away from emergency services	Site with no safety facilities but at easy location with mobile phone coverage and located less than 30 minutes away from emergency services	Site with safety facilities (fences, stairs, handrails, etc.), mobile phone coverage and located less than 30 minutes 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 minutes away from the site	Toilets, and restaurants for groups of 50 persons <15 minutes 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 minutes away from the site	There is an occurrence of association with one ecological or cultural value or one other touristic site <30 minutes away from the site	There are multiple occurrences of associations with ecological and/or cultural values or several other touristic sites <30 minutes away from the site	There are multiple occurrences of associations with ecological and/or cultural values and several touristic sites <15 minutes 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

8.4.4 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 8.9). 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.

Table 8.9 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

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 8.10. 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 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 8.10 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

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 (Woor et al., 2022) 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.

8.4.5 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 (2022), were ranked for the three value dimensions by the authors. Table 8.11 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, 2019b). 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)

Table 8.11 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). 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.

	Scientific value			Educational value			Touristic value		
	Total (weighted)	Rank	Rank using Brilha (2016)	Total (weighted)	Rank	Rank using Brilha (2016)	Total (weighted)	Rank	Rank using Brilha (2016)
Ras Dadnah Leucogranite	61.5	1	1	68.66	2	2	61.25	5	2
Wadi Wurayah	60.75	2	4	84.99	1	1	76.5	1	1
SKH highway MTZ Outcrop	51.25	3	2	29.58	16	16	35.75	14	13
Wadi Maydaq - Tufa formations	50.75	4	2	55.24	4	7	61.75	4	4
Wadi Ghub Canyon	49.5	5	9	53.33	5	5	62.5	3	5
Wahalah Copper mine/ sheeted dyke	49.25	6	5	52.74	6	5	53.75	6	8
Silicified Serpentinite Outcrops	48	7	5	38.00	10	11	43.75	10	15
Al-Habhab Rock shelters	43.75	8	15	41.75	9	8	49	9	9
Masafi Schist/ Metamorphic Window	40	9	8	51.66	7	4	49.75	8	7
Wadi Midnah Rock shelters	39.5	10	7	44.00	8	9	42	11	9
Tawiyayn Shamal Chert Formation	36.25	11	11	36.83	11	9	35	15	5
Al Hala Alkaline Volcanics	32.5	12	10	34.41	13	12	37.5	13	16
Wadi Sayraq Rock shelters	32	13	16	33.00	14	12	34.5	16	14
Wadi Mai Sheeted Dyke	30.5	14	12	36.00	12	15	50.75	7	11
Al-Aqah Rock shelters	29	15	17	58.25	3	2	63.25	2	3
Wadi Liban Ophiolite	28.75	16	14	19.67	17	17	22.5	17	17
Wahalah Pillow Lava	24.75	17	13	31.41	15	12	41.25	12	12
Qurayyah	17.5	18	18	2.25	18	18	11.75	18	18

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 8.10 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.

The rank differences between the new method developed in this study and the method by Brilha (2016) emphasise the necessity of a regional method. For all three values, the top five locations are different sites in different orders. Noteworthy changes in ranks include the scientific value of Wadi Wurayyah (2nd to 4th) and Wadi Ghub (from 4th to 7th), the educational value of Wadi Maydaq (4th to 7th) and Masafi Schist/ Metamorphic Window (7th to 4th), and the touristic value of Ras Dadnah Leucogranite (5th to 2nd) and Tawiyayn Shamal Chert Formation (15th to 5th). The high touristic rank of the Tawiyayn Shamal Chert Formation in the Brilha (2016) method was especially surprising, as it is a site with low interpretive potential, and it lacks aesthetic features. These differences in the top sites are highly consequential in the process of selecting sites for conservation and promotion. As can be seen from the higher educational rank of Wadi Maydaq, the method produced by this study provides a result that is closer to the preferences of sites shown by experts during site visits, which highlights the importance of regional evaluation methods.

One important issue to note in this new 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 8.12. 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 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.

Table 8.12 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	
	Rank (Value)	Rank (Potential)
Wadi Wurayah Outcrops and Quaternary Fluvial Deposits	1	1
Ras Dadnah Leucogranite	2	2
Al-Aqah Rock Shelters	3	10
Wadi Maydaq - Tufa Formations	4	3
Wadi Ghub Canyon (Chert and Limestone)	5	4
Wahalah Copper Mine and Sheeted Dyke Complex	6	5
Masafi Schist and Metamorphic Window	7	6
Wadi Midnah Rock Shelters	8	14
Al-Habhab Rock Shelters	9	9
Silicified Serpentinite Outcrops	10	7
Tawiyayn Shamal Chert Formation	11	13
Wadi Mai Sheeted Dyke Complex	12	11
Al Hala Alkaline Volcanic Formation	13	8
Wadi Sayraq Rock Shelters	14	14
Wahalah Pillow Lava	15	12
Sheikh Khalifa bin Zayed Highway Moho Transition Zone Outcrop	16	16
Wadi Liban Ophiolite Complex and Tonalite Body	17	17
Qurayyah	18	18

(b)

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

8.5 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.

Section E: Discussion and conclusions

Chapter 9 Discussion and conclusions

9.1 Introduction

This thesis was developed with the aim of providing evidence to build a foundation for successful geoheritage conservation in southeast Arabia, with a focus on Quaternary geoheritage sites. Three research questions, as set out in Chapter 4.1, were addressed through the four empirical research chapters (Chapters 5–8). This chapter synthesises the findings and discusses the overall contribution of this thesis in three ways. First, it provides an analysis of the contribution of this thesis towards geoheritage conservation in southeast Arabia through a supply and demand framework. This analysis demonstrates the extent of previously unavailable or unidentified supply and demand of geoheritage conservation in southeast Arabia, and how new knowledge to fill such gaps could be identified and/or made available through this thesis. In discussing supply, this chapter focuses on the supply of frameworks and tools necessary for geoheritage conservation, rather than the supply of geoheritage sites available in southeast Arabia. This discussion synthesises the contribution of this thesis towards the three stages of geoheritage conservation (i.e. interpretation and promotion, inventory, and quantitative assessment) that it has addressed. On the other hand, the discussion on demand elucidates the demand towards geoheritage conservation demonstrated and identified through this thesis in terms of the different parties involved. In these discussions, the need for future studies and legislative/development measures will also be identified. Second, it outlines the implications of the findings from this thesis for regions beyond southeast Arabia. Finally, the thesis concludes by summarising its overall contributions, considering the

extent to which the research questions have been answered, and suggesting ways forward for achieving sustainable and successful geoheritage conservation in southeast Arabia.

9.2 Supply and demand for geoheritage conservation in southeast Arabia

As described in Chapter 2.3.2, a consideration of supply and demand is important in advancing efforts related to geoheritage conservation. In southeast Arabia, where only a few studies had previously focused on geoheritage conservation, this thesis revealed various aspects of supply and demand for geoheritage conservation in this region. The following discussion clarifies the extent of supply and demand that had been previously identified, identified through this thesis, and requires future investigations. Through the supply and demand framework, this chapter presents an updated *status quo* of geoheritage conservation in southeast Arabia and provide a roadmap for further advancements.

9.2.1 Supply

This chapter analyses the extent of the supply of frameworks and provisions necessary for evidence-based geoheritage conservation initiatives in southeast Arabia. In doing so, it identifies supply that had existed prior to the thesis, has been made available through this thesis, and requires further investigation in the future. The discussion has been divided to include the three key stages of geoheritage conservation addressed through this thesis, as well as the provision of infrastructure and tourism products. By addressing these key stages, this chapter also serves as a holistic overview of the main findings of this thesis. Table 9.1 summarises the contribution of this thesis towards the supply of features related to geoheritage conservation in southeast Arabia.

Table 9.1 Summary of the supply of frameworks and provisions necessary for geoheritage conservation in southeast Arabia

	Existing prior to this thesis	Provided through this thesis	Required in the future
Inventory	A few inventories of key sites in the region	An inventory of Quaternary geosites studied in the region (Chapter 5)	Expansion of the inventory and endangerment analysis for wider types of geoheritage sites
Evaluation	Scientific evaluation of sites in Oman based on experiences of a single researcher	Knowledge holder-based evaluation methods for Quaternary geoheritage sites (Chapter 7) and geoheritage sites in general (Chapter 8)	Evaluation of more sites using the methods developed Inclusion of local communities for a more holistic assessment
Interpretation and promotion	Signs and information boards at protected sites and museums Mobile app by the Omani Ministry of Tourism Books targeting non-specialists	Two videos to introduce regional Quaternary geoheritage sites (Chapter 6) Quantitative evidence on the efficacy of well-planned communication strategies, especially with the geocultural context (Chapter 6)	Accelerated efforts to advance geosciences communication Assessment of the efficacy of the geocultural context towards a wider public
Infrastructure and tourism products	Protection and increased accessibility of a few sites Tour packages developed by public and private entities	Evidence from collaborators highlighting missed opportunities and potential due to the lack of infrastructure (Chapter 8)	Improved accessibility to key sites Additional signage and information to promote geotourism, beyond general nature tourism

9.2.1.1 Inventory

Several inventories for geoheritage sites have previously been produced in southeast Arabia, mainly in Oman, namely the works by Searle (2014, 2019a) and Hoffmann et al. (2016). These inventories provide a great overview of the key geoheritage sites of the region, but their analysis only provides scientific perspectives and justifications for the protection and/or promotion of these sites, without much consideration of their endangerment or cultural/archaeological connections. Also, these inventories did not include many Quaternary sites, especially those without striking aesthetic features.

To supplement this gap, this thesis developed a database that serves as an inventory of Quaternary geoheritage sites in southeast Arabia, focusing on sites studied in the academic literature. This inventory also included an endangerment analysis of each site, revealing that 27% were destroyed or are in critical condition. This extensive inventory adds to the existing supply of geoheritage inventories in southeast Arabia and provides a methodology for a rapid analysis of the endangerment of geosites using satellite imagery. Beyond the methodological contribution of the endangerment analysis, this inventory presents two key strengths. First, it is an open-access spatial database that can be utilised by anyone with internet access. The availability of this dataset facilitates future research in geosciences and geoheritage conservation. Information on more geosites, even those beyond the Quaternary, can be added in the future to create an integrated inventory for all types of geoheritage sites in the region. The other strength of this database is its inclusion of archaeological sites, which enables spatial analyses of relationships between Quaternary and archaeological sites in the region. This feature adds depth to the inventory by highlighting the nature-culture interconnection of Quaternary geoheritage sites and facilitates the interpretation of these sites.

Overall, with contributions from this thesis, a reasonable baseline supply of inventories has been made available to kickstart geoheritage conservation in southeast Arabia. Future work can improve the database through typological expansion and improved user-friendliness to make geoheritage sites more accessible for anyone around the world interested in this topic.

9.2.1.2 Evaluation

As mentioned in Chapter 3.6, in southeast Arabia, evaluations of geoheritage sites have previously only been conducted for a limited number of sites in Oman, through an

analysis that reflected only the scientific significance of the sites, derived from the expertise of a single academic researcher (Searle, 2014). This qualitative approach, although rigorous in its description, does not align well with the parametric, multi-value-based approach endorsed in the geoheritage literature. Furthermore, the method used in this previous evaluation does not serve well for other sites in the region, as it relies heavily on the experiences and opinions of an expert. Therefore, a gap in the supply of geoheritage evaluation could be identified in both the number of sites evaluated (especially in the UAE) and methods available to conduct such evaluations.

This thesis addressed these supply deficiencies by developing two evaluation methods relevant for geoheritage sites in the region and providing the first systematic evaluation of geoheritage sites in Fujairah, UAE. The two methods developed in Chapters 7 and 8 have been developed to reflect the opinions of relevant experts and provide clear rubrics for the evaluation of geoheritage sites from three perspectives: scientific, educational, and touristic. The incorporation of the opinions of these experts makes the evaluation process more representative of the regional context and the distinction of the three values help decision makers determine which sites to protect for what reason.

The two methods, with one focusing on Quaternary sites and the other focusing on geoheritage sites in general, have been developed in alignment with the development of the geoheritage literature, which has emphasised the need to reflect the uniqueness of Quaternary sites in their evaluation. Indeed, some key differences can be identified when comparing the two methods developing the two methods in this thesis, including the higher importance of scientific knowledge (+3.8), rarity (+3.1%), and archaeological/anthropological connections (+2.2%), and the lower importance of

geodiversity (-3.5%) and integrity (-2.9%) in considering Quaternary sites. Although the method for Quaternary sites developed in Chapter 7 only accounts for scientific evaluation, the analysis by Santos et al. (2019) has shown that there are only small differences between the evaluation methods for general and Quaternary geoheritage sites, when considering educational and touristic values. Therefore, the method developed in Chapter 8 for educational and touristic values can suitably supplement the method from Chapter 7 in conducting a holistic evaluation of Quaternary geoheritage sites in the region.

Although the two methods captured the three values of geoheritage sites often discussed in the geoheritage literature through the opinions of regional experts, the perspectives of local residents are not considered or represented (see Chapter 9.2.2.3 for a further discussion). Even in Chapter 8, which aimed to develop a bottom-up evaluation scheme for geoheritage sites using regional input, local residents were not involved in the process at all. The gap may result in conservation and development strategies that benefit universities, schools, and tourism companies without much merit for the local community. This imbalance, as discussed in the previous literature, may lead to animosity between communities and governments, producing an unconducive outcome for geoheritage conservation.

To involve local communities in geoheritage evaluation, another important consideration is the limitation of a quantitative approach to fully encompass the relationships that particular communities may have with a geosite or landscape. For scientific, educational, and touristic values, the quantitative approach could be appropriate, as these values are relatively clear-cut in their definition and scope. However, the considerations required for

local cultural values are more diverse and are difficult to parameterise in a standard way. As proposed by Semeniuk et al. (2015), through a case study in Australia where a clearer recognition of the cultural values of landscapes exists, qualitative approaches may be necessary to conduct such a nuanced assessment.

In summary, this thesis contributed to the supply of evaluation for geoheritage sites in southeast Arabia in both practical and methodological ways. Methods developed in this thesis have been designed to include a wider range of perspectives in evaluating geoheritage sites. However, in doing so, it poses a question about the completeness of evaluations that are currently popular and available in the geoheritage literature. Meaningful involvement of local communities must be considered to realise a more holistic assessment of geoheritage sites in future.

9.2.1.3 Interpretation and promotion

Multiple forms of supply for interpretation and promotion of geoheritage sites have been made available in southeast Arabia over the last 20 years. At protected sites, such as Al Hoota Cave in Oman (Afifi & Negm, 2020), and Buhais Geology Park (Pintos, 2020) and Al Wathba Fossilised Dunes (Neild, 2022) in the UAE, interpretations of geosites are available as information boards, interactive panels, documentary-style films, and guided tours. Beyond on-site provisions, in Oman, a mobile application on geoheritage sites has been made available (Oman Ministry of Tourism, 2019), and a few books (Glennie, 2006; Hoffmann et al., 2016) targeting the non-specialist public have been published. Although these practical measures are positive advances, academic contributions have been limited in this domain. Beyond a few suggestions on how to introduce and utilise key sites such as the Semail Ophiolite (Lawrence, 2010), interpretation and/or promotion efforts have mostly involved top-down efforts in which specialists, by using their own

experiences, explain the geoscientific features in ways digestible and understandable by an audience without much geoscientific knowledge.

This thesis contributed to the supply of interpretation and promotion efforts for geoheritage sites in two ways, largely through the study presented in Chapter 6. First, this study produced two videos on Quaternary geoheritage sites, with statistically significant positive impacts of increasing the viewers' knowledge and their sense of need for protection towards these sites. On top of the straightforward contribution of adding to the rather meagre array of interpretation/promotional materials for geoheritage conservation in southeast Arabia, the study using these videos provides quantitative evidence that such science communication materials, if produced carefully with tailored contents and strategic delivery, can be effective to improve the perception of relevant sites at the grassroots level. Also, for producers of similar videos in the future, the key points identified in the focus groups and mentioned by the viewers as feedback, such as the need for a storyline, aesthetic visuals, and local knowledge holder perspectives, can serve as helpful guidelines. These videos, already available online to the public through the Oxford University Research Archive, are planned to be advertised via social media in collaboration with regional university geosciences clubs and geological societies, once the study has been published in an academic journal.

This thesis also provided evidence to support the use of geocultural context in interpretation and promotion efforts for geoheritage sites in southeast Arabia, especially for Quaternary sites. Chapter 6 demonstrated how the geocultural context provides better outcomes as a tool for science communication on Quaternary geoheritage sites in this region, through the mechanisms of improving the viewers' knowledge retention as well as

their awareness on the need to protect related sites. The value of the geocultural context was further emphasised in Chapters 8 and 9, in which global and regional specialists in academia, education, and tourism all acknowledged the importance of the relationship between geoheritage sites and the regional archaeology/history. This unanimous recognition of the importance of geocultural context for evaluation adds evidence to demonstrate the overarching utility of this approach for geoheritage conservation in southeast Arabia. This strategic contribution provides a basis to increase the evidence-based, effective supply of interpretation and promotion efforts for geoheritage sites in the region.

The supply of interpretation and promotion products for geoheritage sites in southeast Arabia has been limited, although it has been increasing gradually over the last 20 years. With additional supply of effective videos and an evidenced-based strategy presented through this thesis, it is hoped that these efforts will accelerate, especially with the use of the geocultural context.

9.2.1.4 Infrastructure and tourism products

With the recent establishment of formally protected areas, infrastructure for geoheritage conservation (e.g. accessible roads, safe trails, visitor regulations, and visitor facilities) is slowly becoming more available in southeast Arabia. In the case of Fujairah, UAE, although no sites are under legal protection, with the rise of adventure tourism, 11 trails have been made available and a code of conduct for visitors and tourism agencies has been established (Al Amir, 2023). In terms of tourism products, Lawrence (2010) has identified the supply of a few specialised tourism packages that targets geology enthusiasts. However, as mentioned in most geotourism-related publications (Afifi &

Negm, 2020; Allan, 2013; Nasir, 2023), these products are still underdeveloped and leave potential for further popularisation.

This thesis provided additional data, mainly in Chapter 8, to emphasise the lack of supply in infrastructure towards geoheritage resources in southeast Arabia. In Chapter 8, a large difference was observed between the current potential values of geoheritage sites in Fujairah, demonstrating the need for improved investments in infrastructure to maximise the value of regional geoheritage resources. The current state of missed opportunities was especially evident for the educational value of sites, as many sites with high potential for educational enrichment did not meet the relatively higher levels of safety and accessibility required for school visits. Improved infrastructure supply is essential in the future to fully capitalise on the potential of geoheritage sites in this region.

On the other hand, in terms of the supply of tourism products, the information provided through the expert engagement in Chapter 8 has already led to additional resources. One of the sites introduced in the site visits for the tourism professionals, Wahalah Copper Mine, which had not been identified previously as an adventure tourism destination, has now been included in the list of sites introduced by Fujairah Adventures, the government organisation responsible for regulatory and promotional measures related to adventure tourism in Fujairah, UAE (Fujairah Adventures, 2024). Although this site remains underdeveloped in terms of accessibility, signage, and monitoring, this development shows a tangible outcome of the expert engagement activities conducted through this thesis.

9.2.2 Demand

This chapter outlines the extent of demand for geoheritage conservation that has been identified or indicated from relevant parties. Table 9.2 summarises the contribution of this thesis towards understanding the demand for geoheritage conservation in southeast Arabia.

Table 9.2 Summary of demand for geoheritage conservation in southeast Arabia demonstrated by different relevant parties.

	Previously known	Identified through this thesis	Required future considerations
Scientific Community	Endangerment and loss of particular sites Inventory and evaluation of key sites in Oman	Critical endangerment of many Quaternary sites (Chapter 5) High enthusiasm of the academic community (within and beyond geosciences) to contribute to geoheritage research (Chapter 7&8)	A better understanding of the borderline between geoheritage and geosites A coordinated effort by researchers to publicise this demand
Wider Public	No data on the demand and enthusiasm from the non-specialist public	Identification of the geocultural context as a useful tool to improve awareness (Chapter 6)	Conducting a larger study to understand demand from a sample that is more representative of the wider public perspective
Potential Visitors	The existence of potential for sites with interest for geotourists	High demand to support geoheritage conservation (Chapter 6)	Direct input from visitors to understand their preferences and needs
Local residents	No previous consideration of local communities	Documentation of local community experiences highlighting the high expectation as a tool for economic vitalisation (Chapter 6)	Studies focused on the willingness of local communities to geoheritage conservation initiatives
Education sector	No previous consideration from a demand perspective	High potential demand for the use of geoheritage sites for local science education (Chapter 8) High willingness of the wider public to learn about the sites (Chapter 6) Demand for further infrastructure development (Chapter 8)	Identification of specific educational demand for each geoheritage site Strategies for educational outreach at geoheritage sites

Tourism sector	Identified potential and demand for more research and information	High demand from adventure tourism professionals and potential for development of previously unvisited sites (Chapter 8) High demand as leisure destinations by the wider public (Chapter 6)	Consideration of demand beyond the adventure tourism industry Additional input from visitors
Local and national governments	The protection of few sites in both the UAE and Oman	Documentation of governmental willingness through focus groups (Chapter 8)	Additional work with governmental agencies Development of high-level strategies

9.2.2.1 Scientific community

Prior to this thesis, several academic reports had suggested the demand for geoheritage conservation in southeast Arabia from the scientific community. This demand was identified both tangentially through the recognition of endangerment (Lokier, 2013) and loss (Atkinson et al., 2013) and directly through the listing and evaluation of key sites (Searle, 2014). This thesis has expanded on this demand from the scientific community by highlighting two additional perspectives: endangerment of sites and enthusiasm for conservation.

In Chapter 5, the GDSA (Geocultural Database of Southeast Arabia) provided a large-scale analysis of the endangerment of Quaternary palaeoenvironmental sites in southeast Arabia studied by researchers. This analysis revealed the destruction of 13% of all sites and the critical endangerment of 15% of sites. Although direct comparisons with other regions are difficult due to the lack of large-scale analyses of geoheritage site endangerment in the literature, the fact that the percentage of critically endangered and/or destroyed sites exceeds that of archaeological sites in the MENA region (EAMENA Project Team, 2024) suggests a high rate of endangerment. This high level of endangerment indicates a significant lack of protection measures for these sites and underscores the need for their conservation to support future research and preserve history of paleoenvironmental studies in this region.

In Chapters 7 and 8, the high response rate from the regional academics, particularly the 55% response rate (21 responses from 38 request emails) in Chapter 8, demonstrated a strong enthusiasm for supporting geoheritage conservation. In responses to the survey, multiple participants mentioned the need to consider site endangerment, despite this not being explicitly asked, indicating a recognition of the lack of protection for geoheritage sites. Furthermore, Chapter 8 highlighted the demand and appreciation for Quaternary geoheritage sites from archaeologists and evolutionary anthropologists, demonstrating that the scientific demand for geoheritage conservation extends beyond the geoscientific community. Given this interdisciplinary demand, future studies must consider how to galvanise these academics to contribute to the protection of geoheritage conservation. A coordinated effort from the academic community may be helpful to advance formal conservation measures, such as the legal protection of key sites.

On the other hand, the GDSA demonstrated that many Quaternary sites are situated in environments challenging for conservation. Specifically, numerous sites, including outcrops and sections, are found and studied by researchers in opportunistic settings such as quarries and industrial areas. As exemplified by the megadune site in Figure 9.1, these locations, made accessible by inherently destructive activities, raise questions about what should be considered as geoheritage sites. Although these sites may present high scientific value, researchers may be studying them with the expectation that they will soon be destroyed. If this is the case, such an expectation contradicts with the consideration of these sites as geoheritage sites, as it could be considered fruitless to advocate for the conservation of sites that are predetermined to be destroyed. The science community's perception of geoheritage may require further investigation to truly capture the extent of their demand for geoheritage conservation in this region. In this

regard, it is especially important to establish a standard to determine the difference between a geosite and a geoheritage site.



Figure 9.1 A megadune section in the UAE made available by destructive activities. (Photo courtesy of Professor Andrew Goudie)

9.2.2.2 Wider public

Prior to this thesis, demand for geoheritage conservation in southeast Arabia had been primarily documented through academic and scientific channels, with few non-academic publications targeting the public (Glennie, 1998; Hoffmann et al., 2016). There were no concrete data indicating the general public's demand for geoheritage conservation in the region. Chapter 6 of this thesis aimed to provid the first empirical data on geoheritage conservation from the perspective of the wider community level, but the participant pool was limited to highly educated local residents. Over 100 participants were surveyed to gauge their knowledge of and interest in geoheritage, particularly Quaternary sites.

A key consideration in discussing the results from Chapter 6, however, is the representativeness of the participants of this study. The 104 participants who answered at least two of the three surveys represent a rather limited extent of diversity. First, given

ethical considerations, none of the participants were under 18. Additionally, the education level of the participants is much higher than the overall population of this region, with 100% of the participants either currently studying at university or having an undergraduate degree. With the percentage of university graduates in Oman at 19.1% and at 47.2% in the UAE (World Bank, 2023), the demand for geoheritage observed in this thesis could be categorised as being from the highly educated, elite portion of the wider public.

The third issue was the fact that almost half of the participants had a higher education background in geosciences, leading to the data being skewed towards a population with higher knowledge of the field than the average citizen. As discussed in Chapter 6, the geoscientific knowledge of an average citizen in this region is not very high, given the lack of geosciences education in primary and secondary schools (Al Ghfeli, 2016; Ambusaidi & Al-Balushi, 2015). This knowledge gap issue was recognised and circumvented by conducting statistical analyses with specialists and non-specialists treated separately. By analysing the two groups separately, the study found interesting differences in reactions between the specialists and the non-specialists, such as the variation in the extent of knowledge retention. On the other hand, although most analyses could be conducted with statistical significance, meaning that the results were not derived by pure chance, it also highlighted the issue of representativeness, with a rather small sample size for the non-specialist group, which was used to represent the more general population.

Finally, the study participants consisted predominantly of people with strong pro nature conservation sentiments. Even before watching the video on geoheritage sites, the mean

value of all participants towards the question asking the importance of protecting geoheritage site in the region was 9.05 out of 10, although over 20% did not know of any local geoheritage sites. This result could partly be explained by the nature of questionnaire research in which the participants try to answer in ways that they expect to be most desirable by the survey administrator (Grønmo, 2019). On the other hand, given that the study required watching a nine-minute video with little incentive, it is likely that the study design could have discouraged more casual participants without high interest in nature conservation to take part. Regardless of the cause, even the non-specialist group is from a highly educated portion of the population, with pro-nature conservation attitudes.

Overall, this thesis served an important first step in demonstrating a high demand for geoheritage conservation from a portion of the public. However, future studies must consider ways to include a wider profile of participants to gain an understanding of the demand for geoheritage conservation from the wider public. Perhaps a potential solution could be the use of paid services such as Amazon's Mechanical Turk (Thomas & Clifford, 2017), where study participants can be recruited online through financial incentives.

9.2.2.3 Potential Visitors

As described in Chapter 3.6, only a few studies have investigated geoheritage sites in southeast Arabia. However, geotouristic potential of the region has been the focus of many of the currently available studies (Afifi & Negm, 2020; Allan, 2013, 2023; Nasir, 2023). Through theoretical analyses, studies have identified that the unique geological landscape of this region provides attractive destinations for both casual and dedicated geotourists. On the other hand, no empirical studies have been conducted to analyse the

needs and preferences of the visitors to geoheritage sites in this region. Furthermore, promotion of these sites for potential visitors had never been considered.

Through the experiment in Chapter 6, this thesis provided the first empirical evidence on how to communicate and promote geoheritage sites to a targeted group of potential visitors to geoheritage sites. Using data from 104 participants, who fit the profile of likely visitors to geoheritage sites (as identified in Chapter 2.3.6), this study demonstrated overwhelming support and demand for Quaternary geoheritage conservation, especially by participants who watched the video on the relationship between Quaternary sites and regional culture. This demand provides important quantitative evidence that could help justify the conservation of key sites.

Despite these findings, knowledge gaps still exist in the needs and preferences of visitors to geoheritage sites in the region. Although a sense of visitor demands could be identified via questionnaires toward nature tourism professionals conducted in Chapter 8, direct input from tourists would be essential to better understand how best geoheritage sites can be developed and promoted. A potential way forward may be conducting a site evaluation using input from visitors, adapting features of the M-GAM approach (Tomić & Božić, 2014), and also collecting qualitative data in the process to enable a nuanced analysis of how geoheritage sites can be enjoyable and attractive for potential visitors.

9.2.2.4 Local residents

Another dimension of the public that had not been previously considered is the viewpoint of the local communities. As clarified in Chapter 2.3.7 in discussing critical perspectives towards geoheritage conservation, understanding the demand of the people whose ancestral landscapes will be influenced by the conservation measures must not be

ignored. In southeast Arabia, as discussed in Chapter 3.4, given the high rate of foreign nationals in the region, many residents may not have ancestral connections to the region. Therefore, the local residents considered in this discussion will be limited to local resident nationals with long-term ties to the region.

This thesis provided such a local scale perspective by including two local residents to the focus group in the UAE (Chapter 6). These focus group participants, working in the geology-related museum that opened in the last five years, mentioned how geoheritage related development was seen positively as an economic opportunity for the local community. From a researcher's perspective, the focus group in Oman presented some models for successful knowledge exchange with local residents that give these people a sense of ownership and need for protection towards geoheritage and archaeological heritage sites. Furthermore, the Omani focus group also provided a cautionary perspective towards a top-down approach that imposes information and conservation onto the local people, highlighting the delicate need to respect their demand.

Although these inputs are important, as no similar perspectives have been considered in the previous geoheritage literature in southeast Arabia, their contribution is rather limited as they were all anecdotal, brief, and unsystematically collected. To gain a holistic understanding of such grassroots demand requires a larger sample size, perhaps with an interview to capture the nuance of the connections that the local communities have with geosites and the perspectives they provide in evaluating the geosite's importance in their terms. Currently, such an in-depth understanding of the local community's demand for geoheritage conservation is still not available for any geosites in southeast Arabia.

9.2.2.5 Education sector

In the existing literature, educational potential for geoheritage sites in southeast Arabia has been suggested briefly for the Abu Dhabi Sabkha, UAE (Lokier, 2013) and Al Hoota Cave, Oman (Lawrence, 2010). However, no data have been provided on the educational demand for geoheritage sites, from either the educator or the learner perspective.

This thesis made two main contributions to advance the understanding of educational demand for geoheritage conservation. First, in a direct way, Chapter 8 demonstrated the high demand from school science teachers to use geoheritage sites for education, with two out of three evaluated sites having an average site assessment value over four out of five. Although these teachers were generally unfamiliar with the geoheritage concept, and their preferences changed considerably after site visits, their answers indicated enthusiasm for using regional geoheritage sites for outdoor education, with identification of specific examples of modules that a particular site can address. Although accessibility and safety were identified as key concerns in taking students to some of the geosites, demand for educational use of geoheritage sites could largely be identified in this study, especially if the right infrastructure could be developed through conservation efforts.

Furthermore, Chapter 6 revealed indirectly a learner-based demand and willingness towards learning about the geosciences through Quaternary geoheritage sites. In the survey, although 57% of the participants answered that they did not know what Quaternary geoheritage sites were, their level of interest towards these sites was high with a mean of 3.13 out of four. As mentioned in Chapter 9.2.2.2, the highly pro-conservation disposition of the respondents must not be forgotten in analysing this outcome, but this disparity between the low level of knowledge and the high level of interest implies a sense of demand to learn about geoheritage sites. One of the outcomes of this study, the

improvement of priority for Quaternary geoheritage conservation after watching videos on the topic, also suggest that the educational use of geoheritage sites may help increase the wider public's demand for geoheritage conservation, which could potentially lead to a positive loop for geoheritage conservation altogether. Overall, although data from a larger sample may be ideal and necessary, this thesis demonstrates a level of educational demand for geoheritage sites and geoheritage conservation in southeast Arabia from both educators and learners.

9.2.2.6 Tourism sector

In previous geoheritage related literature on southeast Arabia, the touristic potential of geosites in the region has been the main focus. In both the UAE (Allan, 2013, 2016) and Oman (Afifi & Negm, 2020; Lawrence, 2010; Nasir, 2023), studies have highlighted how geotourism may serve an important role as a new avenue of tourism in this region. The demand for geotourism has been addressed directly by Allan (2023) in the context of the UAE. These studies have made important contributions to kickstart geotourism efforts in southeast Arabia, but the discussion has almost always been on the potential and the need for research on geotourism in the region, rather than analysing data collected from the tourism industry or potential tourists. As with educational demand, this thesis identified the demand for geoheritage conservation, directly from tourism professionals, and indirectly from potential tourists.

In Chapter 8, questionnaire responses from adventure tourism professionals showed that these professionals, although they may not be familiar with the term geoheritage, had a good understanding of the touristic value of these sites. After site visits, two of three evaluated sites, which had not been previously developed as sites for tourism, received an average evaluation of above four out of five. The familiarity of tourism professionals

towards geosites demonstrated their high touristic value and demand, and the improved evaluation of underdeveloped sites revealed further potential for geoheritage sites in this region.

In Chapter 6, the study participants' answers to questions related to visiting Quaternary geoheritage sites revealed both existing and potential touristic demand for these sites. In the after-video survey, 90% (94/104) of participants mentioned that they have already visited Quaternary sites in the region and in the three-months-after video, 91% (75/82) of them answered that the video made them want to visit the Quaternary sites. Of these 75 participants, 34 of them (41% of all participants for Wave 3) said that they had visited a Quaternary site within the three-month period between the second and the third surveys, which may be an indication of the capacity for promotion and interpretation to expand the demand for these sites. For geoheritage sites overall, the extent of data is limited, as it was not the focus of this chapter, but even before watching the video, 70% of participants had already visited geoheritage sites, with a high popularity of mountain and cave sites. As mentioned in the previous section, the profile of the participants must be taken into consideration in analysing these numbers. Nevertheless, the high level of interest and the possible positive influence of knowledge transfer towards increased visits to the introduced type of sites imply the high demand and potential for geoheritage conservation from a tourist perspective.

9.2.2.7 Local and national governments

The level of demand for geoheritage conservation from a government perspective had previously been partially demonstrated through reports on the establishment of protected geosites, such as the Al Wathba Fossil Dunes, UAE (Neild, 2022) and Al Hoota

Cave, Oman (Lawrence, 2010), or the commissioning of a report on geoheritage sites from the government (Parker & Bretzke, 2022).

This thesis has made a further contribution to understanding this high-level demand by including an official from Sharjah Investment and Development Authority and the Omani Ministry of Heritage and Tourism in the focus group to discuss the promotion of Quaternary geoheritage sites (Chapter 6). Inputs from these participants, along with their willingness to participate in the focus group, demonstrated a baseline level of enthusiasm in both the UAE and Oman to protect, promote, and utilise geoheritage sites of the country.

Overall, however, the extent of the government demand for geoheritage conservation remains unclear in southeast Arabia. With no strategic plans targeting the conservation of geoheritage sites in either Oman or the UAE, it is difficult to gauge the level of importance that the governments place towards related initiatives. The results of this thesis, especially the schemes for evaluation and the strategy for interpretation of sites, could be useful tools to guide the budding demand within governments towards implementation. A clearer vision for related efforts would help clarify the level of demand for geoheritage conservation from this governmental perspective. Further works with or by governmental agencies are awaited to develop strategic plans for geoheritage conservation in southeast Arabia.

9.3 Implications for other regions

Although this thesis focused on geoheritage conservation in southeast Arabia, it presents multiple findings relevant for geoheritage conservation beyond the regional boundaries.

Most notably, the methods introduced in this thesis can help diversify the approaches taken in geoheritage studies worldwide.

For the inventory, the satellite imagery-based assessment of geoheritage sites presented in Chapter 5 can be used anywhere in the world to conduct analyses on the endangerment of geoheritage sites. Its use of freely available software makes it especially suitable for use in locations where resources available for geoheritage initiatives are limited. For the evaluation of sites, the methods used in Chapters 7 and 8, although more resource-intensive, present potential ways forward for a more participatory, regional approach in assessing the values of geoheritage sites. This contribution is especially relevant today, given the rapid global growth of geoheritage conservation efforts around the world.

Perhaps the most valuable wider contribution of this thesis is found in Chapter 6, not only through its methodology, but also through its findings. Methodologically, this study demonstrates the possibility and utility of an experimental approach in studying the efficacy of interpretation/promotion of geoheritage sites, which had rarely been used in the previous literature. In terms of study outcomes, it provided the first statistical evidence to support the use of the cultural context in introducing Quaternary geoheritage sites. Although the relevant cultural element would vary between regions, the value of the cultural context, as a core concept, is likely to hold internationally, although the degree of its impact may be different. Variations in the importance of such cultural contexts in different cultures and geographical settings may be an interesting direction for future international research. This study also demonstrated the importance of assessing the

longer-term impact of interpretation/promotion efforts, with clear changes in participant responses between the second and third waves of the survey.

Overall, interdisciplinary adaptations of methods used in this thesis push the horizon of geoheritage research. The use of methods from archaeological heritage conservation (Chapter 5), science communication (Chapter 6), and statistical analysis common in social sciences research (Chapters 7 and 8) have identified avenues to diversify the breadth of geoheritage research and present further need for interdisciplinary collaborations to resolve knowledge gaps in this field.

Beyond presenting new methods applicable in other regions, this thesis offers another transregional implication in the form of challenging the prevailing framework for geoheritage conservation and its key stages. First, as described in Chapter 4.1.2, it questions the occurrence of the interpretation and promotion stage after the stages of inventory, evaluation, and conservation (Brilha, 2005). If geoheritage conservation efforts are to be embedded within local communities with the objective of bringing sustainable benefits at the grassroots level, the entire process needs to be conducted with as much engagement as possible with a wide array of influenced parties (e.g. local residents, educational specialists, tourism professionals). Therefore, interpretation and promotion must be considered a prerequisite process in realising this wider participation.

In reflecting these wider grassroot perspectives, the quantitative nature of evaluation is also questioned. For the three types of values (i.e. scientific, educational, and touristic) considered in most existing evaluation methods, a quantitative approach may be appropriate. However, if community-based cultural values of geoheritage sites are to be incorporated in the evaluation scheme, a standardised, quantitative, parametric method

would likely not be the most appropriate approach. Instead, a more nuanced, qualitative approach may be required. This is an important consideration that requires further research from geoheritage researchers and practitioners worldwide.

9.4 Conclusions

This thesis aimed to provide evidence to help build the foundation for successful geoheritage conservation in southeast Arabia, with a focus on Quaternary geoheritage sites. To achieve this aim, three guiding research questions were presented as follows (Chapter 4.1):

1. What is the nature, scale, and conservation status of southeast Arabian Quaternary? (inventory)
2. What are the benefits of a geocultural approach, if any, in interpreting and better communicating to non-specialists about Quaternary geoheritage sites in southeast Arabia? (interpretation and promotion)
3. How do the values and significance of geoheritage sites in southeast Arabia perceived by regional specialists and knowledge holders differ from those identified in other parts of the world? (quantitative assessment)

With regards to the three questions, outcomes of this thesis provide the following answers:

Question 1. Although a few sites in southeast Arabia have been protected for their geoheritage values in the last five years, most Quaternary geosites remain unprotected, with 13% of them already destroyed and 15% of them under

imminent threat. Although aeolian sites face the highest level of endangerment in terms of numbers, fluvial sites face the most imminent need for protection, given their highest proportion of endangerment. The most common cause of destruction/threat towards Quaternary sites in this region include urban development, infrastructure development, and quarrying. These Quaternary geosites present intricate relationships with the regional archaeological sites, both spatially and chronologically, with some under protection given their archaeological relevance. Overall, the inventory provided in the GDSA suggests the potential of employing a geocultural approach to integrate the protection of archaeological sites and Quaternary geosites in southeast Arabia.

