



Geoheritage Assessment of the Geosites in Tuwaiq Mountain, Saudi Arabia: in the Perspective of Geoethics, Geotourism, and Geoconservation

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Abstract

Tuwaiq Mountain is in the central portion of Saudi Arabia and is characterised by several denuded landscapes and geological features. A total of 10 geosites have been identified for the quantitative assessment. Scarp, cuesta, mesa, butte, pinnacles, gully network, wadi, and cave are the geomorphological features, and Jurassic fossil remains are part of the geological features. Geoheritage score was prepared based on scientific, educational, tourism, and degradational values. The study indicates that most of the sites fall within moderate to high scores. Low to high degradation risk of the geosites suggests the need for geoconservation. Geoethics is also a significant aspect of generating local awareness of the value of geomorphological and geological features with outstanding values and potential for tourism development.

Keywords Geoheritage · Geotourism · Escarpment · Wadi · Geopark

Introduction

Geoheritage study has gained attention since the eighteenth century but was rediscovered in the last 25 years and still needs more attention to discover (Reynard and Brilha 2018). However, various country or regional inventory and geoheritage assessment studies show a growing interest in geoconservation, management, and geotourism. One of the essential steps towards implementing the management plan is the inventory (Mucivuna et al. 2022). In the last few years, inventories were prepared in Brazil (Ferreira et al. 2019; Pereira and Farias 2020; Tavares et al. 2020), Cameroon (Bidias et al. 2020; Tefogoum et al. 2019, 2020), Chile (Benado et al. 2019), Costa Rica (Pérez-Umaña et al. 2019; Quesada-Román and Pérez Umaña 2020; Qussesa-Román and Pérez Umaña 2020), Ethiopia (Asrat 2018; Williams 2020), Morocco (Arrad et al. 2020; Beraaouz et al.

2019; Bouzekraoui et al. 2018; Aoulad-Sidi-Mhend et al. 2019; Mehdioui et al. 2020), Saudi Arabia (Moufti et al. 2015a, b; Moufti and Németh 2013; Németh and Moufti 2017), and Tunisia (Boukhchim et al. 2018). Moreover, geotourism is a growth sector surrounding any site's geological and geomorphological attraction (Dowling and Newsome 2006; Ólafsdóttir and Tverijonaite 2018). Therefore, UNESCO Global Geoparks Network increased from 20 geoparks in 2004 to 140 in 2018 (Ólafsdóttir 2019). Various erosional landforms are documented worldwide in IUCN geoheritage list (Goudie and Seely 2011). But it needs to mention that several potential landscapes with majestic viewpoints are neglected, overlooked, and underrated; it is better to say that they are poorly exposed to the general public (Migoñ and Pijet-Migoñ 2016; 2017). Promoting geoheritage to geotourism is also significant for a country's alternative approach to revenue generation and employment opportunities (Žáček et al. 2017).

Tuwaiq Mountain in central Saudi Arabia, geoheritage study is characterised by various landforms and landscapes, like scarp, mesa, and butte (Sen et al. 2023). However, a detailed geoheritage assessment was not done before. This paper focuses on the assessment of the various landforms in Tuwaiq Mountain. Especially, geological and geomorphological features like fossil remains, escarpment, mesa, butte, pinnacles, and waterfalls are described and assessed from a

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geoheritage perspective and the development of geotourism. Compared to the qualitative and quantitative study for inventory development is limited. Therefore, a site's scientific, education, tourism value, and land degradation are not well assessed and even underrated. Thus, the assessment method proposed by Brilha (2016, 2018) is followed to develop an inventory and assess the geoheritage. This assessment will bridge the gap for the geoheritage evaluation in central Saudi Arabia and provide a tool for the geoconservation and development of strategy.

Regional Geology and Geomorphology of Study Area

Tuwaiq Mountain is the most prominent geomorphic unit of central part of Saudi Arabia. It is an escarpment of 800 km long, and 600–1080 m elevation, extends from the southern margin of the Al Nafud Sand Sea southward to the northwest margin of Rub'Al Khali Basin (Fig. 1). Two main national

wildlife protected areas in Tuwaiq Mountain are Thadiq National Park and Tuwaiq Reserve. Urug Bani Muarid Protected Area located in the southern portion of Tuwaiq Mountain (Biodiversity (ncw.gov.sa)). The valley and mountain terrain of Tuwaiq is a well-known Ibex protectorate. The floral biodiversity of the Tuwaiq Reserve includes 21 species of perennial plants from 15 families and the most prevalent ones are from the genus *Acacia* (Al-Olayan 2015; Al Dhafer et al. 2012; Cunningham and Wronski 2009).

In the central portion of Saudi Arabia, Tuwaiq Mountain was developed in Late Miocene through Early Quaternary times due to the lithosphere uplifting associated with the opening of the Red Sea (Fig. 2). Uplifting and tilting started 30 Ma ago during the Oligocene and intensified in the Miocene at around 14 Ma (Rausch et al. 2014). The Tuwaiq Mountain is north–south curved belt through the Central Arabian plate (Al-Hinai et al. 1997). The lithology of these cuestas is mainly hard reefal limestone. The cuestas of the Tuwaiq escarpment have been faulted and then eroded by the dendritic drainage pattern, which pours into the southward