Question 2. By incorporating the cultural context in introducing Quaternary geoheritage sites of southeast Arabia, non-specialist residents of the region, who fit the profile of potential geotourists, could better retain their knowledge on the topic, compared to those who were introduced to the sites through a purely geoscientific perspective. For the conservation of Quaternary sites, the retained knowledge also led to a stronger sense of need to protect the sites, especially among the non-specialist participants. Although further research is required to understand the exact mechanism that led to such positive outcomes, qualitative analysis indicates that the geocultural context and its narrative may provide the aforementioned benefits by helping facilitate the creation of cognitive connections between the new knowledge on Quaternary geoheritage with the participants' existing knowledge.

Question 3. For both Quaternary geoheritage sites (scientific value) and geoheritage sites in general (scientific, touristic, and educational values), evaluation methods produced in this thesis with input from regional specialists demonstrated various differences from methods produced in previous literature for international application. For scientific value, for both Quaternary sites and general geoheritage sites, key differences could be found in the relatively low importance of representativeness and historic value, as well as the need to include an assessment of the relevance of the site for archaeology and anthropology. For educational and touristic values, key distinctions included the relatively high importance of safety and uniqueness of sites.

Beyond answering these three research questions, this thesis has made additional contributions to the fields of geoheritage research, Quaternary science, archaeology, and science communication, including the following:

i. Creating the first open-source database of Quaternary palaeoenvironmental sites and palaeolithic archaeological sites in southeast Arabia (Quaternary science, archaeology)
ii. Demonstrating new evidence to substantiate the need for adjustments in geoheritage evaluation based on regional context (geoheritage research)
iii. Developing new methods to incorporate experiences and knowledge of regional specialists into geoheritage evaluation (geoheritage research)
iv. Producing the first quantitative data related to the efficacy of interpretation and promotion efforts related to geoheritage sites in Arabia (geoheritage research)

v. Providing the first evidence of the utility of the geocultural context in science communication efforts on Quaternary geoheritage sites (Quaternary science, science communication, geoheritage research)

At the same time, the findings from the thesis suggest the need for future research to (i) produce further evidence on the benefits of geoheritage conservation in southeast Arabia; (ii) further improve the understanding of how geocultural context can benefit geoheritage conservation; and (iii) understand how local community members can be better integrated into all stages of geoheritage conservation. More specifically, in both southeast Arabia and internationally, future studies should:

I. Provide data on tangible and intangible outcomes of geoheritage related activities

This data is not only limited to the assessment of the economic benefit of geoheritage sites through tourism, but also pedagogical outcomes from educational activities and cultural benefits such as affinity and pride towards local residents and strengthened community cohesion. The nature of these data should be both quantitative and qualitative, as not all these benefits can be easily quantified. These contributions would help provide evidence and create a portfolio that can be used to persuade local and national governments to engage in geoheritage conservation efforts. The involvement of relevant researchers such as economists (for the analysis of economic benefits) and anthropologists (for the analysis of its influence on cultural pride/affinity) should be encouraged in conducting these studies.

II. Produce further evidence on the benefit of incorporating a geocultural context in geosciences communication

More studies should be conducted to provide further evidence on the utility of the geocultural context in interpreting and promoting geoheritage sites. Although the outcomes from this thesis suggest that the benefit of this approach is transferrable to different geographical settings and types of geoheritage sites, more studies, preferably with a larger sample size, would not only make the benefits of the geocultural context more certain, but also help understand why the geocultural context works so well, and how its use can be optimised. Additionally, an even longer timeframe could be useful to further understand the extent of need for longitudinal studies related to geosciences communication.

III. Consult local communities on their eagerness to contribute towards geoheritage conservation and how they envision such engagements

Sustainable geoheritage conservation cannot be realised without support and enthusiasm from the local community. However, in many cases, the lack of proper consultation and engagement have led to an unfortunate scenario of unrealistic expectation, disillusionment, and, in the worst-case scenario, conflict and/or violence (Babou, 2020; Ristiawan et al., 2023). Nevertheless, such efforts are still rare, and no established guidelines exist. This continuous consultation process needs more consideration in geoheritage research, and its outcomes should be incorporated into conservation strategies.

IV. Create a geoheritage evaluation method that incorporates the local perceptions of the cultural values of geoheritage sites and landscapes

As discussed in Chapter 9.2.2.3, currently prevailing paradigms for geoheritage evaluation focus on quantitative assessment of three values: scientific, educational,

and touristic. With the identification of the importance of the geocultural context in this thesis, the cultural value of geoheritage sites needs more emphasis in the evaluation process as well. In conducting such an assessment, however, a quantitative framework may not be appropriate. Studies should be conducted with input from fields such as ethnography and intangible cultural heritage research to identify ways forward in producing a more holistic method to evaluate geoheritage sites in the future.

Given the rapid practical advances in geoheritage conservation worldwide, academic research must pave the way for successful and sustainable efforts in this field. This thesis serves as an initial roadmap for geoheritage conservation efforts in southeast Arabia. It identifies the demand for geoheritage conservation from various perspectives and offers a toolbox and strategies for implementing practical conservation measures. It is hoped that this thesis encourages further research and practical implementations in the near future.

References

Abadie, A. (2005). Semiparametric Difference-in-Differences Estimators. *The Review of Economic Studies*, *72*(1), 1-19. https://doi.org/10.1111/0034-6527.00321

AbdelMaksoud, K. M., Abdulsamad, E. O., Muftah, A. M., & Aly, M. F. (2022). Geomorphosite Inventory of Apollonia and Cyrene in Northeast Libya: involvement in Geotourism Promotion. *Geoheritage*, *14*(4), 114. https://doi.org/10.1007/s12371-022-00747-z

AbdelMaksoud, K. M., Al-Metwaly, W. M., Ruban, D. A., & Yashalova, N. N. (2018). Geological heritage under strong urbanization pressure: El-Mokattam and Abu Roash as examples from Cairo, Egypt. *Journal of African Earth Sciences*, *141*, 86-93. https://doi.org/https://doi.org/10.1016/j.jafrearsci.2018.02.008

AbdelMaksoud, K. M., Al-Metwaly, W. M., Ruban, D. A., & Yashalova, N. N. (2019). Sand dune migration as a factor of geoheritage loss: Evidence from the Siwa Oasis (Egypt) and implications for geoheritage management. *Proceedings of the Geologists' Association*, *130*(5), 599-608. https://doi.org/https://doi.org/10.1016/j.pgeola.2019.07.001

Abdi, H., & Williams, L. J. (2010). Principal component analysis. *WIREs Computational Statistics*, *2*(4), 433-459. https://doi.org/https://doi.org/10.1002/wics.101

Abou Arrage, J., & Chamra, C. (2022). Geo-landscape and geo-heritage assessment to promote geo-tourism and geo-conservation of Ehden region in North Lebanon. *International Journal of Geoheritage and Parks*, *10*(4), 635-654.

ACHS. (2012). *Manifesto 2012*. Association of Critical Heritage Studies. Retrieved 22/02 from https://www.criticalheritagestudies.org/history

Afifi, G., & Negm, M. (2020). Geological Sites as a Safe Resort for Post-COVID-19 Tourism: The Case of Al Jabal Al Akhdar, Oman. *Journal of Environmental Management & Tourism*, *11*(6), 1520-1536. https://doi.org/10.14505/jemt.v11.6(46).23

Aitken, M. J., & Stokes, S. (1997). Climatostratigraphy. In R. E. Taylor & M. J. Aitken (Eds.), *Chronometric Dating in Archaeology* (pp. 1-30). Springer US. https://doi.org/10.1007/978-1-4757-9694-0_1

Al Amir, S. (2023, 03/03/2023). Fujairah to fine tourism companies Dh50,000 if they jepoardise the safety of hikers. *The National*. https://www.thenationalnews.com/uae/2023/03/03/fujairah-to-fine-tourism-companies-dh50000-if-they-jepoardise-the-safety-of-hikers/

Al Ghfeli, M. (2016). United Arab Emirates. In I. V. S. Mullis, M. O. Martin, S. Goh, & K. Cotter (Eds.), *TIMSS 2015 Encyclopedia: Education Policy and Curriculum in Mathematics and Science*. Boston: Boston College, TIMSS & PIRLS International Study Center

Al Mohaya, J., & Elassal, M. (2022). Assessment of Geosites and Geotouristic Sites for Mapping Geotourism: A Case Study of Al-Soudah, Asir Region, Saudi Arabia. *Geoheritage*, *15*(1), 7. https://doi.org/10.1007/s12371-022-00774-w

Al-Afifi, Z. M. M. (2018). *The Conservation, Sustainable use and Management of Mangrove Habitats in Oman* University of York]. York, UK.

Al-Suleimani, Z. K. (2006). *World Heritage Nommination File, Aflaj Irrigation Systems of Oman*. Paris France: UNESCO

Alcalá, L., Lockley, M., Cobos, A., Mampel, L., & Royo-Torres, R. (2016). Evaluating the dinosaur track record: an integrative approach to understanding the regional and global distribution, scientific importance, preservation, and management of tracksites. In P. L. Falkingham, D. Marty, & A. Richter (Eds.), *Dinosaur tracks: the next steps* (pp. 101-111). Indiana University Press.

Allan, M. (2013). Geotourism: the potential of geotourism development in the United Arab of Emirates. Second International Conference on Emerging Research Paradigms in Business and Social Sciences, Dubai, UAE,

Allan, M. (2016). Exploring the potential for geotourism development in the United Arab Emirates. *Anatolia*, *27*(3), 401-404. https://doi.org/10.1080/13032917.2016.1191772

Allan, M. (2023). Geotourism in the United Arab of Emirates (UAE). In M. Allan & R. Dowling (Eds.), *Geotourism in the Middle East* (pp. 263-271). Springer International Publishing. https://doi.org/10.1007/978-3-031-24170-3_16

Allan, M., Dowling, R. K., & Sanders, D. (2015). The motivations for visiting geosites: the case of Crystal Cave, Western Australia. *GeoJournal of Tourism and Geosites*, *16*(2), 141-152.

Allan, M., & Shavanddasht, M. (2019). Rural geotourists segmentation by motivation in weekends and weekdays. *Tourism and Hospitality Research*, *19*(1), 74-84. https://www.jstor.org/stable/26618721

Alsharhan, A. S. (1989). PETROLEUM GEOLOGY OF THE UNITED ARAB EMIRATES. *Journal of Petroleum Geology*, *12*(3), 253-288. https://doi.org/https://doi.org/10.1111/j.1747-5457.1989.tb00197.x

Alsumaiti, T. S., Hussein, K., & Al-Sumaiti, A. S. (2017). Mangroves of Abu Dhabi Emirate, UAE, in a global context: a review. *International Journal of Environmental Sciences*, *6*(4), 110-121.

Amaro, S., Chaves, N. B., Henriques, C., & Barroco, C. (2023). Motivation-Based Segmentation of Visitors to a UNESCO Global Geopark. *Geoheritage*, *15*(2), 79. https://doi.org/10.1007/s12371-023-00848-3

Ambrose, T. K., & Searle, M. P. (2019). 3-D Structure of the Northern Oman-UAE Ophiolite: Widespread, Short-Lived, Suprasubduction Zone Magmatism. *Tectonics*, *38*(1), 233-252. https://doi.org/https://doi.org/10.1029/2018TC005038

Ambusaidi, A., & Al-Balushi, S. (2015). Science Education in the Sultanate of Oman. In N. Mansour & S. Al-Shamrani (Eds.), *Science Education in the Arab Gulf States: Visions, Sociocultural Contexts and Challenges* (pp. 189-203). SensePublishers. https://doi.org/10.1007/978-94-6300-049-9_10

Ansori, C., Setiawan, N. I., Warmada, I. W., & Yogaswara, H. (2022). Identification of geodiversity and evaluation of geosites to determine geopark themes of the Karangsambung-Karangbolong National Geopark, Kebumen, Indonesia. *International Journal of Geoheritage and Parks*, *10*(1), 1-15. https://doi.org/https://doi.org/10.1016/j.ijgeop.2022.01.001

Aquino, R. S., Schänzel, H. A., & Hyde, K. F. (2018). Unearthing the geotourism experience: Geotourist perspectives at Mount Pinatubo, Philippines. *Tourist Studies*, *18*(1), 41-62. https://doi.org/10.1177/1468797617717465

Armitage, S. J., Jasim, S. A., Marks, A. E., Parker, A. G., Usik, V. I., & Uerpmann, H.-P. (2011). The southern route "out of Africa": evidence for an early expansion of modern humans into Arabia. *Science*, *331*(6016), 453-456.

Arrad, T. Y., Errami, E., & Ennih, N. (2018). From scientific inventory to socio-economic sustainable development: Tidzi Diapir geosite (Essaouira basin, Morocco). *Journal of Chemical, Biological and Physical Sciences*, *9*. https://doi.org/10.24214/jcbps.D.9.1.00117.

Arrad, T. Y., Errami, E., Ennih, N., Brahim, O., El Mostafa, E., & Said, B. (2020). From geoheritage inventory to geoeducation and geotourism implications: Insight from Jbel Amsittene (Essaouira province, Morocco). *161*, 103656. https://doi.org/10.1016/j.jafrearsci.2019.103656

Atkinson, O. A., Thomas, D. S., Goudie, A. S., & Bailey, R. M. (2011). Late Quaternary chronology of major dune ridge development in the northeast Rub'al-Khali, United Arab Emirates. *Quaternary research*, *76*(1), 93-105.

Atkinson, O. A., Thomas, D. S., Goudie, A. S., & Parker, A. G. (2012). Holocene development of multiple dune generations in the northeast Rub'al-Khali, United Arab Emirates. *The Holocene*, *22*(2), 179-189.

Atkinson, O. A. C., Thomas, D. S. G., Parker, A. G., & Goudie, A. S. (2013). Late Quaternary humidity and aridity dynamics in the northeast Rub' al-Khali, United Arab Emirates: Implications for early human dispersal and occupation of eastern Arabia. *Quaternary International*, *300*, 292-301. https://doi.org/https://doi.org/10.1016/j.quaint.2012.12.014

Avelar, S., Mansur, K. L., Anjos, S. C., & Vasconcelos, G. F. (2015). Community Perceptions for Geoconservation of a Coastal Area in Rio de Janeiro, Brazil. *Geoheritage*, *7*(3), 275-283. https://doi.org/10.1007/s12371-014-0130-z

Azil, C., Rezzaz, M. A., & Bendaoud, A. (2020). Aspiring Hoggar and Tidikelt geoparks in Algeria. *Arabian Journal of Geosciences*, *13*(20), 1078. https://doi.org/10.1007/s12517-020-06017-y

Azzopardi, E., Kenter, J. O., Young, J., Leakey, C., O'Connor, S., Martino, S., Flannery, W., Sousa, L. P., Mylona, D., Frangoudes, K., Béguier, I., Pafi, M., da Silva, A. R., Ainscough, J., Koutrakis, M., da Silva, M. F., & Pita, C. (2023). What are heritage values? Integrating natural and cultural heritage into environmental valuation. *People and Nature*, *5*(2), 368-383. https://doi.org/https://doi.org/10.1002/pan3.10386

Babou, I. (2020). Natural Heritage, Participatory Democracy and UNESCO: a Structure of Disillusionment? In Y. Girault (Ed.), *UNESCO Global Geoparks: Tension Between Territorial Development and Heritage Enhancement* (pp. 1-21). John Wiley and Sons. https://doi.org/https://doi.org/10.1002/9781119681489.ch1

Bar-Matthews, M., & Ayalon, A. (2011). Mid-Holocene climate variations revealed by high-resolution speleothem records from Soreq Cave, Israel and their correlation with cultural changes. *The Holocene*, *21*(1), 163-171. https://doi.org/10.1177/0959683610384165

Barettino, D., Wimbledon, W. A. P., & Gallego, E. (2000). *Geological Heritage: Its Conservation and Management*. Instituto Tecnológico GeoMinero de España. https://books.google.co.uk/books?id=fGAtSnF3n_QC

Bengtsson, M. (2016). How to plan and perform a qualitative study using content analysis. *NursingPlus Open*, *2*, 8-14. https://doi.org/https://doi.org/10.1016/j.npls.2016.01.001

Beraaouz, M., Macadam, J., Bouchaou, L., Ikenne, M., Ernst, R., Tagma, T., & Masrour, M. (2019). An inventory of geoheritage sites in the Draa Valley (Morocco): a

contribution to promotion of geotourism and sustainable development. *Geoheritage*, *11*, 241-255.

Bergé, L. (2018). *Efficient estimation of maximum likelihood models with multiple fixed-effects: the R package FENmlm*.

Berger, J. F., Charpentier, V., Crassard, R., Martin, C., Davtian, G., & López-Sáez, J. A. (2013). The dynamics of mangrove ecosystems, changes in sea level and the strategies of Neolithic settlements along the coast of Oman (6000–3000 cal. BC). *Journal of Archaeological Science*, *40*(7), 3087-3104. https://doi.org/10.1016/j.jas.2013.03.004

Berred, S., Fadli, D., El Wartiti, M., Zahraoui, M., Berred, K., & Sadki, R. (2019). Geomorphosites of the Semi-arid Tata Region: Valorization of an Unknown Geoheritage for Geotourism Sustainable Development (Anti-Atlas, South Morocco). *Geoheritage*, *11*(4), 1989-2004. https://doi.org/10.1007/s12371-019-00414-w

Bewley, R., Wilson, A., Kennedy, D., Mattingly, D., Banks, R., Bishop, M., Bradbury, J., Cunliffe, E., Fradley, M., & Jennings, R. (2016). Endangered archaeology in the Middle East and North Africa: Introducing the EAMENA project. CAA2015. Keep the Revolution Going: Proceedings of the 43rd Annual Conference on Computer Applications and Quantitative Methods in Archaeology,

Bishop, P. A., & Herron, R. L. (2015). Use and Misuse of the Likert Item Responses and Other Ordinal Measures. *Int J Exerc Sci*, *8*(3), 297-302.

Blechschmidt, I., Matter, A., Preusser, F., & Rieke-Zapp, D. (2009). Monsoon triggered formation of Quaternary alluvial megafans in the interior of Oman. *Geomorphology*, *110*(3), 128-139. https://doi.org/https://doi.org/10.1016/j.geomorph.2009.04.002

Böer, B. (1997). An introduction to the climate of the United Arab Emirates. *Journal of Arid Environments*, *35*(1), 3-16. https://doi.org/https://doi.org/10.1006/jare.1996.0162

Boukhchim, N., Fraj, T. B., & Reynard, E. (2018). Lateral and "Vertico-Lateral" Cave Dwellings in Haddej and Guermessa: Characteristic Geocultural Heritage of Southeast Tunisia. *Geoheritage*, *10*(4), 575-590. https://doi.org/10.1007/s12371-017-0251-2

Bouzekraoui, H., Barakat, A., El Youssi, M., Touhami, F., Mouaddine, A., & Hafid, A. (2018). Mapping geosites as gateways to the geotourism management in Central High-Atlas (Morocco). *Quaestiones Geographicae*, *37*(1), 87–102.

Bouzekraoui, H., Barakat, A., Mouaddine, A., El Youssi, M., Touhami, F., & Hafid, A. (2018). Mapping geoheritage for geotourism management, a case study of Aït Bou Oulli Valley in Central High-Atlas (Morocco). *Environmental Earth Sciences*, *77*. https://doi.org/10.1007/s12665-018-7589-x

Bowring, S. A. (2014). Perceptions of Time Matter: The Importance of Geoscience Outreach. In V. C. H. Tong (Ed.), *Geoscience Research and Outreach: Schools and Public Engagement* (pp. 11-15). Springer Netherlands. https://doi.org/10.1007/978-94-007-6943-4_2

Boylan, P. J. (2008). Geological site designation under the 1972 UNESCO World Heritage Convention. *Geological Society, London, Special Publications*, *300*(1), 279-304. https://doi.org/10.1144/sp300.22

Božić, S., & Tomić, N. (2015). Canyons and gorges as potential geotourism destinations inSerbia: comparative analysis from two perspectives – generalgeotourists' and pure geotourists'. *Open Geosciences*, *7*(1). https://doi.org/doi:10.1515/geo-2015-0040

Brame, C. J. (2016). Effective Educational Videos: Principles and Guidelines for Maximizing Student Learning from Video Content. *CBE—Life Sciences Education*, *15*(4), es6. https://doi.org/10.1187/cbe.16-03-0125

Bratić, M., Marjanović, M., Radivojević, A. R., & Pavlović, M. (2020). M-GAM method in function of tourism potential assessment: Case study of the Sokobanja basin in eastern Serbia. *Open Geosciences*, *12*(1), 1468-1485. https://doi.org/doi:10.1515/geo-2020-0116

Bretzke, K., Armitage, S. J., Parker, A. G., Walkington, H., & Uerpmann, H.-P. (2013). The environmental context of Paleolithic settlement at Jebel Faya, Emirate Sharjah, UAE. *Quaternary International*, *300*, 83-93. https://doi.org/https://doi.org/10.1016/j.quaint.2013.01.028

Bretzke, K., Conard, N. J., & Uerpmann, H.-P. (2014). Excavations at Jebel Faya—The FAY-NE1 shelter sequence. Proceedings of the Seminar for Arabian Studies,

Bretzke, K., & Herkert, K. (2023). Jebel Faya and the middle to late Pleistocene transition: settlement continuity and behavioural flexibility. *Paléorient. Revue pluridisciplinaire de préhistoire et de protohistoire de l'Asie du Sud-Ouest et de l'Asie centrale*(49-1), 63-81.

Bretzke, K., Preusser, F., Jasim, S., Miller, C., Preston, G., Raith, K., Underdown, S. J., Parton, A., & Parker, A. G. (2022). Multiple phases of human occupation in Southeast Arabia between 210,000 and 120,000 years ago. *Scientific Reports*, *12*(1). https://doi.org/10.1038/s41598-022-05617-w

Bridgland, D. R. (2013). Geoconservation of Quaternary sites and interests. *Proceedings of the Geologists' Association*, *124*(4), 612-624. https://doi.org/https://doi.org/10.1016/j.pgeola.2012.10.004

Brilha, J. (2005). *Património geológico e geoconservação : a conservação da natureza na sua vertente geológica*. Palimamage Editores.

Brilha, J. (2016). Inventory and Quantitative Assessment of Geosites and Geodiversity Sites: a Review. *Geoheritage*, *8*, 119-134. https://doi.org/10.1007/s12371-014-0139-3

Brilha, J. (2018a). Geoheritage and Geoparks. In E. Reynard & J. Brilha (Eds.), *Geoheritage: Assessment, Protection, and Management* (pp. 323-335). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-809531-7.00018-6

Brilha, J. (2018b). Geoheritage: Inventories and Evaluation. In E. Reynard & J. Brilha (Eds.), *: Assessment, Protection, and Management* (pp. 69-85). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-809531-7.00004-6

Brockington, D., & Igoe, J. (2006). Eviction for Conservation: A Global Overview. *Conservation and Society*, *4*(3), 424-470. https://journals.lww.com/coas/fulltext/2006/04030/eviction_for_conservation__a_global_overview.7.aspx

Brocx, M., & Semeniuk, V. (2007). Geoheritage and geoconservation-history, definition, scope and scale. *Journal of the Royal Society of Western Australia*, *90*(2), 53-87.

Brocx, M., & Semeniuk, V. (2009). Developing a tool-kit for geoheritage and geoconservation in Western Australia. *ProGeo Newsletter*, *1*, 5-9.

Brocx, M., & Semeniuk, V. (2015a). Determining Geoheritage Values. In M. Kennish (Ed.), *Encyclopedia of Estuaries* (pp. 187-196). Springer.
Brocx, M., & Semeniuk, V. (2015b). *Using the Geoheritage Tool-Kit to identify inter-related geological features at various scales for designating geoparks: Case studies from Western Australia*. Springer, Cham. https://doi.org/https://doi.org/10.1007/978-3-319-10708-0_17
Brocx, M., & Semeniuk, V. (2019). The '8Gs'—a blueprint for Geoheritage, Geoconservation, Geo-education and Geotourism. *Australian Journal of Earth Sciences*, *66*(6), 803-821. https://doi.org/10.1080/08120099.2019.1576767
Bruno, B. C., & Wallace, A. (2019). Interpretive Panels for Geoheritage Sites: Guidelines for Design and Evaluation. *Geoheritage*, *11*(4), 1315-1323. https://doi.org/10.1007/s12371-019-00375-0
Bruschi, V., & Cendrero, A. (2009). Direct and parametric methods for the assessment of geosites and geomorphosites. In E. Reynard, P. Coratza, & G. Regolini-Bissig (Eds.), *Geomorphosites* (pp. 73-88). Verlag Dr. Friedrich Pfeil.
Bruschi, V. M., & Cendrero, A. (2005). Geosite evaluation; can we measure intangible values? *Alpine and Mediterranean Quaternary*, *18*(1), 293-306.
Bruschi, V. M., Cendrero, A., & Albertos, J. A. C. (2011). A Statistical Approach to the Validation and Optimisation of Geoheritage Assessment Procedures. *Geoheritage*, *3*(3), 131-149. https://doi.org/10.1007/s12371-011-0038-9
Bryman, A. (2006). Integrating quantitative and qualitative research: how is it done? *Qualitative Research*, *6*(1), 97-113. https://doi.org/10.1177/1468794106058877
Burek, C. V. (2012). The importance of quaternary geoconservation. *Quaternary Newsletter*, *126*, 25-33. http://hdl.handle.net/10034/254453
Byrne, D., & Ween, G. B. (2015). Bridging Cultural and Natural Heritage. In *Global Heritage* (pp. 94-111). https://doi.org/https://doi.org/10.1002/9781394261154.ch4
Campbell, D. T., Stanley, J. C., & Gage, N. L. (1963). *Experimental and quasi-experimental designs for research*. Houghton, Mifflin and Company.
Carcavilla Urquí, L. (2007). *Patrimonio geológico y geodiversidad: investigación, conservación, gestión y relación con los espacios naturales protegidos* (Vol. 7). Instituto Geológico y Minero de España.
Carifio, J., & Perla, R. (2008). Resolving the 50-year debate around using and misusing Likert scales. *Medical Education*, *42*(12), 1150-1152. https://doi.org/https://doi.org/10.1111/j.1365-2923.2008.03172.x
Cashman, K. V., & Cronin, S. J. (2008). Welcoming a monster to the world: Myths, oral tradition, and modern societal response to volcanic disasters. *Journal of Volcanology and Geothermal Research*, *176*(3), 407-418. https://doi.org/https://doi.org/10.1016/j.jvolgeores.2008.01.040
Cayla, N. (2014). An Overview of New Technologies Applied to the Management of Geoheritage. *Geoheritage*, *6*(2), 91-102. https://doi.org/10.1007/s12371-014-0113-0
Cayla, N., Hoblea, F., Biot, V., Delamette, M., & Guyomard, A. (2012). De l'invisibilité des géomorphosites à la révélation géopatrimoniale. *Géocarrefour*, *87*(3-4), 171-186.
Chakraborty, A., & Jones, T. E. (2018). Mount Fuji: The Volcano, the Heritage, and the Mountain. In A. Chakraborty, K. Mokudai, M. Cooper, M. Watanabe, & S. Chakraborty (Eds.), *Natural Heritage of Japan: Geological, Geomorphological,*

and Ecological Aspects (pp. 167-175). Springer International Publishing. https://doi.org/10.1007/978-3-319-61896-8_16

Chepstow‐Lusty, A., Frogley, M. R., Bauer, B. S., Bush, M. B., & Herrera, A. T. (2003). A late Holocene record of arid events from the Cuzco region, Peru. *Journal of Quaternary Science: Published for the Quaternary Research Association*, *18*(6), 491-502.

Cheung, L. T. O. (2016). The Effect of Geopark Visitors' Travel Motivations on their Willingness to pay for Accredited Geo-guided Tours. *Geoheritage*, *8*(3), 201-209. https://doi.org/10.1007/s12371-015-0154-z

Cheung, L. T. O., Fok, L., & Fang, W. (2014). Understanding geopark visitors' preferences and willingness to pay for global geopark management and conservation. *Journal of Ecotourism*, *13*(1), 35-51. https://doi.org/10.1080/14724049.2014.941848

Chrobak, A., Ugolini, F., Pearlmutter, D., & Raschi, A. (2020). Thermal Tourism and Geoheritage: Examining Visitor Motivations and Perceptions. *Resources*, *9*(5), 58. https://doi.org/10.3390/resources9050058

Churchward, C., Palmer, J., Nassauer, J., & Swanwick, C. (2013). *Evaluation of Methodologies for Visual Impact Assessments*. Transportation Research Board, National Academy of Sciences.

Chylińska, D. (2019). The Role of the Picturesque in Geotourism and Iconic Geotourist Landscapes. *Geoheritage*, *11*(2), 531-543. https://doi.org/10.1007/s12371-018-0308-x

CIA. (2024a, 24/04/2024). *Oman*. CIA. Retrieved 24/04 from https://www.cia.gov/the-world-factbook/countries/oman/

CIA. (2024b, 24/04/2024). *United Arab Emirates*. CIA. Retrieved 29/04 from https://www.cia.gov/the-world-factbook/countries/united-arab-emirates/

Clarke, J., Brooks, N., Banning, E. B., Bar-Matthews, M., Campbell, S., Clare, L., Cremaschi, M., Di Lernia, S., Drake, N., & Gallinaro, M. (2016). Climatic changes and social transformations in the Near East and North Africa during the 'long'4th millennium BC: A comparative study of environmental and archaeological evidence. *Quaternary Science Reviews*, *136*, 96-121.

Clarke, M. W. H. (1988). Stratigraphy and rock unit nomenclature in the oil‐producing area of interior Oman. *Journal of Petroleum Geology*, *11*(1), 5-60.

Clarkson, C., Jacobs, Z., Marwick, B., Fullagar, R., Wallis, L., Smith, M., Roberts, R. G., Hayes, E., Lowe, K., Carah, X., Florin, S. A., Mcneil, J., Cox, D., Arnold, L. J., Hua, Q., Huntley, J., Brand, H. E. A., Manne, T., Fairbairn, A., . . . Pardoe, C. (2017). Human occupation of northern Australia by 65,000 years ago. *Nature*, *547*(7663), 306-310. https://doi.org/10.1038/nature22968

Clary, R. M. (2021). "Location, Location, Location": Challenges of Effective Geoscience Education Within Geotourism Opportunities at Coastal US Fossil Park Sites. In R. B. Singh, D. Wei, & S. Anand (Eds.), *Global Geographical Heritage, Geoparks and Geotourism: Geoconservation and Development* (pp. 187-204). Springer Singapore. https://doi.org/10.1007/978-981-15-4956-4_11

Clifford, P., & Semeniuk, V. (2019). Sedimentary processes, stratigraphic sequences and middens: the link between archaeology and geoheritage—a case study from the Quaternary of the Broome region, Western Australia. *Australian Journal of Earth Sciences*, *66*(6), 955-972. https://doi.org/10.1080/08120099.2018.1563826

Cochran, W. G., & Chambers, S. P. (1965). The Planning of Observational Studies of Human Populations. *Journal of the Royal Statistical Society. Series A (General)*, *128*(2), 234-266. https://doi.org/10.2307/2344179

Coleman, R. (2019). *Designing Experiments for the Social Sciences: How to Plan, Create, and Execute Research Using Experiments* https://doi.org/10.4135/9781071878958

Coratza, P., Gauci, R., Schembri, J., Soldati, M., & Tonelli, C. (2016). Bridging Natural and Cultural Values of Sites with Outstanding Scenery: Evidence from Gozo, Maltese Islands. *Geoheritage*, *8*(1), 91-103. https://doi.org/10.1007/s12371-015-0167-7

Coratza, P., & Giusti, C. (2005). Methodological proposal for the assessment of the scientific quality of geomorphosites. *Italian Journal of Quaternary Sciences*, *18(1)*, 307–313.

Coratza, P., & Hobléa, F. (2018). The Specificities of Geomorphological Heritage. In E. Reynard & J. Brilha (Eds.), *: Assessment, Protection, and Management* (pp. 87-106). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-809531-7.00005-8

Coratza, P., & Marchetti, M. (2002). Geomorphological Sites: research, assessment and improvement. Proceedings of the Workshop held in Modena, Italy, on June,

Coratza, P., Vandelli, V., & Ghinoi, A. (2023). Increasing geoheritage awareness through non-formal learning. *Sustainability*, *15*(1), 868.

Costa-Casais, M., & Alves, M. I. C. (2013). Geological Heritage at Risk in NW Spain. Quaternary Deposits and Landforms of Southern Coasî (Baiona-A Garda). *Geoheritage*, *5*, 227-248.

Cotto, K.-Y., Al-Bakri, S., & Al-Asmi, K. S. (2000). *State of conservation report of the Archaeological Sites of Bat, Al-Khturn and Al-Ayn*. Paris, France: UNESCO

Cox, J., Searle, M., & Pedersen, R. (1999). The petrogenesis of leucogranitic dykes intruding the northern Semail ophiolite, United Arab Emirates: field relationships, geochemistry and Sr/Nd isotope systematics. *Contributions to Mineralogy and Petrology*, *137*(3), 267-287. https://doi.org/10.1007/s004100050550

Creswell, J. W. (2017). *Qualitative inquiry and research design : choosing among five approaches* (Third edition. ed.). SAGE Publications.

Creswell, J. W., & Plano Clark, V. L. (2017). *Designing and conducting mixed methods research* (Third edition. ed.). Sage.

Crofts, R. (2018). Putting Geoheritage Conservation on All Agendas. *Geoheritage*, *10*(2), 231-238. https://doi.org/10.1007/s12371-017-0239-y

Cronin, S. J., Gaylord, D. R., Charley, D., Alloway, B. V., Wallez, S., & Esau, J. W. (2004). Participatory methods of incorporating scientific with traditional knowledge for volcanic hazard management on Ambae Island, Vanuatu. *Bulletin of Volcanology*, *66*(7), 652-668. https://doi.org/10.1007/s00445-004-0347-9

Dahlstrom, M. F., & Scheufele, D. A. (2018). (Escaping) the paradox of scientific storytelling. *PLOS Biology*, *16*(10), e2006720. https://doi.org/10.1371/journal.pbio.2006720

Datta, K., & Sarkar, S. (2022). Development of Geomatrix and Its Application on Geomorphosite Impact Assessment (GIA): an Innovative Approach Applied to Mama Bhagne Pahar, West Bengal, India. *Geoheritage*, *14*(1), 32. https://doi.org/10.1007/s12371-022-00668-x

Davies, S. (2012). *The Artful Species: Aesthetics, Art, and Evolution*. OUP Oxford. https://books.google.co.uk/books?id=4VNq6M6FOiYC

De Lima, F. F., Brilha, J. B., & Salamuni, E. (2010). Inventorying Geological Heritage in Large Territories: A Methodological Proposal Applied to Brazil. *2*(3-4), 91-99. https://doi.org/10.1007/s12371-010-0014-9

De Pourcq, K., Thomas, E., Arts, B., Vranckx, A., Léon-Sicard, T., & Van Damme, P. (2017). Understanding and Resolving Conflict Between Local Communities and Conservation Authorities in Colombia. *World Development*, *93*, 125-135. https://doi.org/https://doi.org/10.1016/j.worlddev.2016.12.026

De Vaus, D., Petri, P. A., Kidd, S., & Shaw, D. (2013). *Surveys in Social Research*. Taylor & Francis Group. http://ebookcentral.proquest.com/lib/oxford/detail.action?docID=1582675

De Winter, J. C., & Dodou, D. (2010). Five-point Likert items: t test versus Mann-Whitney-Wilcoxon. *Practical assessment, research & evaluation*, *15*(11), 1-12.

Demeter, F., Shackelford, L., Westaway, K., Barnes, L., Duringer, P., Ponche, J.-L., Dumoncel, J., Sénégas, F., Sayavongkhamdy, T., Zhao, J.-X., Sichanthongtip, P., Patole-Edoumba, E., Dunn, T., Zachwieja, A., Coppens, Y., Willerslev, E., & Bacon, A.-M. (2017). Early Modern Humans from Tam Pà Ling, Laos: Fossil Review and Perspectives. *Current Anthropology*, *58*(S17), S527-S538. https://doi.org/10.1086/694192

Derafshi, K., & Seyedhamzeh, M. (2022). Synthesis of Quantitative Geosite Assessment Models and Its Application on Sistan and Baluchestan Province Natural Heritages, Potential Geotourism Destination of Iran. *Geoheritage*, *14*(4), 124. https://doi.org/10.1007/s12371-022-00752-2

Dhanhani, H. A. G. (2010). *Evaluation of the response capability of the United Arab Emirates (UAE) to the impact of natural hazards* University of Bedfordshire]. Bedfordshire, UK.

Dollma, M. (2019). Geotourism potential of Thethi National Park (Albania). *International Journal of Geoheritage and Parks*, *7*(2), 85-90. https://doi.org/10.1016/j.ijgeop.2019.05.002

Dolphin, G., Dutchak, A., Karchewski, B., & Cooper, J. (2019). Virtual field experiences in introductory geology: Addressing a capacity problem, but finding a pedagogical one. *Journal of Geoscience Education*, *67*(2), 114-130. https://doi.org/10.1080/10899995.2018.1547034

Dottori, F., Alfieri, L., Salamon, P., Bianchi, A., Feyen, L., & Hirpa, F. (2016). *Flood hazard map of the World - 50-year return period*.

Dowling, R., & Allan, M. (2018). Who are geotourists? A case study from Jordan. In R. Dowling & D. Newsome (Eds.), *Handbook of geotourism* (pp. 76-86). Edward Elgar Publishing.

Dowling, R. K. (2011). Geotourism's Global Growth. *Geoheritage*, *3*(1), 1-13. https://doi.org/10.1007/s12371-010-0024-7

Dowling, R. K. (2012). Conference Report: The Third Global Geotourism Conference, 30 Oct–1 Nov 2011, Sultanate of Oman. *Geoheritage*, *4*(3), 221-223.

Dowling, R. K. (2013). Global geotourism–an emerging form of sustainable tourism. *Czech Journal of Tourism*, *2*(2), 59-79.

Dudley, M. Z., Squires, G. K., Petroske, T. M., Dawson, S., & Brewer, J. (2023). The Use of Narrative in Science and Health Communication: A Scoping Review. *Patient*

Education and Counseling, *112*, 107752. https://doi.org/https://doi.org/10.1016/j.pec.2023.107752

Dunn, M. E., Mills, M., & Veríssimo, D. (2020). Evaluating the impact of the documentary series Blue Planet II on viewers' plastic consumption behaviors. *Conservation Science and Practice*, *2*(10), e280. https://doi.org/https://doi.org/10.1111/csp2.280

Dziuban, C. D., & Shirkey, E. C. (1974). When is a correlation matrix appropriate for factor analysis? Some decision rules. *Psychological bulletin*, *81*(6), 358-361. https://doi.org/10.1037/h0036316

EAMENA Project Team. (2024). *Endangered Archaeology in the Middle East and North Africa* Version 4).

el-Masri, S., Plana, I., Ahmad Aqil, A., al Tikriti, W. Y., Beech, M., Sheehan, P., & Fawaz, K. (2010). *The Cultural Sites of Al Ain (Hafit, Hili, Bidaa Bint Saud and Oases Areas) Serial Property Nomination File*. Paris, France: UNESCO

Elassal, M. (2020). Geomorphological Heritage Attractions Proposed for Geotourism in Asir Mountains, Saudi Arabia. *Geoheritage*, *12*(4), 78.

Elias, S. A. (2007). Societal Relevance of Quaternary Research. In S. A. Elias (Ed.), *Encyclopedia of Quaternary Science* (pp. 1-10). Amsterdam: Elsevir.

English Heritage, Drury, P., & McPherson, A. (2008). *Conservation principles: policies and guidance for the sustainable management of the historic environment*.

Erhartič, B. (2010). Geomorphosite assessment. *Acta geographica Slovenica*, *50*(2), 295-319. https://doi.org/10.3986/AGS50206

Errami, E., Schneider, G., Ennih, N., Randrianaly, H., Bendaoud, A., Noubhani, A., Norman, N., Allan, M., Vasconcelos, L., Costa, L., Al-Wosabi, M., Al-Subbary, A., Mabvuto-Ngwira, P., Okunlola, G., Salisu, L. H., Andrianaivo, L., Siby, S., Ketchemen, B. a., Gauly, M., & Bobrowsky, P. (2015). Geoheritage and Geoparks in Africa and the Middle-East: Challenges and Perspectives. In *From Geoheritage to Geoparks Case Studies from Africa and Beyond* (pp. 3-23). https://doi.org/10.1007/978-3-319-10708-0_1

Ettinger, J., Walton, P., Painter, J., & DiBlasi, T. (2021). Climate of hope or doom and gloom? Testing the climate change hope vs. fear communications debate through online videos. *Climatic change*, *164*(1), 19. https://doi.org/10.1007/s10584-021-02975-8

European Geoparks Network. (2013). *What is a Geopark*. European Geoparks Network. Retrieved 09/07 from https://www.europeangeoparks.org/?page_id=165

Ewers, M. C. (2016). Oil, human capital and diversification: the challenge of transition in the UAE and the Arab Gulf States. *The Geographical Journal*, *182*(3), 236-250. https://doi.org/https://doi.org/10.1111/geoj.12138

Fairchild, I., & McMillan, E. (2007). Speleothems as indicators of wet and dry periods. *International Journal of Speleology*, *36*. https://doi.org/10.5038/1827-806X.36.2.2

Fanwei, Z. (2014). An evaluation of residents' perceptions of the creation of a geopark: a case study on the geopark in Mt. Huaying Grand Canyon, Sichuan Province, China. *Environmental Earth Sciences*, *71*(3), 1453-1463. https://doi.org/10.1007/s12665-013-2550-5

Farrant, A. R., Duller, G. A. T., Parker, A. G., Roberts, H. M., Parton, A., Knox, R. W. O., & Bide, T. (2015). Developing a framework of Quaternary dune accumulation in the

northern Rub' al-Khali, Arabia. *Quaternary International*, *382*, 132-144. https://doi.org/https://doi.org/10.1016/j.quaint.2015.02.022
Farsani, N. T., Coelho, C., & Costa, C. (2011). Geotourism and geoparks as novel strategies for socio-economic development in rural areas. *International Journal of Tourism Research*, *13*(1), 68-81. https://doi.org/https://doi.org/10.1002/jtr.800
Farsani, N. T., Esfahani, M. A. G., & Shokrizadeh, M. (2019). Understanding Tourists' Satisfaction and Motivation Regarding Mining Geotours (Case Study: Isfahan, Iran). *Geoheritage*, *11*(3), 681-688. https://doi.org/10.1007/s12371-018-0318-8
Fassoulas, C., Mouriki, D., Dimitriou-Nikolakis, P., & Iliopoulos, G. (2012). Quantitative Assessment of Geotopes as an Effective Tool for Geoheritage Management. *Geoheritage*, *4*(3), 177-193. https://doi.org/10.1007/s12371-011-0046-9
Federal Competitiveness and Statistics Centre, U. (2023). *Gross Domestic Product at Current Prices 2022-2023*. https://fcsc.gov.ae/en-us/Pages/Statistics/NSDP.aspx
Fepuleai, A., Németh, K., & Muliaina, T. (2021). Geopark Impact for the Resilience of Communities in Samoa, SW Pacific. *Geoheritage*, *13*(3), 50. https://doi.org/10.1007/s12371-021-00578-4
Fepuleai, A., Weber, E., Németh, K., Muliaina, T., & Iese, V. (2017). Eruption Styles of Samoan Volcanoes Represented in Tattooing, Language and Cultural Activities of the Indigenous People. *Geoheritage*, *9*(3), 395-411. https://doi.org/10.1007/s12371-016-0204-1
Feulner, G. (2014). *The flora of Wadi Wurayah National Park-Fujairah, United Arab Emirates*.
Field, J. H., Dodson, J. R., & Prosser, I. P. (2002). A Late Pleistocene vegetation history from the Australian semi-arid zone. *Quaternary Science Reviews*, *21*(8-9), 1023-1037.
Finzi, Y., Avni, S., Maroz, A., Avriel-Avni, N., Ashckenazi-Polivoda, S., & Ryvkin, I. (2019). Extraordinary Geodiversity and Geoheritage Value of Erosional Craters of the Negev Craterland. *Geoheritage*, *11*(3), 875-896. https://doi.org/10.1007/s12371-018-0335-7
Fleitmann, D., Burns, S., Mudelsee, M., U., N., J., K., Mangini, A., & Matter, A. (2003). Holocene Forcing of the Indian Monsoon Recorded in a Stalagmite from Southern Oman. *Science*, *300*(5626), 1737-1739. https://doi.org/10.1126/science.1083130
Fleitmann, D., Burns, S. J., Neff, U., Mangini, A., & Matter, A. (2003). Changing moisture sources over the last 330,000 years in Northern Oman from fluid-inclusion evidence in speleothems. *Quaternary research*, *60*(2), 223-232. https://doi.org/10.1016/s0033-5894(03)00086-3
Fleitmann, D., & Matter, A. (2009). The speleothem record of climate variability in Southern Arabia. *Comptes Rendus Geoscience*, *341*(8-9), 633-642. https://doi.org/10.1016/j.crte.2009.01.006
Flohr, P. (2017). The Endangered Archaeology in the Middle East and North Africa (EAMENA) Project: Protecting cultural heritage using remote sensing. 8th International Conference on Science and Technology in Archaeology and Conservation, Amman.
Fontanella Pisa, P. (2024). Understanding memory transmission in disaster risk reduction practices: A case study from Japan. *International Journal of Disaster Risk Reduction*, *100*, 104112. https://doi.org/https://doi.org/10.1016/j.ijdrr.2023.104112

Fox, N., Graham, L. J., Eigenbrod, F., Bullock, J. M., & Parks, K. E. (2022). Geodiversity Supports Cultural Ecosystem Services: an Assessment Using Social Media. *Geoheritage*, *14*(1), 27. https://doi.org/10.1007/s12371-022-00665-0

Fredheim, L. H., & Khalaf, M. (2016). The significance of values: heritage value typologies re-examined. *International Journal of Heritage Studies*, *22*(6), 466-481. https://doi.org/10.1080/13527258.2016.1171247

Freer, C., & Kherfi, Y. (2020). Narratives of nationalism in culture and heritage production of the Arabian Peninsula: bringing the state back in. *Middle Eastern Studies*, *56*(6), 988-1004. https://doi.org/10.1080/00263206.2020.1786369

Frey, B. S. (1997). The Evaluation of Cultural Heritage: Some Critical Issues. In M. Hutter & I. Rizzo (Eds.), *Economic Perspectives on Cultural Heritage* (pp. 31–49). Palgrave Macmillan UK. https://doi.org/10.1007/978-1-349-25824-6_11

Fritz, M., & Berger, P. D. (2015). Comparing two designs (or anything else!) using paired sample T-tests. In M. Fritz & P. D. Berger (Eds.), *Improving the User Experience Through Practical Data Analytics* (pp. 71-89). Morgan Kaufmann. https://doi.org/https://doi.org/10.1016/B978-0-12-800635-1.00003-3

Fujairah Adventures. (2024). Fujairah Adventures. In F. Adventures (Ed.), *Online*. Fujairah, UAE.

Fujairah Statistics Centre. (2023). *Statistical year book 2022*.

Fung, C. K., & Jim, C. Y. (2015). Segmentation by motivation of Hong Kong Global Geopark visitors in relation to sustainable nature-based tourism. *International journal of sustainable development & world ecology*, *22*(1), 76-88.

Gaines, S., Asrat, A., & Sadrack, F. T. (2012). Taking the pulse of Earth sciences in Africa. *A World of Science*, *10*(1), 17–19.

García-Cortés, A., Vegas, J., Carcavilla, L., & Díaz-Martínez, E. (2019). *Conceptual base and methodology of the Spanish Inventory of Sites of Geological Interest (IELIG)*. Madrid, Spain: Instituto Geológico y Minero de España

Gass, I. G., Ries, A. C., Shackleton, R. M., & Smewing, J. D. (1990). Tectonics, geochronology and geochemistry of the Precambrian rocks of Oman. *Geological Society, London, Special Publications*, *49*(1), 585-599. https://doi.org/doi:10.1144/GSL.SP.1992.049.01.35

Gates, A. E. (2006). Geotourism: a perspective from the USA. In R. Dowling & D. Newesome (Eds.), *Geotourism* (pp. 157-179). Routledge.

Glennie, K. W. (1974). Geology of the Oman mountains. *Verhandelingen van het Koninklink Nederlands Geologisch Mijnbouwkundig Genootchachp*, *1*, 423.

Glennie, K. W. (1998). The desert of southeast Arabia: A product of Quaternary climatic change. In A. S. Alsharhan, Glennie, K.W., Whittle, G.L., Kendall, C.G.St.C (Ed.), *Quaternary Deserts and Climate Change* (pp. 279-291). A. A. Balkema Publishers. https://doi.org/10.1201/9781003077862-30

Glennie, K. W. (2006). *Oman's Geological Heritage* (2 ed.). Petroleum Development Oman. https://books.google.co.uk/books?id=2NCsQQAACAAJ

Glennie, K. W., & Singhvi, A. K. (2002). Event stratigraphy, paleoenvironment and chronology of SE Arabian deserts. *Quaternary Science Reviews*, *21*(7), 853-869. https://doi.org/https://doi.org/10.1016/S0277-3791(01)00133-0

Global Forest Review. (2024). *Tropical Forest Loss Drops Steeply in Brazil and Colombia, but High Rates Persist Overall*. https://research.wri.org/gfr/latest-analysis-deforestation-trends

Global Geoparks Network International Association. (2024). *UNESCO Global Geoparks*. Global Geoparks Network/UNESCO. Retrieved 26/04 from https://www.visitgeoparks.org

Göb, R., McCollin, C., & Ramalhoto, M. F. (2007). Ordinal Methodology in the Analysis of Likert Scales. *Quality & Quantity*, *41*(5), 601-626. https://doi.org/10.1007/s11135-007-9089-z

Goebel, T., Hockett, B., Rhode, D., & Graf, K. (2021). Prehistoric human response to climate change in the Bonneville basin, western north America: The Bonneville Estates Rockshelter radiocarbon chronology. *Quaternary Science Reviews*, *260*, 106930. https://doi.org/https://doi.org/10.1016/j.quascirev.2021.106930

Goldberg, M. H., van der Linden, S., Ballew, M. T., Rosenthal, S. A., Gustafson, A., & Leiserowitz, A. (2019). The Experience of Consensus: Video as an Effective Medium to Communicate Scientific Agreement on Climate Change. *Science Communication*, *41*(5), 659-673. https://doi.org/10.1177/1075547019874361

Goldman, S., & McDermott, R. (2007). Staying the Course With Video Analysis. In R. Goldman, R. Pea, B. Barron, & S. Derry (Eds.), *Video Research in the Learning Sciences* (pp. 101-113). Routledge.

Gordon, J. (2018). Geoheritage, Geotourism and the Cultural Landscape: Enhancing the Visitor Experience and Promoting Geoconservation. *Geosciences*, *8*(4), 136. https://doi.org/10.3390/geosciences8040136

Gordon, J. E., Crofts, R., & Díaz-Martínez, E. (2018). Geoheritage Conservation and Environmental Policies: Retrospect and Prospect. In E. Reynard & J. Brilha (Eds.), *Geoheritage: Assessment, Protection, and Management* (pp. 213-235). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-809531-7.00012-5

Goudie, A., & Seely, M. (2011). World heritage desert landscapes: potential priorities for the recognition of desert landscapes and geomorphological sites on the World Heritage List. *International Union for Conservation of Nature (IUCN), Gland, Switzerland*.

Goudie, A. S., Colls, A., Stokes, S., Parker, A., White, K., & Al‐Farraj, A. (2000). Latest Pleistocene and Holocene dune construction at the north‐eastern edge of the Rub Al Khali, United Arab Emirates. *Sedimentology*, *47*(5), 1011-1021.

Gravis, I., Németh, K., & Procter, J. N. (2017). The Role of Cultural and Indigenous Values in Geosite Evaluations on a Quaternary Monogenetic Volcanic Landscape at Ihumātao, Auckland Volcanic Field, New Zealand. *Geoheritage*, *9*(3), 373-393. https://doi.org/10.1007/s12371-016-0198-8

Gravis, I., Németh, K., Twemlow, C., & Németh, B. (2020). The Case for Community-Led Geoheritage and Geoconservation Ventures in Māngere, South Auckland, and Central Otago, New Zealand. *Geoheritage*, *12*(1). https://doi.org/10.1007/s12371-020-00449-4

Gray, J. M. (2004). *Geodiversity: valuing and conserving abiotic nature* (FIrst edition. ed.). Wiley-Blackwell.

Gray, M. (2008). Geodiversity: a new paradigm for valuing and conserving geoheritage. *Geoscience Canada*, *35*(2), 51–59.

Greenbaum, T. (1998). *The Handbook for Focus Group Research* (2 ed.) https://doi.org/10.4135/9781412986151

Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a Conceptual Framework for Mixed-Method Evaluation Designs. *Educational Evaluation and Policy Analysis*, *11*(3), 255-274. https://doi.org/10.3102/01623737011003255

Grobbelaar, L., Bouwer, S., & Hermann, U. P. (2019). An exploratory investigation of visitor motivations to the Barberton-Makhonjwa Geotrail, South Africa. *Geo Journal of Tourism and Geosites*, *25*(2), 283-292.

Grønmo, S. (2019). *Social Research Methods: Qualitative, Quantitative and Mixed Methods Approaches*. SAGE Publications. https://books.google.co.uk/books?id=8vW4wgEACAAJ

Groucutt, H. S., Grün, R., Zalmout, I. A. S., Drake, N. A., Armitage, S. J., Candy, I., Clark-Wilson, R., Louys, J., Breeze, P. S., Duval, M., Buck, L. T., Kivell, T. L., Pomeroy, E., Stephens, N. B., Stock, J. T., Stewart, M., Price, G. J., Kinsley, L., Sung, W. W., . . . Petraglia, M. D. (2018). Homo sapiens in Arabia by 85,000 years ago. *Nature Ecology & Evolution*, *2*(5), 800-809. https://doi.org/10.1038/s41559-018-0518-2

Groucutt, H. S., White, T. S., Scerri, E. M. L., Andrieux, E., Clark-Wilson, R., Breeze, P. S., Armitage, S. J., Stewart, M., Drake, N., Louys, J., Price, G. J., Duval, M., Parton, A., Candy, I., Carleton, W. C., Shipton, C., Jennings, R. P., Zahir, M., Blinkhorn, J., . . . Petraglia, M. D. (2021). Multiple hominin dispersals into Southwest Asia over the past 400,000 years. *Nature*, *597*(7876), 376-380. https://doi.org/10.1038/s41586-021-03863-y

Guerra, A. L., Gidel, T., & Vezzetti, E. (2016). Toward a common procedure using likert and likert-type scales in small groups comparative design observations. DS 84: Proceedings of the DESIGN 2016 14th International Design Conference, Dubrovnik, Croantia.

Gunawardhana, L. N., & Al-Rawas, G. A. (2016). A comparison of trends in extreme rainfall using 20-year data in three major cities in Oman [Article]. *Journal of Engineering Research*, *13*(2), 137-148. https://doi.org/10.24200/tjer.vol13iss2pp137-148

Gunawardhana, L. N., Al-Rawas, G. A., & Al-Hadhrami, G. (2018). Quantification of the changes in intensity and frequency of hourly extreme rainfall attributed climate change in Oman. *Natural Hazards*, *92*(3), 1649-1664. https://doi.org/10.1007/s11069-018-3271-6

Guo, P. J., Kim, J., & Rubin, R. (2014). How video production affects student engagement: An empirical study of MOOC videos. Proceedings of the first ACM conference on Learning@ scale conference,

Habibi, T., Ponedelnik, A. A., Yashalova, N. N., & Ruban, D. A. (2018). Urban geoheritage complexity: Evidence of a unique natural resource from Shiraz city in Iran. *Resources Policy*, *59*, 85-94. https://doi.org/https://doi.org/10.1016/j.resourpol.2018.06.002

Hamacher, D. W., & Goldsmith, J. (2013). Aboriginal Oral Traditions of Australian Impact Craters. *Journal of Astronomical History and Heritage*, *16*(3), 295-311. https://doi.org/https://doi.org/10.3724/SP.J.1440-2807.2013.03.06

Harmon, D. (2007). A Bridge over the Chasm: Finding Ways to Achieve Integrated Natural and Cultural Heritage Conservation. *International Journal of Heritage Studies*, *13*(4-5), 380-392. https://doi.org/10.1080/13527250701351098

Harrison, R. (2015). Beyond “Natural” and “Cultural” Heritage: Toward an Ontological Politics of Heritage in the Age of Anthropocene. *Heritage & Society*, *8*(1), 24-42. https://doi.org/10.1179/2159032X15Z.00000000036

Hattam, C., Böhnke-Henrichs, A., Börger, T., Burdon, D., Hadjimichael, M., Delaney, A., Atkins, J. P., Garrard, S., & Austen, M. C. (2015). Integrating methods for ecosystem service assessment and valuation: Mixed methods or mixed messages? *Ecological economics*, *120*, 126-138. https://doi.org/10.1016/j.ecolecon.2015.10.011

Heathcote, J., & King, S. (1998). Umm as Samim, Oman: a sabkha with evidence for climatic change. In A. S. Alsharhan, Glennie, K.W., Whittle, G.L., Kendall, C.G.C. (Ed.), *Quaternary deserts and climatic change* (pp. 141-153). Balkema.

Hellqvist, M. (2019). Teaching Sustainability in Geoscience Field Education at Falun Mine World Heritage Site in Sweden. *Geoheritage*, *11*(4), 1785-1798. https://doi.org/10.1007/s12371-019-00387-w

Henriques, M. H., & Brilha, J. (2017). UNESCO Global Geoparks: a strategy towards global understanding and sustainability. *Episodes*, *40*, 349-355.

Henriques, M. H., dos Reis, R. P., Brilha, J., & Mota, T. (2011). Geoconservation as an emerging geoscience. *Geoheritage*, *3*(2), 117-128.

Herrera-Franco, G., Apolo-Masache, B., Escandón-Panchana, P., Jácome-Francis, K., Morante-Carballo, F., Mata-Perelló, J., & Carrión-Mero, P. (2022). Perception of the Geological-Mining Heritage to Promote Geotourism in Guayaquil, Ecuador. *Geosciences*, *12*(9), 322. https://www.mdpi.com/2076-3263/12/9/322

Herrera-Franco, G., Carrión-Mero, P., Montalván-Burbano, N., Caicedo-Potosí, J., & Berrezueta, E. (2022). Geoheritage and Geosites: A Bibliometric Analysis and Literature Review. *Geosciences*, *12*(4), 169. https://www.mdpi.com/2076-3263/12/4/169

Herrmann, J. T., Casana, J., & Qandil, H. S. (2012). A sequence of inland desert settlement in the Oman peninsula: 2008–2009 excavations at Saruq al‐Hadid, Dubai, UAE. *Arabian Archaeology and Epigraphy*, *23*(1), 50-69. https://doi.org/10.1111/j.1600-0471.2011.00349.x

Hershkovitz, I., Weber, G. W., Quam, R., Duval, M., Grün, R., Kinsley, L., Ayalon, A., Bar-Matthews, M., Valladas, H., Mercier, N., Arsuaga, J. L., Martinón-Torres, M., Bermúdez de Castro, J. M., Fornai, C., Martín-Francés, L., Sarig, R., May, H., Krenn, V. A., Slon, V., . . . Weinstein-Evron, M. (2018). The earliest modern humans outside Africa. *Science*, *359*(6374), 456. https://doi.org/10.1126/science.aap8369

Hoare, J. (2020). The practice and potential of heritage emotion research: an experimental mixed-methods approach to investigating affect and emotion in a historic house. *International Journal of Heritage Studies*, *26*(10), 955-974. https://doi.org/10.1080/13527258.2020.1714696

Hoblea, F., Delannoy, J.-J., Jaillet, S., Ployon, E., & Sadier, B. (2014). Digital Tools for Managing and Promoting Karst Geosites in Southeast France. *Geoheritage*, *6*(2), 113-127. https://doi.org/10.1007/s12371-014-0112-1

Hoffmann, G., Meschede, M., Zacke, A., & Al Kindi, M. (2016). *Field guide to the geology of Northeastern Oman*. Borntraeger Science Publishers.

Holgado–Tello, F. P., Chacón–Moscoso, S., Barbero–García, I., & Vila–Abad, E. (2010). Polychoric versus Pearson correlations in exploratory and confirmatory factor

analysis of ordinal variables. *Quality & Quantity*, *44*(1), 153-166. https://doi.org/10.1007/s11135-008-9190-y
Hose, T. A. (2005). Geotourism and interpretation. In D. Newsome & R. Dowling (Eds.), *Geotourism* (1 ed., pp. 221–241). Routledge.
Hose, T. A. (2012). 3G's for Modern Geotourism. *Geoheritage*, *4*(1), 7-24. https://doi.org/10.1007/s12371-011-0052-y
Hose, T. A. (2016). Three centuries (1670–1970) of appreciating physical landscapes. *Geological Society, London, Special Publications*, *417*(1), 1-23. https://doi.org/doi:10.1144/SP417.15
Hsu, L. S., & Obe, R. (2021). *PostGIS in Action, Third Edition*. Manning Publications. https://books.google.co.uk/books?id=-GKGzQEACAAJ
Hurtado, H., Dowling, R., & Sanders, D. (2014). An exploratory study to develop a geotourism typology model. *International Journal of Tourism Research*, *16*(6), 608-613.
Hussain, A. I. (2022). Geodiversity of Smaquli area as a potential geopark in Kurdistan region, Iraq. *International Journal of Geoheritage and Parks*, *10*(4), 477-490. https://doi.org/https://doi.org/10.1016/j.ijgeop.2022.07.005
Hutter, M., & Rizzo, I. (1997). *Economic perspectives on cultural heritage* (1 ed.). Palgrave Macmillan London.
Ickert, J., & Stewart, I. S. (2016). Earthquake risk communication as dialogue – insights from a workshop in Istanbul's urban renewal neighbourhoods. *Nat. Hazards Earth Syst. Sci.*, *16*(5), 1157-1173. https://doi.org/10.5194/nhess-16-1157-2016
Illingworth, S. (2023). A spectrum of geoscience communication: from dissemination to participation. *Geosci. Commun.*, *6*(4), 131-139. https://doi.org/10.5194/gc-6-131-2023
Illingworth, S., Stewart, I., Tennant, J., & von Elverfeldt, K. (2018). Editorial: Geoscience Communication – Building bridges, not walls. *Geosci. Commun.*, *1*(1), 1-7. https://doi.org/10.5194/gc-1-1-2018
Immenhauser, A., Dublyansky, Y. V., Verwer, K., Fleitman, D., & Pashenko, S. E. (2007). Textural, Elemental, and Isotopic Characteristics of Pleistocene Phreatic Cave Deposits (Jabal Madar, Oman). *Journal of Sedimentary Research*, *77*(2), 68-88. https://doi.org/10.2110/jsr.2007.012
International Trade Administration. (2024). *Oman - Country Commercial Guide*. U.S. Department of Commerce. Retrieved 29/04 from https://www.trade.gov/country-commercial-guides/oman-oil-gas
Isoda, Y., Muranaka, A., Tanibata, G., Hanaoka, K., Ohmura, J., & Tsukamoto, A. (2019). Strengths of Exaggerated Tsunami-Originated Placenames: Disaster Subculture in Sanriku Coast, Japan. *ISPRS International Journal of Geo-Information*, *8*(10), 429. https://www.mdpi.com/2220-9964/8/10/429
IUCN. (1995). *Messel Pit Fossil Site (Germany) World Heritage Nomination IUCN Summary*. (720). IUCN
IUCN. (2024). *United Arab Emirates*. IUCN. Retrieved 24/06 from https://iucngreenlist.org/country/united-arab-emirates/
Jaafar, M., Nordin, A. O. S., Abdullah, S., & Marzuki, A. (2014). Geopark ecotourism product development: A study on tourist differences. *Asian Social Science*, *10*(11), 42.

Jennings, R. P., Singarayer, J., Stone, E. J., Krebs-Kanzow, U., Khon, V., Nisancioglu, K. H., Pfeiffer, M., Zhang, X., Parker, A., Parton, A., Groucutt, H. S., White, T. S., Drake, N. A., & Petraglia, M. D. (2015). The greening of Arabia: Multiple opportunities for human occupation of the Arabian Peninsula during the Late Pleistocene inferred from an ensemble of climate model simulations. *Quaternary International*, *382*, 181-199. https://doi.org/10.1016/j.quaint.2015.01.006

Jones, C. (2008). History of Geoparks. *Geological Society, London, Special Publications*, *300*(1), 273-277. https://doi.org/doi:10.1144/SP300.21

Jones, J. C., & Washko, S. (2022). More than fun in the sun: The pedagogy of field trips improves student learning in higher education. *Journal of Geoscience Education*, *70*(3), 292-305. https://doi.org/10.1080/10899995.2021.1984176

Joshi, A. U., Gorania, P., Limaye, M. A., Chauhan, G. D., & Thakkar, M. G. (2022). Geoheritage Values of the Champaner-Pavagadh Archaeological Park, UNESCO World Heritage Site, Gujarat, Western India. *Geoheritage*, *14*(3), 88. https://doi.org/10.1007/s12371-022-00720-w

Kaim, A., Jaffe, E., Siman-Tov, M., Khairish, E., & Adini, B. (2020). Impact of a Brief Educational Intervention on Knowledge, Perceived Knowledge, Perceived Safety, and Resilience of the Public During COVID-19 Crisis. *International Journal of Environmental Research and Public Health*, *17*(16), 5971. https://www.mdpi.com/1660-4601/17/16/5971

Kazancı, N., & Lopes, Ö. A. (2022). Stones of Göbeklitepe, SE Anatolia, Turkey: an Example of the Shaping of Cultural Heritage by Local Geology Since the Early Neolithic. *Geoheritage*, *14*(2), 57. https://doi.org/10.1007/s12371-022-00694-9

Khalaf, E. E. D. A. H. (2022). Karst Heritage as a Tourist Attraction: a Case Study in the White Desert National Park, Western Desert, Egypt. *Geoheritage*, *14*(3), 94.

Kharbish, S., Henaish, A., & Zamzam, S. (2020). Geodiversity and geotourism in Greater Cairo area, Egypt: implications for geoheritage revival and sustainable development. *Arabian Journal of Geosciences*, *13*(12), 451. https://doi.org/10.1007/s12517-020-05457-w

Khoshraftar, R., & Farsani, N. T. (2022). An Introduction to Geotourism of the Mahneshan County. *Geoheritage*, *14*(1), 28. https://doi.org/10.1007/s12371-022-00671-2

Kiernan, K. (2013). The Nature Conservation, Geotourism and Poverty Reduction Nexus in Developing Countries: A Case Study from the Lao PDR. *Geoheritage*, *5*(3), 207-225. https://doi.org/10.1007/s12371-013-0084-6

Kiernan, K. (2015). Landforms as Sacred Places: Implications for Geodiversity and Geoheritage. *Geoheritage*, *7*(2), 177-193. https://doi.org/10.1007/s12371-014-0128-6

Kim, S. S., Kim, M., Park, J., & Guo, Y. (2008). Cave Tourism: Tourists' Characteristics, Motivations to Visit, and the Segmentation of Their Behavior. *Asia Pacific Journal of Tourism Research*, *13*(3), 299-318. https://doi.org/10.1080/10941660802280448

King, D. N., & Goff, J. R. (2010). Benefitting from differences in knowledge, practice and belief: Māori oral traditions and natural hazards science. *Nat. Hazards Earth Syst. Sci.*, *10*(9), 1927-1940. https://doi.org/10.5194/nhess-10-1927-2010

Kinnebrew, E., Shoffner, E., Farah-Pérez, A., Mills-Novoa, M., & Siegel, K. (2021). Approaches to interdisciplinary mixed methods research in land-change science

and environmental management. *Conservation Biology*, *35*(1), 130-141. https://doi.org/https://doi.org/10.1111/cobi.13642

Kirk, R. (2013). *Experimental Design: Procedures for the Behavioral Sciences* (4 ed.) https://doi.org/10.4135/9781483384733

Kirkham, A., & Evans, G. (2019). Aspects of the Abu Dhabi Sabkha. In B. Gul, B. Böer, M. A. Khan, M. Clüsener-Godt, & A. Hameed (Eds.), *Sabkha Ecosystems: Volume VI: Asia/Pacific* (pp. 15-40). Springer International Publishing. https://doi.org/10.1007/978-3-030-04417-6_3

Knapik, R., Jała, Z., Sobczyk, A., Migoń, P., Aleksandrowski, P., Szuszkiewicz, A., Krąpiec, M., Madej, S., & Krakowski, K. (2009). *Inwentaryzacja i waloryzacja geostanowisk Karkonoskiego Parku Narodowego i jego otuliny oraz wykonanie mapy geologicznej tego obszaru*.

Knapp, T. R. (1990). Treating Ordinal Scales as Interval Scales: An Attempt To Resolve the Controversy. *Nursing Research*, *39*(2). https://journals.lww.com/nursingresearchonline/fulltext/1990/03000/treating_ordinal_scales_as_interval_scales__an.19.aspx

Koike, T., & Kikuchi, T. (2016). Relationships between Landscape Evaluations of Geo-tour Participants and Interpretations of Geo-tour Guides: . *Journal of Geography (Chigaku Zasshi)*, *125*(6), 857-870. https://doi.org/10.5026/jgeography.125.857

Konsa, K. (2016). Natural and Cultural Heritage: Framing Meanings and Practices. *The International Journal of Sustainability in Economic, Social and Cultural Context*, *12*(4), 9-18. https://doi.org/https://doi.org/10.18848/2325-1115/CGP/v12i04/9-18

Koo, T. K., & Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine*, *15*(2), 155-163. https://doi.org/https://doi.org/10.1016/j.jcm.2016.02.012

Kortz, K. M., Grenga, A. M., & Smay, J. J. (2017). Establishing and Applying Literature-Based Criteria for Effective Communication of Science to Novices Via Introductory Geology Textbooks. *Journal of Geoscience Education*, *65*(1), 48-59. https://doi.org/10.5408/16-205.1

Krosnick, J. A. (1999). Survey research. *Annual Review of Psychology*, *50*(1), 537-567.

Krueger, R. A., & Casey, M. A. (2000). *Focus groups : a practical guide for applied research* (Vol. 3rd ed) [Book]. SAGE Publications, Inc. https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,shib&db=nlebk&AN=63273&site=ehost-live&authtype=ip,uid

Kubalíková, L. (2013). Geomorphosite assessment for geotourism purposes. *Czech Journal of Tourism*, *2*(2), 80-104.

Kubalíková, L., Bajer, A., & Balková, M. (2021). Brief Notes on Geodiversity and Geoheritage Perception by the Lay Public. *Geosciences*, *11*(2), 54. https://www.mdpi.com/2076-3263/11/2/54

Kubalíková, L., Kirchner, K., Kuda, F., & Bajer, A. (2020). Assessment of Urban Geotourism Resources: An Example of Two Geocultural Sites in Brno, Czech Republic. *Geoheritage*, *12*(1). https://doi.org/10.1007/s12371-020-00434-x

Kulp, S. A., & Strauss, B. H. (2019). New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. *Nature Communications*, *10*(1), 4844. https://doi.org/10.1038/s41467-019-12808-z

Kwarteng, A. Y., Dorvlo, A. S., & Vijaya Kumar, G. T. (2009). Analysis of a 27 - year rainfall data (1977–2003) in the Sultanate of Oman. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *29*(4), 605-617.

Lagally, U., Loth, R., & Schindelmann, C. (2015). The "Day of Geosites" in Germany — a Successful Promotion Tool for Earth Sciences. *Geoheritage*, *7*(2), 195-204. https://doi.org/10.1007/s12371-014-0127-7

Lansigu, C., Bosse-Lansigu, V., & Le Hebel, F. (2014). Tools and Methods Used to Represent Geological Processes and Geosites: Graphic and Animated Media as a Means to Popularize the Scientific Content and Value of Geoheritage. *Geoheritage*, *6*(2), 159-168. https://doi.org/10.1007/s12371-014-0101-4

Larwood, J., & Prosser, C. (1998). Geotourism, conservation and society. *Geologica balcanica*, *28*, 97-100.

Lawrence, A. (2010). Geotourism in the Sultanate of Oman. In R. N. Dowling, David (Ed.), *Global Geotourism Perspectives*. Goodfellow Publishers, Limited. https://doi.org/10.23912/978-1-906884-17-8-1138

Lee, Y., & Jayakumar, R. (2021). Economic impact of UNESCO Global Geoparks on local communities: Comparative analysis of three UNESCO Global Geoparks in Asia. *International Journal of Geoheritage and Parks*, *9*(2), 189-198. https://doi.org/https://doi.org/10.1016/j.ijgeop.2021.02.002

Leighton, C. L., Bailey, R. M., & Thomas, D. S. G. (2014). Interpreting and modelling late Quaternary dune accumulation in the southern Arabian Peninsula. *Quaternary Science Reviews*, *102*, 1-13. https://doi.org/https://doi.org/10.1016/j.quascirev.2014.08.002

León, B., & Bourk, M. (2018). *Communicating Science and Technology Through Online Video: Researching a New Media Phenomenon*. Taylor & Francis. https://books.google.co.uk/books?id=GxdSDwAAQBAJ

Leppink, J., Winston, K., & O'Sullivan, P. (2016). Statistical significance does not imply a real effect. *Perspectives on Medical Education*, *5*(2), 122-124. https://doi.org/10.1007/s40037-016-0256-6

Lewis, E. B. (2008). Content is not enough: A history of secondary earth science teacher preparation with recommendations for today. *Journal of Geoscience Education*, *56*(5), 445-455.

Lézine, A.-M., Robert, C., Cleuziou, S., Inizan, M.-L., Braemer, F., Saliège, J.-F., Sylvestre, F., Tiercelin, J.-J., Crassard, R., Méry, S., Charpentier, V., & Steimer-Herbet, T. (2010). Climate change and human occupation in the Southern Arabian lowlands during the last deglaciation and the Holocene. *Global and Planetary Change*, *72*(4), 412-428. https://doi.org/https://doi.org/10.1016/j.gloplacha.2010.01.016

Liritzis, I., Singhvi, A. K., Feathers, J. K., Wagner, G. A., Kadereit, A., Zacharias, N., & Li, S.-H. (2013). *Luminescence dating in archaeology, anthropology, and geoarchaeology: an overview*. Springer.