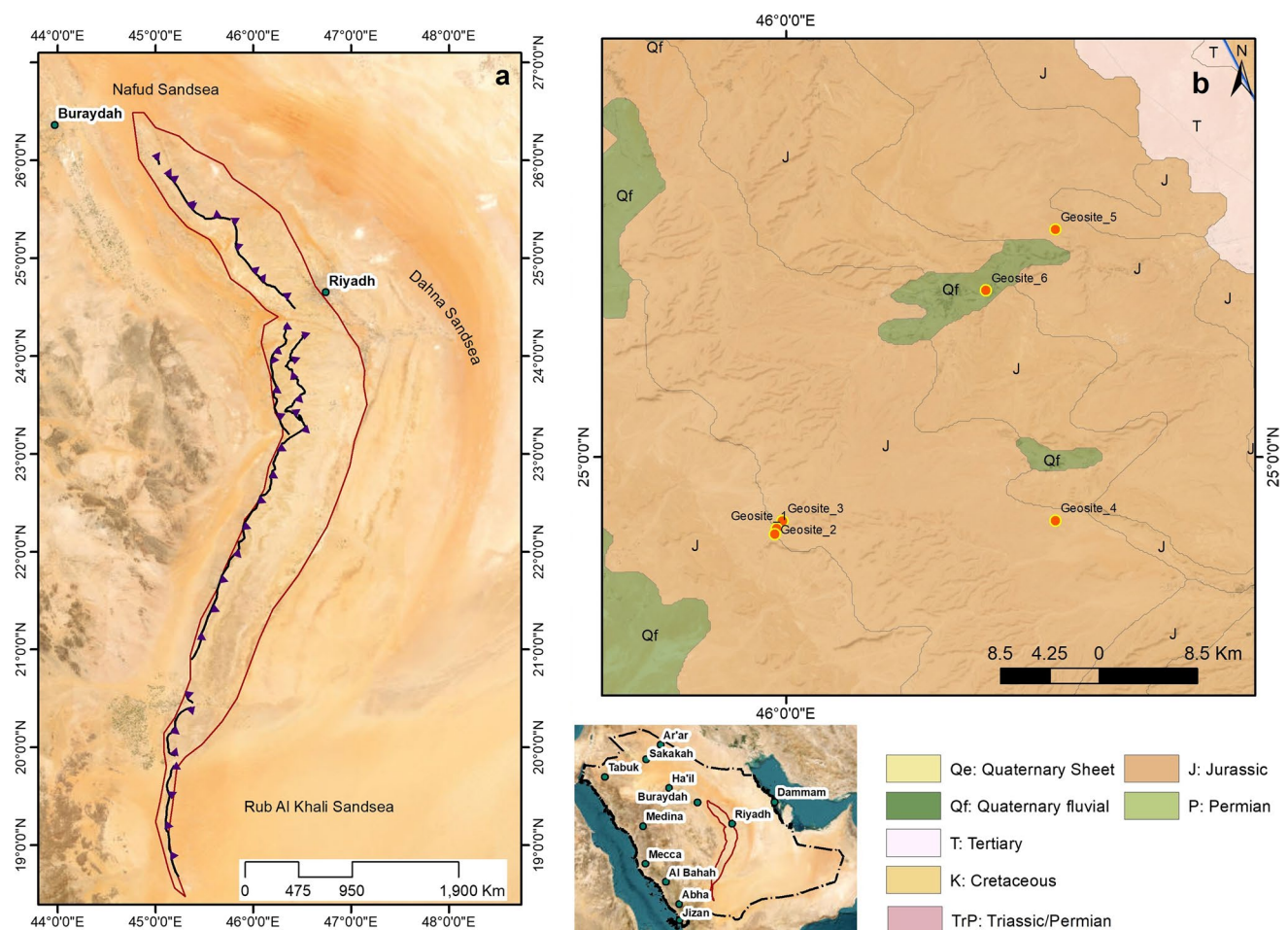


Fig. 1 Location map shows the Tuwaiq Mountain in the central portion of Saudi Arabia (a). Regional geological map of the study area extracted from Sen et al. (2023) (data source: USGS) (b)