Liverman, D., G. E. (2008). Environmental geoscience; communication challenges. *Geological Society, London, Special Publications*, *305*(1), 197-209. https://doi.org/10.1144/SP305.17

Liverman, D., & Jaramillo, M. (2011). Communicating environmental geoscience; An international survey. *International Union of Geological Sciences Episodes*, *34*(1), 25-31. https://doi.org/10.18814/epiiugs/2011/v34i1/004

Lokier, S. W. (2013). Coastal Sabkha Preservation in the Arabian Gulf. *Geoheritage*, *5*(1), 11-22. https://doi.org/10.1007/s12371-012-0069-x
Lokier, S. W., Bateman, M. D., Larkin, N. R., Rye, P., & Stewart, J. R. (2015). Late Quaternary sea-level changes of the Persian Gulf. *Quaternary research*, *84*(1), 69-81. https://doi.org/10.1016/j.yqres.2015.04.007
Lowenthal, D. (1994). Identity, Heritage, and History. In R. G. John (Ed.), *Commemorations* (pp. 41-58). Princeton University Press. https://doi.org/doi:10.1515/9780691186658-005
Lowenthal, D. (2005). Natural and cultural heritage. *International Journal of Heritage Studies*, *11*(1), 81-92. https://doi.org/10.1080/13527250500037088
Lu, C. Y. (2009). Observational studies: a review of study designs, challenges and strategies to reduce confounding. *International Journal of Clinical Practice*, *63*(5), 691-697. https://doi.org/https://doi.org/10.1111/j.1742-1241.2009.02056.x
Luan, F., & Wang, F. (2023). Tourists' Perceptions of Popular Science Education in Tianshan Tianchi National Geopark in Xinjiang. *Geoheritage*, *15*(4), 120. https://doi.org/10.1007/s12371-023-00886-x
Ludwin, R. S., Smits, G. J., Carver, D., James, K., Jonientz-Trisler, C., McMillan, A., Losey, R., Dennis, R., Rasmussen, J., & De Los Angeles, A. (2007). Folklore and earthquakes: Native American oral traditions from Cascadia compared with written traditions from Japan. *Geological Society, London, Special Publications*, *273*(1), 67-94.
Lugeri, F. R., Farabollini, P., Greco, R., & Amadio, V. (2015). The Geological Characterization of Landscape in Major TV Series: A Suggested Approach to Involve the Public in the Geological Heritage Promotion. *Sustainability*, *7*(4), 4100-4119. https://www.mdpi.com/2071-1050/7/4/4100
Madella, M., & Fuller, D. Q. (2006). Palaeoecology and the Harappan Civilisation of South Asia: a reconsideration. *Quaternary Science Reviews*, *25*(11-12), 1283-1301.
Magee, P. (2014). Eastern Arabia from 3000 to 2000 BC. In P. Magee (Ed.), *The Archaeology of Prehistoric Arabia: Adaptation and Social Formation from the Neolithic to the Iron Age* (pp. 87-125). Cambridge University Press. https://doi.org/DOI: 10.1017/CBO9781139016667.005
Magee, P., Uerpmann, H.-P., Uerpmann, M., Jasim, S. A., Händel, M., Barber, D., Fritz, C., & Hammer, E. (2009). Multi-disciplinary research on the past human ecology of the east Arabian coast: excavations at Hamriya and Tell Abraq (Emirate of Sharjah, United Arab Emirates). *Arabian Archaeology and Epigraphy*, *20*(1), 18-29. https://doi.org/10.1111/j.1600-0471.2008.00304.x
Maghsoudi, M., Moradi, A., Moradipour, F., & Nezammahalleh, M. A. (2019). Geotourism Development in World Heritage of the Lut Desert. *Geoheritage*, *11*(2), 501-516. https://doi.org/10.1007/s12371-018-0303-2
Manasrah, A., Masoud, M., & Jaradat, Y. (2021). Short Videos, or Long Videos? A Study on the Ideal Video Length in Online Learning. 2021 International Conference on Information Technology (ICIT), Amman, Jordan.
Mani, L., Cole, P. D., & Stewart, I. (2016). Using video games for volcanic hazard education and communication: an assessment of the method and preliminary results. *Nat. Hazards Earth Syst. Sci.*, *16*(7), 1673-1689. https://doi.org/10.5194/nhess-16-1673-2016

Mariani, G. S., & Melis, R. T. (2022). The Potential for Valorisation of Archaeo-geosites Through Climate Change: Exploratory Study of the Nora Site (Sardinia, Italy). *Geoheritage*, *14*(4), 118. https://doi.org/10.1007/s12371-022-00759-9
Mason, V., & Stanley, M. (2000). *RIGS Handbook*. GeoConservationUK.
Matias, A., Carrasco, A. R., Ramos, A. A., & Borges, R. (2020). Engaging children in geosciences through storytelling and creative dance. *Geosci. Commun.*, *3*(2), 167-177. https://doi.org/10.5194/gc-3-167-2020
Matter, A., Neubert, E., Preusser, F., Rosenberg, T., & Al-Wagdani, K. (2015). Palaeo-environmental implications derived from lake and sabkha deposits of the southern Rub' al-Khali, Saudi Arabia and Oman. *Quaternary International*, *382*, 120-131. https://doi.org/10.1016/j.quaint.2014.12.029
Mauerhofer, L., Reynard, E., Asrat, A., & Hurni, H. (2018). Contribution of a Geomorphosite Inventory to the Geoheritage Knowledge in Developing Countries: the Case of the Simien Mountains National Park, Ethiopia. *Geoheritage*, *10*(4), 559-574. https://doi.org/10.1007/s12371-017-0234-3
Mauldin, R. (2020). *Foundations of Social Work Research*. Mavs Open Press. https://books.google.co.uk/books?id=ixl2zAEACAAJ
Mc Keever, P., & Zouros, N. C. (2005). Geoparks: Celebrating Earth heritage, sustaining local communities. *International Union of Geological Sciences Episodes*, *28*(4), 274-278. https://doi.org/10.18814/epiiugs/2005/v28i4/006
Meffe, G. K., Ehrenfeld, D., & Noss, R. F. (2006). Conservation Biology at Twenty. *Conservation Biology*, *20*(3), 595-596. https://doi.org/https://doi.org/10.1111/j.1523-1739.2006.00441.x
Mehdioui, S., El Hadi, H., Tahiri, A., Brilha, J., El Haibi, H., & Tahiri, M. (2020). Inventory and Quantitative Assessment of Geosites in Rabat-Tiflet Region (North Western Morocco): Preliminary Study to Evaluate the Potential of the Area to Become a Geopark. *Geoheritage*, *12*(2), 35. https://doi.org/10.1007/s12371-020-00456-5
Mehdioui, S., Hadi, H. E., Tahiri, A., Haibi, H. E., Tahiri, M., Zoraa, N., & Hamoud, A. (2022). The Geoheritage of Northwestern Central Morocco Area: Inventory and Quantitative Assessment of Geosites for Geoconservation, Geotourism, Geopark Purpose and the Support of Sustainable Development. *Geoheritage*, *14*(3), 86. https://doi.org/10.1007/s12371-022-00712-w
Mehdipour Ghazi, J., & Audra, P. (2022). Travertine Park in Azarshahr (NW Iran): an Opportunity for Geoheritage Conservation and Diminishing Geohazards Risk. *Geoheritage*, *14*(3), 99. https://doi.org/10.1007/s12371-022-00734-4
Mehdipour Ghazi, J., Hamdollahi, M., & Moazzen, M. (2021). Geotourism of mining sites in Iran: An opportunity for sustainable rural development. *International Journal of Geoheritage and Parks*, *9*(1), 129-142. https://doi.org/https://doi.org/10.1016/j.ijgeop.2021.02.004
Meister, J., Hubaishan, M. A., Kilian, N., & Oberprieler, C. (2006). Temporal and spatial diversification of the shrub Justicia areysiana Deflers (Acanthaceae) endemic to the monsoon affected coastal mountains of the southern Arabian Peninsula. *Plant Systematics and Evolution*, *262*(3/4), 153-171. http://ezproxy-prd.bodleian.ox.ac.uk:2154/stable/23655688
Melelli, L., Bizzarri, R., Baldanza, A., & Gregori, L. (2016). The Etruscan “Volumni Hypogeum” Archeo-Geosite: New Sedimentological and Geomorphological

Insights on the Tombal Complex. *Geoheritage*, *8*(4), 301-314. https://doi.org/10.1007/s12371-015-0162-z

Melendez, G., Fermeli, G., & Koutsouveli, A. (2007). Analyzing geology textbooks for secondary school curricula in Greece and Spain: educational use of geological heritage. *Bulletin of the Geological Society of Greece*, *40*(4), 1819–1832. https://doi.org/10.12681/bgsg.17143

Migoń, P. (2018). Geoheritage and World Heritage Sites. In E. Reynard & J. Brilha (Eds.), *Geoheritage: Assessment, Protection, and Management* (pp. 237-249). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-809531-7.00013-7

Migoń, P., & Pijet-Migoń, E. (2017). Interpreting Geoheritage at New Zealand's Geothermal Tourist Sites—Systematic Explanation Versus Storytelling. *Geoheritage*, *9*(1), 83-95. https://doi.org/10.1007/s12371-016-0185-0

Migowski, C., Stein, M., Prasad, S., Negendank, J. F., & Agnon, A. (2006). Holocene climate variability and cultural evolution in the Near East from the Dead Sea sedimentary record. *Quaternary research*, *66*(3), 421-431.

Mikhailenko, A. V., Ruban, D. A., & Ermolaev, V. A. (2021). Accessibility of Geoheritage Sites—A Methodological Proposal. *Heritage*, *4*(3), 1080-1091. https://www.mdpi.com/2571-9408/4/3/60

Ministry of Culture and Youth, U. A. E. (2021). *Wadi Wurayah National Park*. Retrieved from https://whc.unesco.org/en/tentativelists/6554/

Ministry of Education, U. A. E. (2023, 04/06/2023). *Electives Model*. Ministry of Education, United Arab Emirates. Retrieved 20/02 from https://www.moe.gov.ae/En/MediaCenter/Announcements/Electives/Pages/default.aspx

Mitchell, N. (2013). *Study on the Application of Criterion (vii): Considering superlative natural phenomena and exceptional natural beauty within the World Heritage Convention*.

Molchanova, T. K., & Ruban, D. A. (2019). New Evidence of the Bangestan Geoheritage Resource in Iran: Beyond Hydrocarbon Reserves. *Resources*, *8*(1), 35. https://www.mdpi.com/2079-9276/8/1/35

Morad, S., Al-Aasm, I., Nader, F., Ceriani, A., Gasparrini, M., & Mansurbeg, H. (2012). Impact of diagenesis on the spatial and temporal distribution of reservoir quality in the Jurassic Arab D and C Members, offshore Abu Dhabi oilfield, United Arab Emirates. *Geoarabia -Manama-*, *17*, 17-56. https://doi.org/10.2113/geoarabia170317

Moradi, A., Maghsoudi, M., Moghimi, E., Yamani, M., & Rezaei, N. (2021). A Comprehensive Assessment of Geomorphodiversity and Geomorphological Heritage for Damavand Volcano Management, Iran. *Geoheritage*, *13*(2), 39. https://doi.org/10.1007/s12371-021-00551-1

Moradipour, F., Moghimi, E., Beglou, M. J., & Yamani, M. (2020). Assessment of Urban Geomorphological Heritage for Urban Geotourism Development in Khorramabad City, Iran. *Geoheritage*, *12*(2), 40. https://doi.org/10.1007/s12371-020-00466-3

Moreira, J. C. (2012). Interpretative Panels About the Geological Heritage—a Case Study at the Iguassu Falls National Park (Brazil). *Geoheritage*, *4*(1), 127-137. https://doi.org/10.1007/s12371-012-0053-5

Moreno, R., & Mayer, R. E. (1999). Cognitive Principles of Multimedia Learning: The Role of Modality and Contiguity. *Journal of educational psychology*, *91*(2), 358-368. https://doi.org/10.1037/0022-0663.91.2.358

Morgan, C., Jamsranjav, B., Tumurbaatar, T., & Barton, L. (2022). Paleolakes, archaeology, and late Quaternary paleoenvironments in northwestern Mongolia. *Quaternary research*, *109*, 1-15.

Morgan, D. L. (1996). Focus Groups. *Annual Review of Sociology*, *22*(Volume 22, 1996), 129-152. https://doi.org/https://doi.org/10.1146/annurev.soc.22.1.129

Morgan, D. L., & Krueger, R. A. (1993). When to Use Focus Groups and Why. In D. L. Morgan (Ed.), *Successful Focus Groups: Advancing the State of the Art*. SAGE Publications, Inc. https://doi.org/10.4135/9781483349008

Mortimore, M., Anderson, S., Cotula, L., Davies, J., Faccer, K., Hesse, C., Morton, J., Nyangena, W., Skinner, J., & Wolfangel, C. (2009). *Dryland Opportunies: A new paradigm for people, ecosystems and development*.

Moufti, M., Németh, K., El-Masry, N., & Qaddah, A. (2013). Geoheritage values of one of the largest maar craters in the Arabian Peninsula: the Al Wahbah Crater and other volcanoes (Harrat Kishb, Saudi Arabia). *Central European Journal of Geosciences*, *5*(2), 254-271. https://doi.org/doi:10.2478/s13533-012-0125-8

Moufti, M. R., Németh, K., El-Masry, N., & Qaddah, A. (2015). Volcanic Geotopes and Their Geosites Preserved in an Arid Climate Related to Landscape and Climate Changes Since the Neogene in Northern Saudi Arabia: Harrat Hutaymah (Hai'il Region). *Geoheritage*, *7*(2), 103-118. https://doi.org/10.1007/s12371-014-0110-3

Mucivuna, V. C., Motta Garcia, M. D. G., & Reynard, E. (2022). Comparing quantitative methods on the evaluation of scientific value in geosites: analysis from the Itatiaia National Park, Brazil. *Geomorphology*, *396*, 107988. https://doi.org/10.1016/j.geomorph.2021.107988

Mucivuna, V. C., Reynard, E., & Garcia, M. d. G. M. (2019). Geomorphosites Assessment Methods: Comparative Analysis and Typology. *Geoheritage*, *11*(4), 1799-1815. https://doi.org/10.1007/s12371-019-00394-x

Myers, D., Dalgity, A., & Avramides, I. (2016). The Arches heritage inventory and management system: a platform for the heritage field. *Journal of Cultural Heritage Management and Sustainable Development*.

Naimi, M. N., & Cherif, A. (2020). Inventory and assessment of significant scientific Algerian geoheritage: Case of remarkable geosites from Orania (Western Algeria). *International Journal of Geoheritage and Parks*. https://doi.org/10.1016/j.ijgeop.2020.09.001

Nasir, S. (2023). Geotourism in the Sultanate of Oman: Samail Ophiolite Geosites–A Concept of Sustainable Geotourism. In M. Allan & R. Dowling (Eds.), *Geotourism in the Middle East* (pp. 135-157). Springer International Publishing. https://doi.org/10.1007/978-3-031-24170-3_10

National Academies of Sciences, E., & Medicine. (2017). *Communicating Science Effectively: A Research Agenda*. The National Academies Press. https://doi.org/doi:10.17226/23674

National Centre for Statistics & Information. (2022, 15/06/2022). *Data Portal - Population*. National Centre for Statistics & Information. Retrieved 27/08 from https://data.gov.om/OMPOP2016/population?region=1000010&indicator=1000030&nationality=1000000&sex=1000020&age-group=1000000&lang=en

Nature Conservancy Council. (1990). Earth Science Conservation in Great Britain: A Strategy. In. Peterborough: Northminster House, Nature Conservancy Council
Neild, B. (2022). Abu Dhabi Fossil Dunes: A beautiful frozen landscape created by climate change [Article]. Retrieved 03/11/2023, from
Németh, B., Németh, K., Procter, J. N., & Farrelly, T. (2021). Geoheritage Conservation: Systematic Mapping Study for Conceptual Synthesis. *Geoheritage*, *13*(2), 45. https://doi.org/10.1007/s12371-021-00561-z
Newman, J. A., Varner, G., & Linquist, S. (2017). Should Biodiversity Be Conserved for Its Aesthetic Value? In G. Varner, J. A. Newman, & S. Linquist (Eds.), *Defending Biodiversity: Environmental Science and Ethics* (pp. 354-386). Cambridge University Press. https://doi.org/DOI: 10.1017/9781139024105.014
Newmark, W. D., Leonard, N. L., Sariko, H. I., & Gamassa, D.-G. M. (1993). Conservation attitudes of local people living adjacent to five protected areas in Tanzania. *Biological Conservation*, *63*(2), 177-183. https://doi.org/https://doi.org/10.1016/0006-3207(93)90507-W
Newsome, D., & Dowling, R. (2018). Geoheritage and Geotourism. In E. Reynard & J. Brilha (Eds.), *Geoheritage: Assessment, Protection, and Management* (pp. 305-321). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-809531-7.00017-4
Nguyen-Thuy, D., Ta, P. H., Nguyen-Van, H., Van Dinh, H., Van Dang, B., Dang, N. H., Do, H. T. T., Nguyen, A. T. K., Tran, T. D., Van Bui, V., Nguyen, A. N., & Hoang, T. T. (2019). Evaluation of Geological Heritage of Geosites for a Potential Geopark in Binh Thuan–Ninh Thuan Coastal Zone, Vietnam. *Geoheritage*, *11*(3), 689-702. https://doi.org/10.1007/s12371-018-0324-x
Nicholson, S. L., Hosfield, R., Groucutt, H. S., Pike, A. W. G., & Fleitmann, D. (2021). Beyond arrows on a map: The dynamics of Homo sapiens dispersal and occupation of Arabia during Marine Isotope Stage 5. *Journal of Anthropological Archaeology*, *62*, 101269. https://doi.org/10.1016/j.jaa.2021.101269
Nicholson, S. L., Pike, A. W. G., Hosfield, R., Roberts, N., Sahy, D., Woodhead, J., Cheng, H., Edwards, R. L., Affolter, S., Leuenberger, M., Burns, S. J., Matter, A., & Fleitmann, D. (2020). Pluvial periods in Southern Arabia over the last 1.1 million-years. *Quaternary Science Reviews*, *229*, 106112. https://doi.org/10.1016/j.quascirev.2019.106112
Norrish, L., Sanders, D., & Dowling, R. (2014). Geotourism product development and stakeholder perceptions: a case study of a proposed geotrail in Perth, Western Australia. *Journal of Ecotourism*, *13*(1), 52-63. https://doi.org/10.1080/14724049.2014.938654
Oguchi, T., & Oguchi, C. T. (2010). Mt. Fuji: The Beauty of a Symmetric Stratovolcano. In P. Migoń (Ed.), *Geomorphological Landscapes of the World* (pp. 303-309). Springer Netherlands.
Ólafsdóttir, R., & Tverijonaite, E. (2018). Geotourism: A Systematic Literature Review. *Geosciences*, *8*(7), 234. https://www.mdpi.com/2076-3263/8/7/234
Oman Ministry of Tourism. (2019). *Oman Geoheritage Guide* [Smartphone Application].
Onwuegbuzie, A. J., Dickinson, W. B., Leech, N. L., & Zoran, A. G. (2009). A Qualitative Framework for Collecting and Analyzing Data in Focus Group Research. *International Journal of Qualitative Methods*, *8*(3), 1-21. https://doi.org/10.1177/160940690900800301

Osborne, R. (2000). Geodiversity: “green” geology in action. *Proceedings- Linnean Society of New South Wales*, *122*, 151-175.

Panizza, M. (2001). Geomorphosites: Concepts, methods and examples of geomorphological survey. *Chinese Science Bulletin*, *46*(S1), 4-5. https://doi.org/10.1007/bf03187227

Panizza, M., & Piacente, S. (2003). *Geomorfologia Culturale*. Pitagora Editrorice.

Panizza, M., & Piacente, S. (2009). Cultural geomorphology and geodiversity. *Geomorphosites. Pfeil Verlag, Munich*, 35-48.

Parga Dans, E., & Alonso González, P. (2019). Sustainable tourism and social value at World Heritage Sites: Towards a conservation plan for Altamira, Spain. *Annals of Tourism Research*, *74*, 68-80. https://doi.org/https://doi.org/10.1016/j.annals.2018.10.011

Parker, A. (2009). Pleistocene Climate Change in Arabia: Developing a Framework for Hominin Dispersal over the Last 350 ka. In M. Petraglia & J. I. Rose (Eds.), *Evolution of Human Populations in Arabia: Paleoenvironments, Prehistory and Genetics* (pp. 39-49). Springer. https://doi.org/10.1007/978-90-481-2719-1_3

Parker, A., Eckersley, L., Smith, M., Goudie, A., Stokes, S., Ward, S., White, K., & Hodson, M. (2004). Holocene vegetation dynamics in the northeastern Rub'al‐Khali desert, Arabian Peninsula: a phytolith, pollen and carbon isotope study. *Journal of Quaternary Science*, *19*(7), 665-676.

Parker, A., & Goudie, A. (2007). Development of the Bronze Age landscape in the southeastern Arabian Gulf: new evidence from a buried shell midden in the eastern extremity of the Rub’al‐Khali desert, Emirate of Ras al‐Khaimah, UAE. *Arabian Archaeology and Epigraphy*, *18*(2), 132-138.

Parker, A. G., & Bretzke, K. (2022). *Report on sites of special geological and archaeological interest in Fujairah* [Unpublished report prepared for Fujairah Natural Resources Corportation]. Fujairah Natural Resources Corportation.

Parker, A. G., Preston, G. W., Parton, A., Walkington, H., Jardine, P. E., Leng, M. J., & Hodson, M. J. (2016). Low-latitude Holocene hydroclimate derived from lake sediment flux and geochemistry. *Journal of Quaternary Science*, *31*(4), 286-299. https://doi.org/https://doi.org/10.1002/jqs.2859

Parton, A., & Bretzke, K. (2020). The PalaeoEnvironments and ARchaeological Landscapes (PEARL) project: Recent findings from Neolithic sites in Northern Oman. *Arabian Archaeology and Epigraphy*, *31*(1), 194-201. https://doi.org/10.1111/aae.12152

Parton, A., Farrant, A., Leng, M., Telfer, M., Groucutt, H., Petraglia, M., & Parker, A. (2015a). Alluvial fan records from southeast Arabia reveal multiple windows for human dispersal. *Geology*, *43*, 295-298. https://doi.org/10.1130/G36401.1

Parton, A., Farrant, A. R., Leng, M. J., Schwenninger, J.-L., Rose, J. I., Uerpmann, H.-P., & Parker, A. G. (2013). An early MIS 3 pluvial phase in Southeast Arabia: Climatic and archaeological implications. *Quaternary International*, *300*, 62-74. https://doi.org/https://doi.org/10.1016/j.quaint.2013.02.016

Parton, A., Farrant, A. R., Leng, M. J., Telfer, M. W., Groucutt, H. S., Petraglia, M. D., & Parker, A. G. (2015b). Alluvial fan records from southeast Arabia reveal multiple windows for human dispersal. *Geology*, *43*(4), 295-298. https://doi.org/10.1130/g36401.1

Parton, A., White, T. S., Parker, A. G., Breeze, P. S., Jennings, R., Groucutt, H. S., & Petraglia, M. D. (2015). Orbital-scale climate variability in Arabia as a potential motor for human dispersals. *Quaternary International*, *382*, 82-97. https://doi.org/https://doi.org/10.1016/j.quaint.2015.01.005

Pasquaré Mariotto, F., & Venturini, C. (2017). Strategies and Tools for Improving Earth Science Education and Popularization in Museums. *Geoheritage*, *9*(2), 187-194. https://doi.org/10.1007/s12371-016-0194-z

Patten, M. L. (2016). *Questionnaire Research : A Practical Guide* (4th ed.). Routledge.

Patzelt, A. (2015). Synopsis of the flora and vegetation of Oman, with special emphasis on patterns of plant endemism. *Abhandlungen der Braunschweigischen Wissenschaftlichen Gesellschaft*, *282*, 317.

Pedersoli Jr, J. L., Antomarchi, C., & Michalski, S. (2016). *A guide to risk management of cultural heritage*. ICCROM.

Pediaditi, K., & Moquay, P. (2022). Landscape injustices in polarised communities: unearthing perceptions at Sitia UNESCO Geopark, Greece. *Landscape Research*, *47*(6), 767-782. https://doi.org/10.1080/01426397.2021.2000951

Pereira, P., & Pereira, D. (2010). Methodological guidelines for geomorphosite assessment. (2/2010), 215-222. https://doi.org/10.4000/geomorphologie.7942

Pereira, P., Pereira, D., & Caetano Alves, M. I. (2007). Geomorphosite assessment in Montesinho Natural Park (Portugal). *Swiss Journal of Geography*, *62*(3), 159. https://doi.org/10.5194/gh-62-159-2007

Pescatore, E., Bentivenga, M., Giano, S. I., & Siervo, V. (2019). Geomorphosites: Versatile Tools in Geoheritage Cultural Dissemination. *Geoheritage*, *11*(4), 1583-1601. https://doi.org/10.1007/s12371-019-00378-x

Petraglia, M. D., Groucutt, H. S., Guagnin, M., Breeze, P. S., & Boivin, N. (2020). Human responses to climate and ecosystem change in ancient Arabia. *Proceedings of the National Academy of Sciences*, *117*(15), 8263. https://doi.org/10.1073/pnas.1920211117

Petraglia, M. D., Haslam, M., Fuller, D. Q., Boivin, N., & Clarkson, C. (2010). Out of Africa: new hypotheses and evidence for the dispersal ofHomo sapiensalong the Indian Ocean rim. *Annals of human biology*, *37*(3), 288-311. https://doi.org/10.3109/03014461003639249

Phillips, A., & Young, C. (2017). Culture and Nature – two sides of the same World Heritage coin. In J. Larwood, S. France, & C. Mahon (Eds.), *Culturally natural or naturally cultural? Exploring the relationship between nature and culture through World Heritage* (pp. 1–9). IUCN National Committee UK Secretaruat.

Pica, A., Fredi, P., & Del Monte, M. (2014). The ernici mountains geoheritage (Central Apennines, Italy): Assessment of the geosites for geotourism development. *GeoJournal of Tourism and Geosites*, *7*(2), 14.

Pica, A., Fredi, P., & Del Monte, M. (2015). Geoheritage, geotourist value and itineraries proposal in the Trisulti of Collepardo area (Ernici Mounts, Lazio). *RENDICONTI ONLINE DELLA SOCIETÀ GEOLOGICA ITALIANA*, *33*, 75-78.

Pica, A., Reynard, E., Grangier, L., Kaiser, C., Ghiraldi, L., Perotti, L., & Del Monte, M. (2018). GeoGuides, Urban Geotourism Offer Powered by Mobile Application Technology. *Geoheritage*, *10*(2), 311-326. https://doi.org/10.1007/s12371-017-0237-0

Picton, O. J. (2010). Usage of the concept of culture and heritage in the United Arab Emirates – an analysis of Sharjah heritage area. *Journal of Heritage Tourism*, *5*(1), 69-84. https://doi.org/10.1080/17438730903469813

Pintos, P. (2020). The Buhais Geology Park Interpretive Centre / Hopkins Architects. *ArchDaily*. https://www.archdaily.com/932365/the-buhais-geology-park-interpretive-centre-hopkins-architects/

Pirlea, A. F. (2023a). *Country Profile - Oman* https://databank.worldbank.org/views/reports/reportwidget.aspx?Report_Name=CountryProfile&Id=b450fd57&country=OMN

Pirlea, A. F. (2023b). *Country Profile - United Arab Emirates* https://databank.worldbank.org/views/reports/reportwidget.aspx?Report_Name=CountryProfile&Id=b450fd57&country=UAE

Planas-Batlle, X., Tort-Donada, J., & Corominas, J. (2023). Reconocimiento de zonas afectadas por fenómenos geológicos peligrosos a través de la toponimia. El alto Pirineo catalán, andorrano y áreas circundantes como caso de estudio. *Revista de la Sociedad Geológica de España*, *36*(2), 3-15.

Plyusnina, E. E., Sallam, E. S., & Ruban, D. A. (2016). Geological heritage of the Bahariya and Farafra oases, the central Western Desert, Egypt. *Journal of African Earth Sciences*, *116*, 151-159.

Pollastro, R. M., Karshbaum, A. S., & Viger, R. J. (1999). *Maps showing geology, oil and gas fields and geologic provinces of the Arabian Peninsula* [Report](97-470B). (Open-File Report, Issue. U. S. G. Survey. http://pubs.er.usgs.gov/publication/ofr97470B

Popa, R.-G., Popa, D.-A., & Andrăşanu, A. (2017). The SEA and Big-S Models for Managing Geosites as Resources for Local Communities in the Context of Rural Geoparks. *Geoheritage*, *9*(2), 175-186. https://doi.org/10.1007/s12371-016-0192-1

Potts, D. T. (2000). *Ancient Magan: the secrets of tell Abraq*. Trident Press.

Pourahmad, A., Hosseini, A., Pourahmad, A., Zoghi, M., & Sadat, M. (2018). Tourist Value Assessment of Geotourism and Environmental Capabilities in Qeshm Island, Iran. *Geoheritage*, *10*(4), 687-706. https://doi.org/10.1007/s12371-017-0273-9

Powers, R., Ramirez, L. F., Redmond, C., & Elberg Jr, E. (1966). *Geology of the Arabian Peninsula: sedimentary geology of Saudi Arabia* (2330-7102).

Pralong, J.-P. (2005a). A method for assessing tourist potential and use of geomorphological sites. *Géomorphologie : relief, processus, environnement*, *3*. https://doi.org/10.4000/geomorphologie.350

Pralong, J.-P. (2005b). A method for assessing tourist potential and use of geomorphological sites. *Géomorphologie: relief, processus, environnement*, *11*(3), 189-196. https://journals.openedition.org/geomorphologie/350

Preston, G. W., Thomas, D. S. G., Goudie, A. S., Atkinson, O. A. C., Leng, M. J., Hodson, M. J., Walkington, H., Charpentier, V., Méry, S., Borgi, F., & Parker, A. G. (2015). A multi-proxy analysis of the Holocene humid phase from the United Arab Emirates and its implications for southeast Arabia's Neolithic populations. *Quaternary International*, *382*, 277-292. https://doi.org/https://doi.org/10.1016/j.quaint.2015.01.054

Price, V. (2008). The public and public opinion in political theories. In W. Donsbach & M. W. Traugottt (Eds.), *The SAGE Handbook of Public Opinion Research*. SAGE Publications Ltd. https://doi.org/10.4135/9781848607910

Pümpin, R. J. C. (2010). A new approach to central Omani Prehistory. *Proceedings of the Seminar for Arabian Studies*, *40*, 185–200. https://doi.org/10.2307/41224019

Qureshi, J. A., Khan, M., Sikandar, S., Khan, G., Abbas, N., Khan, A., Alam, M., Karim, R., & Halvorson, S. J. (2021). Inventory and Quantitative Valuation of Geological and Geomorphological Sites from Gilgit-Baltistan, Northern Pakistan. *Geoheritage*, *13*(4), 94. https://doi.org/10.1007/s12371-021-00617-0

R Core Team. (2024). *R: A Language and Environment for Statistical Computing*. In R Foundation for Statistical Computing. https://www.R-project.org/

Radies, D., Hasiotis, S., Preusser, F., Neubert, E., & Matter, A. (2005). Paleoclimatic significance of Early Holocene faunal assemblages in wet interdune deposits of the Wahiba Sand Sea, Sultanate of Oman. *Journal of Arid Environments*, *62*(1), 109-125.

Rayne, L., Bradbury, J., Mattingly, D., Philip, G., Bewley, R., & Wilson, A. (2017). From Above and on the Ground: Geospatial Methods for Recording Endangered Archaeology in the Middle East and North Africa. *Geosciences*, *7*(4), 100. https://doi.org/10.3390/geosciences7040100

Reimer, P. J., Austin, W. E., Bard, E., Bayliss, A., Blackwell, P. G., Ramsey, C. B., Butzin, M., Cheng, H., Edwards, R. L., & Friedrich, M. (2020). The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon*, *62*(4), 725-757.

Reinhart, H., Rafida, M. R., Sofie, T., Putra, R. D., Matoka, M. C. R., Maulita, N. S., & Baiquni, M. (2023). Assessment of geological diversity, geosites, and geotourism potencies at Menoreh Mountain for designation of geopark area. *International Journal of Geoheritage and Parks*, *11*(3), 385-406. https://doi.org/https://doi.org/10.1016/j.ijgeop.2023.05.005

Reis, J., Póvoas, L., Barriga, F. J. A. S., Lopes, C., Santos, V. F., Ribeiro, B., Cascalho, J., & Pinto, A. (2014). Science Education in a Museum: Enhancing Earth Sciences Literacy as a Way to Enhance Public Awareness of Geological Heritage. *Geoheritage*, *6*(3), 217-223. https://doi.org/10.1007/s12371-014-0105-0

Reis, J. B., J; Barriga, F; Lopes, C; Povoas, L (2010). O Museu Nacional de História Natural como promotor do Património Geológico: caracterização preliminar dos visitantes do Departamento de Mineralogia e Geologia. In. In J. C. Brandão, P; Mateus, O; Castro, P (Ed.), *Colecções e Museus de Geologia: Missão e Gestão* (pp. 369–376). Centro de Estudos de História e filosofia da Ciência.

Ren, F., Simonson, L., & Pan, Z. (2013). Interpretation of Geoheritage for Geotourism – a Comparison of Chinese geoparks and National Parks in the United States. *Czech Journal of Tourism*, *2*(2), 105-125. https://doi.org/doi:10.2478/cjot-2013-0006

Reynard, E. (2009). The assessment of geomorphosites. In E. Reynard, P. Coratza, & G. Regolini-Bissig (Eds.), *Geomorphosites* (pp. 63-71). Verlag Dr. Friedrich Pfeil.

Reynard, E. (2013). Geosite. In A. Goudie (Ed.), *Encyclopedia of geomorphology* (2 ed., Vol. 1, pp. 440). London, UK: Routledge.

Reynard, E., Ben Ouezdou, H., Ouaja, M., Ben Fraj, T., Abichou, H., Clivaz, M., & Ghram Messedi, A. (2018). *Géoparc du Dahar. Feuille de route pour la création d'un géoparc UNESCO dans le Sud-est tunisien*.

Reynard, E., & Brilha, J. (2018). Geoheritage: A Multidisciplinary and Applied Research Topic. In E. Reynard & J. Brilha (Eds.), *Geoheritage* (pp. 3-9). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-809531-7.00030-7

Reynard, E., Coratza, P., & Regolini-Bissig, G. (2009). *Geomorphosites*. Verlag Dr. Friedrich Pfeil Munich, Germany.

Reynard, E., Fontana, G., Kozlik, L., & Scapozza, C. (2007). A method for assessing the scientific and additional values of geomorphosites. *Geographica Helvetica*, *62*(3), 148-158.

Reynard, E., & Giusti, C. (2018). The Landscape and the Cultural Value of Geoheritage. In E. Reynard & J. Brilha (Eds.), *Geoheritage: Assessment, Protection, and Management* (pp. 147-166). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-809531-7.00008-3

Reynard, E., Perret, A., Bussard, J., Grangier, L., & Martin, S. (2016). Integrated approach for the inventory and management of geomorphological heritage at the regional scale. *Geoheritage*, *8*(1), 43-60.

Ristiawan, R., Huijbens, E., & Peters, K. (2023). Projecting Development through Tourism: Patrimonial Governance in Indonesian Geoparks. *Land*, *12*(1), 223. https://www.mdpi.com/2073-445X/12/1/223

Rizk, Z., & Alsharhan, A. (2003). Water resources in the United Arab Emirates. *Developments in Water Science*, *50*, 245-264. https://doi.org/10.1016/S0167-5648(03)80022-9

Robinson, A. M. (2008). Geotourism: Who is a geotourist. Proceedings of the Inaugural National Conference on Green Travel, Climate Change and Ecotourism, Adelaide, Australia,

Rodrigues, J., Castro, C., Costa e Silva, E., & Pereira, D. I. (2023). Geoscientists' views about science communication: predicting willingness to communicate geoscience. *Geosci. Commun.*, *6*(1), 15-25. https://doi.org/10.5194/gc-6-15-2023

Rodrigues, J., Costa e Silva, E., & Pereira, D. I. (2023). How Can Geoscience Communication Foster Public Engagement with Geoconservation? *Geoheritage*, *15*(1), 32.

Rogers, J., & Révész, A. (2020). Experimental and quasi-experimental designs. In J. McKinley & H. Rose (Eds.), *The Routledge handbook of research methods in applied linguistics* (pp. 133–143). Routledge.

Rogers, S. L., Giles, S., Dowey, N., Greene, S. E., Bhatia, R., Van Landeghem, K., & King, C. (2024). “you just look at rocks, and have beards” Perceptions of Geology From the United Kingdom: A Qualitative Analysis From an Online Survey [Original Research]. *Earth Science, Systems and Society*, *4*. https://doi.org/10.3389/esss.2024.10078

Rohling, E. J., Liu, Q. S., Roberts, A. P., Stanford, J. D., Rasmussen, S. O., Langen, P. L., & Siddall, M. (2009). Controls on the East Asian monsoon during the last glacial cycle, based on comparison between Hulu Cave and polar ice-core records. *Quaternary Science Reviews*, *28*(27), 3291-3302. https://doi.org/https://doi.org/10.1016/j.quascirev.2009.09.007

Rollinson, H. (2015). Slab and sediment melting during subduction initiation: granitoid dykes from the mantle section of the Oman ophiolite. *Contributions to Mineralogy and Petrology*, *170*(3), 32. https://doi.org/10.1007/s00410-015-1177-9

Rollinson, H., Searle, M., Abbasi, I., Al-lazki, A., & Kindi, M. (2014). Tectonic evolution of the Oman Mountains: an introduction. *Geological Society Special Publication*, *392*. https://doi.org/10.1144/SP392.1

Rose, J. I., Hilbert, Y. H., Usik, V. I., Marks, A. E., Jaboob, M. M. A., Černý, V., Crassard, R., & Preusser, F. (2019). 30,000-Year-Old Geometric Microliths Reveal Glacial Refugium in Dhofar, Southern Oman. *Journal of Paleolithic Archaeology*, *2*(3), 338-357. https://doi.org/10.1007/s41982-019-00027-3

Rosenberg, T., Preusser, F., Fleitmann, D., Schwalb, A., Penkman, K., Schmid, T., Al-Shanti, M., Kadi, K., & Matter, A. (2011). Humid periods in southern Arabia: windows of opportunity for modern human dispersal. *Geology*, *39*(12), 1115-1118.

Rosenberg, T. M., Preusser, F., Blechschmidt, I., Fleitmann, D., Jagher, R., & Matter, A. (2012). Late Pleistocene palaeolake in the interior of Oman: a potential key area for the dispersal of anatomically modern humans out - of - Africa? *Journal of Quaternary Science*, *27*(1), 13-16.

Rössler, M. (2000). World Heritage Cultural Landscapes. *The George Wright Forum*, *17*(1), 27-34. http://www.jstor.org.ezproxy-prd.bodleian.ox.ac.uk/stable/43597660

Różycka, M., & Migoń, P. (2018). Customer-Oriented Evaluation of Geoheritage—on the Example of Volcanic Geosites in the West Sudetes, SW Poland. *Geoheritage*, *10*(1), 23-37. https://doi.org/10.1007/s12371-017-0217-4

Ruban, D. A. (2010). Quantification of geodiversity and its loss. *Proceedings of the Geologists' Association*, *121*(3), 326-333. https://doi.org/https://doi.org/10.1016/j.pgeola.2010.07.002

Ruban, D. A. (2015). Geotourism — A geographical review of the literature. *Tourism Management Perspectives*, *15*, 1-15. https://doi.org/https://doi.org/10.1016/j.tmp.2015.03.005

Ruban, D. A., Sallam, E. S., Khater, T. M., & Ermolaev, V. A. (2021). Golden Triangle Geosites: Preliminary Geoheritage Assessment in a Geologically Rich Area of Eastern Egypt. *Geoheritage*, *13*(3), 54. https://doi.org/10.1007/s12371-021-00582-8

Ruzi, S. A., Lee, N. M., & Smith, A. A. (2021). Testing how different narrative perspectives achieve communication objectives and goals in online natural science videos. *PLoS ONE*, *16*(10), e0257866. https://doi.org/10.1371/journal.pone.0257866

Sadry, B. N. (2009). *Fundamentals of geotourism with a special emphasis on Iran*. Samt Organization Publishers.

Sadry, B. N., Mohammadi-Aragh, A., Fehrest, F., Bayatani, A., & Haji-Moradi, A. (2021). Identifying and Assessing Geodiversities Around Takht-e Soleyman World Heritage Site to Propose the Territory as the Third Geopark in Iran. In R. B. Singh, D. Wei, & S. Anand (Eds.), *Global Geographical Heritage, Geoparks and Geotourism: Geoconservation and Development* (pp. 15-42). Springer Singapore. https://doi.org/10.1007/978-981-15-4956-4_2

Sagala, S., Rosyidie, A., Sasongko, M. A., & Syahbid, M. M. (2018). Who gets the benefits of geopark establishment? A study of Batur Geopark Area, Bali Province, Indonesia. *IOP Conference Series: Earth and Environmental Science*, *158*(1), 012034. https://doi.org/10.1088/1755-1315/158/1/012034

Salamzadeh, A., Ebrahimi, P., Soleimani, M., & Fekete-Farkas, M. (2021). An AHP Approach to Identify the Barriers of Sustainable Geotourism Development in Iran: an Economic View. *Geoheritage*, *13*(3), 65. https://doi.org/10.1007/s12371-021-00581-9

Sallam, E. S., Abd El-Aal, A. K., Fedorov, Y. A., Bobrysheva, O. R., & Ruban, D. A. (2018). Geological heritage as a new kind of natural resource in the Siwa Oasis, Egypt: The first assessment, comparison to the Russian South, and sustainable development issues. *Journal of African Earth Sciences*, *144*, 151-160. https://doi.org/https://doi.org/10.1016/j.jafrearsci.2018.04.008

Sallam, E. S., Abd El-Samee, M. A., Bobrysheva, O. R., Yashalova, N. N., & Ruban, D. A. (2020). Geological heritage of Luxor and its vicinities, Egypt: a new assessment and geotourism perspectives. *Arabian Journal of Geosciences*, *13*(2), 76. https://doi.org/10.1007/s12517-019-5038-0

Sallam, E. S., Fathy, E. E., Ruban, D. A., Ponedelnik, A. A., & Yashalova, N. N. (2018). Geological heritage diversity in the Faiyum Oasis (Egypt): A comprehensive assessment. *Journal of African Earth Sciences*, *140*, 212-224. https://doi.org/https://doi.org/10.1016/j.jafrearsci.2018.01.010

Sallam, E. S., Ruban, D. A., Mostafa, M. T., Elkhodery, M. K., Alwilily, R. L., Molchanova, T. K., & Zorina, S. O. (2020). Unique desert caves as a valuable geological resource: first detailed geological heritage assessment of the Sannur Cave, Egypt. *Arabian Journal of Geosciences*, *13*(3), 141. https://doi.org/10.1007/s12517-020-5176-4

Sánchez-Martín, J.-M., Rengifo-Gallego, J.-I., & Martín-Delgado, L.-M. (2019). Characterization of the Tourist Demand of the Villuercas–Ibores–Jara Geopark: A Destination with the Capacity to Attract Tourists and Visitors. *Geosciences*, *9*(8), 335. https://www.mdpi.com/2076-3263/9/8/335

Santos, D. S., Mansur, K. L., Seoane, J. C. S., Mucivuna, V. C., & Reynard, E. (2020). Methodological Proposal for the Inventory and Assessment of Geomorphosites: An Integrated Approach focused on Territorial Management and Geoconservation. *Environmental Management*, *66*(3), 476-497. https://doi.org/10.1007/s00267-020-01324-2

Santos, D. S., Reynard, E., Mansur, K. L., & Seoane, J. C. S. (2019). The Specificities of Geomorphosites and Their Influence on Assessment Procedures: a Methodological Comparison. *Geoheritage*, *11*(4), 2045-2064. https://doi.org/10.1007/s12371-019-00411-z

Sanz, J., Zamalloa, T., Maguregi, G., Fernandez, L., & Echevarria, I. (2020). Educational Potential Assessment of Geodiversity Sites: a Proposal and a Case Study in the Basque Country (Spain). *Geoheritage*, *12*(1), 23. https://doi.org/10.1007/s12371-020-00432-z

Sayama, K. (2024). Promoting diversity in geoheritage evaluation: creating an evaluation method for the scientific value of Quaternary sites in arid environments. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *382*(2269), 20230138. https://doi.org/doi:10.1098/rsta.2023.0138

Sayama, K., Parker, A. G., Parton, A., & Viles, H. (2022). Developing a Geocultural Database of Quaternary Palaeoenvironmental Sites and Archaeological Sites in Southeast Arabia: Inventory, Endangerment Assessment, and a Roadmap for Conservation. *Sustainability*, *14*(21), 14096.