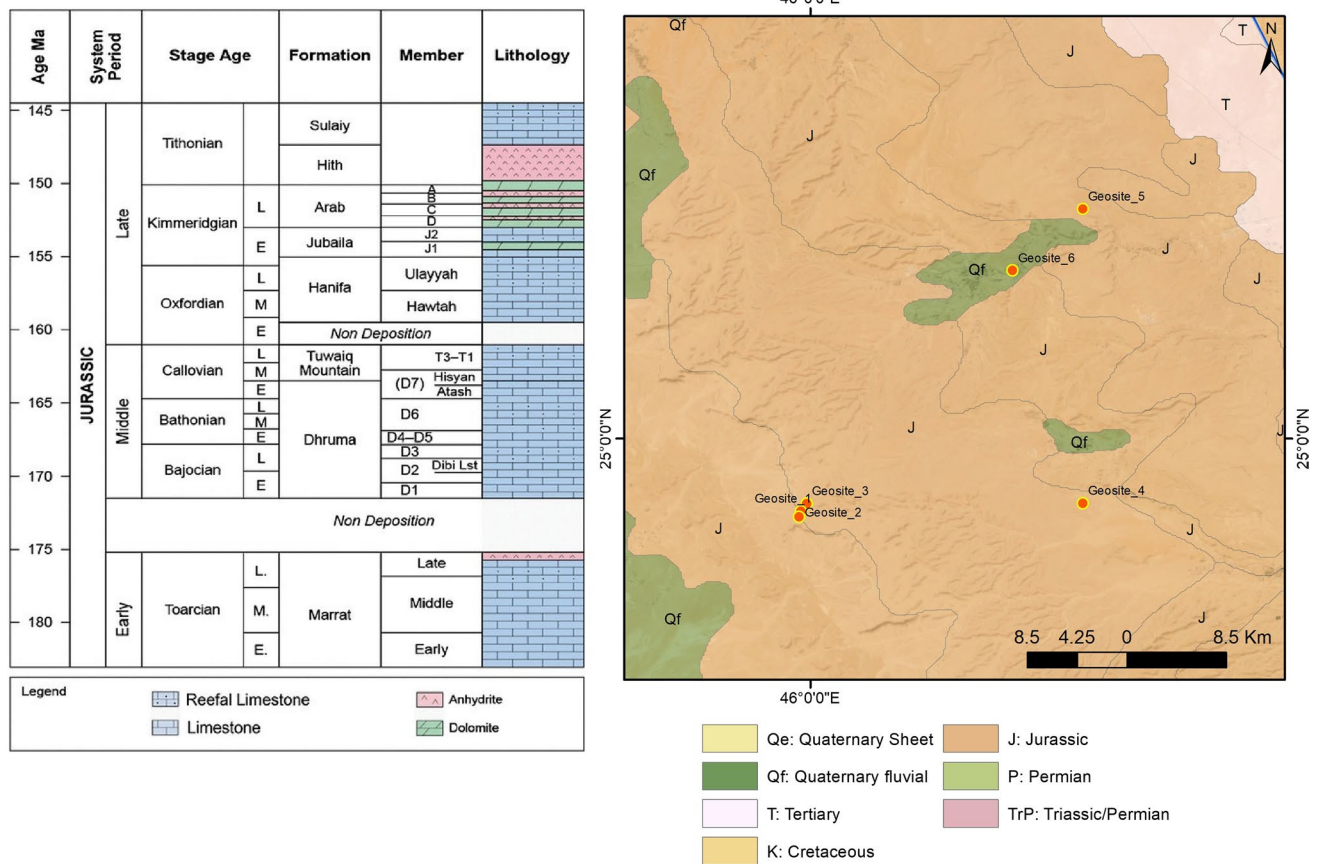


Fig. 2 General stratigraphic of the Tuwaiq Mountain shows different geological formation (extracted from Carrigan et al. 1995 and El-Asmar et al. 2015)

running wadis, for example, Wadi Hanifah valley. Tectonic settings and their faulting play a significant role in forming several geomorphic features, notably cuesta, plateau, and butte (Thompson 2000; Grainger 2007).

Materials and Method

The methodology of the present study includes inventory preparation based on the appraisal field survey, documentation of the potential geosites, and assessment of the scientific, educational, tourism, and degradational value. The geological map is extracted from United States Geological Survey (USGS). Online available data is also considered for assessing the various viewpoints. Arc GIS Base maps are used to prepare the maps and initial identification of the field spot.

Field Survey

An appraisal survey was conducted in various parts of Tuwaiq Mountain to document several geological

formations, unique landforms, and natural importance with photographs, coordinate, and fill the description card of the specific site. A detailed list of potential geosites, geological features, and framework was prepared, which can be points of attraction to the public, geomorphologists, and geologists.

Assessment of Geosites

The present study follows the existing methodology proposed by Brilha (2016, 2018) for the geosite assessment. According to this method, four assessment criteria are scientific value (SV), educational value (EV), tourism value (TV), and degradation value (DV). The details of the scoring and weightage value and obtaining the final value have been discussed as follows.

SV was calculated based on representativeness, key locality, scientific knowledge, integrity, geological diversity, rarity, and limitations. Each category was divided into three sub-categories, assigning points like 4, 2, and 1. As per the suitability score is identified. EV was calculated based on vulnerability, accessibility, use limitations, safety, logistics, population density, associations with other values, scenery,

uniqueness, observation conditions, didactic potential, and geological diversity. In the present work, geomorphological diversity was also considered. TV is connected to EV, and the assessment is based on three criteria: interpretative potential, economic level, and proximity of recreational areas. Each criterion EV and TV is given 1, 2, 3, and 4 value categories. EV indicates the aesthetics of a site. Visitors who view the landform can easily identify it without any geomorphological and geological background. Therefore, EV and TV values need to be discussed together. DR was calculated as deterioration of geological elements, proximity to areas/activities with the potential to cause degradation, legal protection, accessibility, and density of population. Like EV and TV, DR also classified as 1, 2, 3, and 4. Weights for the different criteria were assigned on SV, EV, TV, and DR. The sum of SV, EV, TV, and DR values is 400. The final value of SV, EV, TV, and DR is categorised as very low (0–100), low (100–200), moderate (200–300), and high (300–400). Therefore, four different values will be generated for each geosite.

Result and Discussion

Geosites can be categorised as geological and geomorphological sites with scientific, educational, touristic, and degradation value. Geomorphological sites include various landforms related to fluvial, tectonic, and weathering, whereas geological areas include rock, minerals, fossils, and bedding structures (Panizza 2001; Reynard and Panizza 2005; Reynard 2020). Sites with outstanding value are described below, qualifying the criteria for geosite. The first geosites of the Tuwaiq Mountain are documented in the recent work of Sen et al. (2023), where such landscape is proposed to be part of 'IUCN Theme 3: Erosional Landform'. The present work is the continuation of work, where geosites are assessed further and enhanced in the following sections. A detailed description of the geosites has been illustrated in Table 1.

Geosite 1: Escarpment (Fig. 3)

Tuwaiq Mountain represents a broad picture of the cuesta extending from Nafud to Rub Al Khali (N-S extension). It possesses the main landform unit in the central portion of Saudi Arabia. Scarp is in the western part of Tuwaiq Mountain, intersected by numerous east–west extended fault-pass. Several landforms like vertical cliffs and talus in the foothill characterise the slope-face of the scarp. The horizontal bedding is exposed from the cliff. The main viewpoint of the escarpment is 99 km away from the main road. However, being connected to the mobile network is not very prominent. Similarly, the viewpoint is accessible through the 4×4 car only. Moreover, the sharp cliffs, rocky off-road, and

adverse climate in summer are still significant constraints to reaching the viewpoint.

Geosite 2: Cuesta (Fig. 4)

Cuesta is a massive, tilted structure formed by massive tectonic activities, with a cliff on one side and gentle titration on the other. Several recent works explained the genesis of such cuesta structures in the central portion of Saudi Arabia (Rausch et al. 2014; Sen et al. 2023). Due to the limestone formation, the rocks are prone to erosion by rainfall, thus numerous fluvial channels dissecting the cuesta structures. Cuesta can be viewed from around 90 km of driving distance from Riyadh.