Scriven, S. (2019). The Jurassic Coast Story Book: An approach to geoheritage interpretation from the Jurassic Coast World Heritage Site. *Proceedings of the Geologists' Association*, *130*(3-4), 493-506. https://doi.org/10.1016/j.pgeola.2018.09.005

Searle, M. (2014). Preserving Oman's geological heritage: proposal for establishment of World Heritage Sites, National GeoParks and Sites of Special Scientific Interest (SSSI). *Geological Society Special Publication*, *392*(1), 9-44. https://doi.org/doi:10.1144/SP392.2

Searle, M. (2019a). Geo-heritage and Conservation. In M. Searle (Ed.), *Geology of the Oman Mountains, Eastern Arabia* (pp. 445-463). Springer International Publishing. https://doi.org/10.1007/978-3-030-18453-7_17

Searle, M. (2019b). *Geology of the Oman Mountains, Eastern Arabia*. Springer International Publishing. https://books.google.co.uk/books?id=MRaaDwAAQBAJ

Searle, M., & Cox, J. (1999). Tectonic setting, origin, and obduction of the Oman ophiolite. *GSA Bulletin*, *111*(1), 104-122. https://doi.org/https://doi.org/10.1130/0016-7606(1999)111%3C0104:TSOAOO%3E2.3.CO;2

Semeniuk, V., Semeniuk, C., Trend, F., & Brocx, M. (2015). Microscale geology and micropalaeontology of the Becher Point Cuspate Foreland, Australia: Significant geoheritage values at the smallest scale–a model for identifying similar features in Geosites and Geoparks. *From geoheritage to geoparks–case studies from Africa and beyond*, 261-269.

Sen, S., Abouelresh, M. O., Joydas, T. V., Almusabeh, A., Al-Ismail, F. S., & Pulido, B. (2024). Geoheritage and Geotourism Potential of NEOM, Saudi Arabia: Linking Geoethics, Geoconservation, and Geotourism. *Geoheritage*, *16*(1), 27. https://doi.org/10.1007/s12371-024-00932-2

Shahhoseini, H., Modabberi, S., & Shahabi, M. (2017). Study of Factors Influencing the Attitude of Local People Toward Geotourism Development in Qeshm National Geopark, Iran. *Geoheritage*, *9*(1), 35-48. https://doi.org/10.1007/s12371-015-0171-y

Shander, S. (2014). *Social Impact Analysis of How Geoparks Contribute to Sustainable Economic Development: A Case Study of Meteorum Geopark in Dalarna, Sweden* (Publication Number 195) Uppsala University]. Uppsala.

Sillitoe, P. (2009). *Local Science Vs Global Science-Approaches to Indigenous Knowledge in International Development* (1 ed.). Berghahn Books. http://www.jstor.org/stable/j.ctt9qdfbm

Siuki, H. S., & Kowalczyk, A. (2012). Criteria of Selection by Potential Tourists of Destinations of Geotourism Value (Based on the Example of the Region of Khorasan, Iran). *Problems of Tourism and Recreation*, *1*, 41-57.

Siuki, H. S., Kowalczyk, A., & Atefeh, E. (2012). A tourism demand based method of geosites assessment on geotourism prioritization modeling: The case of Razavi Khorasan Province. *Journal of Hospitality Management and Tourism*, *3*(5), 82-94.

Solarska, A., & Jary, Z. (2010). Geoheritage and Geotourism Potential of the Strzelin Hills (Sudetic Foreland, SW Poland). *Geographica Pannonica*, *14*(4), 118-125.

Soltan, B. H. (2021). Characteristic Features of the Proposed Jabal Sanam Geopark Southern Iraq. *Geoheritage*, *13*(3), 77. https://doi.org/10.1007/s12371-021-00599-z

Sousa, A., García-Murillo, P., Sahin, S., Morales, J., & García-Barrón, L. (2010). Wetland place names as indicators of manifestations of recent climate change in SW Spain (Doñana Natural Park). *Climatic change*, *100*(3), 525-557. https://doi.org/10.1007/s10584-009-9794-9

Stewart, I. S., & Nield, T. (2013). Earth stories: context and narrative in the communication of popular geoscience. *Proceedings of the Geologists' Association*, *124*(4), 699-712. https://doi.org/https://doi.org/10.1016/j.pgeola.2012.08.008

Stoffelen, A. (2020). Where is the community in geoparks? A systematic literature review and call for attention to the societal embedding of geoparks. *Area*, *52*(1), 97-104. https://doi.org/https://doi.org/10.1111/area.12549

Štrba, Ľ. (2019). Analysis of Criteria Affecting Geosite Visits by General Public: a Case of Slovak (Geo)Tourists. *Geoheritage*, *11*(2), 291-300. https://doi.org/10.1007/s12371-018-0283-2

Štrba, Ľ., Balaz, B., & Lukáč, M. (2016). Roadside geotourism - An alternative approach to geotourism. *e-Review of Tourism Research*, *13*, 598-609.

Štrba, Ľ., Kršák, B., & Sidor, C. (2018). Some Comments to Geosite Assessment, Visitors, and Geotourism Sustainability. *Sustainability*, *10*(8), 2589. https://www.mdpi.com/2071-1050/10/8/2589

Štrba, Ľ., Rybár, P., Baláž, B., Molokáč, M., Hvizdák, L., Kršák, B., Lukáč, M., Muchová, L., Tometzová, D., & Ferenčíková, J. (2015). Geosite assessments: comparison of methods and results. *Current Issues in Tourism*, *18*(5), 496-510. https://doi.org/10.1080/13683500.2014.882885

Styles, M., Ellison, R., Arkley, S., Crowley, Q. G., Farrant, A., Goodenough, K. M., McKervey, J., Pharaoh, T., Phillips, E., & Schofield, D. (2006). *The geology and geophysics of the United Arab Emirates: Volume 2, geology*. Ministry of Energy, United Arab Emirates.

Subedi, S., Hetényi, G., & Shackleton, R. (2020). Impact of an educational program on earthquake awareness and preparedness in Nepal. *Geosci. Commun.*, *3*(2), 279-290. https://doi.org/10.5194/gc-3-279-2020

Suzuki, D. A., & Takagi, H. (2018). Evaluation of Geosite for Sustainable Planning and Management in Geotourism. *Geoheritage*, *10*(1), 123-135. https://doi.org/10.1007/s12371-017-0225-4

Tavares, A., Henriques, M., Domingos, A., & Bala, A. (2015). Community Involvement in Geoconservation: A Conceptual Approach Based on the Geoheritage of South Angola. *Sustainability*, *7*(5), 4893-4918. https://doi.org/10.3390/su7054893

Tebaa, O., & Boujrouf, S. (2020). Patrimonialization and the Geopark Label: for Which Development Model in the South? The Case of Morocco. In Y. Girault (Ed.), *UNESCO Global Geoparks: Tension Between Territorial Development and Heritage Enhancement* (pp. 77-90). John Wiley and Sons. https://doi.org/https://doi.org/10.1002/9781119681489.ch4

Tessema, G. A., van der Borg, J., Van Rompaey, A., Van Passel, S., Adgo, E., Minale, A. S., Asrese, K., Frankl, A., & Poesen, J. (2022). Benefit Segmentation of Tourists to Geosites and Its Implications for Sustainable Development of Geotourism in the Southern Lake Tana Region, Ethiopia. *Sustainability*, *14*(6), 3411. https://www.mdpi.com/2071-1050/14/6/3411

The Geological Society of America. (2012, April, 2012). *GSA Position Statement Geoheritage* https://rock.geosociety.org/net/documents/gsa/positions/pos20_Geoheritage.pdf

The International Congress of Geotourism. (2011, 12/11/2011). *Arouca Declaration*. European Geoparks Network. Retrieved 31/08 from www.aroucageopark.pt/documents/78/Declaration_Arouca_EN.pdf

Thomas, B., & Ellison, R. (2014). *Geological evolution of the United Arab Emirates. Over six hundred million years of Earth History*. British Geological Survey.

Thomas, D. S. G. (2011). *Arid Zone Geomorphology* (3rd ed.). Wiley. https://books.google.co.uk/books?id=s1vuAAAAMAAJ

Thomas, K. A., & Clifford, S. (2017). Validity and Mechanical Turk: An assessment of exclusion methods and interactive experiments. *Computers in Human Behavior*, *77*, 184-197.

Tibaldi, A., Bonali, F. L., Vitello, F., Delage, E., Nomikou, P., Antoniou, V., Becciani, U., de Vries, B. V. W., Krokos, M., & Whitworth, M. (2020). Real world–based immersive Virtual Reality for research, teaching and communication in volcanology. *Bulletin of Volcanology*, *82*(5), 38. https://doi.org/10.1007/s00445-020-01376-6

Tikriti, W. Y. A. (2002). The south-east Arabian origin of the falaj system. *Proceedings of the Seminar for Arabian Studies*, *32*, 117-138. http://www.jstor.org/stable/41223728

Tomić, N., & Božić, S. (2014). A modified Geosite Assessment Model (M-GAM) and its Application on the Lazar Canyon area (Serbia). *International Journal of Environmental Research*, *8*, 1041-1052.

Tomić, N., Sepehriannasab, B., Marković, S. B., Hao, Q., & Lobo, H. A. S. (2021). Exploring the Preferences of Iranian Geotourists: Case Study of Shadows Canyon and Canyon of Jinns. *Sustainability*, *13*(2), 798. https://www.mdpi.com/2071-1050/13/2/798

Tormey, D. (2019). New approaches to communication and education through geoheritage. *International Journal of Geoheritage and Parks*, *7*(4), 192-198. https://doi.org/https://doi.org/10.1016/j.ijgeop.2020.01.001

Tourenq, C., Khassim, A., Sawaf, M., Shuriqi, M. K., Smart, E., Ziolkowski, M., Brook, M., Selwan, R., & Perry, L. (2009). Characterisation of the Wadi Wurayah catchment basin, the first mountain protected area in the United Arab Emirates. *International Journal of Ecology and Environmental Sciences*, *35*(4), 289-311.

Trend, R. (1998). An investigation into understanding of geological time among 10 - and 11 - year - old children. *International Journal of Science Education*, *20*(8), 973-988. https://doi.org/10.1080/0950069980200805

Trend, R. (2001). An Investigation into the Understanding of Geological Time among 17-year-old Students, with Implications for the Subject Matter Knowledge of Future Teachers. *International Research in Geographical and Environmental Education*, *10*(3), 298-321. https://doi.org/10.1080/10382040108667447

U.S. Energy Information Administration. (2022). *Petroleum and Other Liquids*.

Uerpmann, H.-P., Uerpmann, M., Kutterer, A., & Jasim, S. A. (2013). The Neolithic period in the Central Region of the Emirate of Sharjah (UAE). *Arabian Archaeology and Epigraphy*, *24*(1), 102-108. https://doi.org/10.1111/aae.12019

UNEP-WCMC, & IUCN. (2024). *Protected Planet: The World Database on Protected Areas (WDPA) and World Database on Other Effective Area-based Conservation Measures (WD-OECM) [Online]* www.protectedplanet.net
UNESCO. (1972). *Convention Concerning the Protection of the World Cultural and Natural Heritage*. Paris
UNESCO. (1994). *Inscription: Arabian Oryx Sanctuary (Oman)*. (18 COM XI). Paris: UNESCO
UNESCO. (2007). *DECISIONS ADOPTED AT THE 31st SESSION OF THE WORLD HERITAGE COMMITTEE (CHRISTCHURCH, 2007)* (World Heritage List, Issue. UNESCO. https://whc.unesco.org/en/list/654/
UNESCO. (2015). *Statutes of the International Geoscience and Geoparks Program*. (IGGP/2015/ST). Paris, France: UNESCO
UNESCO. (2016). *UNESCO global geoparks. Celebrating earth heritage, sustaining local communities*. (SC-2017/WS/7 REV.). Paris: UNESCO Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000247511
UNESCO. (2021a). *Operational Guidelines for the Implementation of the World Heritage Convention*. Paris, France: UNESCO
UNESCO. (2021b). *UNESCO Global Geoparks Council 6th Session (virtual) Report*.
UNESCO. (2022a). *6th October: International Geodiversity Day*. Paris: UNESCO Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000382298
UNESCO. (2022b, 20/04/2023). *Grants to support the creation of geoparks in Africa and the Arab States*. UNESCO. Retrieved 03/11 from https://www.unesco.org/en/articles/grants-support-creation-geoparks-africa-and-arab-states?hub=67817&TSPD_101_R0=080713870fab2000ffe85f78716cf15bf8e747f85b69019bf66259ff59de63bd59cf7000d37db3ea08aefdf7e5143000d1cfaa5f100d760a04218517c116dc4105ca1551ba1cd65028dca82d9225729bdc5e187da12370b3965b8aa946e264c5#:~:text=News-,Grants%20to%20support%20the%20creation%20of%20geoparks%20in%20Africa%20and,applications%20is%2030%20April%202022.
UNESCO. (2022c). Grants to support the creation of geoparks in Small Island Developing States [Article]. Retrieved 09/03/2022, from https://www.unesco.org/en/articles/grants-support-creation-geoparks-small-island-developing-states
UNESCO. (2023a). *Operational Guidelines for the Implementation of the World Heritage Convention*. Paris, France: UNESCO
UNESCO. (2023b, 18/08/2023). *States Parties-World Heritage Convention*. UNESCO. Retrieved 22/04 from https://whc.unesco.org/en/statesparties/
UNESCO. (2023c). *UNESCO Global Geoparks-2023*. Retrieved 03/11 from https://unesdoc.unesco.org/ark:/48223/pf0000385482
UNESCO. (2024). *UNESCO World Heritage Centre - World Heritage List*. UNESCO. Retrieved 23/04 from https://whc.unesco.org/en/list/
UNESCO Institute for Statistics. (2024). *Conservation of natural heritage*. UNESCO. Retrieved 23/04 from https://uis.unesco.org/en/glossary-term/conservation-natural-heritage
United Nations Population Division. (2024). *International migrant stock* World Bank.

Vaccaro, I., & Beltran, O. (2010). Turning nature into collective heritage :The social framework of the process of patrimonialization of nature. In X. Roigé & J. Frigolé Reixach (Eds.), *Constructing cultural and natural heritage : parks, museums and rural heritage* (pp. 63-73). Documenta Universitaria. https://doi.org/10.1400/241926

Van Loon, A. F., Lester-Moseley, I., Rohse, M., Jones, P., & Day, R. (2020). Creative practice as a tool to build resilience to natural hazards in the Global South. *Geosci. Commun.*, *3*(2), 453-474. https://doi.org/10.5194/gc-3-453-2020

Van Loon, A. J. (2008). Geological education of the future. *Earth-Science Reviews*, *86*(1-4), 247-254. https://doi.org/10.1016/j.earscirev.2007.08.005

Vujičić, M. D., Vasiljević, D. A., Marković, S. B., Hose, T. A., Lukić, T., Hadžić, O., & Janićević, S. (2011). Preliminary geosite assessment model (gam) and its application on Fruška gora mountain, potential geotourism destination of Serbia. *Acta geographica Slovenica*, *51*(2), 361-376. https://doi.org/10.3986/ags51303

Warmold, D. (2017). Deep Time: A public engagement literature review. In *Learning and Audience Research Department, Natural History Museum, London*.

Warner, M. (2005). *Publics and counterpublics*. Zone Books.

Watanabe, M. (2011). 世界ジオパークネットワークと日本のジオパーク. *地学雑誌*, *120*(5), 733-742. https://doi.org/10.5026/jgeography.120.733

Welchman, J. (2020). Commentary on Jonathan A. Newman, Gary Varner, and Stefan Linquist: Defending Biodiversity: Environmental Science and Ethics, chapter 11: should biodiversity be conserved for its aesthetic value? *Biology & Philosophy*, *35*(1), 13. https://doi.org/10.1007/s10539-019-9720-0

Welsby, D. A. (2021). Human adaptation to environmental change in the northern Dongola reach. In G. Emberling & B. Williams (Eds.), *The Oxford handbook of ancient Nubia* (pp. 309–326). Oxford University Publishing.

WHO. (2007). *The WHO e-atlas of disaster risk for the Eastern Mediterranean Region: Volume 1, Exposure to Natural Hazards* World Health Organization.

Whyte, K. P., Brewer, J. P., & Johnson, J. T. (2016). Weaving Indigenous science, protocols and sustainability science. *Sustainability Science*, *11*(1), 25-32. https://doi.org/10.1007/s11625-015-0296-6

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D. A., François, R., Grolemund, G., Hayes, A., Henry, L., & Hester, J. (2019). Welcome to the Tidyverse. *Journal of open source software*, *4*(43), 1686.

Williams, A. N., Veth, P., Steffen, W., Ulm, S., Turney, C. S., Reeves, J. M., Phipps, S. J., & Smith, M. (2015). A continental narrative: Human settlement patterns and Australian climate change over the last 35,000 years. *Quaternary Science Reviews*, *123*, 91-112.

Wilson, E. O. (1984). *Biophilia*. Harvard University Press. https://books.google.co.uk/books?id=CrDqGKwMFAkC

Wimbledon, W., Benton, M., Bevins, R., Black, G., Bridgland, D., Cleal, C., Cooper, R., & May, V. (1995). The development of a methodology for the selection of British geological sites for conservation: part 1. *Modern Geology*, *20*, 159-202.

Woo, K. S., & Kim, L. (2018). Geoheritage Evaluation of Caves in Korea: A Case Study of Limestone Caves. In E. Reynard & J. Brilha (Eds.), *Geoheritage* (pp. 373-386). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-809531-7.00021-6

Woor, S., Buckland, C., Parton, A., & Thomas, D. S. G. (2022). Assessing the robustness of geochronological records from the Arabian Peninsula: A new synthesis of the last 20 ka. *Global and Planetary Change*, *209*, 103748. https://doi.org/10.1016/j.gloplacha.2022.103748

World Bank. (2022a). *Country Profile: Oman*. World Bank. Retrieved 24/04 from https://databank.worldbank.org/views/reports/reportwidget.aspx?Report_Name=CountryProfile&Id=b450fd57&tbar=y&dd=y&inf=n&zm=n&country=OMN

World Bank. (2022b). *Country Profile: United Arab Emirates*. World Bank. Retrieved 24/04 from https://databank.worldbank.org/views/reports/reportwidget.aspx?Report_Name=CountryProfile&Id=b450fd57&tbar=y&dd=y&inf=n&zm=n&country=ARE

World Bank. (2023). *Educational attainment, at least Bachelor's or equivalent, population 25+, total (%) (cumulative)*

Yadav, A., Phillips, M. M., Lundeberg, M. A., Koehler, M. J., Hilden, K., & Dirkin, K. H. (2011). If a picture is worth a thousand words is video worth a million? Differences in affective and cognitive processing of video and text cases. *Journal of Computing in Higher Education*, *23*(1), 15-37. https://doi.org/10.1007/s12528-011-9042-y

Yamane, T. (1967). *Statistics: An Introductory Analysis* (2 ed.). Harper & Row. https://books.google.ae/books?id=Wr7rAAAAMAAJ

Yang, G., Chen, Z., Tian, M., Wu, F., Wray, R., & Ping, Y. (2011). On the growth of National Geoparks in China: Distribution, interpretation, and regional comparison. *Episodes*, *34*. https://doi.org/10.18814/epiiugs/2011/v34i3/003

Yilmaz, A. G., Abdallah;, S., Merabtene, T., Atabay, S., & Kayemah, N. (2020). Rainfall trends and intensity-frequency-duration relationships in Sharjah City, UAE. *International Journal of Hydrology Science and Technology*, *10*(5), 487-503. https://doi.org/10.1504/ijhst.2020.109949

Zawacki, E. E., Bohon, W., Johnson, S., & Charlevoix, D. J. (2022). Exploring TikTok as a promising platform for geoscience communication. *Geosci. Commun.*, *5*(4), 363-380. https://doi.org/10.5194/gc-5-363-2022

Zerboni, A., Perego, A., Mariani, G. S., Brandolini, F., Al Kindi, M., Regattieri, E., Zanchetta, G., Borgi, F., Charpentier, V., & Cremaschi, M. (2020). Geomorphology of the Jebel Qara and coastal plain of Salalah (Dhofar, southern Sultanate of Oman). *Journal of Maps*, *16*(2), 187-198. https://doi.org/10.1080/17445647.2019.1708488

Zgłobicki, W., & Baran-Zgłobicka, B. (2013). Geomorphological Heritage as a Tourist Attraction. A Case Study in Lubelskie Province, SE Poland. *Geoheritage*, *5*(2), 137-149. https://doi.org/10.1007/s12371-013-0076-6

Zorlu, K., & Dede, V. (2023). Assessment of glacial geoheritage by multi-criteria decision making (MCDM) methods in the Yalnızçam Mountains, Northeastern Türkiye. *International Journal of Geoheritage and Parks*, *11*(1), 100-117. https://doi.org/https://doi.org/10.1016/j.ijgeop.2023.01.001

Zouros, N. (2004). The European Geoparks Network-Geological heritage protection and local development. *Episodes Journal of International Geoscience*, *27*(3), 165-171.

Zouros, N. C. (2007). Geomorphosite assessment and management in protected areas of Greece Case study of the Lesvos island–coastal geomorphosites. *Geographica Helvetica*, *62*(3), 169-180.

Zwoliński, Z., Najwer, A., & Giardino, M. (2018). Methods for assessing geodiversity. In E. Reynard & J. Brilha (Eds.), *Geoheritage: Assessment, Protection, and Management* (pp. 27-52). Elsevier.

Appendix A: author contribution

The vast majority of work completed in this thesis was done by the candidate. As all four submitted papers were co-authored, both the contributions of the candidate (underlined) and the co-authors are outlined below.

Paper 1 (Chapter 5): Conceptualisation, K.S., A.P., H.V.; Data Curation, A.G.P. and K.S.; Formal Analysis, K.S.; Funding Acquisition, K.S., Investigation, K.S.; Methodology, K.S.; Project Administration, K.S.; Software, K.S.; Supervision, A.P., H.V., A.G.P.; Validation, K.S. and A.P.; Visualisation, K.S.; Writing—Original Draft Preparation, K.S.; Writing—Review and Editing, H.V., A.G.P.; All authors have read and agreed to the published version of the manuscript.

Paper 2 (Chapter 6): Conceptualisation, K.S., H.V.; Data curation, K.S. H.A.R., R.A.F.; Formal analysis, K.S., R.A.F.; Funding acquisition, K.S.; Investigation, K.S., H.A.R., R.A.F.; Methodology, K.S., R.A.F., H.V., A.G.P.; Project administration, K.S., H.A.R.; Software, R.A.F, K.S.; Supervision, H.V., A.G.P.; Validation, K.S., R.A.F; Visualisation, K.S., R.A.F.; Writing—original draft, K.S.; Writing—review and editing, K.S., R.A.F., H.V., A.G.P. All authors have read and agreed to the published version of the manuscript.

Paper 3 (Chapter 7): Conceptualisation, K.S.; Data curation, K.S.; Formal analysis, K.S.; Methodology, K.S.; Project administration, K.S.; Resources, K.S.; Validation, K.S.; Visualisation, K.S.; Writing—original draft, K.S.; Writing—review and editing, K.S. All authors have read and agreed to the published version of the manuscript.

Paper 4 (Chapter 8): Conceptualisation, K.S. H.V., A.P, A.G.P.; Data curation, K.S.; Formal analysis, K.S.; Funding acquisition, A.G.P., K.S.; Investigation, K.S.; Methodology, K.S., H.V., A.G.P.; Project administration, K.S., A.G.P.; Resources, K.S.; Software, K.S.; Supervision, H.V., A.G.P., A.P.; Validation, K.S.; Visualisation, K.S.; Writing—original draft, K.S.; Writing—review and editing, K.S., H.V., A.G.P. All authors have read and agreed to the published version of the manuscript.

By signing the Statement of Authorship, you are certifying that the candidate made a substantial contribution to the publications, and that the description above is accurate.

Signed (Kenta Sayama, K.S.):  Date: 9th July 2024

Signed (Heather Viles, H.V.):  Date: 9th July 2024

Signed (Adrian G. Parker, A.G.P):  Date: 9th July 2024

Signed (Ash Parton, A.P.);  Date: 9th July, 2024

Signed (Husam Al Rawahi, H.A.R.):  Date: 8th July 2024

Signed (Robert A. Fahey, R.A.F.):  Date: 8th July 2024

Appendix B: Chapter 5– template codes for GDSA

PALAEOENVIRONMENTAL RECORDS

1. *All palaeoenvironmental records*

SELECT DISTINCT

qr.source_summary, qr.type, qr.record_information, qr.climatic_implications, qr.agebpka*1000 AS qp_chronology, qr.two_sigma_range, qr.two_sigma_start, qr.two_sigma_end, qr.osl_error_ka, qr.landform_type, qr.woor_2022_assessment, qr.mis, qs.geom, qs.easting, qs.northing

FROM qprecord qr

JOIN qpsite qs ON qs.siteid=qr.siteid

2. *Palaeoenvironmental records from papers from a certain author*

SELECT DISTINCT

qr.source_summary, qr.type, qr.record_information, qr.climatic_implications, qr.agebpka*1000 AS qp_choronology, qr.two_sigma_range, qr.two_sigma_start, qr.two_sigma_end, qr.osl_error_ka, qr.landform_type, qr.woor_2022_assessment, qr.mis, qs.geom, qs.easting, qs.northing

FROM qprecord qr

JOIN qpsite qs ON qs.siteid=qr.siteid

WHERE qr.source_summary LIKE '%%**%%' -- Replace ** with the last name of the first author or the name of the paper in in-text citation form (e.g. Parton et al. (2013)).

3. *Palaeoenvironmental records from a certain MIS*

SELECT DISTINCT

qr.source_summary, qr.type, qr.record_information, qr.climatic_implications, qr.agebpka*1000 AS qp_chronology, qr.two_sigma_range, qr.two_sigma_start, qr.two_sigma_end, qr.osl_error_ka, qr.landform_type, qr.woor_2022_assessment, qr.mis, qs.geom, qs.easting, qs.northing

FROM qprecord qr

JOIN qpsite qs ON qs.siteid=qr.siteid

WHERE qr.mis = 'MIS*' -- Replace * with the number of the MIS you want to specify

4. *Palaeoenvironmental records from a certain chronological period*

SELECT DISTINCT

qr.source_summary, qr.type, qr.record_information, qr.climatic_implications, qr.agebpka, qr.two_sigma_range, qr.two_sigma_start, qr.two_sigma_end, qr.osl_error_ka, qr.landform_type, qr.woor_2022_assessment, qr.mis, qs.geom, qs.easting, qs.northing

FROM qprecord qr

JOIN qpsite qs ON qs.siteid=qr.siteid

WHERE qr.agebpka*1000 BETWEEN ** AND ** -- replace the ** with the period you would like to specify in BP. The younger age should be the first number and the older age should be the second e.g. BETWEEN 120000 AND 130000)

5. *Holocene Palaeoenvironmental records with robust or acceptable data*

SELECT DISTINCT

qr.source_summary, qr.climatic_implications, qr.type, qr.record_information, qr.agebpka, qr.two_sigma_range, qr.two_sigma_start, qr.two_sigma_end, qr.osl_error_ka, qr.landform_type, qr.woor_2022_assessment, qr.mis, qs.geom, qs.easting, qs.northing

FROM qprecord qr

JOIN qpsite qs ON qs.siteid=qr.siteid

WHERE qr.woor_2022_assessment= 'G' or qr.woor_2022_assessment= 'A'

6. *Palaeoenvironmental records with certain climatic implications*

SELECT DISTINCT

qr.source_summary, qr.climatic_implications, qr.type, qr.record_information, qr.agebpka*1000 AS qp_chronology, qr.two_sigma_range, qr.two_sigma_start, qr.two_sigma_end, qr.osl_error_ka, qr.landform_type, qr.woor_2022_assessment, qr.mis, qs.geom, qs.easting, qs.northing

FROM qprecord qr

JOIN qpsite qs ON qs.siteid=qr.siteid

WHERE qr.climatic_implications= '**' -- replace ** with the climatic implication you would like to specify. Options include Arid, Humid, Unclear, Intermediary, Active Spring, Short lived humidity, Short lived aridity. These options are case sensitive.

7. *Palaeoenvironmental records from a certain landform type*

SELECT DISTINCT

qr.source_summary, qr.climatic_implications, qr.type, qr.record_information, qr.agebpka*1000 AS qp_chronology, qr.two_sigma_range, qr.two_sigma_start, qr.two_sigma_end, qr.osl_error_ka, qr.landform_type, qr.woor_2022_assessment, qr.mis, qs.geom, qs.easting, qs.northing

FROM qprecord qr

JOIN qpsite qs ON qs.siteid=qr.siteid

WHERE qr.landform_type= '**' -- replace ** with the landform type you would like to specify. Options include Aeolian, Caves, Coastal Sabkha, Fluvial, Mangrove, Palaeolake, Palaeosols, Coastal Shorelines, Springs, and Wetlands. These options are case sensitive.

8. *Palaeoenvironmental sites under a certain level of endangerment*

SELECT DISTINCT

qr.source_summary, qs.overall_assessment, qs.risk_summary, qs.easting, qs.northing, qs.geom, qs.development_threat, qs.quarrying_threat, qs.infrastructure_transport_threat, qs.industrial_productive_threat, qs.dune_movement_threat, qs.inland_flood_threat, qs.sea_level_rise_threat, qs.protection_status, qs.desig_type

FROM qpsite qs

JOIN qprecord qr ON qs.siteid=qr.siteid

WHERE qs.overall_assessment= '**' -- replace ** with the level of endangerment that you would like to specify. Options include Destroyed, Irreversible Ascertained Danger, Reversible Ascertained Danger, Continuous Ascertained Danger, Irreversible Potential Danger, Reversible Potential Danger, Continuous Potential Danger, and No Observable Danger. These options are case sensitive.

9. *Palaeoenvironmental records from a certain Emirate (UAE)/Governorate (Oman)*

```
SELECT DISTINCT

qr.source_summary, qr.type, qr.record_information, qr.climatic_implications,
qr.agebpka*1000 AS qp_chronology, qr.two_sigma_range, qr.two_sigma_start,
qr.two_sigma_end, qr.osl_error_ka, qr.landform_type, qr.woor_2022_assessment,
qr.mis,  qs.geom, qs.easting, qs.northing, qs.emirate_governorate, qs.wilayat,
qs.nearest_city, qs.overall_assessment

FROM qprecord qr

JOIN qpsite qs ON qs.siteid=qr.siteid


WHERE qs.emirate_governorate = '**' -- replace ** with the name of the Emirate or the
Governorate
```

ARCHAEOLOGICAL RECORDS

1. *All archaeological records*

SELECT DISTINCT

sou.authors, sou.year, arr.record_type, arr.mean_calibrated_chronology, arr.calibrated_chronology_start, arr.calibrated_chronology_end, arr.archaeological_period, arr.precise_chronology, ars.geom, ars.easting, ars.northing, ars.site_code

FROM archrecord arr

JOIN archsite ars ON arr.archsiteid=ars.archsiteid

JOIN sources sou ON sou.sourceid=ars.sourceid

2. *Archaeological records from a certain source*

SELECT DISTINCT

sou.authors, sou.year, arr.record_type, arr.mean_calibrated_chronology, arr.calibrated_chronology_start, arr.calibrated_chronology_end, arr.archaeological_period, arr.precise_chronology, ars.geom, ars.easting, ars.northing, ars.site_code

FROM archrecord arr

JOIN archsite ars ON arr.archsiteid=ars.archsiteid

JOIN sources sou ON sou.sourceid=ars.sourceid

WHERE sou.authors LIKE '%%**%%' -- Replace ** with the name of the author of the source

AND sou.year = ** -- replace ** with the year that the paper was published. Delete this line if you only want to specify by the name of the author

3. *Dated archaeological records from a certain period*

SELECT DISTINCT

sou.authors, sou.year, arr.record_type, arr.mean_calibrated_chronology, arr.calibrated_chronology_start, arr.calibrated_chronology_end,

arr.archaeological_period, arr.precise_chronology, ars.geom, ars.easting, ars.northing, ars.site_code

FROM archrecord arr

JOIN archsite ars

ON arr.archsiteid=ars.archsiteid

JOIN sources sou

ON sou.sourceid=ars.sourceid

WHERE

arr.mean_calibrated_chronology BETWEEN ** AND **

-- replace the ** with the period you would like to specify in BP. The younger age should be the first number and the older age should be the second *e.g. BETWEEN 120000 AND 130000)

RELATIONSHIP BETWEEN QP SITES AND ARCHAEOLOGICAL SITES

1. *Find qprecords that correspond chronologically with archaeological records from a certain archaeological region*

SELECT DISTINCT

qr.source_summary, qr.agebpka*1000 as qp_chronology, qr.climatic_implications, qr.type, qr.record_information, qr.two_sigma_range, qr.two_sigma_start, qr.two_sigma_end, qr.osl_error_ka*1000 AS osl_error_bp, qs.geom, qs.easting, qs.northing

FROM qprecord qr JOIN qpsite qs ON qs.siteid=qr.siteid

JOIN archrecord arr ON arr.mean_calibrated_chronology BETWEEN qr.agebpka*1000-** AND qr.agebpka*1000+**

-- Replace the ** with numbers in years to specify the chronological range to relate the qp sites and archaeological sites (if you would like to show qp records within plus/minus 500 years within the chronology of the archaeological records, replace ** with 500)

JOIN archsite ars ON arr.archsiteid=ars.archsiteid

WHERE ars.region = '**' --Replace ** with the name of the region for the archaeological site of your interest (e.g. Jebel faya, ar-Ruways)

-- ADD THIS line if you want to spcify it to a certain record from the archaeological region: AND arr.mean_calibrated_chronology = ** --Replace ** with the age of the archaeological record you want to specify

;

2. *Find archaeological records that correspond chronologically with qp records from a certain paper*

SELECT DISTINCT

sou.authors, sou.year, arr.record_type, arr.mean_calibrated_chronology, arr.calibrated_chronology_start, arr.calibrated_chronology_end, arr.archaeological_period, arr.precise_chronology, ars.geom, ars.easting, ars.northing, ars.site_code

FROM qprecord qr

JOIN archrecord arr

ON arr.mean_calibrated_chronology BETWEEN qr.agebpka*1000-** and qr.agebpka*1000+** -- Replace ** with numbers in years to specify the chronological range to relate the archaeological sites and the qp sites (e.g. if you would like to show archaeological records within plus/minus 500 years within the chronology of the qp records, replace both ** with 500)

JOIN archsite ars ON ars.archsiteid=arr.archsiteid

JOIN sources sou ON ars.sourceid=sou.sourceid

WHERE qr.source_summary LIKE '%%**%%' --replace ** with the name of the paper you want the data from in the form of in-text citation (e.g. Parton et al. (2013))

;

3. *Palaeoenvironmental sites/records within a certain distance from an archaeological site*

SELECT DISTINCT

qr.source_summary, qr.climatic_implications, qr.type, qr.record_information, qr.agebpka*1000 AS qp_chronology, qr.two_sigma_range, qr.two_sigma_start, qr.two_sigma_end, qr.osl_error_ka, qr.landform_type, qr.woor_2022_assessment, qr.mis, qs.geom, qs.easting, qs.northing

FROM qpsite qs

JOIN qprecord qr ON qs.siteid=qr.siteid

JOIN archsite ars ON ST_Dwithin(ST_Transform(qs.geom,32640),ST_Transform(ars.geom,32640),**)-- Replace ** with the distance of the buffer you would like to set from the archaeological site in meters.

WHERE

ars.site_code= '**' --Replace ** with the name of the site(e.g. FAY-NE21, RA-3)

OR ars.region= '**' ; --Replace ** with the name of the archaeological region(e.g. Jebel Faya, ar-Ruways). This part is optional if you have specified the site code.

Appendix C: Chapter 5– instructions to use the GDSA

The database is hosted online and can be accessed using QGIS or any administration and development platforms for PostgreSQL

The easiest way to access the database is via QGIS.

If you do not have QGIS installed on your computer, you can download it by following the steps on www.qgis.org for free.

Instructions

1. After opening QGIS, go to browser and find PostgreSQL. If the browser is not showing, go to "layer" on the pane on the top, and click on Data Source Manager.