Geosite 3: Canyon with Waterfall (Fig. 5)

The canyon is the structural fluvial valley mainly formed due to the tectonic activities, as observed in this geosite (Fig. 5a). However, this valley started due to tectonic movements, later modified by fluvial activities. The structural steps form the cascade waterfall (Fig. 5b, c). Due to the irregular rainfall in the aeolian environment, seasonal waterfall development along the cliff feeds the wadis. Cascade waterfalls are observed in various places. Such features are prevalent in different parts of Tuwaiq Mountain. The valley bottom is covered with a waterbody that supports biodiversity. Such valleys are very common in various parts of Tuwaiq Mountain.

Geosite 4: Mesa (Fig. 6)

This is a flat top mound with a steep slope, formed on the western edge of the Tuwaiq Mountain due to the detachment of the portion of landmass from the main cuesta structure. Rainwater percolates through the fisher and joint, gradually elongates due to prolonged weathering. The photograph is representative of the mesa formed in the western portion of the cuesta.

Geosite 5: Butte (Fig. 7)

Butte is an isolated rock tower detached from the main cuesta, which is very common geomorphic process in cuesta landforms (see Migoñ et al. 2019; 2020). In the advanced stage of the evolution and denudation of the side-wall slope, butte features are formed in the western portion of the scarp. The retreat of the scarp and gradual degradation of the hill creates a cliff slope and talus deposit.

Table 1 Description of 10 geosites in Tuwaiq Mountain

Site code	Site name	Location	Owner	Legal protection	Accessibility	Fragility and vulnerability	Geology	Remarkable geological framework	Suitable time for field work	Limitation for sampling
Geosite 1	Escarpment	24°56'40.49"N, 45°59'33.82"E	Tuwaiq Reserve	No	Off-road	Fragile cliff slope	Limestone	Cliff and talus	November–April	Cliff is vulnerable in the rainy season
Geosite 2	Cuesta	24°56'24.23"N, 45°59'29.02"E	Tuwaiq Reserve	No	Off-road	Fragile cliff slope	Limestone	Denudated limestone structures	November–April	
Geosite 3	Canyon	25°10'36.0"N, 46°12'33.4"E	Public	No	Off-road		Tectonic structures	Structural valley and waterfall	November–April	
Geosite 4	Mesa	25°29'07.8"N, 46°25'12.5"E	Public	No	Off-road	Fragile	Limestone	Cliff and talus	November–April	Easily accessible to study
Geosite 5	Butte	25°29'07.8"N, 46°25'12.5"E	Public	No	Off-road	Fragile	Limestone	Cliff and talus	November–April	
Geosite 6	Pinnacle	24°37'16.84"N, 46°15'31.45"E	Public	No	Off-road	Fragile	Limestone	Rock pillar and talus deposit	November–April	
Geosite 7	Gully network	24°57'1.26"N, 45°59'49.68"E	Public	No	Off-road	Fragile	Quaternary	Rills, gully, dried-up spars, tableland	November–April	
Geosite 8	Wadi	24°46'44.98"N, 46° 8'2.10"E	Public	Partially	Road	Partially fragile	Quaternary	Flora and fauna biodiversity	Any time, preferably from November to April	
Geosite 9	Cave	24°46'33.57"N, 46° 7'57.68"E	Public	No	Off-road	Fragile	Limestone	Several bat species were recorded in a cave tunnel	Any time	
Geosite 10	Fossil	25°07'46.1"N, 46°09'19.6"E	Public	Road	Road	Prone to destruction	Jurassic	Marine fossil	November–April	



Fig. 3 View of the free-face of the escarpment and the erosion plain (facing towards the west)



Fig. 4 A view of cuesta surface, with flat surface. The gully head originated from the head of the cuesta

Geosite 6: Pinnacle

Narrow rock pillars in the western portion of Tuwaiq are very common (see Rausch et al. 2014). The little taper upward pillar with in situ deposit of weathered material forms a unique structure. Such landform is one of the ultimate stages of the cuesta landform evolution. The landform degradation from cuesta, mesa, butte, and pinnacle represents the journey of the landform under various geomorphic processes.

Geosite 7: Gully Network (Fig. 8)

Numerous quaternary fluvial channels are bifurcating the Tuwaiq Mountain, mostly forming a dendritic channel

network; considering the present arid environment, such a large dendritic drainage pattern is entirely misfit to the current climatic condition. This well-form fluvial system indicates the existence of the vast drainage system in the near past, which plays a key role in forming the valley and evolution of the scarps. The weak geological structures and limestone lithology are prone to erosion. Considering the massive gully networks, as Sen et al. (2023) explained, cuesta is widely dissected, and fault scarps are modified.

Geosite 8: Wadi (Fig. 9)

Several wadis dissect the Tuwaiq Mountain result from the left-lateral displacement of the Central Arabian transtensional system (Bamoussa et al. 2020). The Tuwaiq Mountain shows cuestas that dip gently towards the east direction. Wadi is a valley of various shapes, ‘I’ and ‘V’, depending on the causes of origin. Due to the prevalence of the seasonal water flow in wadi, various flora and fauna form valley habitats. Rocky cliffs, talus, and quaternary deposits characterise the wadi.

Geosite 9: Cave (Fig. 10)

The cave is exposed to the surface with a narrow opening (Fig. 10a, b). Unlike the cave in the tropical region, non-karstic cave features in the arid region are devoid of stalactite, stalagmites, and pillars (Fig. 10c). Despite that, sizeable hollow caves and tunnels are formed. Tunnels are getting narrower inside and linear in shape (Fig. 10d). Various collapses of rock structures from the cave ceiling have been observed. Bat species in the cave tunnels have been observed that enhance the ecological importance of the cave habitat and propose for further ecological research in caves.