2. Right click on PostgreSQL and click on New Connection

3. Add the name gdsa_public for the Database

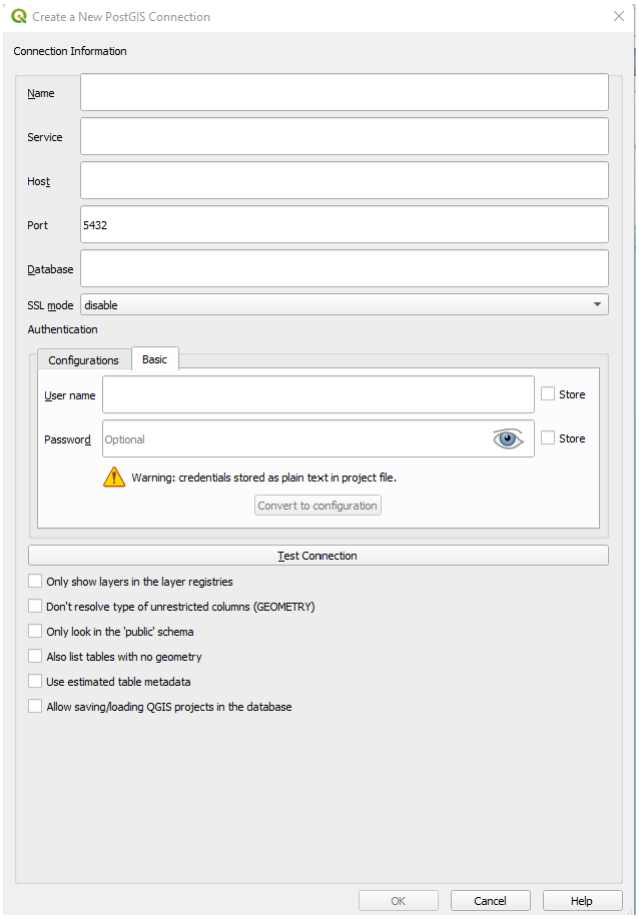
4. Copy and paste "postgresql-gdsa.alwaysdata.net" for the Host (leave the Service column empty)

5. On the Authentication pane, click on the Basic tab and add
   username: gdsa_guest
   password: ArabiaGeocultural

   ** By default, you will be able to access the database at read-only level. If you need further access, such as adding new data to the database, please contact Kenta Sayama at kenta.sayama@ouce.ox.ac.uk

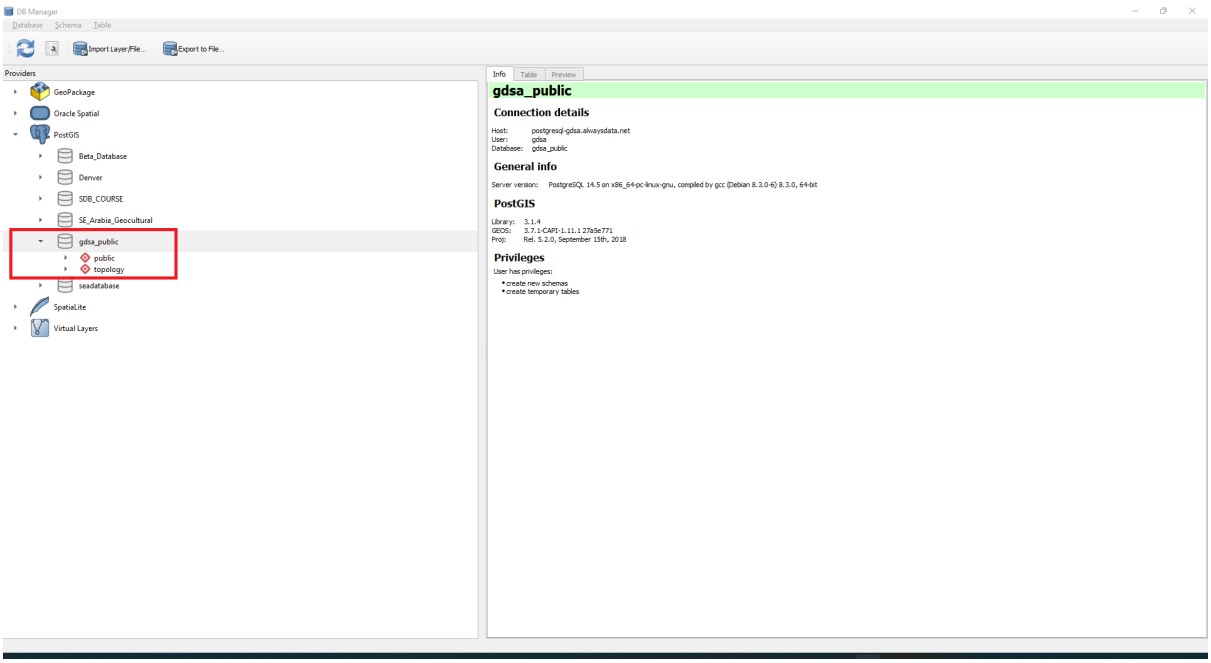
6. Click on Test Connection to establish the connection.

7. Click on OK at the bottom to finalise the connection.

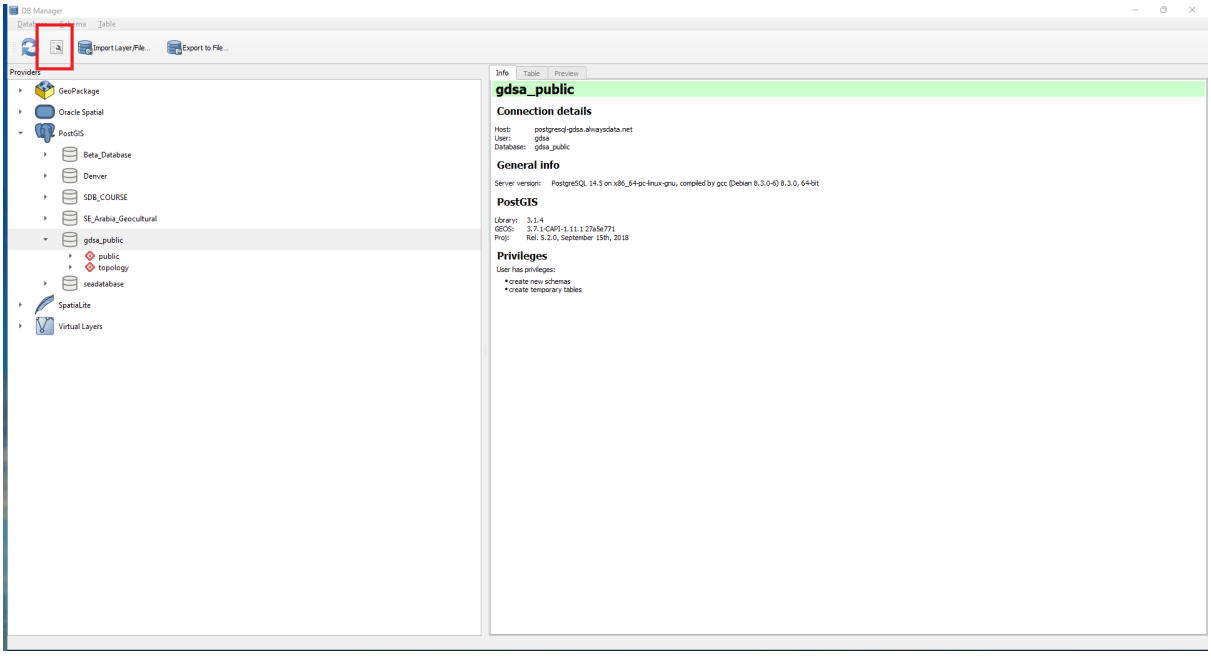


8. Once the connection has been established, go back to the browser and find Database and click on DB Manager.

9. Click on PostGIS and then click on gdsa_public. At this point, you may be prompted to enter the username and the password again (username: gdsa_guest, password: ArabiaGeocultural).

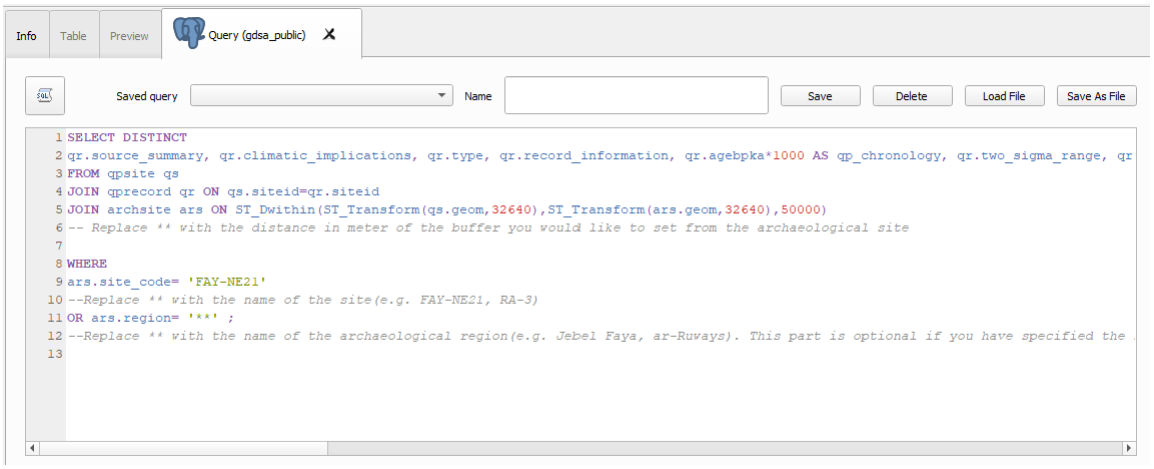


10. Click on the icon on top as shown in the photo to open the SQL window.

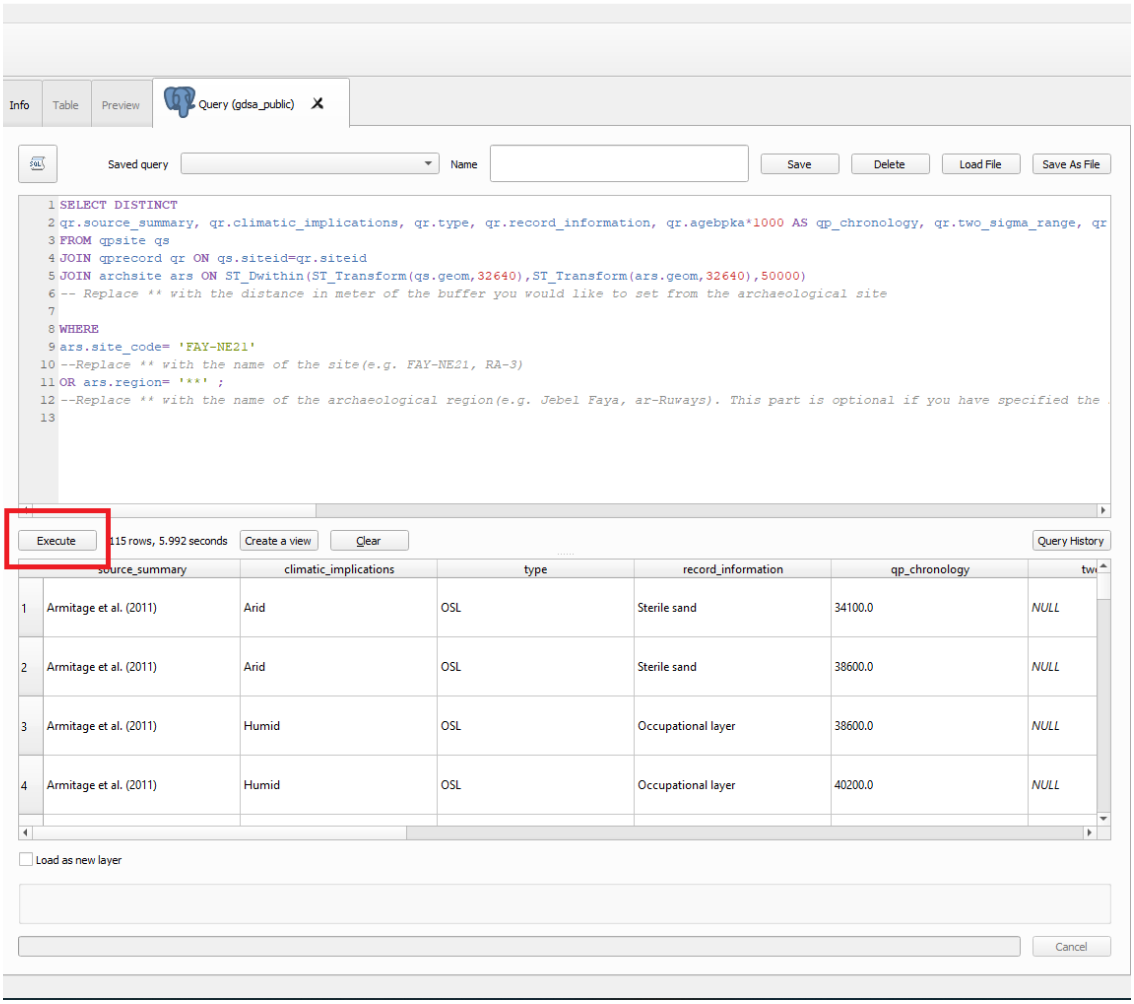


11. Copy and paste the search function of your interest from the list of functions to conduct SQL searches that you require.

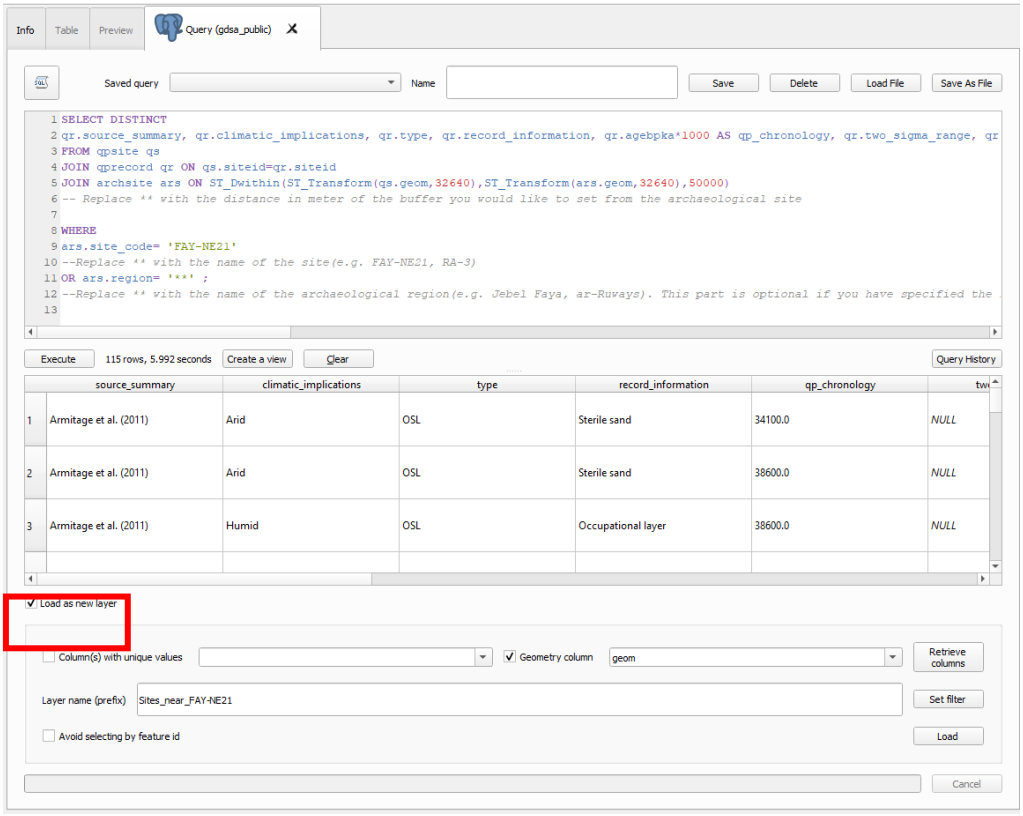
12. Replace ** to inputs of your choice of your choice, following the instructions in the code itself.



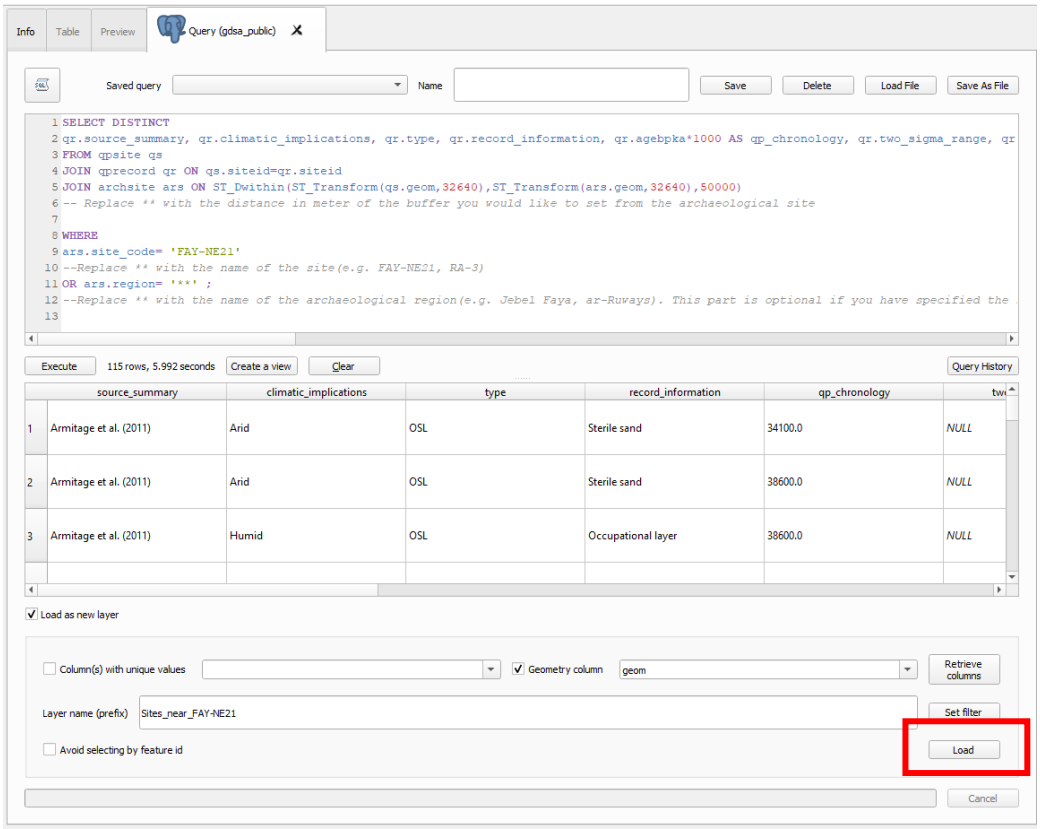
13. Click on execute to run the code.



14. Click on Load as a new layer and fill out the data.

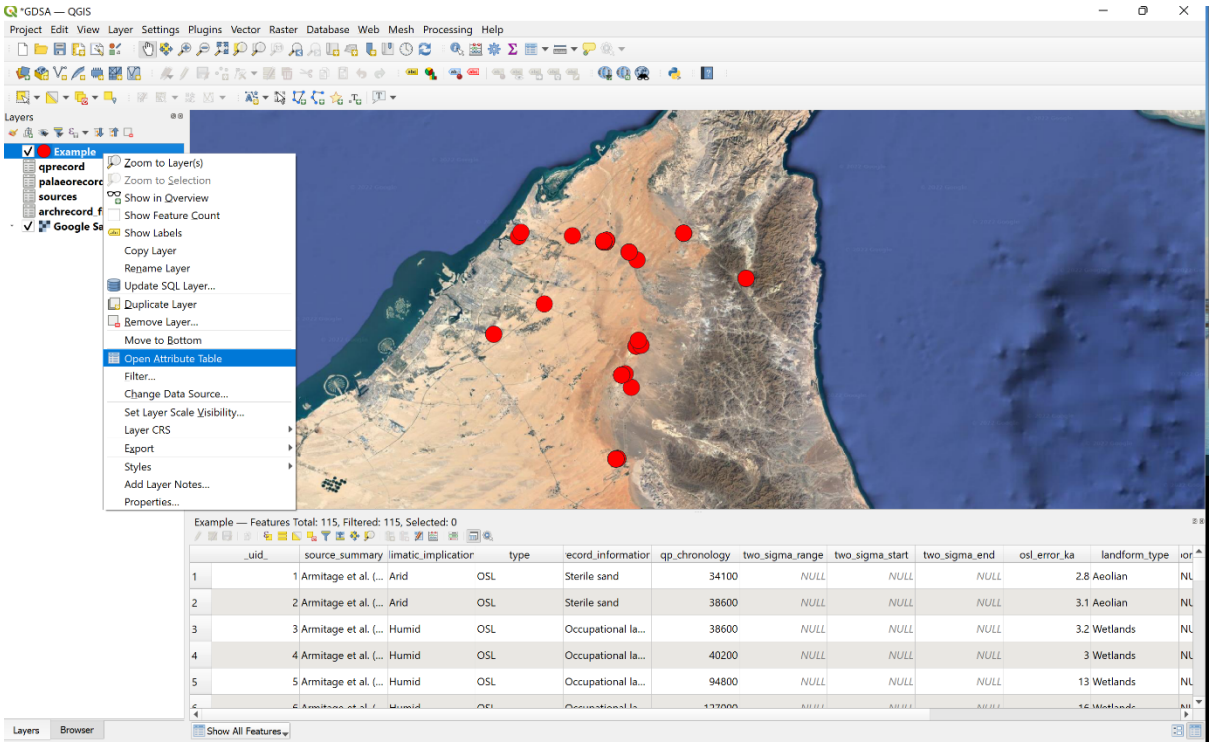


15. Click Load layer and the data will be added to the QGIS Layers list.

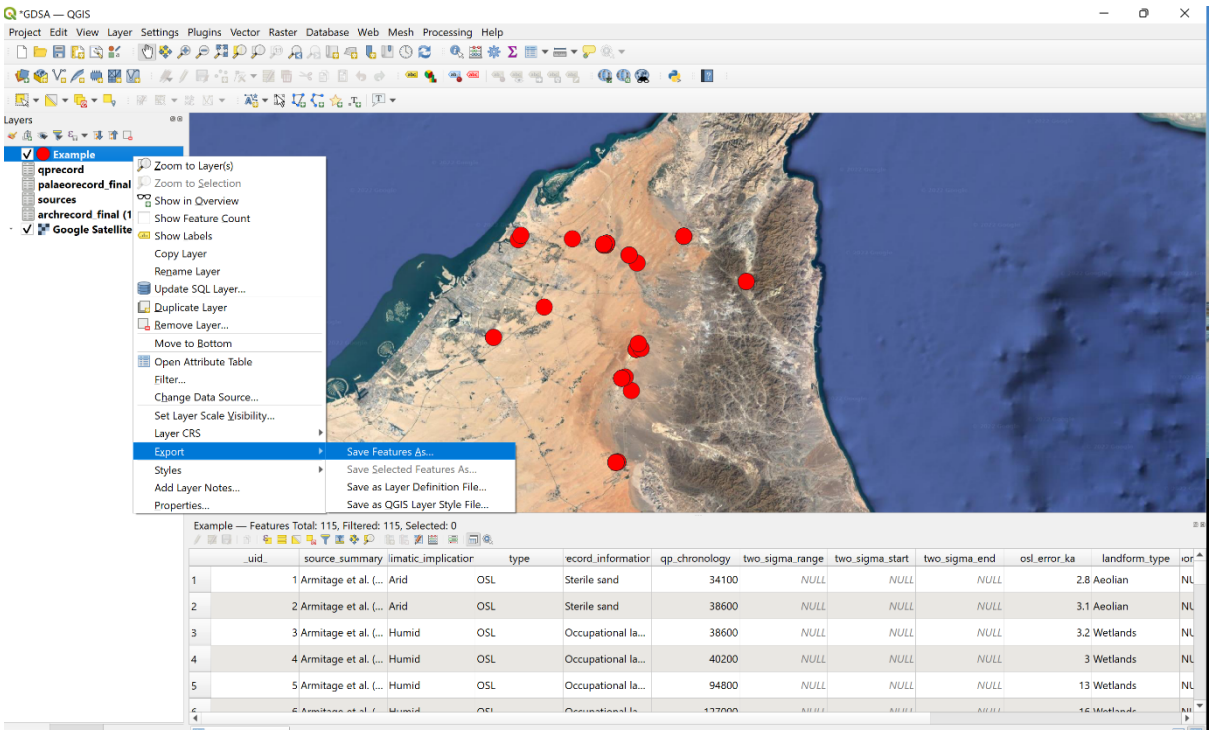


16. Check the data on the Layers tab.

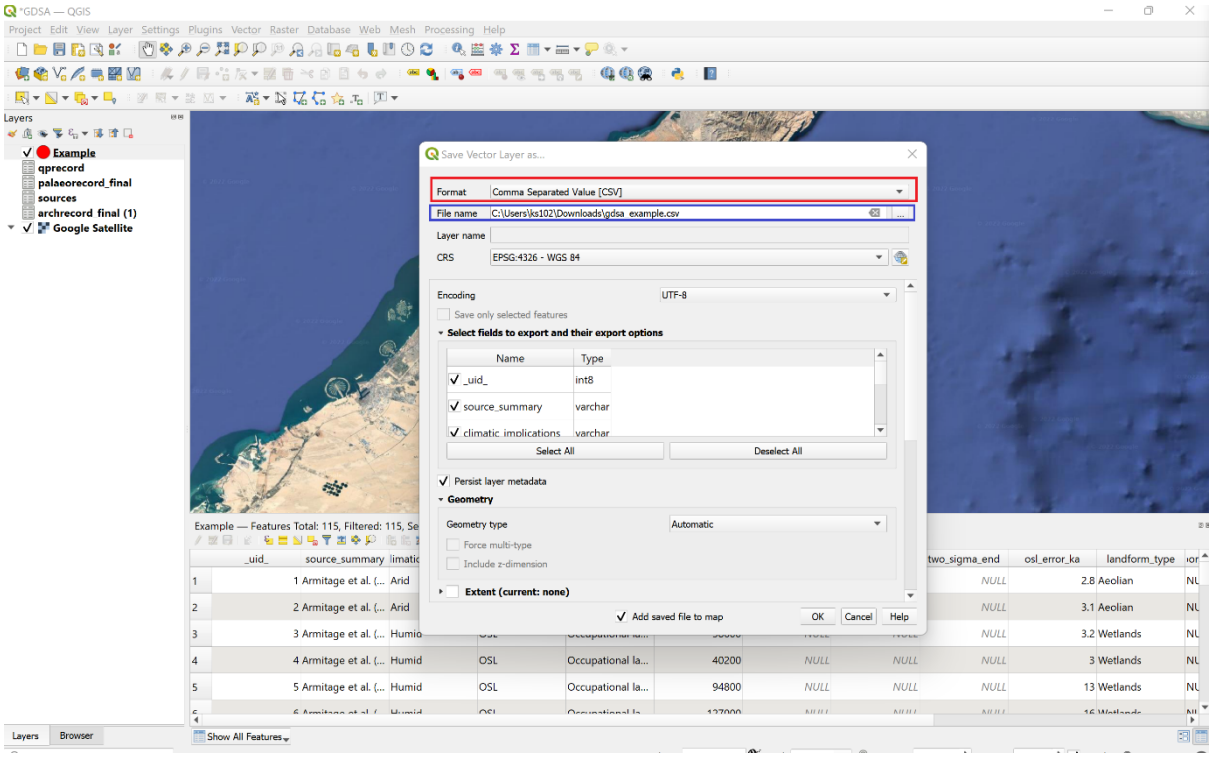
To check the data of the sites and records appearing on the map, right click on the layer (e.g. the Layer called example in the photo) and go to Open Attribute Table



17. To export the data into different formats, right click on the layer and go to Export -> Save Feature as.



18. Choose the type of file you want to export to (excel, KML for Google Earth etc.) and choose the location on your computer where you want to save the file. Then click OK. The layer should be uploaded to your map.



If you have any questions about how to use the database or additional functions that you require, please email Kenta Sayama at kenta.sayama@ouce.ox.ac.uk.

Appendix D: Chapter 6– questionnaires

Wave 1: Survey Registration+Pre-video

The impact of short videos on attitudes toward natural heritage conservation in Southeast Arabia CUREC (Ethics) Approval Reference: SOGE C1A 23 15 Survey 1 (registration and ideas before watching video) This survey will register you to the project, and help us understand your preferences and views before you watch the video. Please note that participation is voluntary. You may withdraw at any point for any reason before submitting your answers by pressing the closing the browser. **General Information** The aim of this study is to understand if and to what extent short videos can influence people's views on natural heritage conservation in Southeast Arabia. To raise awareness of protecting natural heritage sites, communicating the importance of different types of sites is very important. This study aims to understand if and how different short videos can affect the viewers differently. We appreciate your interest in participating in this questionnaire. You have been invited to participate as you are an adult (above 18-years-old) studying at a university in Southeast Arabia, or you are an adult visitor to heritage-related museums/parks/centres, in this region. Please read through this information before agreeing to participate (if you wish to) by ticking the 'yes' box below. You may ask any questions before deciding to take part by contacting the researcher (details below). The Principal Investigator (PI) is Kenta Sayama who is attached to the School of Geography and the Environment at the University of Oxford. This project is being completed under the supervision of Dr Ash Parton, Professor Heather Viles, and Professor Adrian Parker. Through this study, you will be asked to watch a video on natural heritage sites, and answer three questionnaires (before, immediately after, and three months after watching the video). The questionnaires will ask for your opinions toward different types of natural heritage sites in Southeast Arabia, and some questions will ask for your knowledge on them. The length of the video is about 10 minutes and each survey should take about 10-15 minutes. No background knowledge is required. The collected data will be used in analysis to understand how effective the content of each video was in raising awareness of and influencing views towards different types of natural heritage sites in Southeast Arabia. Upon completing the three surveys, you may have a chance to enter a lottery to win merchandise from the University of Oxford, if you have are from one of the universities with geosciences departments in the region, or you registered through the National Museum of Oman, or Mleiha Archaeology Centre. **Do I have to take part?** No. Please note that participation is voluntary. If you do decide to take part, you may withdraw at any point for any reason before submitting your answers by pressing the closing the browser. All questions are optional, except for questions that confirms your eligibility to participate in this study. If you do not want to answer a question, you are welcome to leave the question blank.

How will my data be used? The data we will collect that could identify you will be your name, nationality, place of residence, and contact details. If you do not wish to disclose any of these information, you may leave the answer blank. Your IP address will not be stored[1]. We will take all reasonable measures to ensure that data remain confidential. The responses you provide will be stored in a password-protected electronic file on University of Oxford secure servers and may be used in academic publications, conference presentations, reports for external organisations, and a website. Identifiable information will be deleted as soon as it is no longer required for the research. **Who will have access to my data?** The University of Oxford is the data controller with respect to your personal data and, as such, will determine how your personal data is used in the study. The University will process your personal data for the purpose of the research outlined above. Research is a task that we perform in the public interest. Further information about your rights with respect to your personal data is available from https://compliance.admin.ox.ac.uk/individual-rights. The results will be written up for an academic paper that will contribute to a DPhil (PhD equivalent) degree. **Who has reviewed this study?** This project has been reviewed by, and received ethics clearance through, a subcommittee of the University of Oxford Central University Research Ethics Committee [SOGE C1A 23 15]. **Who do I contact if I have a concern**

or I wish to complain? If you have a concern about any aspect of this study, please speak to Kenta Sayama (kenta.sayama@ouce.ox.ac.uk) or their supervisor Professor Heather Viles (heather.viles@ouce.ox.ac.uk) and we will do our best to answer your query. We will acknowledge your concern within 10 working days and give you an indication of how it will be dealt with. If you remain unhappy or wish to make a formal complaint, please contact the Chair of the Research Ethics Committee at the University of Oxford who will seek to resolve the matter as soon as possible: Social Sciences & Humanities Interdivisional Research Ethics Committee; Email: ethics@socsci.ox.ac.uk; Address: Research Services, University of Oxford, Boundary Brook House, Churchill Drive, Headington, Oxford OX3 7GB

You do not have to prepare anything before answering this survey. It is not a test, and you are not expected to know everything about the questions you are being asked. Please do not worry if you answer "I don't know" to any of these questions. All questions to this survey are optional. If you do not want to answer a question, you are welcome to leave the question blank. If you have a concern about any aspect of this study, please speak to Kenta Sayama (kenta.sayama@ouce.ox.ac.uk) or his supervisor Professor Heather Viles (heather.viles@ouce.ox.ac.uk) and we will do our best to answer your query. We will acknowledge your concern within 10 working days and give you an indication of how it will be dealt with. If you remain unhappy or wish to make a formal complaint, please contact the Chair of the Research Ethics Committee at the University of Oxford who will seek to resolve the matter as soon as possible: Social Sciences & Humanities Interdivisional Research Ethics Committee; Email: ethics@socsci.ox.ac.uk; Address: Research Services, University of Oxford, Boundary Brook House, Churchill Drive, Headington, Oxford OX3 7GB

Qi Please note that you may only participate in this survey if you are 18 years of age or over.

- ○ I certify that I am 18 years of age or over (1)

Qii If you have read the information above and agree to participate with the understanding that the data (including any personal data) you submit will be processed accordingly, please tick the box below to start the survey.

- ○ Yes, I agree to take part (1)

Q1 What is your name?

_____

Q2 What is your nationality?

- Oman (1)
- UAE (2)
- Other (3) _____

Q3 Where do you live?

- Oman (1)
- UAE (2)
- Other (3) _____

Q4 How can the researchers contact you (regarding links to surveys, reminders to answer surveys)?

- Only through email (1)
- Through email and WhatsApp (2)

Q5 What is your email address?

_____

Display This Question:

If How can the researchers contact you (regarding links to surveys, reminders to answer surveys)? = Through email and WhatsApp

Q6 What is your phone (WhatsApp) number?

Q7 Please describe your profession

- ○ University student (geology) (1)
- ○ University student (archaeology) (2)
- ○ University student (other disciplines) (3)
- ○ Working (geology related) (4)
- ○ Working (archaeology related) (5)
- ○ Working (another field) (6)
- ○ Retired (7)
- ○ Unemployed (8)
- ○ Other (9) _____

Q8 What is your highest educational background

- ○ Secondary School Graduate (1)
- ○ Studying in University (undergraduate) (2)
- ○ Studying in University (postgraduate) (3)
- ○ Undergraduate degree (4)
- ○ Postgraduate degree (5)
- ○ Other (6) _____

Q9 Where did you hear about this study?

- ○ German University of Technology in Oman (1)
- ○ Khalifa University (2)
- ○ Mleiha Archaeological Centre (3)
- ○ Oman National Museum (4)
- ○ Sultan Qaboos University (5)
- ○ UAE University (6)
- ○ University of Sharjah (7)
- ○ Social Media (9)
- ○ Friends (10)
- ○ NYUAD (11)
- ○ Sorbonne Abu Dhabi (12)
- ○ Other (8) _____

Q10 Do you prefer to answer the surveys in English or in Arabic?

- ○ English (1)
- ○ Arabic (2)

In this section, you will be answering questions about Natural Heritage Sites.
Natural Heritage sites are all types of heritage sites that involve natural features, including plants, landscapes, rivers, forests, caves, and animals.

Q1 How much do you know about Natural Heritage sites?

- I don’t know anything about it (1)
- I don’t know very much about it (2)
- I have some knowledge about it (3)
- I have a good amount of knowledge about it (4)
- I have extensive knowledge about it (5)
- I prefer not to answer (0)

Q2 How interested are you to learn about Natural Heritage sites?

- I am very interested (I would look for information about it myself) (1)
- I am interested (I would learn about it if I get an opportunity) (2)
- I am a little interested (I would read a few sentences about it if I see it on the news or on my social media feed) (3)
- I am not so interested (I am not sure if I would learn about it even if it is on the news or on my social media feed) (4)
- I am not interested at all (5)
- I prefer not to answer (0)

Q3 Which types of these Natural Heritage sites in the UAE or Oman have you visited?
[You can choose multiple answers for this question]

- ☐ Mountains (1)
- ☐ Beaches (2)
- ☐ Sand Dunes (3)
- ☐ Sabkhas (4)
- ☐ Water Springs (5)
- ☐ Waterfalls (6)
- ☐ Tufas (rock waterfalls) (7)
- ☐ Wadis (8)
- ☐ Caves (9)
- ☐ Others (10) _____
- ☐ None above (11)
- ☐ I prefer not to answer (12)

Q4 Out of 0 (not at all important) to 10 (top priority), how important is it for you to protect Natural Heritage sites?

0 1 2 3 4 5 6 7 8 9 10

Importance of Natural Heritage Sites ()	

n this section, you will be answering questions about Geoheritage, or Geological Heritage sites. Geoheritage sites include Natural Heritage sites that are related to non-living features of nature. In other words, these sites are natural heritage sites without parts that involve live animals or plants.

Geoheritage sites are important to understand the evolution of the Planet Earth and to think about topics such as natural resources, natural hazards, and evolution of life.

Q5 How much do you know about Geoheritage sites?

- I don't know anything about it (1)
- I don't know very much about it (2)
- I have some knowledge about it (3)
- I have a good amount of knowledge about it (4)
- I have extensive knowledge about it (5)
- I prefer not to answer (0)

Q6 Do you know of any Geoheritage sites in Oman or the UAE?

- Yes (1)
- No (2)
- I prefer not to answer (0)

Display This Question:

If Do you know of any Geoheritage sites in Oman or the UAE? = Yes

Q6.1 Which geoheritage sites do you know of?

- [ ] Semail (Oman/UAE) ophiolite (1)
- [ ] Al Hoota Cave (2)
- [ ] Jebel Faya/Jebel Buhais (3)
- [ ] Rub Al Khali Desert (4)
- [ ] As Shaqiyya Sands (Wahiba Sands) (5)
- [ ] Bimma Sink Hole (6)
- [ ] Jebel Hafeet (7)
- [ ] Jebel Al Akhdar (8)
- [ ] Abu Dhabi Sabkha (9)
- [ ] Bander Al Khyran lagoons (10)
- [ ] Ruwais Fossil Site (11)
- [ ] Duqm Rock Garden (12)
- [ ] Al Wathba Fossil Dunes (13)
- [ ] Others (14) _____

Display This Question:

If Do you know of any Geoheritage sites in Oman or the UAE? = Yes

Q6.2 Have you visited any geoheritage sites in the UAE or Oman

- ○ Yes (1)
- ○ No (2)
- ○ I prefer not to answer (0)

Display This Question:

If Have you visited any geoheritage sites in the UAE or Oman = Yes

Q6.3 Which geoheritage sites have you visited? [You can select multiple answers for this question]

- ☐ Semail (Oman/UAE) ophiolite (1)
- ☐ Al Hoota Cave (2)
- ☐ Jebel Faya/Jebel Buhais (3)
- ☐ Rub Al Khali Desert (4)
- ☐ As Shaqiyya Sands (Wahiba Sands) (5)
- ☐ Bimma Sink Hole (6)
- ☐ Jebel Hafeet (7)
- ☐ Jebel Al Akhdar (8)
- ☐ Abu Dhabi Sabkha (9)
- ☐ Bander Al Khyran lagoons (10)

- [ ] Ruwais Fossil Site (11)
- [ ] Duqm Rock Garden (12)
- [ ] Al Wathba Fossil Dunes (13)
- [ ] Others (14) _____

Q7 How interested are you to learn about Geoheritage sites?

- ○ I am very interested (I would look for information about it myself) (1)
- ○ I am interested (I would learn about it if I get an opportunity) (2)
- ○ I am a little interested (I would read a few sentences about it if I see it on the news or on my social media feed) (3)
- ○ I am not so interested (I am not sure if I would learn about it even if it is on the news or on my social media feed) (4)
- ○ I am not interested at all (5)
- ○ I prefer not to answer (0)

Q8 Out of 0 (not important at all) to 10 (top priority), how important is it for you to protect Geoheritage sites?

	0 1 2 3 4 5 6 7 8 9 10
Importance of Geoheritage Sites ()	

In this section, you will be answering questions about Quaternary Geoheritage sites.
Quaternary geoheritage sites are Geoheritage sites from the Quaternary period, which is the past 2.5

million years. This period is very important to understand the Earth as we know today and to understand humans and other animals that live in our planet right now. If you do not know anything about these sites, please do not hesitate to answer that you do not know.

Quaternary Geoheritage sites include different landforms that are considered very young as a Geoheritage site. They are important to understand why the landscape in today's world look the way it does, and to understand climate change in the past, present, and the future.

Q9 How much do you know about Quaternary Geoheirtage sites?

- I don't know anything about it (1)
- I don't know very much about it (2)
- I have some knowledge about it (3)
- I have a good amount of knowledge about it (4)
- I have extensive knowledge about it (5)
- I prefer not to answer (0)

Q10 Do you know of any Quaternary Geoheritage sites in Oman or the UAE?

- Yes (1)
- No (2)
- I prefer not to answer (0)

Display This Question:

If Do you know of any Quaternary Geoheritage sites in Oman or the UAE? = Yes

Q10.1 Which Quaternary Geoheritage sites do you know?
(If you cannot remember the name of the site, please describe what the site to the best of your ability)

_____

Display This Question:

If Do you know of any Quaternary Geoheritage sites in Oman or the UAE? = Yes

Q10.2 Have you visited any Quaternary Geoheritage sites in the UAE or Oman

- Yes (1)
- No (2)
- I prefer not to answer (0)

Display This Question:

If Have you visited any Quaternary Geoheritage sites in the UAE or Oman = Yes

Q10.3 Which Quaternary Geoheritage sites have you visited?
(If you cannot remember the name of the site, please describe what the site to the best of your ability)

_____

Q11 Please select all photos that you think are from Quaternary Geoheritage sites from the photos below. [Please select multiple, if you think there are more than one correct answers]. If you have no idea about the answer, please feel free to select "I don't know the answer".