Geosite 10: Fossil (Fig. 11)

As mentioned in Sen et al. (2023), the Tuwaiq Mountain Formation is also very rich in macrofauna like ammonites (Fig. 11a), gastropods (Fig. 11b), nautiloids, brachiopods, and ostracods. (Fischer et al. 2001). Jurassic ammonites have been documented from Tuwaiq Mountain (Arkell 1952). El-hedeny (2012) mentioned that trace fossils of the Tuwaiq include *Chondrites intricatus* (Brongniart 1828), *Chondrites stellaris* (Uchman 1999), *Curvolithus simplex* (Fritsch 1908), *Hillichnus agriensis* (Pazos and Fernandez 2010), *Palaeophycus cf. tubularis* (Hall 1847), *Phycodes cf. palmatus* (Hall 1852), and *Thalassinoides horizontalis* (Myrow 1995).

Fig. 5 Canyon is formed due to the tectonic activity (a). The photograph shows the break of slope, forming a seasonal waterfall (b). Waterbody formed in the base of the canyon fed by rainwater (c and d)

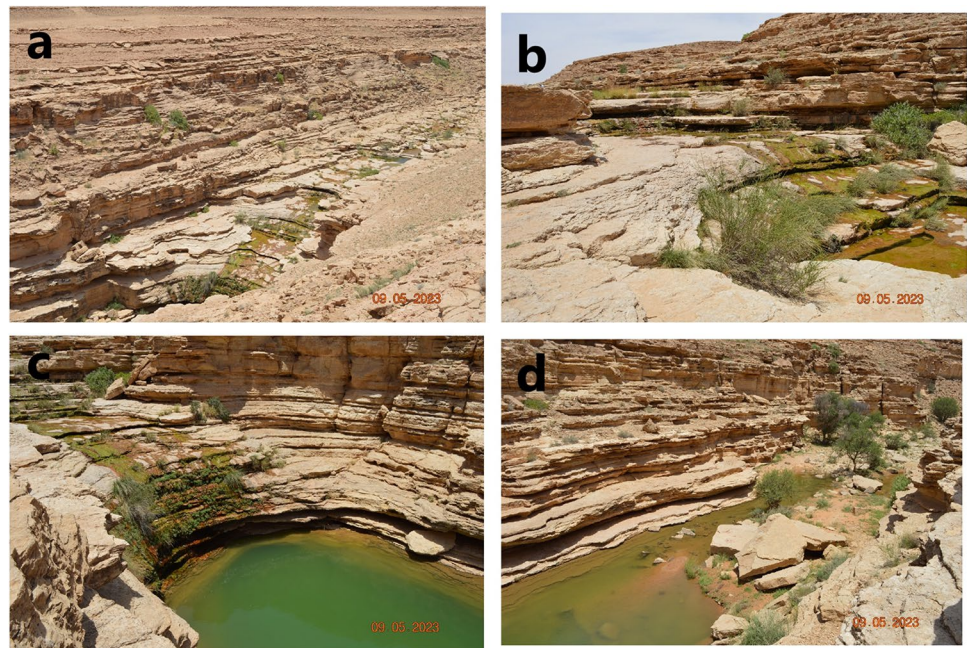


Fig. 6 Mesa is formed in the western portion of the Tuwaiq Mountain as an isolated upland



Fig. 7 Butte formed as a rocky upland with a flat top and was surrounded by cliffs, gradually forming a pinnacle

Assessment of Geosites

The assessment of the geosites scientific value and degradation risk is an important tool for developing geoconservation strategies (Mehdioui et al. 2020). In addition, this assessment was also done to quantify the potential educational and touristic uses of the 10 geosites (Fig. 12). Escarpment and cuesta geosites are characterised by moderate-high scientific value. Four geosites have a moderate scientific value, and only geosites have moderate-low scientific value (fossil and wadi). These results are justified by the high geodiversity and unique geological features.

The scientific value (SV) is calculated based on the seven (7) criteria. Scarp, cuesta, mesa, butte, pinnacle,

and cave show high scientific value within the range of 300 to 400. However, canyon, wadi, and fossil sites score 200 to 300 (Table 2). EV is calculated for 10 geosites based on twelve (12) criteria. Scarp scored high value (320), whereas other sites range between 200 and 300 (Table 3). TV is linked with the EV value, where some criteria are similar, like vulnerability, accessibility, use limitations, safety, logistics, density of population, association with other values, scenery, uniqueness, and observation conditions. TV value of cave, mesa, and butte range to high tourist value, and remains are falling within the range of 200 to 300. However, the scarp score is 290, close to the high range (Table 4). DR values for all the geosites is calculated to understand the geological elements, proximity



Fig. 8 The network of wadis originated in the foothill of Tuwaiq Mountain, gradually amalgamated and forming networks



Fig. 9 A view of the biodiversity in the wadi, protected by MEWA, Saudi Arabia

to areas with the potential to cause degradation, legal protection, accessibility, and density of population. DR value for most geosites is falling from 100 to 300, except for cuesta (Table 5).

The assessment also shows that one geosite has moderate-high educational value (scarp), and nine geosites have a moderate educational value. In comparison, seven geosites have a reasonable touristic value, except three geosite have high touristic value. Interestingly, all the geosites are score as moderate to high scientific value. Regarding the degradation risk assessment (Fig. 12), three geosites have low risk (canyon, pinnacle, and cave), and five geosites have moderate risk. In contrast, only one geosite (cuesta) has high risk. It has been observed that scarp has high scientific value but moderate low risk. The combination of high scientific value and low to high degradation risk justifies top priority in implementing management strategies of the geosite.

Geothics and Geotourism

Geothics provides an opportunity to understand the value of geoheritage, geoeeducation, and conservation of the environment (see Zafeiropoulos et al. 2021). The significant landform with outstanding value and biodiversity can be conserved based involvement of the local people. The diversity of landforms and ecological importance of the landscapes in Tuwaiq Mountain needs to conserve in such a way geological, geomorphological, and biodiversity need to the conserved on one side; on the other hand, geotourism can be promoted to more significant audiences.

In geotourism, the majestic view of the landform and landscape is a significant feature to attract tourists. The various geomorphic processes, with time, develop different natural monuments (see Chylińska 2019, Elassal 2020, Goudie 2002, Quesada-Román 2020, Qussesada-Román 2020 and Reynard et al. 2009). The top viewpoint at the scarp is a suitable area to observe the scarp and the landscape of the seasonal stream that originated from the toe portion of the scarp. Worldwide, such scarp features are prevalent, also in Saudi Arabia. Due to the accessibility to the edge of the scarp, diverse views of attractive landscapes enhance the site's aesthetic value, which is crucial in showcasing a place to qualify for geotourism. Due to the aeolian environment, rainfall is limited, which also helps the researcher to visit most of the sloppy terrain for hiking. Viewing a landscape from the top and bottom provides a different understanding of landscape evolution. A view from the top will help to understand the connectivity of the two entirely different geomorphic units and habitats, although they are connected but endowed with their characteristics. For example, from the upper portion of Tuwaiq, one can observe the genesis of the various fluvial channels, dendritic pattern formation, and parts of the flat-top mesa. On the contrary, from the down, one can identify the valley formation and the biodiversity of the wadi.

Geoconservation

In Saudi Arabia, government agencies like the Ministry of Tourism, National Center for Wildlife, National Center for Vegetation Cover, and Royal Commission for Riyadh City initiated various steps to conserve the biodiversity in Tuwaiq Mountain. The Royal Commission for Riyadh City and The Saudi Commission for Tourism and National Heritage adopted several conservation approaches to promote the tourism of heritage sites in Saudi Arabia. To date, ad Dir'iyah, Turif District is one of the UNESCO Heritage sites close to the Tuwaiq Mountain (Saudi Arabia—UNESCO World Heritage Convention). Qiddiyah project initiated various tourist sports and theme parks in Riyadh that showcase nature-based tourism (see <https://qiddiya.com/>).

Fig. 10 A cave formed in Tuwaiq Mountain. Opening of the cave on the surface (a). A view of the inside of the cave (b). The ceiling of the cave without stalactite (c). A view of the narrow and linear tunnel (d)

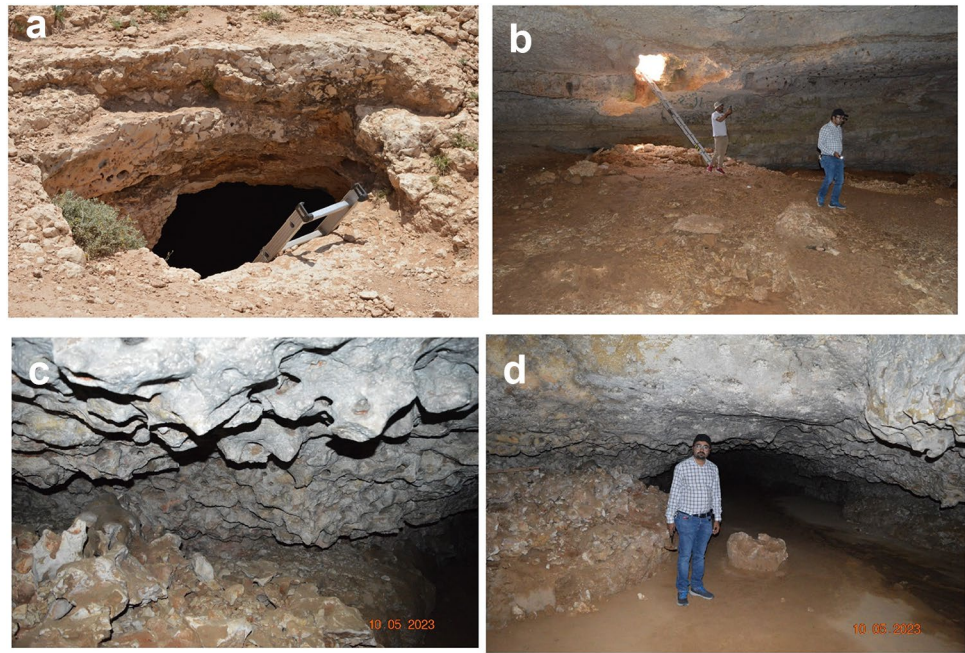
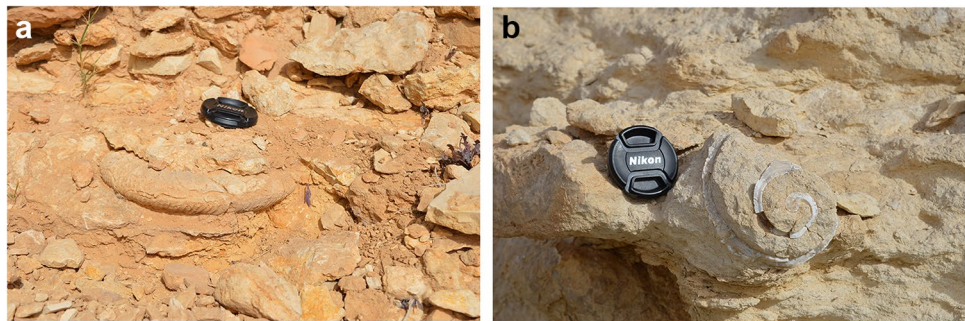


Fig. 11 Ammonite fossils are widespread in the lower part of Tuwaiq Mountain (a). View of cast developed by gastropod species. Calcite crystallised on the internal wall of fossil (b)



Vision 2030 of the Kingdom of Saudi Arabia prioritises developing heritage sites. Slowly but surely, the national organisations of Saudi Arabia realised the potentialities of geotourism in its territory (Al-Omari and Al-Marghirani 2017). Geoconservation is extremely important to protect and manage a site for easy accessibility to the geological and geomorphological sites, allowing scientific exploration and tourism purposes (Prosser et al. 2011). Urbanisation and lateral expansion of Riyadh City need various infrastructural set-ups and are expected to increase soon. Therefore, the gully and the different cliff slopes may be affected due to road construction. Cliff is also susceptible to slope failure in the rainy season, which needs protection. Fossils are observed in various parts of Tuwaiq Mountain; therefore, awareness campaigns and policies must be developed to protect the geoheritage.