- [ ] 1 (1)
- [ ] 2 (2)
- [ ] 3 (3)
- [ ] 4 (4)
- [ ] 5 (5)
- [ ] I don't know the answer (6)
- [ ] I prefer not to answer (0)

Q12 How interested are you to learn about Quaternary Geoheritage sites?

- ○ I am very interested (I would look for information about it myself) (1)
- ○ I am interested (I would learn about it if I get an opportunity) (2)
- ○ I am a little interested (I would read a few sentences about it if I see it on the news or on my social media feed) (3)
- ○ I am not so interested (I am not sure if I would learn about it even if it is on the news or on my social media feed) (4)
- ○ I am not interested at all (5)
- ○ I prefer not to answer (0)

Q13 Out of 0 (not important at all) to 10 (top priority), how important is it for you to protect Quaternary Geoheritage sites?

	0 1 2 3 4 5 6 7 8 9 10
Importance of Quaternary Geoheritage Sites ()	

In this section, you will be answering questions about Archaeological sites.

Archaeological sites include sites related to lives of humans in the past.

Archaeological sites are important to understand the lives of humans in the past and to think about the development of the human society.

Q14 How much do you know about Archaeological sites?

- ○ I don’t know anything about it (1)
- ○ I don’t know very much about it (2)
- ○ I have some knowledge about it (3)
- ○ I have a good amount of knowledge about it (4)
- ○ I have extensive knowledge about it (5)
- ○ I prefer not to answer (0)

Q15 Do you know of any Archaeological sites in Oman or the UAE?

- ○ Yes (1)
- ○ No (2)
- ○ I prefer not to answer (0)

Display This Question:

If Do you know of any Archaeological sites in Oman or the UAE? = Yes

Q15.1 Which Archaeological sites do you know of? [You can select multiple answers for this question]

- ☐ Al Bidya Mosque (1)
- ☐ Bat, Al-Khutm and Al-Ayn (Oman) (2)
- ☐ Jebel Faya/Jebel Buhais (Mleiha Archaeological Centre) (3)
- ☐ Hili Archaeological Park (4)
- ☐ Qalhat (5)
- ☐ Jebel Hafit (6)
- ☐ Bayt Al Qefl (7)
- ☐ Wadi Ghadun (8)
- ☐ Others (9) _____

Display This Question:

If Do you know of any Archaeological sites in Oman or the UAE? = Yes

Q15.2 Have you visited any archaeological in the UAE or Oman?

- ○ Yes (1)
- ○ No (2)
- ○ I prefer not to answer (0)

Q16 How interested are you to learn about Archaeological sites?

- ○ I am very interested (I would look for information about it myself) (1)
- ○ I am interested (I would learn about it if I get an opportunity) (2)
- ○ I am a little interested (I would read a few sentences about it if I see it on the news or on my social media feed) (3)
- ○ I am not so interested (I am not sure if I would learn about it even if it is on the news or on my social media feed) (4)
- ○ I am not interested at all (5)
- ○ I prefer not to answer (0)

Q17 Out of 0 (not important at all) to 10 (top priority), how important is it for you to protect Archaeological sites?

	0 1 2 3 4 5 6 7 8 9 10
Importance of Archaeological sites ()	

In this section you will be answering questions about the Geocultural connections, or the connections between Quaternary Geoheritage sites and Archaeological sites.

Quaternary Geoheritage sites have developed and changed after humans were living on the Earth, so there are relationships that you can find between these two types of sites, which can be very interesting for scientists and for the public. This section will ask you about these relationships.

Q18 Do you know anything about how Quaternary geology and archaeology are related?

- No (1)
- Yes, I know a little bit (2)
- Yes, I know a lot (3)
- I prefer not to answer (0)

Display This Question:

If Do you know anything about how Quaternary geology and archaeology are related? = Yes, I know a little bit

Or Do you know anything about how Quaternary geology and archaeology are related? = Yes, I know a lot

Q18.1 Which of these are examples of the relationship between the Quaternary geology and archaeology in Southeast Arabia. [Please select multiple, if you think there are more than one correct answers]

- [ ] Ancient people making stone tools out of specific types of local rocks (1)
- [ ] The relationship between people moving to different areas for better lives and changes in the climate/environment (2)
- [ ] The relationship between location of tall mountains and location of forts/castles (3)
- [ ] The relationship between the location of ancient lakes/rivers and archaeological sites (4)
- [ ] The relationship between dinosaurs and asteroids (5)
- [ ] The local type of rocks and the materials used to construct buildings in the past (6)
- [ ] The change in animals that people hunted for food and the change in climate/environment (7)
- [ ] I prefer not to answer (0)

Q19 How interested are you to learn about the Geocultural relationship, or the relationship between Quaternary Geoheritage sites and Archaeological sites?

- ○ I am very interested (I would look for information about it myself) (1)
- ○ I am interested (I would learn about it if I get an opportunity) (2)
- ○ I am a little interested (I would read a few sentences about it if I see it on the news or on my social media feed) (3)
- ○ I am not so interested (I am not sure if I would learn about it even if it is on the news or on my social media feed) (4)
- ○ I am not interested at all (5)
- ○ I prefer not to answer (0)

Wave 2: Survey Post-Video

The impact of short videos on attitudes toward natural heritage conservation in Southeast Arabia CUREC (Ethics) Approval Reference: SOGE C1A 23 15 Survey 2 (After watching video) This survey will help us understand if and how your preferences and views have changed after you watched the video. Please note that participation is voluntary. You may withdraw at any point for any reason before submitting your answers by pressing the closing the browser.

The only preparation you need before answering is watching the video that you received with the link to this survey. It is not a test, and you do not have to know answers to every question. Please do not worry if you answer "I don't know" to any of these questions. All questions to this survey are optional. If you do not want to answer a question, you are welcome to leave the question blank. If you have a concern about any aspect of this study, please speak to Kenta Sayama (kenta.sayama@ouce.ox.ac.uk) or their supervisor Professor Heather Viles (heather.viles@ouce.ox.ac.uk) and we will do our best to answer your query. We will acknowledge your concern within 10 working days and give you an indication of how it will be dealt with. If you remain unhappy or wish to make a formal complaint, please contact the Chair of the Research Ethics Committee at the University of Oxford who will seek to resolve the matter as soon as possible: Social Sciences & Humanities Interdivisional Research Ethics Committee; Email: ethics@socsci.ox.ac.uk; Address: Research Services, University of Oxford, Boundary Brook House, Churchill Drive, Headington, Oxford OX3 7GB

In this section, you will be answering questions about Geoheritage, or Geological Heritage sites in general. Geoheritage sites include Natural Heritage sites that are related to non-living features of nature. In other words, these sites are natural heritage sites without parts that involve live animals or plants.

Geoheritage sites are important to understand the evolution of the Planet Earth and to think about topics such as natural resources, natural hazards, and evolution of life.

Q6 How interested are you to learn about Geoheritage sites in general?

- ○ I am very interested (I would look for information about it myself) (1)
- ○ I am interested (I would learn about it if I get an opportunity) (2)
- ○ I am a little interested (I would read a few sentences about it if I see it on the news or on my social media feed) (3)
- ○ I am not so interested (I am not sure if I would learn about it even if it is on the news or on my social media feed) (4)
- ○ I am not interested at all (5)
- ○ I prefer not to answer (0)

Q7 Out of 0 (not important at all) to 10 (top priority), how important is it for you to protect Geoheritage sites?

	0 1 2 3 4 5 6 7 8 9 10
Importance of Geoheritage Sites ()	

In this section, you will be answering questions about Quaternary Geoheritage sites.
Quaternary geoheritage sites are Geoheritage sites from the Quaternary period, which is the past 2.5 million years. This period is very important to understand the Earth as we know today and to understand humans and other animals that live in our planet right now.

Quaternary Geoheritage sites include different landforms that are considered very young as a Geoheritage site. They are important to understand why the landscape in today's world look the way it does, and to understand climate change in the past, present, and the future.

Q1 How much do you know about Quaternary Geoheirtage sites?

- Very well (1)
- Quite well (2)
- I know the basics (3)
- Not very much (4)
- None at all (5)
- I prefer not to answer (0)

Q2 Do you know of any Quaternary Geoheritage sites in Oman or the UAE?

- Yes (1)
- No (2)
- I prefer not to answer (0)

Display This Question:

If Do you know of any Quaternary Geoheritage sites in Oman or the UAE? = Yes

Q2.1 Which Quaternary Geoheritage sites do you know?
(If you cannot remember the name of the site, please describe what the site to the best of your ability)

_____

Display This Question: ilf Do you know of any Quaternary Geoheritage sites in Oman or the UAE? = Yes

Q2.2 Have you visited any Quaternary Geoheritage sites in the UAE or Oman

- ○ Yes (1)
- ○ No (2)
- ○ I prefer not to answer (0)

Display This Question:

If Have you visited any Quaternary Geoheritage sites in the UAE or Oman = Yes

Q2.3 Which Quaternary Geoheritage sites have you visited?
(If you cannot remember the name of the site, please describe what the site to the best of your ability)

_____

Q3 Please select all photos that you think are from Quaternary Geoheritage sites from the photos below. If you have no idea about the answer, please feel free to select "I don't know the answer".

- ☐ 1 (1)
- ☐ 2 (2)
- ☐ 3 (3)
- ☐ 4 (4)
- ☐ 5 (5)
- ☐ I don't know the answer (0)

Q4 How interested are you to learn about Quaternary Geoheritage sites?

- ○ I am very interested (I would look for information about it myself) (1)
- ○ I am interested (I would learn about it if I get an opportunity) (2)
- ○ I am a little interested (I would read a few sentences about it if I see it on the news or on my social media feed) (3)
- ○ I am not so interested (I am not sure if I would learn about it even if it is on the news or on my social media feed) (4)
- ○ I am not interested at all (5)
- ○ I prefer not to answer (0)

Q5 Out of 0 (not important at all) to 10 (top priority), how important is it for you to protect Quaternary Geoheritage sites?

	0 1 2 3 4 5 6 7 8 9 10
Importance of protecting Quaternary Geoheritage Sites ()	

In this section, you will be answering questions about Archaeological sites.

Archaeological sites include sites related to lives of humans in the past.

Archaeological sites are important to understand the lives of humans in the past and to think about the development of the human society.



Q8 How much do you know about Archaeological sites?

- ○ Very well (1)
- ○ Quite well (2)
- ○ I know the basics (3)
- ○ Not very much (4)
- ○ None at all (5)
- ○ I prefer not to answer (0)

Q9 Do you know of any Archaeological sites in Oman or the UAE?

- ○ Yes (1)
- ○ No (2)



Q10 How interested are you to learn about Archaeological sites?

- ○ I am very interested (I would look for information about it myself) (1)
- ○ I am interested (I would learn about it if I get an opportunity) (2)
- ○ I am a little interested (I would read a few sentences about it if I see it on the news or on my social media feed) (3)
- ○ I am not so interested (I am not sure if I would learn about it even if it is on the news or on my social media feed) (4)
- ○ I am not interested at all (5)
- ○ I prefer not to answer (0)

Q11 Out of 0 (not important at all) to 10 (top priority), how important is it for you to protect Archaeological sites?

	0 1 2 3 4 5 6 7 8 9 10
Importance of protecting Archaeological sites ()	

In this section you will be answering questions about the Geocultural connections, or the connections between Quaternary Geoheritage sites and Archaeological sites.

Quaternary Geoheritage sites have developed and changed after humans were living on the Earth, so there are relationships that you can find between these two types of sites, which can be very interesting for scientists and for the public. This section will ask you about these relationships.

Q12 Do you know anything about how Quaternary geology and archaeology are related?

- Yes, I know a lot (1)
- Yes, I know a little bit (2)
- No (3)
- I prefer not to answer (0)

Display This Question:

If Do you know anything about how Quaternary geology and archaeology are related? = Yes, I know a little bit

Or Do you know anything about how Quaternary geology and archaeology are related? = Yes, I know a lot

Q12.1 Which of these are examples of the relationship between the Quaternary geology and archaeology in Southeast Arabia. [Please select multiple, if you think there are more than one correct answers]

- [ ] Ancient people making tools out of specific types of local rocks (1)
- [ ] The relationship between people moving to different areas for better lives and changes in the climate/environment (2)
- [ ] The relationship between location of tall mountains and location of forts/castles (3)
- [ ] The relationship between ancient lakes/rivers and archaeological finds (4)
- [ ] The relationship between dinosaurs and asteroids (5)
- [ ] The local type of rocks and the materials used to construct buildings (6)
- [ ] The change in animals that people hunted for food and the change in climate/environment (7)

Q13 How interested are you to learn about the Geocultural relationship, or the relationship between Quaternary Geoheritage sites and Archaeological sites?

- ○ I am very interested (I would look for information about it myself) (1)
- ○ I am interested (I would learn about it if I get an opportunity) (2)
- ○ I am a little interested (I would read a few sentences about it if I see it on the news or on my social media feed) (3)
- ○ I am not so interested (I am not sure if I would learn about it even if it is on the news or on my social media feed) (4)
- ○ I am not interested at all (5)
- ○ I prefer not to answer (0)

Q14 Having watched the video, out of 0 (will definitely NOT read or watch anything) to 10 (will definitely read or watch some of the materials), how likely are you to read or watch materials provided with the video?

	0 1 2 3 4 5 6 7 8 9 10
Likelihood of reading or watching more materials ()	

Wave 3: Survey 3-months-after

The impact of short videos on attitudes toward natural heritage conservation in Southeast Arabia
CUREC (Ethics) Approval Reference: SOGE C1A 23 15 Final Survey (3-months after watching Video)

This survey will help us understand how your preferences and views have changed in a longer timeframe. It will also help understand how much you remember from the surveys as well. Please note that participation is voluntary. You may withdraw at any point for any reason before submitting your answers by pressing the closing the browser.

You do not need any preparation before answering this survey. It is not a test, and you do not have to know answers to every question. Please do not worry if you answer "I don't know" to any of these questions.

All questions to this survey are optional. If you do not want to answer a question, you are welcome to leave the question blank.

If you have a concern about any aspect of this study, please speak to Kenta Sayama (kenta.sayama@ouce.ox.ac.uk) or their supervisor Professor Heather Viles (heather.viles@ouce.ox.ac.uk) and we will do our best to answer your query. We will acknowledge your concern within 10 working days and give you an indication of how it will be dealt with. If you remain unhappy or wish to make a formal complaint, please contact the Chair of the Research Ethics Committee at the University of Oxford who will seek to resolve the matter as soon as possible: Social Sciences & Humanities Interdivisional Research Ethics Committee; Email: ethics@socsci.ox.ac.uk; Address: Research Services, University of Oxford, Boundary Brook House, Churchill Drive, Headington, Oxford OX3 7GB

In this section, you will be answering questions about how the video affected you. We are keen to learn what you thought about the video!

Q1 How many times have you watched the video?

- ○ 1 time
- ○ 2 times
- ○ more than 3 times

Q2 Do you remember the contents of the video?

- ○ Yes
- ○ No
- ○ I remember some aspects

Q3 [Multiple choice] what aspects of the video left the strongest impressions for you?

- ○ Beautiful scenery
- ○ Scientific importance of geoheritage sites
- ○ Connections between Quaternary geology and culture/archaeology
- ○ Interviews with local geoscientists
- ○ Importance of protecting geoheritage sites
- ○ The connection between Quaternary geology and climate change
- ○ Other _____

Q4 What did you think of the length of the video

- ○ Too short
- ○ Little too short
- ○ Just right
- ○ Little too long
- ○ Too long

Q5 Please write any comments if you remember what you liked about the video or what you learned from the video.

_____

Q6 Please write any comments if you have ideas on how the video could have been improved.

_____

In this section, you will be answering questions about Geoheritage, or Geological Heritage sites in general. Geoheritage sites include Natural Heritage sites that are related to non-living features of nature. In other words, these sites are natural heritage sites without parts that involve live animals or plants.

Geoheritage sites are important to understand the evolution of the Planet Earth and to think about topics such as natural resources, natural hazards, and evolution of life.

Q6 How interested are you to learn about Geoheritage sites in general?

- ○ I am very interested (I would look for information about it myself)
- ○ I am interested (I would learn about it if I get an opportunity)
- ○ I am a little interested (I would read a few sentences about it if I see it on the news or on my social media feed)
- ○ I am not so interested (I am not sure if I would learn about it even if it is on the news or on my social media feed)
- ○ I am not interested at all

Q7 Out of 0 (not important at all) to 10 (top priority), how important is it for you to protect Geoheritage sites?

	0 1 2 3 4 5 6 7 8 9 10
Importance of Geoheritage Sites	

Q8 How did the video affect your level of interest in geoheritage sites?

- ○ It made me less interested in geoheritage sites
- ○ It made me a little less interested in geoheritage sites
- ○ It did not change my interest in geoheritage sites
- ○ It made me a little more interested in geoheritage sites
- ○ It made me more entered in geoheritage sites

In this section, you will be answering questions about Quaternary Geoheritage sites.
Quaternary geoheritage sites are Geoheritage sites from the Quaternary period, which is the past 2.5 million years. This period is very important to understand the Earth as we know today and to understand humans and other animals that live in our planet right now.

Quaternary Geoheritage sites include different landforms that are considered very young as a Geoheritage site. They are important to understand why the landscape in today's world look the way it does, and to understand climate change in the past, present, and the future.

Q9 How much do you know about Quaternary Geoheritage sites?

- ○ Very well
- ○ Quite well
- ○ I know the basics
- ○ Not very much
- ○ None at all

Q10 Do you know of any Quaternary Geoheritage sites in Oman or the UAE?

- ○ Yes
- ○ No

Q11 Please select all photos that you think are from Quaternary Geoheritage sites from the photos below. If you have no idea about the answer, please feel free to select "I don't know the answer".

- [ ] Image:Pillow lava
- [ ] Image:Wadi ghub
- [ ] Image:Sabkha 6 white lake ish
- [ ] Image:Cave photo
- [ ] Image:Rub al khali goudie
- [ ] I don't know the answer

Q12 How interested are you to learn more about Quaternary Geoheritage sites?

- ○ I am very interested (I would look for information about it myself)
- ○ I am interested (I would learn about it if I get an opportunity)
- ○ I am a little interested (I would read a few sentences about it if I see it on the news or on my social media feed)
- ○ I am not so interested (I am not sure if I would learn about it even if it is on the news or on my social media feed)
- ○ I am not interested at all

Q13 How did the video affect your level of interest in Quaternary geoheritage sites?

- ○ It made me less interested in Quaternary geoheritage sites
- ○ It made me a little less interested in Quaternary geoheritage sites
- ○ It did not change my interest in Quaternary geoheritage sites
- ○ It made me a little more interested in Quaternary geoheritage sites
- ○ It made me more entered in Quaternary geoheritage sites

Q14 Out of 0 (not important at all) to 10 (top priority), how important is it for you to protect Quaternary Geoheritage sites?

	0 1 2 3 4 5 6 7 8 9 10
Importance of protecting Quaternary Geoheritage Sites	

In this section, you will be answering questions about Archaeological sites.

Archaeological sites include sites related to lives of humans in the past.

Archaeological sites are important to understand the lives of humans in the past and to think about the development of the human society.

Q15 Do you know of any Archaeological sites in Oman or the UAE?

- ○ Yes
- ○ No

Q16 How interested are you to learn more about Archaeological sites?

- ○ I am very interested (I would look for information about it myself)
- ○ I am interested (I would learn about it if I get an opportunity)
- ○ I am a little interested (I would read a few sentences about it if I see it on the news or on my social media feed)
- ○ I am not so interested (I am not sure if I would learn about it even if it is on the news or on my social media feed)
- ○ I am not interested at all

Q17 Out of 0 (not important at all) to 10 (top priority), how important is it for you to protect Archaeological sites?

	0 1 2 3 4 5 6 7 8 9 10
Importance of protecting Archaeological sites	

Q24 How did the video affect your level of interest in archaeological sites?

- ○ It made me less interested in archaeological sites
- ○ It made me a little less interested in archaeological sites
- ○ It did not change my interest in archaeological sites
- ○ It made me a little more interested in archaeological sites
- ○ It made me more interested in Quaternary geoheritage sites

In this section you will be answering questions about the Geocultural connections, or the connections between Quaternary Geoheritage sites and Archaeological sites.

Quaternary Geoheritage sites have developed and changed after humans were living on the Earth, so there are relationships that you can find between these two types of sites, which can be very interesting for scientists and for the public. This section will ask you about these relationships.

Q18 Do you know anything about how Quaternary geology and archaeology are related?

- Yes, I know a lot
- Yes
- Yes, I know a little bit
- No

Display This Question:

If Q18 = Yes

Or Q18 = Yes, I know a lot

Or Q18 = Yes, I know a little bit

Q19.1 Which of these are examples of the relationship between the Quaternary geology and archaeology in Southeast Arabia. [Please select multiple, if you think there are more than one correct answers]

- [ ] Ancient people making tools out of specific types of local rocks
- [ ] The relationship between people moving to different areas for better lives and changes in the climate/environment
- [ ] The relationship between location of tall mountains and location of forts/castles
- [ ] The relationship between ancient lakes/rivers and archaeological finds
- [ ] The relationship between dinosaurs and asteroids
- [ ] The local type of rocks and the materials used to construct buildings
- [ ] The change in animals that people hunted for food and the change in climate/environment

Q20 How interested are you to learn about the Geocultural relationship, or the relationship between Quaternary Geoheritage sites and Archaeological sites?

- ○ I am very interested (I would look for information about it myself)
- ○ I am interested (I would learn about it if I get an opportunity)
- ○ I am a little interested (I would read a few sentences about it if I see it on the news or on my social media feed)
- ○ I am not so interested (I am not sure if I would learn about it even if it is on the news or on my social media feed)
- ○ I am not interested at all

In this section, you will be asked about your activities over the last 3 months, after watching the video for this study for the first time.

Please answer the questions honestly, to the best of your ability.

Q21 After watching the video for this study, did you watch or read anything more about Quaternary geoheritage, archaeology, or geoheritage in general?

- ○ Yes
- ○ No

Q22 In the last 3 months, did you visit any Quaternary geoheritage sites?

- ○ Yes
- ○ No

Display This Question:

If Q22 = Yes

Q22.1 Did you go to one of the sites introduced in the video?

- ○ Yes
- ○ No
- ○ I don't remember

Q23 Did the video make you more interested to visit Quaternary Geoheritage sites?

- ○ Yes
- ○ No

Appendix E: Chapter 6– details of the difference in differences analyses

List of abbreviations

WaveNum: This represents the DiD coefficient which presents the interaction effect between the treatment group and the specified survey wave. For example, WaveNum = 2 × TreatGroup indicates how much better the treatment group did in the 2nd Wave, relative to the control group.

Num.Obs.: Number of observations used in the analysis.

R2: Coefficient of determination or R-squared, which indicates the proportion of variance in the dependent variable explained by the independent variables in the regression model. In simple terms, it is a measure of the explanatory power of the independent variables in interpreting changes in the dependent variable.

R2 Adj.: Adjusted R-squared, which adjusts the R-squared value for the number of predictors in the model.

R2 Within: R-squared within, which represents the extent of variance in the dependent variable explained by the independent variables within each group or category.

R2 Within Adj.: Adjusted R-squared within, which adjusts the R-squared within value by the number of predictors in the model within each group or category.

AIC: Akaike Information Criterion, which measures the relative quality of a statistical model for a given set of data. Lower AIC values indicate better-fitting models. These values are used in comparison with results from competing models to determine the model with the best fit for the data.

BIC: Bayesian Information Criterion, which is a value similar to AIC that measures the relative quality of the statistical model for a given set of data. Compared to the AIC, it penalises more complex models more heavily. Lower values here indicate better-fitting models.

RMSE: Root Mean Square Error, which represents the average deviation between predicted and observed outcomes from the analysis. A lower RMSE indicates a better fitting model that provides a more reliable and accurate estimates of the treatment effect.

Std.Errors: Standard errors of the coefficients estimated in the model.

FE: Fixed Effects, which indicates whether there was the inclusion of fixed effects in the regression model for specific categories such as W1_ExperimentGroup, survey_wave, and WaveNum.

p: p-value for the each analysis, which shows the significance of the estimated treatment effect.

Chapter 6.4.3.4.1

Self-reported interested in Quaternary Geoheritage—Overall

	Overall	By Wave
	0.070***	
WaveNum = 2 × TreatGroup		0.067***
WaveNum = 3 × TreatGroup		0.073***
Num.Obs.	225	225
R2	0.054	0.054
R2 Adj.	0.037	0.033
R2 Within	0.001	0.001
R2 Within Adj.	-0.004	-0.009
AIC	490.4	492.4
BIC	507.5	512.9
RMSE	0.70	0.70
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: survey_wave	X	
FE: WaveNum		X

* p < 0.1, ** p < 0.05, *** p < 0.01

Self-reported interested in Quaternary Geoheritage —Separated by level of expertise

	Specialist	**Non-Specialist**
WaveNum = 2 × TreatGroup	0.056***	0.003***
WaveNum = 3 × TreatGroup	-0.056***	0.155***
Num.Obs.	108	117
R2	0.044	0.131
R2 Adj.	-0.003	0.092
R2 Within	0.001	0.003
R2 Within Adj.	-0.018	-0.015
AIC	204.2	261.4
BIC	220.3	278.0
RMSE	0.59	0.70
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: WaveNum	X	X

* p < 0.1, ** p < 0.05, *** p < 0.01

Chapter 6.4.3.4.2

Self-reported level of knowledge about Quaternary Geoheritage—Overall

	Overall	By Wave
	-0.169***	
WaveNum = 2 × TreatGroup		-0.251***
WaveNum = 3 × TreatGroup		-0.087***
Num.Obs.	234	234
R2	0.211	0.212
R2 Adj.	0.197	0.195
R2 Within	0.002	0.003
R2 Within Adj.	-0.003	-0.006
AIC	660.6	662.4
BIC	667.9	683.1
RMSE	0.97	0.97
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: survey_wave	X	
FE: WaveNum		X

* p < 0.1, ** p < 0.05, *** p < 0.01

Self-reported level of knowledge about Quaternary Geoheritage —Separated by level of expertise

	Specialist	**Non-Specialist**
WaveNum = 2 × TreatGroup	-0.302***	-0.106***
WaveNum = 3 × TreatGroup	-0.222***	-0.101***
Num.Obs.	117	117
R2	0.285	0.259
R2 Adj.	0.253	0.225
R2 Within	0.005	0.001
R2 Within Adj.	-0.013	-0.017
AIC	328.2	311.0
BIC	344.8	327.5
RMSE	0.93	0.87
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: WaveNum	X	X

* p < 0.1, ** p < 0.05, *** p < 0.01

Chapter 6.4.3.4.3

Photo quiz on Quaternary geoheritage sites, score—Overall

	Overall	By Wave
	-0.117***	
WaveNum = 2 × TreatGroup		-0.422***
WaveNum = 3 × TreatGroup		0.189***
Num.Obs.	312	312
R2	0.111	0.121
R2 Adj.	0.100	0.107
R2 Within	0.001	0.012
R2 Within Adj.	-0.003	0.005
AIC	994	992.4
BIC	1012.7	1014.9
RMSE	1.17	1.16
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: survey_wave	X	
FE: WaveNum		X

* p < 0.1, ** p < 0.05, *** p < 0.01

Photo quiz on Quaternary geoheritage sites, score—Separated by level of expertise

	Specialist	**Non-Specialist**
WaveNum = 2 × TreatGroup	-0.458***	-0.386***
WaveNum = 3 × TreatGroup	0.490***	-0.045***
Num.Obs.	144	168
R2	0.110	0.153
R2 Adj.	0.078	0.127
R2 Within	0.021	0.008
R2 Within Adj.	0.007	-0.004
AIC	500.6	472.7
BIC	518.4	491.5
RMSE	1.32	0.95
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: WaveNum	X	X

* p < 0.1, ** p < 0.05, *** p < 0.01

Chapter 6.4.3.4.4

Protection Priority for Quaternary Geoheritage Sites—Overall

	Overall	By Wave
	0.428***	
WaveNum = 2 × TreatGroup		0.537***
WaveNum = 3 × TreatGroup		0.319***
Num.Obs.	222	222
R2	0.050	0.050
R2 Adj.	0.032	0.028
R2 Within	0.004	0.004
R2 Within Adj.	-0.001	-0.005
AIC	869.6	871.4
BIC	886.6	891.8
RMSE	1.68	1.68
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: survey_wave	X	
FE: WaveNum		X

* p < 0.1, ** p < 0.05, *** p < 0.01

Protection Priority for Quaternary Geoheritage Sites—Separated by level of expertise

	Specialist	**Non-Specialist**
WaveNum = 2 × TreatGroup	0.227***	0.517***
WaveNum = 3 × TreatGroup	0.196***	0.308***
Num.Obs.	105	117
R2	0.029	0.091
R2 Adj.	-0.020	0.050
R2 Within	0.002	0.003
R2 Within Adj.	-0.0019	-0,015
AIC	359.9	488.7
BIC	375.8	505.2
RMSE	1.27	1.86
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: WaveNum	X	X

* p < 0.1, ** p < 0.05, *** p < 0.01

Chapter 6.4.3.4.4

Protection Priority for Quaternary Geoheritage Sites—Overall

	Overall	By Wave
	0.428***	
WaveNum = 2 × TreatGroup		0.537***
WaveNum = 3 × TreatGroup		0.319***
Num.Obs.	222	222
R2	0.050	0.050
R2 Adj.	0.032	0.028
R2 Within	0.004	0.004
R2 Within Adj.	-0.001	-0.005
AIC	869.6	871.4
BIC	886.6	891.8
RMSE	1.68	1.68
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: survey_wave	X	
FE: WaveNum		X

* p < 0.1, ** p < 0.05, *** p < 0.01

Protection Priority for Quaternary Geoheritage Sites—Separated by level of expertise

	Specialist	**Non-Specialist**
WaveNum = 2 × TreatGroup	0.227***	0.517***
WaveNum = 3 × TreatGroup	0.196***	0.308***
Num.Obs.	105	117
R2	0.029	0.091
R2 Adj.	-0.020	0.050
R2 Within	0.002	0.003
R2 Within Adj.	-0.019	-0.015
AIC	359.9	488.7
BIC	375.8	505.2
RMSE	1.27	1.86
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: WaveNum	X	X

* p < 0.1, ** p < 0.05, *** p < 0.01

Chapter 6.4.3.5.1

Self-reported interest in the geocultural relationship—Overall

	Overall	By Wave
	0.261***	
WaveNum = 2 × TreatGroup		0.165***
WaveNum = 3 × TreatGroup		0.357***
Num.Obs.	225	225
R2	0.045	0.048
R2 Adj.	0.028	0.026
R2 Within	0.008	0.011
R2 Within Adj.	0.003	0.002
AIC	488.5	489.9
BIC	505.6	510.3
RMSE	0.70	0.70
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: survey_wave	X	
FE: WaveNum		X

* p < 0.1, ** p < 0.05, *** p < 0.01

Self-reported interest in the geocultural relationship—Separated by level of expertise

	Specialist	**Non-Specialist**
WaveNum = 2 × TreatGroup	0.067***	0.193***
WaveNum = 3 × TreatGroup	0.167***	0.562***
Num.Obs.	114	111
R2	0.011	0.105
R2 Adj.	-0.035	0.063
R2 Within	0.003	0.023
R2 Within Adj.	-0.015	0.004
AIC	359.9	488.7
BIC	375.8	505.2
RMSE	1.27	1.86
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: WaveNum	X	X

* p < 0.1, ** p < 0.05, *** p < 0.01

Chapter 6.4.3.5.2

Self-reported knowledge in the geocultural relationship—Overall

	Overall	By Wave
	0.037***	
WaveNum = 2 × TreatGroup		-0.007***
WaveNum = 3 × TreatGroup		0.080***
Num.Obs.	165	165
R2	0.07	0.041
R2 Adj.	0.046	0.041
R2 Within	0	0.001
R2 Within Adj.	-0.006	-0.011
AIC	298.3	300.2
BIC	313.9	318.8
RMSE	0.58	0.58
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: survey_wave	X	
FE: WaveNum		X

* p < 0.1, ** p < 0.05, *** p < 0.01

Self-reported knowledge in the geocultural relationship—Separated by level of expertise

	Specialist	**Non-Specialist**
WaveNum = 2 × TreatGroup	-0.091***	0.011***
WaveNum = 3 × TreatGroup	0	0.135***
Num.Obs.	66	99
R2	0.205	0.093
R2 Adj.	0.138	0.044
R2 Within	0.002	0.003
R2 Within Adj.	-0.032	-0.019
AIC	114.9	179.6
BIC	128	195.1
RMSE	0.53	0.56
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: WaveNum	X	X

* p < 0.1, ** p < 0.05, *** p < 0.01

Chapter 6.4.3.5.3

Quiz on geocultural relationship, score—Overall

	Overall	By Wave
	-0.008***	
WaveNum = 2 × TreatGroup		0.026***
WaveNum = 3 × TreatGroup		-0.043***
Num.Obs.	312	312
R2	0.044	0.044
R2 Adj.	0.031	0.028
R2 Within	0.000	0.000
R2 Within Adj.	-0.003	-0.006
AIC	908.4	910.3
BIC	927.1	932.8
RMSE	1.02	1.02
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: survey_wave	X	
FE: WaveNum		X

* p < 0.1, ** p < 0.05, *** p < 0.01

Quiz on geocultural relationship, score—Separated by level of expertise

	Specialist	Non-Specialist
WaveNum = 2 × TreatGroup	-0.098***	0.124***
WaveNum = 3 × TreatGroup	-0.133***	0.038***
Num.Obs.	144	168
R2	0.065	0.039
R2 Adj.	0.031	0.009
R2 Within	0.001	0.001
R2 Within Adj.	-0.014	-0.012
AIC	431.0	488.0
BIC	448.8	506.7
RMSE	1.04	1.00
Std.Errors	by: W1_ExperimentGroup	by: W1_ExperimentGroup
FE: W1_ExperimentGroup	X	X
FE: WaveNum	X	X

* p < 0.1, ** p < 0.05, *** p < 0.01

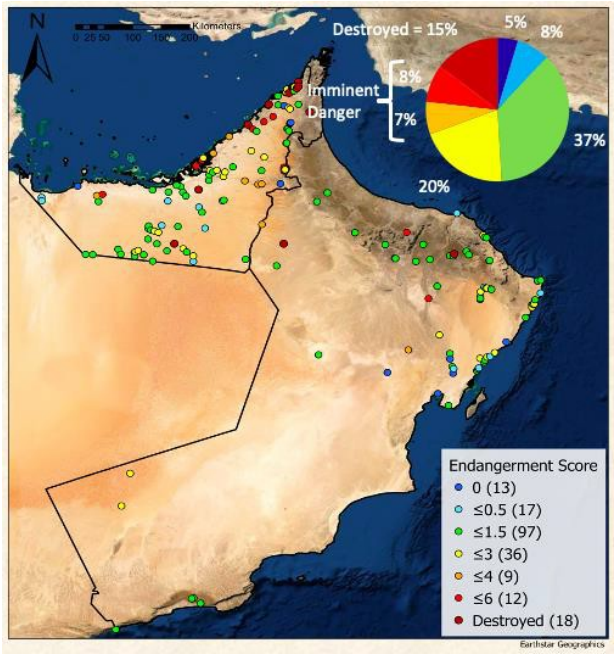
Appendix F: Chapter 7– advert used for participation recruitment

Ethics Approval Reference: [SOGE 1A2020-207]

VOLUNTEERS NEEDED

EVALUATION OF THE SCIENTIFIC VALUE OF QUATERNARY GEOHERITAGE SITES IN ARID ENVIRONMENTS

As shown by the establishment of the UNESCO Global Geoparks program in 2015, conservation of geological heritage sites is growing worldwide. Yet, Quaternary geoheritage sites, such as palaeoenvironmental archives in the MENA region remain largely unprotected, and as shown in this image, many have already been destroyed. To protect these sites, a fair evaluation of their heritage values is important. Yet, in most previous literature, the scientific value of geoheritage sites have been decided using methods developed by the expert knowledge of a few researchers, without input from the broader scientific community. Furthermore, none of these methods have been developed specifically for an arid environment like the Arabian peninsula. To create a more objective and environment specific method of geoheritage scientific value assessment, this



project will collect inputs from scholars from various disciplines, such as palaeoenvironmental scientists, geologists, archaeologists, and anthropologists, with interest in arid environments. The survey will help form an evaluation method that will help academics and conservation specialists working in arid regions to protect the most important sites for future generations.

We are looking for volunteers, who are current postgraduate students or academics in the field of geosciences, evolutionary anthropology, or archaeology, with research interest in arid environments to answer an online questionnaire (To access the survey, please use the QR code or go to https://oxford.onlinesurveys.ac.uk/scientific-evaluation). You will be asked to answer questions about your opinions on the relative importance of various factors related to the evaluation of the scientific value of geoheritage sites in the Middle East region.

If you need more information, please email Kenta Sayama at kenta.sayama@ouce.ox.ac.uk. There is no obligation to take part. The survey will close on Jan. 31st, 2022.

Thank you very much!!

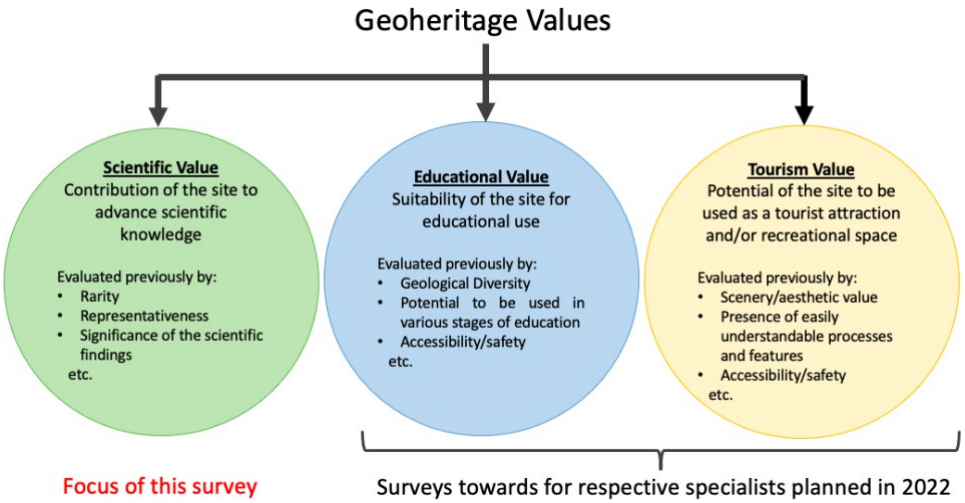


Figure 1. Concept of this survey project



Figure 2. Examples of Quaternary palaeoenvironmental sites. A palaeolake site in Central Oman (left) and a wadi sediment sequence in West Oman (right).



Figure 3. Satellite imageries of the Al Sibetah site from Parton et al. (2013). It was filled by wastewater a year after the fieldwork was conducted.