Several tourism initiatives and infrastructural facilities have recently been developed around Riyadh City. Several tour companies offer a 1-day trip to the Tuwaiq Mountain; therefore, it is a known tourist in the national tourism campaign. The scarp is very well known as the ‘edge of the world’ due to its vast extension and mesmerising view of the scarp face. The denuded cliff is also famous to local travelers as a mountain-hiking and tourist sport. The majestic view of the scarp, seasonal waterfalls in the scarp, flat top cuesta structure, butte, pinnacle, and wadi networks in the potential viewpoint could be exciting sites for developing geotourism attraction sites. Geotourism provides funding and financial gains to geoconservation. At the same time, geoconservation strategies support the sustainable growth of geotourism at a regional and national scale by strengthening the linkages between academia and industry (Hose 2012).

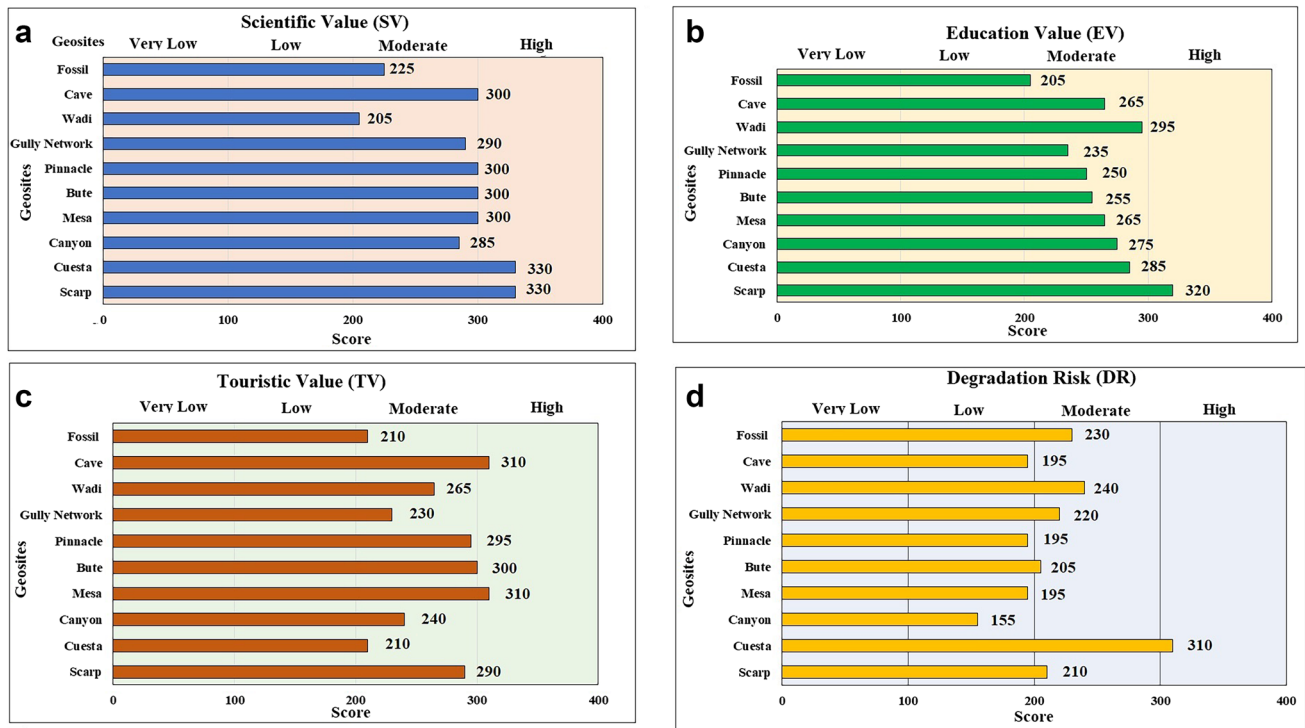


Fig. 12 Scoring of the geosites and assessment based on **a** scientific value (SV), **b** potential education (PV), **c** tourism value (TV), and **d** degradation value (DV)

Table 2 Assessment of the scientific value (SV) for each geosite

Criteria	Scarp	Cuesta	Canyon	Mesa	Butte	Pinnacle	Gully network	Wadi	Cave	Fossil
A. Representativeness	1.2	1.2	1.2	1.2	1.2	1.2	1.2	0.6	1.2	0.6
B. Key locality	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.2	0.4	0.4
C. Scientific knowledge	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
D. Integrity	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
E. Geological diversity	0.2	0.2	0.05	0.2	0.2	0.2	0.1	0.05	0.2	0.2
F. Rarity	0.6	0.6	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.15
G. Use limitation	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Total value	3.3	3.3	2.85	3	3	3	2.9	2.05	3	2.25
Score	330	330	285	300	300	300	290	205	300	225

Conclusion

Around 10 geosites have been assessed from geoheritage and geoconservation perspectives. The various natural heritages in the Tuwaiq Mountain are escarpment, cuesta, mesa, butte, pinnacles, non-karstic cave, and Jurassic fossils. The genesis of the scarp is related to the tectonic upliftment in the centre portion of Saudi Arabia. A major deformation occurs in the western portion of Tuwaiq Mountain. However, the eastern portion is gradually tilted towards the east, thus forming the easterly incline cuesta

structures with sharp cliffs in the west. Later, a massive fluvial system developed in the centre portion of Saudi Arabia due to the prevalence of the rainy season in the geological past. Therefore, considering the marine fossil remains and the dried-up fluvial network indicates the massive transformation of the geomorphologic process induced by the change of environmental set-up in the central portion of Saudi Arabia. The geotourism provides an opportunity to mass audiences to learn about the geomorphic processes in different geological periods and the development of a gigantic landscape in the central portion of Saudi Arabia.

Table 3 Assessment of the education value (EV) for each geosite

Criteria	Scarp	Cuesta	Canyon	Mesa	Butte	Pinnacle	Gully network	Wadi	Cave	Fossil
A. Vulnerability	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.3
B. Accessibility	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.2	0.1
C. Use limitations	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
D. Safety	0.2	0.1	0.3	0.1	0.1	0.1	0.2	0.2	0.1	0.2
E. Logistics	0.1	0.05	0.05	0.1	0.1	0.1	0.05	0.05	0.1	0.05
F. Density of population	0.05	0.05	0.05	0.1	0.1	0.05	0.05	0.05	0.1	0.05
G. Association with other values	0.15	0.2	0.2	0.15	0.2	0.15	0.2	0.15	0.15	0.1
H. Scenery	0.2	0.05	0.05	0.2	0.2	0.2	0.05	0.2	0.2	0.05
I. Uniqueness	0.2	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.2	0.1
J. Observation conditions	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3
K. Didactic potential	0.8	0.8	0.8	0.2	0.2	0.2	0.4	0.8	0.2	0.2
L. Geological diversity	0.4	0.4	0.1	0.4	0.4	0.4	0.1	0.4	0.4	0.4
Total value	3.2	2.85	2.75	2.65	2.6	2.5	2.35	2.95	2.65	2.05
Score	320	285	275	265	255	250	235	295	265	205

Table 4 Assessment of the tourism value (TV) for each geosite

Criteria	Scarp	Cuesta	Canyon	Mesa	Butte	Pinnacle	Gully network	Wadi	Cave	Fossil
A. Vulnerability	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.3
B. Accessibility	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.1
C. Use limitations	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
D. Safety	0.1	0.1	0.3	0.1	0.2	0.1	0.2	0.2	0.1	0.2
E. Logistics	0.1	0.05	0.05	0.15	0.1	0.1	0.1	0.05	0.15	0.05
F. Density of population	0.05	0.05	0.1	0.05	0.1	0.1	0.05	0.05	0.05	0.05
G. Association with other values	0.15	0.2	0.2	0.15	0.2	0.15	0.2	0.15	0.15	0.1
H. Scenery	0.6	0.15	0.15	0.6	0.6	0.6	0.15	0.6	0.6	0.15
I. Uniqueness	0.4	0.2	0.2	0.4	0.4	0.4	0.2	0.2	0.4	0.2
J. Observation conditions	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.15
K. Interpretative potential	0.3	0.3	0.4	0.3	0.3	0.3	0.4	0.3	0.3	0.3
L. Economic level	0.1	0.05	0.05	0.15	0.1	0.1	0.05	0.1	0.15	0.1
M. Proximity of recreational areas	0.2	0.1	0.05	0.2	0.2	0.2	0.05	0.2	0.2	0.2
Total value	2.9	2.1	2.4	3.1	3	2.95	2.3	2.65	3.1	2.1
Score	290	210	240	310	300	295	230	265	310	210

Table 5 Assessment of the anthropogenic factor on the landform based on the degradation value (DV)

Criteria	Scarp	Cuesta	Canyon	Mesa	Butte	Pinnacle	Gully network	Wadi	Cave	Fossil
A. Deterioration of geological elements	0.7	1.4	0.7	0.7	0.7	0.7	0.35	1.05	0.7	1.05
B. Proximity to areas/activities with potential to cause degradation	0.2	0.4	0.2	0.2	0.2	0.2	0.8	0.2	0.2	0.2
C. Legal protection	0.8	0.8	0.4	0.8	0.8	0.8	0.8	0.8	0.8	0.8
D. Accessibility	0.3	0.3	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
E. Density of population	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1
Total value	2.1	3.1	1.55	1.95	2.05	1.95	2.2	2.4	1.95	2.3
Score	210	310	155	195	205	195	220	240	195	230

In the recent publication on Tuwaiq Mountain, geotourism value was well explained (Sen et al. 2023). However, geoconservation and geoethics have been discussed in this work to highlight the importance of conserving various fossil sites and cave structures. Community awareness, a description board, and a proper access route are required to protect the natural heritage. Caves are significant in protecting the bat ecology. Moreover, various landforms in Tuwaiq Mountain also serve as ambient habitats for the growth of flora and fauna. Therefore, geoconservation not only protects the different landforms but also protects biodiversity. Considering the larger scale denuded landscape, this landscape also can be a part of the ‘IUCN Theme 3: Erosional Landform’.

Most of the sites are not accessible from the main road. Therefore, with the immense scientific value of geomorphological and geological heritage, such sites are not gaining popularity. Due to the aesthetic beauty of these sites, most are frequent destinations for weekend travellers. Anthropogenic activity without awareness of natural heritage conservation may hamper the natural landscape. Therefore, geoeducation is very important to involve the local community with attention to protect the landform and biodiversity. Geoconservation and geoethics need to rethink the policy maker to protect the geoheritage of such geosite.

The journey of developing a geopark is a long process, including national policy, community development, and further detailed study. However, this paper can conclude that considering the various aspects, Tuwaiq Mountain will be suitable for promoting geotourism.

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Author Contribution SS contributed a leading role in initiating this research and wrote the first draft of the manuscript, and all authors commented on previous versions. SS, MOA, and AHA-M were involved in fieldwork. FSA-I supported the execution of this research work. AS is involved in data analysis and manuscript preparation.

Data Availability All the data generated based on the field survey. The out-come of the analysis can be used for the policy maker to promote geoheritage and geotourism.

Declarations

Conflict of Interest The authors declare no competing interests.

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