Appendix G: Chapter 7– questionnaire

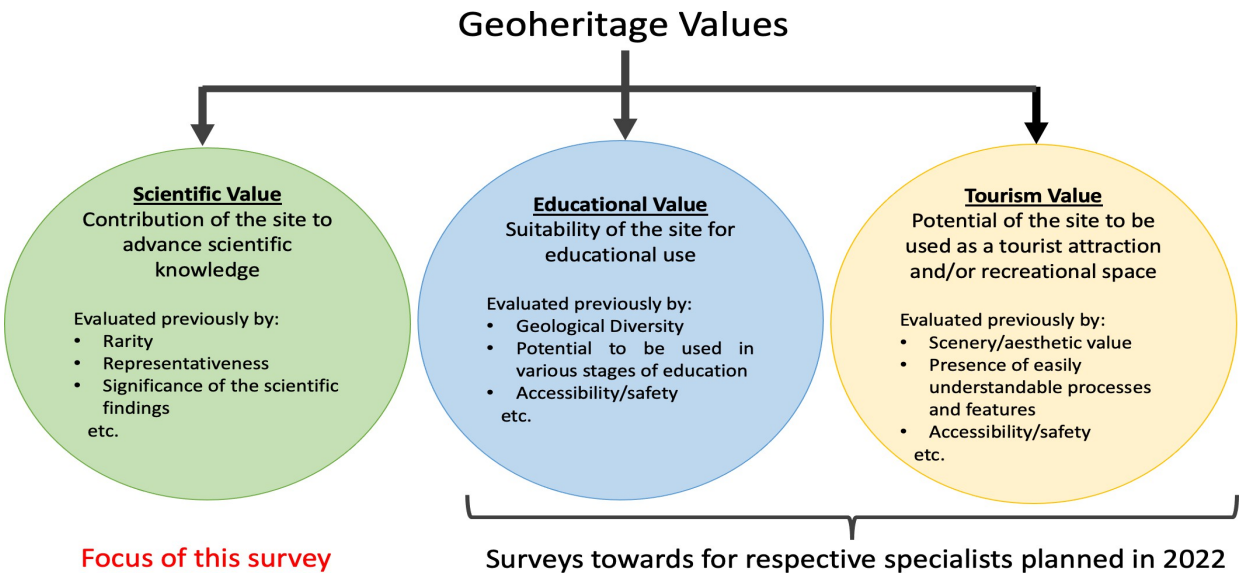
Evaluating the relative importance of factors related to the scientific value of Quaternary geoheritage sites in Arid Environments

CUREC Approval Reference: SOGE 1A2020-207

General Information

The aim of this study is to develop an effective and objective method to assess the scientific value of Quaternary geological heritage (geoheritage) sites in arid environments, especially the Middle East. Despite a growing global interest in geoheritage conservation, Quaternary geoheritage sites in the Middle East remain mostly unprotected. Many have already been destroyed. To protect these sites, a fair evaluation of their heritage values is important. Geoheritage values ranges widely, but in academic literature, such as Brilha et al. (2015), they have been categorised into three main values: scientific value, educational value, and tourism value. This survey focuses on the scientific value.

In most previous literature, the scientific value of geoheritage sites have been decided using calculation methods developed with the expert knowledge of 1 to 3 researchers, without input from the broader scientific community. Furthermore, none of these methods have been developed specifically for an arid environments, such as those commonly found in Arabia. To create a more objective and arid environment specific method of scientific value assessment, this project will collect inputs from experts from various disciplines, such as palaeoenvironmental scientists, geologists, archaeologists, and anthropologists, with interest in arid environments. The result of this study will help academics and conservation specialists working in arid regions to protect the most important geoheritage sites for future generations.



We appreciate your interest in participating in this questionnaire. You have been invited to participate as you are an expert in the field of palaeoenvironmental science, geology, geomorphology, archaeology, or evolutionary anthropology above the undergraduate level. Please read through this information before agreeing to participate (if you wish to) by ticking the 'yes' box below.

You may ask any questions before deciding to take part by contacting the researcher (details below).

The Principal Researcher is Kenta Sayama who is attached to the School of Geography and the Environment at the University of Oxford. This project is being completed under the supervision of Dr Ash Parton, Professor Heather Viles, and Professor Adrian Parker.

You will be asked to answer a questionnaire to rate the relative importance of various factors related to the evaluation of the scientific value of Quaternary geoheritage sites. The term "factors" in this study is used to describe details that the PI of this project have identified as potential contributing factors to a site's scientific value. This should take about 10-15 minutes. No background knowledge is required. The collected data will be used to determine the factors included in creating an assessment methodology for the scientific value of geoheritage sites in the Middle East. It will also determine the weight at which the included factors will be calculated in the method created.

Do I have to take part? No, Please note that participation is voluntary. If you do decide to take part, you may withdraw at any point for any reason before submitting your answers by pressing the closing the browser.

All questions are optional.

How will my data be used?

The data we will collect that could identify you will be your contact details and your field of expertise.

Your IP address will not be stored[1]. We will take all reasonable measures to ensure that data remain confidential.

The responses you provide will be stored in a password-protected electronic file on University of Oxford secure servers and may be used in academic publications, conference presentations, reports for external organisations, and a website. Identifiable information will be deleted as soon as it is no longer required for the research.

Who will have access to my data[2]?

The University of Oxford is the data controller with respect to your personal data and, as such, will determine how your personal data is used in the study. The University will process your personal data for the purpose of the research outlined above. Research is a task that we perform in the public interest. Further information about your rights with respect to your personal data is available from https://compliance.admin.ox.ac.uk/individual-rights.

We would also like your permission to use the data in future studies, and to share data with other researchers (e.g. in online databases). Data will be de-identified before it is shared with other researchers or results are made public.

The results will be written up for an DPhil (PhD equivalent) degree.

Who has reviewed this study?

This project has been reviewed by, and received ethics clearance through, a subcommittee of the University of Oxford Central University Research Ethics Committee [SOGE 1A2020-207].

Who do I contact if I have a concern or I wish to complain?

If you have a concern about any aspect of this study, please speak to Kenta Sayama (kenta.sayama@ouce.ox.ac.uk) or their supervisor Dr Ash Parton (ash.parton@mansfield.ox.ac.uk) and we will do our best to answer your query. We will acknowledge your concern within 10 working days and give you an indication of how it will be dealt with. If you remain unhappy or wish to make a formal complaint, please contact the Chair of the Research Ethics Committee at the

University of Oxford who will seek to resolve the matter as soon as possible:

Social Sciences & Humanities Interdivisional Research Ethics Committee; Email: ethics@socsci.ox.ac.uk; Address: Research Services, University of Oxford, Boundary Brook House, Churchill Drive, Headington, Oxford OX3 7GB

Guidance is available within CUREC's Best Practice Guidance (06) on Internet-mediated research

Guidance is available within CUREC's Best Practice Guidance (09) on Data collection, protection and management

Please note that you may only participate in this survey if you are 18 years of age or over. Required

- I certify that I am 18 years of age or over

Please indicate if you agree to the researchers retaining your personal information to contact you in the future about topics related to this research, including notices of publication, and additional questionnaires. You can contact Kenta Sayama (kenta.sayama@ouce.ox.ac.uk) any time to change this preference. Required

- Yes, I agree to the researchers retaining my personal information and to be contacted for topics related to this research in the future.
- No, do not retain my personal information

If you have read the information above and agree to participate with the understanding that the data (including any personal data) you submit will be processed accordingly, please tick the box below to start. Required

- Yes, I agree to take part

Page 2: Personal Information

Name:

Profession:

- Master's student PhD
- student Academic
- researcher Museum
- worker Heritage
- manager Other
-

If you selected Other, please specify:

Field(s) you consider to be your expertise (please select multiple if applicable):

- [ ] Quaternary geoscience
- [ ] Geoscience (without focus on the Quaternary) Archaeology
- [ ] Evolutionary Anthropology
- [ ] Heritage conservation
- [ ] Environmental science
- [ ] Other
- [ ] Government
- [ ] Environmental Policy

If you selected Other, please specify:

Page 3: Scientific Value Evaluation

From analysis of previous literature on geoheritage and Quaternary palaeoenvironment, we have selected the following 10 factors for you to consider in this survey.

Representativeness: whether the site demonstrates exemplary characteristics of the geological/geomorphological elements or processes.

Integrity: Current state of conservation of the main geological/geomorphological elements of the site.

Geological diversity: Whether the site and its surrounding area covers a diverse array of geological/geomorphological features of scientific interest.

Rarity: Whether the feature is rare or unique in the region, the country, or the world.

Historical value: Importance of the site for the development of the scientific field

Scientific knowledge: The extent of scientific knowledge gained from the site.

Potential for future research: 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.

Chronological resolution: How far back the chronology from the site extends and at what resolution (intervals).

Connection with the regional archaeology/evolutionary anthropology: Whether the site has provided important data (information) for the regional archaeology/anthropology.

Connection with other disciplines: Whether the site has connections with disciplines other than archaeology/anthropology (flood management, natural disaster management, current land use, etc.)

For each of these factors, please answer the following questions.

Whether the factor should be included as a criterion in evaluating the scientific value of a Quaternary geoheritage site.

If you think the factor should be included, from 1 (of the least importance for the evaluation) to 5 (most important for the evaluation), indicate how important the factor is in determining the scientific value of the site. In doing so, please try to consider the relative importance of each factor.

From 1 (least appropriate) to 5 (most appropriate), please indicate the appropriateness of the potential methods to measure or assess each factor. If you can think of better ways of measurement or assessment, please describe it in the space given.

Please add any other factors that you find important in the evaluation process that is missing from the list.

Representativeness: whether the site demonstrates exemplary characteristics of the geological/geomorphological elements or processes

- Should be included
- Should not be included

Relative importance of Representativeness

Please don't select more than 1 answer(s) per row.

	1	2	3	4	5	
Least important						Essential (most important)

Explanation for each value

(Should not be ignored, but comparatively it is not very important)

(Should be considered to some degree)

(Should be considered)

(Very important to determine the scientific value)

(Essential. Most important to determine the scientific value)

What would be appropriate measurement/assessment method(s) for representativeness

Please don't select more than 1 answer(s) per row.

	1 (Least appropriate)	2	3	4	5 (Most appropriate)
Comparative analysis of literature	☐	☐	☐	☐	☐
Comparative analysis of images of the site	☐	☐	☐	☐	☐
Number of articles published on the site	☐	☐	☐	☐	☐

Suggestions for other measurement/assessment methods

Integrity: Current state of conservation of the main geological/geomorphological elements of the site

- Should be included
- Should not be included

Relative importance of Integrity

Please don't select more than 1 answer(s) per row.

	1	2	3	4	5	
Least important						Essential (most important)

Explanation for each value

(Should not be ignored, but comparatively it is not very important)

(Should be considered to some degree)

(Should be considered)

(Very important to determine the scientific value)

(Essential. Most important to determine the scientific value)

What would be appropriate measurement/assessment method(s) for integrity

Please don't select more than 1 answer(s) per row.

	1 (Least appropriate)	2	3	4	5 (Most appropriate)
Analysis of satellite imagery					
Analysis of the protection status					
Site visits					

Suggestions for other measurement/assessment methods

Geological diversity: Whether the site and its surrounding area covers a diverse array of geological/geomorphological features of scientific interest

- Should be included
- Should not be included

Relative importance of geological diversity

Please don't select more than 1 answer(s) per row.

	1	2	3	4	5	
Least important						Essential (most important)

Explanation for each value

(Should not be ignored, but comparatively it is not very important)

(Should be considered to some degree)

(Should be considered)

(Very important to determine the scientific value)

(Essential. Most important to determine the scientific value)

What would be appropriate measurement/assessment method(s) for geological diversity

Please don't select more than 1 answer(s) per row.

	1 (Least appropriate)	2	3	4	5 (Most appropriate)
Literature review					
Discussions with experts					
Site visits					

Suggestions for other measurement/assessment methods

Rarity: Whether the feature is rare or unique in the region, the country, or the world

- Should be included
- Should not be included

Relative importance of rarity

Please don't select more than 1 answer(s) per row.

	1	2	3	4	5	
Least important						Essential (most important)

Explanation for each value

(Should not be ignored, but comparatively it is not very important)

(Should be considered to some degree)

(Should be considered)

(Very important to determine the scientific value)

(Essential. Most important to determine the scientific value)

What would be appropriate measurement/assessment method(s) for rarity

Please don't select more than 1 answer(s) per row.

	1 (Least appropriate)	2	3	4	5 (Most appropriate)
Literature review					

Discussions with experts					

Suggestions for other measurement/assessment methods

Historical value: Importance of the site for the development of the scientific field

- Should be included
- Should not be included

Relative importance of historic value

Please don't select more than 1 answer(s) per row.

	1	2	3	4	5	
Should not be included						Should be included

Explanation for each value

(Should not be ignored, but comparatively it is not very important)

(Should be considered to some degree)

(Should be considered)

(Very important to determine the scientific value)

(Essential. Most important to determine the scientific value)

What would be appropriate measurement/assessment method(s) for historic value

Please don't select more than 1 answer(s) per row.

	1 (Least appropriate)	2	3	4	5 (Most appropriate)
Literature analysis					
Discussions with experts					

Suggestions for other measurement/assessment methods

Scientific knowledge: The extent of scientific knowledge gained from the site

- Should be
- included

Relative importance of scientific knowledge

Please don't select more than 1 answer(s) per row.

	1	2	3	4	5	
Least important						Essential (most important)

Explanation for each value

(Should not be ignored, but comparatively it is not very important)

(Should be considered to some degree)

(Should be considered)

(Very important to determine the scientific value)

(Essential. Most important to determine the scientific value)

What would be appropriate measurement/assessment method(s) for scientific knowledge

Please don't select more than 1 answer(s) per row.

	1 (Least appropriate)	2	3	4	5 (Most appropriate)
Number of citations					
Publication in high-impact journals					
Number of articles published on the site					

Suggestions for other measurement/assessment methods

Potential for future research: 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

- Should be included
- Should not be included

Relative importance of potential for future research

Please don't select more than 1 answer(s) per row.

	1	2	3	4	5	
Least important						Essential (most important)

Explanation for each value

(Should not be ignored, but comparatively it is not very important)

(Should be considered to some degree)

(Should be considered)

(Very important to determine the scientific value)

(Essential. Most important to determine the scientific value)

What would be appropriate measurement/assessment method(s) for the potential for future research

Please don't select more than 1 answer(s) per row.

	1 (Least appropriate)	2	3	4	5 (Most appropriate)
Literature analysis and search for ongoing projects					
Mentions of need for future research at the site in academic literature					
Discussions with experts					

Suggestions for other measurement/assessment methods

Chronological resolution: How far back the chronology from the site extends and at what resolution (intervals)

- Should be included
- Should not be included

Relative importance of the chronological resolution

Please don't select more than 1 answer(s) per row.

	1	2	3	4	5	
Least important						Essential (most important)

Explanation for each value

(Should not be ignored, but comparatively it is not very important)

(Should be considered to some degree)

(Should be considered)

(Very important to determine the scientific value)

(Essential. Most important to determine the scientific value)

What would be appropriate measurement/assessment method(s) for Chronological resolution

Please don't select more than 1 answer(s) per row.

	1 (Least appropriate)	2	3	4	5 (Most appropriate)
Depth of the sequence					
Number of chronological records collected from the site					

Suggestions for other measurement/assessment methods

Connection with the regional archaeology/evolutionary anthropology: Whether the site has provided important data (information) for the regional archaeology/anthropology

- Should be included
- Should not be included

Relative importance of connection with the regional archaeology/evolutionary anthropology

Please don't select more than 1 answer(s) per row.

	1	2	3	4	5	
Least important						Essential (most important)

Explanation for each value

(Should not be ignored, but comparatively it is not very important)

(Should be considered to some degree)

(Should be considered)

(Very important to determine the scientific value)

(Essential. Most important to determine the scientific value)

What would be appropriate measurement/assessment method(s) for the connection with regional archaeology/evolutionary anthropology

	1 (Least appropriate)	2	3	4	5 (Most appropriate)
Citation by archaeology/evolutionary anthropology articles					
Citation in high-impact journal articles on archaeology/evolutionary anthropology					

Chronological proximity/relationship with regional archaeological sites					
Discussions with experts					

Please don't select more than 1 answer(s) per row.

Suggestions for other measurement/assessment methods

Connection with other disciplines: Whether the site has connections with disciplines other than archaeology/anthropology

(flood management, natural disaster management, current land use, etc.)

- Should be included
- Should not be included

Relative importance of connections with other disciplines

Please don't select more than 1 answer(s) per row.

	1	2	3	4	5	
Should not be included						Should be included

Explanation for each value

(Should not be ignored, but comparatively it is not very important)

(Should be considered to some degree)

(Should be considered)

(Very important to determine the scientific value)

(Essential. Most important to determine the scientific value)

What would be appropriate measurement/assessment method(s) for the connection with other disciplines

Please don't select more than 1 answer(s) per row.

	1 (Least appropriate)	2	3	4	5 (Most appropriate)
Citation by non-geoscience, archaeology, or anthropology, articles					
Citation in high impact journals					
Discussions with experts					

Suggestions for other measurement/assessment methods

Recommendations for additional factors

Appendix H: Chapter 8– results of the significance testing

Highlighted values represent valuables with p-values under 0.05 in the parametric statistical methods.

Results from non-parametric methods are listed here as well for robustness checking.

1. Educational value

1.1 Site evaluation (Two sample T test)

Variable	Mean E1	Mean E2	p-value
wadi_ghub	4.19	3.923	0.499
tufa	3.55	4.077	0.227
leukogranite	3.571	4.231	0.143

1.2 Site evaluation (Paired T test)

Variable	Mean Difference	p-value
wadi_ghub	0.545	0.167
tufa	-0.455	0.450
leukogranite	-1.273	0.040

1.3 Relative importance of each criterion (Two sample T test)

Criterion	Mean E1	Mean E2	p-value
accessibility	4.182	4.308	0.703
safety	4.318	4.615	0.306
logistics	3.773	4.077	0.313
population_density	2.773	2.462	0.391
other_values	3.545	3.846	0.369
scenery	3.682	4.154	0.168
uniqueness	4.136	4.231	0.765
observational_conditions	4.409	4.154	0.329
geodiversity	3.955	3.923	0.939
interpretive_potential	4.045	4.231	0.559
didactic_potential	4.136	4.154	0.956
modern_human_issues	3.818	3.308	0.137

1.4 Relative importance of each criterion (Paired T test)

Criterion	Mean Difference	p-value
accessibility	0.417	0.054
safety	0.083	0.754
logistics	-0.417	0.21
population_density	0	1
other_values	-0.167	0.658
scenery	-0.167	0.723
uniqueness	-0.167	0.674
observational_conditions	0.5	0.082
geodiversity	0.333	0.339
interpretive_potential	0.25	0.275
didactic_potential	0.167	0.674
modern_human_issues	0.333	0.22

1.5 Site evaluation (Mann Whitney U test)

Variable	W-Value	p-value
wadi_ghub	166.5	0.26
tufa	96.5	0.201
leukogranite	110.5	0.336

1.6 Site evaluation (Wilcoxon signed-rank Test)

Variable	W-Value	p-value
rainbow_hiking	22	0.188
tufa	15.5	0.435
leukogranite	6	0.053

1.7 Relative importance of each criterion (Mann Whitney U test)

Criterion	W-Value	p-value
accessibility	141	0.955
safety	128	0.557
logistics	114.5	0.309
population_density	161.5	0.514
other_values	116.5	0.354
scenery	108	0.216
uniqueness	130.5	0.661
observational_conditions	167	0.377
geodiversity	138	0.87
interpretive_potential	139	0.898
didactic_potential	142	0.985
modern_human_issues	181.5	0.174

1.8 Relative importance of each criterion (Wilcoxon signed-rank test)

Criterion	W-Value	p-value
accessibility	24	0.0726
safety	3.5	1
logistics	5	0.2837
population_density	18	1
other_values	12	0.7925
scenery	16.5	0.8867
uniqueness	14	0.6153
observational_conditions	18.5	0.1048
geodiversity	37	0.3307
interpretive_potential	20	0.2986
didactic_potential	22	0.6153
modern_human_issues	21	0.2402

2. **Touristic value**

2.1 Site evaluation (Two sample T test)

Variable	Mean T1	Mean T2	p-value
leukogranite	3.412	3.222	0.639
copper_mine	3.471	4.500	0.013
tufa	3.500	4.222	0.145

2.2 Relative importance of each criterion (Two sample T test)

Variable	Mean T1	Mean T2	p-value
accessibility_fujairah	3.350	3.727	0.380
accessibility_other	3.400	3.636	0.500
safety	4.450	4.182	0.382
logistics	3.700	3.818	0.756
population_density	3.158	2.545	0.130
other_values	3.526	3.182	0.316
scenery	4.300	4.091	0.443
uniqueness	4.550	4.364	0.566
observational_conditions	4.053	3.636	0.096
geodiversity	3.600	3.100	0.182
interpretive_potential	3.850	3.455	0.298
economic_level	3.000	2.545	0.269
other_tourist_attractions	3.250	3.455	0.488

2.3 Site evaluation (Mann Whitney U test)

Variable	W-value	p-value
leukogranite	83	0.737
copper_mine	47	0.046
tufa	46.5	0.139

2.4 Relative importance of each criterion (Mann Whitney U test)

Variable	W-value	p-value
accessibility_fujairah	97	0.591
accessibility_other	104	0.811
safety	137	0.224
logistics	102	0.746
population_density	148.5	0.047
other_values	127.5	0.301
scenery	131	0.341
uniqueness	121	0.616
observational_conditions	141.5	0.066
geodiversity	125.5	0.234
interpretive_potential	135	0.289
economic_level	134	0.312
other_tourist_attractions	91	0.415

Appendix I: Chapter 8– correlation coefficients and corresponding p-values for each dataset

1. Scientific value

1.1 Correlation coefficient

	representativeness	integrity	geodiversity	rarity	historical_value	scientific_knowledge	potential_for_future	modern_issues	economic_geology	arch_anth
representativeness	1.000	-0.072	0.296	0.117	-0.112	-0.370	-0.419	-0.253	-0.188	0.066
integrity	-0.072	1.000	-0.102	0.194	0.441	0.452	-0.151	0.289	0.252	0.344
geodiversity	0.296	-0.102	1.000	0.304	0.275	0.028	0.406	0.053	0.414	0.027
rarity	0.117	0.194	0.304	1.000	0.442	0.386	0.067	0.067	0.508	0.586
historical_value	-0.112	0.441	0.275	0.442	1.000	0.396	0.112	0.347	0.414	0.361
scientific_knowledge	-0.370	0.452	0.028	0.386	0.396	1.000	0.310	0.310	0.580	0.416
potential_for_future	-0.419	-0.151	0.406	0.067	0.112	0.310	1.000	0.141	0.398	-0.125
modern_issues	-0.253	0.289	0.053	0.067	0.347	0.310	0.141	1.000	0.444	0.364
economic_geology	-0.188	0.252	0.414	0.508	0.414	0.580	0.398	0.444	1.000	0.309
arch_anth	0.066	0.344	0.027	0.586	0.361	0.416	-0.125	0.364	0.309	1.000

1.2 Statistical significance of correlation coefficients (p-values)

	representativeness	integrity	geodiversity	rarity	historical_value	scientific_knowledge	potential_for_future	modern_issues	economic_geology	arch_anth
representativeness	NA	0.764	0.205	0.624	0.637	0.109	0.066	0.282	0.428	0.782
integrity	0.764	NA	0.670	0.413	0.052	0.045	0.524	0.216	0.284	0.137
geodiversity	0.205	0.670	NA	0.193	0.240	0.908	0.076	0.825	0.070	0.911
rarity	0.624	0.413	0.192847853	NA	0.051	0.093	0.778	0.778	0.022	0.007
historical_value	0.637	0.052	0.239973155	0.051	NA	0.0840	0.6390	0.1339	0.0697	0.1177
scientific_knowledge	0.109	0.045	0.907984006	0.093	0.084	NA	0.183	0.183	0.007	0.068
potential_for_future	0.066	0.524	0.075855351	0.778	0.639	0.183	NA	0.554	0.082	0.600
modern_issues	0.282	0.216	0.824603565	0.778	0.134	0.183	0.554	NA	0.050	0.115
economic_geology	0.428	0.284	0.069708908	0.022	0.070	0.007	0.082	0.050	NA	0.185
arch_anth	0.782	0.137	0.910858061	0.007	0.118	0.068	0.600	0.115	0.185	NA

2. Educational value

2.1 Dataset E1: correlation coefficient

	accessibility	safety	logistics	population_density	other_values	scenery	uniqueness	observational_conditions	geodiversity	interpretive_potential	didactic_potential	modern_human_issues
accessibility	1.000	0.405	0.037	-0.213	0.241	0.208	-0.266	0.304	0.369	0.236	-0.060	-0.108
safety	0.405	1.000	0.259	-0.374	0.000	0.116	0.006	0.137	0.242	0.187	0.055	-0.055
logistics	0.037	0.259	1.000	0.493	0.633	0.162	0.161	0.033	0.211	0.201	0.210	0.459
population_density	-0.213	-0.374	0.493	1.000	0.611	0.208	0.360	-0.085	0.164	-0.142	0.340	0.298
other_values	0.241	0.000	0.633	0.611	1.000	0.286	0.232	0.117	0.511	0.186	0.406	0.227
scenery	0.208	0.116	0.162	0.208	0.286	1.000	0.493	0.159	0.582	0.133	0.048	0.361
uniqueness	-0.266	0.006	0.161	0.360	0.232	0.493	1.000	0.063	0.407	-0.263	0.234	0.290
observational_conditions	0.304	0.137	0.033	-0.085	0.117	0.159	0.063	1.000	0.484	0.571	0.310	0.221
geodiversity	0.369	0.242	0.211	0.164	0.511	0.582	0.407	0.484	1.000	0.307	0.334	0.004
interpretive_potential	0.236	0.187	0.201	-0.142	0.186	0.133	-0.263	0.571	0.307	1.000	0.281	0.250
didactic_potential	-0.060	0.055	0.210	0.340	0.406	0.048	0.234	0.310	0.334	0.281	1.000	0.122
modern_human_issues	-0.108	-0.055	0.459	0.298	0.227	0.361	0.290	0.221	0.004	0.250	0.122	1.000

2.2 Dataset E2: correlation coefficient

	accessibility	safety	logistics	population_density	other_values	scenery	uniqueness	observational_conditions	geodiversity	interpretive_potential	didactic_potential	modern_human_issues
accessibility	1.000	0.231	0.417	-0.205	0.067	-0.284	-0.307	-0.197	0.024	-0.393	-0.067	-0.230
safety	0.231	1.000	0.206	-0.101	-0.395	-0.318	-0.255	-0.197	-0.345	-0.503	0.110	-0.198
logistics	0.417	0.206	1.000	0.610	0.017	0.091	0.080	0.102	0.314	0.103	0.199	-0.439
population_density	-0.205	-0.101	0.610	1.000	0.415	0.220	0.473	0.484	0.338	0.343	0.220	0.015
other_values	0.067	-0.395	0.017	0.415	1.000	-0.071	0.446	0.499	0.432	0.187	-0.175	0.158
scenery	-0.284	-0.318	0.091	0.220	-0.071	1.000	0.454	-0.036	0.381	0.708	0.175	0.038
uniqueness	-0.307	-0.255	0.080	0.473	0.446	0.454	1.000	0.397	0.733	0.410	-0.346	-0.277
observational_conditions	-0.197	-0.197	0.102	0.484	0.499	-0.036	0.397	1.000	0.344	0.364	-0.267	-0.177
geodiversity	0.024	-0.345	0.314	0.338	0.432	0.381	0.733	0.344	1.000	0.570	-0.062	-0.399
interpretive_potential	-0.393	-0.503	0.103	0.343	0.187	0.708	0.410	0.364	0.570	1.000	0.197	0.009
didactic_potential	-0.067	0.110	0.199	0.220	-0.175	0.175	-0.346	-0.267	-0.062	0.197	1.000	0.429
modern_human_issues	-0.230	-0.198	-0.439	0.015	0.158	0.038	-0.277	-0.177	-0.399	0.009	0.429	1.000

2.3 Dataset E1: statistical significance of correlation coefficients (p-values)

	accessibility	safety	logistics	population_density	other_values	scenery	uniqueness	observational_conditions	geodiversity	interpretive_potential	didactic_potential	modern_human_issues
accessibility	NA	0.049	0.863	0.317	0.257	0.329	0.210	0.148	0.076	0.267	0.782	0.615
safety	0.049	NA	0.222	0.072	1.000	0.589	0.976	0.524	0.256	0.380	0.800	0.798
logistics	0.863	0.222	NA	0.014	0.001	0.448	0.452	0.880	0.322	0.347	0.325	0.024
population_density	0.317	0.072	0.014	NA	0.002	0.329	0.084	0.692	0.443	0.507	0.105	0.157
other_values	0.257	1.000	0.001	0.002	NA	0.176	0.275	0.585	0.011	0.385	0.049	0.287
scenery	0.329	0.589	0.448	0.329	0.176	NA	0.014	0.457	0.003	0.536	0.823	0.083
uniqueness	0.210	0.976	0.452	0.084	0.275	0.014	NA	0.770	0.048	0.214	0.271	0.169
observational_conditions	0.148	0.524	0.880	0.692	0.585	0.457	0.770	NA	0.017	0.004	0.140	0.299
geodiversity	0.076	0.256	0.322	0.443	0.011	0.003	0.048	0.017	NA	0.144	0.110	0.986
interpretive_potential	0.267	0.380	0.347	0.507	0.385	0.536	0.214	0.004	0.144	NA	0.183	0.239
didactic_potential	0.782	0.800	0.325	0.105	0.049	0.823	0.271	0.140	0.110	0.183	NA	0.570
modern_human_issues	0.615	0.798	0.024	0.157	0.287	0.083	0.169	0.299	0.986	0.239	0.570	NA

2.4 Dataset E2: statistical significance of correlation coefficients (p-values)

	accessibility	safety	logistics	population_density	other_values	scenery	uniqueness	observational_conditions	geodiversity	interpretive_potential	didactic_potential	modern_human_issues
accessibility	NA	0.449	0.156	0.501	0.828	0.348	0.307	0.520	0.938	0.184	0.828	0.451
safety	0.449	NA	0.500	0.742	0.182	0.290	0.400	0.519	0.248	0.080	0.721	0.517
logistics	0.156	0.500	NA	0.027	0.957	0.768	0.794	0.740	0.297	0.739	0.516	0.133
population_density	0.501	0.742	0.027	NA	0.159	0.471	0.102	0.094	0.259	0.252	0.471	0.960
other_values	0.828	0.182	0.957	0.159	NA	0.817	0.126	0.083	0.141	0.541	0.568	0.606
scenery	0.348	0.290	0.768	0.471	0.817	NA	0.119	0.908	0.200	0.007	0.568	0.903
uniqueness	0.307	0.400	0.794	0.102	0.126	0.119	NA	0.179	0.004	0.164	0.246	0.359
observational_conditions	0.520	0.519	0.740	0.094	0.083	0.908	0.179	NA	0.249	0.221	0.377	0.562
geodiversity	0.938	0.248	0.297	0.259	0.141	0.200	0.004	0.249	NA	0.042	0.839	0.177
interpretive_potential	0.184	0.080	0.739	0.252	0.541	0.007	0.164	0.221	0.042	NA	0.519	0.976
didactic_potential	0.828	0.721	0.516	0.471	0.568	0.568	0.246	0.377	0.839	0.519	NA	0.143
modern_human_issues	0.451	0.517	0.133	0.960	0.606	0.903	0.359	0.562	0.177	0.976	0.143	NA

3. Touristic Value

3.1 Dataset T1: correlation coefficient

	accessibility_fujairah	accessibility_other	safety	logistics	population_density	other_values	scenery	uniqueness	observational_conditions	geodiversity	interpretive_potential	economic_level	other_tourist_attractions
accessibility_fujairah	1.000	0.595	0.039	0.077	0.229	0.174	-0.103	-0.008	-0.267	0.284	-0.048	0.165	0.156
accessibility_other	0.595	1.000	0.022	0.272	0.256	0.176	-0.020	0.150	0.175	0.186	0.048	0.002	0.031
safety	0.039	0.022	1.000	0.270	-0.505	-0.082	0.186	0.264	0.186	-0.031	0.295	0.053	-0.016
logistics	0.077	0.272	0.270	1.000	0.270	0.304	0.109	0.132	0.148	0.201	-0.079	0.425	0.380
population_density	0.229	0.256	-0.505	0.270	1.000	0.395	0.187	-0.026	-0.056	0.285	0.157	0.435	0.329
other_values	0.174	0.176	-0.082	0.304	0.395	1.000	0.436	0.114	0.284	0.152	0.038	0.222	0.725
scenery	-0.103	-0.020	0.186	0.109	0.187	0.436	1.000	0.203	0.294	-0.143	0.282	0.252	0.543
uniqueness	-0.008	0.150	0.264	0.132	-0.026	0.114	0.203	1.000	0.438	0.093	0.178	-0.009	0.230
observational_conditions	-0.267	0.175	0.186	0.148	-0.056	0.284	0.294	0.438	1.000	-0.270	-0.097	-0.173	0.318
geodiversity	0.284	0.186	-0.031	0.201	0.285	0.152	-0.143	0.093	-0.270	1.000	0.306	0.408	0.217
interpretive_potential	-0.048	0.048	0.295	-0.079	0.157	0.038	0.282	0.178	-0.097	0.306	1.000	0.200	0.097
economic_level	0.165	0.002	0.053	0.425	0.435	0.222	0.252	-0.009	-0.173	0.408	0.200	1.000	0.454
other_tourist_attractions	0.156	0.031	-0.016	0.380	0.329	0.725	0.543	0.230	0.318	0.217	0.097	0.454	1.000

3.2 Dataset T2: correlation coefficient

	accessibility_fujairah	accessibility_other	safety	logistics	population_density	other_values	scenery	uniqueness	observational_conditions	geodiversity	interpretive_potential	economic_level	other_tourist_attractions
accessibility_fujairah	1.000	0.234	-0.060	0.349	0.847	0.289	0.039	-0.097	0.722	0.032	-0.348	0.348	-0.380
accessibility_other	0.234	1.000	0.120	0.538	0.349	-0.039	0.064	0.328	0.467	0.395	0.098	0.141	-0.033
safety	-0.060	0.120	1.000	0.049	-0.011	0.097	0.156	-0.393	-0.054	-0.595	-0.117	0.117	-0.564
logistics	0.349	0.538	0.049	1.000	0.279	0.392	0.463	0.411	0.343	0.389	0.483	-0.384	-0.013
population_density	0.847	0.349	-0.011	0.279	1.000	0.498	0.184	0.174	0.813	0.324	-0.405	0.490	-0.223
other_values	0.289	-0.039	0.097	0.392	0.498	1.000	0.460	0.158	0.463	0.366	0.121	-0.342	-0.151
scenery	0.039	0.064	0.156	0.463	0.184	0.460	1.000	0.561	0.077	0.288	0.351	-0.075	0.321
uniqueness	-0.097	0.328	-0.393	0.411	0.174	0.158	0.561	1.000	0.233	0.789	0.332	-0.019	0.815
observational_conditions	0.722	0.467	-0.054	0.343	0.813	0.463	0.077	0.233	1.000	0.224	-0.169	0.169	-0.039
geodiversity	0.032	0.395	-0.595	0.389	0.324	0.366	0.288	0.789	0.224	1.000	0.062	-0.062	0.575
interpretive_potential	-0.348	0.098	-0.117	0.483	-0.405	0.121	0.351	0.332	-0.169	0.062	1.000	-0.627	0.243
economic_level	0.348	0.141	0.117	-0.384	0.490	-0.342	-0.075	-0.019	0.169	-0.062	-0.627	1.000	-0.102
other_tourist_attractions	-0.380	-0.033	-0.564	-0.013	-0.223	-0.151	0.321	0.815	-0.039	0.575	0.243	-0.102	1.000

3.3 Dataset T1: statistical significance of correlation coefficients (p-values)

	accessibility_fujairah	accessibility_other	safety	logistics	population_density	other_values	scenery	uniqueness	observational_conditions	geodiversity	interpretive_potential	economic_level	other_tourist_attractions
accessibility_fujairah	NA	0.004	0.872	0.739	0.332	0.464	0.656	0.973	0.254	0.212	0.835	0.476	0.499
accessibility_other	0.004	NA	0.928	0.233	0.275	0.458	0.93	0.515	0.462	0.418	0.837	0.994	0.895
safety	0.872	0.928	NA	0.249	0.028	0.737	0.432	0.261	0.447	0.895	0.207	0.825	0.946
logistics	0.739	0.233	0.249	NA	0.25	0.193	0.637	0.57	0.534	0.383	0.732	0.055	0.089
population_density	0.332	0.275	0.028	0.25	NA	0.085	0.43	0.912	0.815	0.222	0.509	0.055	0.157
other_values	0.464	0.458	0.737	0.193	0.085	NA	0.055	0.631	0.226	0.524	0.874	0.347	NA
scenery	0.656	0.93	0.432	0.637	0.43	0.055	NA	0.379	0.208	0.535	0.215	0.271	0.011
uniqueness	0.973	0.515	0.261	0.57	0.912	0.631	0.379	NA	0.053	0.689	0.44	0.969	0.317
observational_conditions	0.254	0.462	0.447	0.534	0.815	0.226	0.208	0.053	NA	0.25	0.685	0.465	0.172
geodiversity	0.212	0.418	0.895	0.383	0.222	0.524	0.535	0.689	0.25	NA	0.177	0.066	0.345
interpretive_potential	0.835	0.837	0.207	0.732	0.509	0.874	0.215	0.44	0.685	0.177	NA	0.385	0.676
economic_level	0.476	0.994	0.825	0.055	0.055	0.347	0.271	0.969	0.465	0.066	0.385	NA	0.039
other_tourist_attractions	0.499	0.895	0.946	0.089	0.157	NA	0.011	0.317	0.172	0.345	0.676	0.039	NA

3.4 Dataset T2: statistical significance of correlation coefficients (p-values)

	accessibility_fujairah	accessibility_other	safety	logistics	population_density	other_values	scenery	uniqueness	observational_conditions	geodiversity	interpretive_potential	economic_level	other_tourist_attractions
accessibility_fujairah	NA	0.489	0.861	0.293	0.001	0.389	0.910	0.776	0.012	0.931	0.294	0.294	0.249
accessibility_other	0.489	NA	0.726	0.088	0.293	0.910	0.851	0.324	0.148	0.259	0.775	0.679	0.924
safety	0.861	0.726	NA	0.885	0.975	0.777	0.648	0.232	0.875	0.070	0.732	0.732	0.071
logistics	0.293	0.088	0.885	NA	0.406	0.233	0.152	0.210	0.301	0.267	0.132	0.243	0.969
population_density	0.001	0.293	0.975	0.406	NA	0.119	0.588	0.608	0.002	0.362	0.217	0.126	0.510
other_values	0.389	0.910	0.777	0.233	0.119	NA	0.154	0.644	0.152	0.298	0.724	0.304	0.657
scenery	0.910	0.851	0.648	0.152	0.588	0.154	NA	0.072	0.822	0.420	0.290	0.826	0.336
uniqueness	0.776	0.324	0.232	0.210	0.608	0.644	0.072	NA	0.490	0.007	0.318	0.956	0.002
observational_conditions	0.012	0.148	0.875	0.301	0.002	0.152	0.822	0.490	NA	0.534	0.619	0.619	0.909
geodiversity	0.931	0.259	0.070	0.267	0.362	0.298	0.420	0.007	0.534	NA	0.864	0.864	0.082
interpretive_potential	0.294	0.775	0.732	0.132	0.217	0.724	0.290	0.318	0.619	0.864	NA	0.039	0.472
economic_level	0.294	0.679	0.732	0.243	0.126	0.304	0.826	0.956	0.619	0.864	0.039	NA	0.765
other_tourist_attractions	0.249	0.924	0.071	0.969	0.510	0.657	0.336	0.002	0.909	0.082	0.472	0.765	NA