

Geoheritage Assessment of Scientific Value and Additional Value of Tuwaiq Mountain, Saudi Arabia

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Abstract

Tuwaiq Mountain in the central part of Saudi Arabia is characterized by a spectacular tableland, which comprises Jurassic sedimentary rocks. Tuwaiq Mountain is unique in terms of geological heritage, biodiversity, and culture. However, limited study discussed the scientific and additional value together, towards a holistic geoconservation approach. This paper aims to identify and assess the geoheritage potential of Tuwaiq Mountain considering the scientific and additional value. Scientific value is assessed based on five criteria: representativeness, rarity, key locality, scientific evidence, and integrity. The additional value is evaluated based on ecological, aesthetic, and cultural significance. The key landforms in Tuwaiq Mountain are cuesta, mesas, buttes, pinnacles, gully networks (known as wadis), escarpments, gravel plain, and dunes. An abundance of Jurassic marine fossil colonies reflects major transgressions and regressions, which later transformed into fluvial and wind-blown environments. These fluvial valley, hilly terrain, and the sand sea around the Tuwaiq Mountain is a ambient terrestrial habitat for flora and fauna. Therefore, various protected areas have been developed in Tuwaiq Mountain. Similarly, the seasonally inundated fluvial valley supports the development of cultural of the local community. From a geoeeducational perspective, Tuwaiq Mountain possesses a rare landscape, with high representativeness that preserves the depositional cycle of Jurassic sedimentation and tableland evolution. Therefore, Tuwaiq Mountain can be considered world-class geomorphological geoheritage, with high conservation priority.

Introduction

A tableland is a flat-topped area with a sedimentary succession of horizontal bedding, surrounded by a cliff slope when it is slightly tilted on one side, called a cuesta. Some of the alternate terminologies of tablelands are table hills, table-top hills, or tent hills in Southern Australia (Jack 1915); Tafelberg in Germany, and table mountain in Europe (King 1942); scarpland in Saudi Arabia (Rausch et al. 2014). Due to the prolonged denudation and decay, the tableland forms various landscapes called mesas, buttes, and towering rocks (Duszyński et al. 2019).

Geoconservation of the Tablelands is well appreciated in various UNESCO Global Geoparks and national parks, particularly in Europe (Migoń and Pijet-Migoń 2024; Migoń 2024; Chrobak-Žuffová et al. 2025; Mertlík and Adamovič 2016). Moreover, a growing number of UNESCO Global Geoparks, numerous academic articles, and the participation of new countries in the Global Geoparks Network (GGN) list (Henriques and Brilha 2017; Martínez-Martin et al. 2023; Wang et al. 2022) indicate the growing concern for geoconservation.

In recent case studies from various parts of Saudi Arabia, the various landforms associated with the tableland in Saudi Arabia (Sen 2024 b, c, e) documented the close association of geological value with biodiversity, cultural, historical, and aesthetic values. The AIUla, Wadi Al Disah, and Jabal Al Qarah (Sen et al. 2023a; Sen et al. 2025a, b) exemplify a rare global case of tableland evolution, though they often lack recognition within national or international geopark frameworks despite their significant potential for geoconservation and geotourism. From the aesthetic point of view, escarpments and waterfalls have potential for geotourism destinations in Saudi Arabia (Elassal 2020; Al Mohaya and Elassal 2023). In central Saudi Arabia, notable features include tablelands, mesas, buttes, and dried-up river valleys (Sen et al. 2023b, 2024d). Classifying Saudi Arabia's geoheritage using the IUCN Geoheritage theme enhances the country's comprehensive geoheritage policy (Sen et al. 2024a).

The North Riyadh UNESCO Global Geopark in Tuwaiq Mountain to practice geoconservation (Turki et al. 2025). But therefore is a significant gap in understanding and adaptation of the integrated geoconservation policy for geoheritage, biodiversity heritage, and cultural heritage distributed throughout the Tuwaiq Mountain, which is collected. Further, considering the rapid urbanization in Tuwaiq Mountain, which exceeds our baseline data on geoheritage and geoconservation policy, this paper will support a better understanding of the integrated geoconservation approach. The objective of this paper is, first, to discuss landform diversity and, second, to assess these areas from the perspective of geoheritage.

Tuwaiq Mountain: Evolution and Geology

Tuwaiq Mountain, with an elevation of about 600 meters, is located in central Saudi Arabia (see Fig. 1). It stretches from the southern part of the Nafud Desert to the west of the Rub' al Khali Desert, forming a 120-kilometer-long flat-topped cuesta. The opening of the Red Sea (around 22 million years ago) has significantly influenced the current landforms in this area (Coleman and McGuire 1988; Bartov et al. 1980). Extensive tectonic activity has uplifted the land, creating elevated regions that gave rise to the Central Arc in the central part of Saudi Arabia (see Fig. 2). Simultaneously, graben structures have developed in the lower regions (Sen et al. 2023b). Throughout geological history, central Saudi Arabia has undergone major phases of marine transgression and regression (Al-Mojel et al. 2020).

In central Saudi Arabia, the Permo-Mesozoic sedimentary succession, exposed in the Tuwaiq Mountains, lies on the crystalline basement rocks of the Arabian Shield. The depositional sequence developed during the Permian–Triassic period, including the basal calcareous Khuff Formation, which forms the first prominent scarp above the basement. The top of the Khuff Formation features shales of the Triassic Sudair Formation, capped by the Jilh Formation, which contains sandstones, limestones, and some interlayered shales. Some scarps are formed in this unit and also in the overlying Minjur Formation. Central Saudi Arabia is characterized by the Jurassic Shaqra Group, composed of the Marrat, Dhurma, and Tuwaiq formations (Fig. 2). These formations consist of alternating layers of limestone, sandstone, and shale. The limestone and sandstone layers often form prominent cuestas, while shale creates the base of the scarps and surrounding foreland (Rausch et al. 2014). When the landmass of the central part faulted and uplifted, it formed the cuesta. As a result, marine sediments, coral, and fossils were exposed on the surface of Tuwaiq Mountain. Today,

abundant shallow marine fossils and coral colonies can be observed throughout Tuwaiq Mountain (El-Hedeny 2012; Hewaidy et al. 2017; Tawfik et al. 2016).

Conservation Approach in Tuwaiq Mountain

Tuwaiq Mountain is also important for various national parks, protected areas, and UNESCO Geoparks, including Tuwaiq Reserve, Imam Abdulaziz bin Mohammed Royal Reserve, and King Khaled Royal Reserve. Additionally, Riyadh City is situated near Tuwaiq Mountain, with the city's western expansion extending into the foothills of the mountain, thereby increasing the cultural significance of the area.

Tuwaiq Reserve (Area: 3300 km²) is located close to Riyadh City. Tuwaiq Reserve is managed by the Saudi Wildlife Authority, which safeguards Nubian ibex and other wildlife, part of the IUCN Wildlife Database Protected Area (WDPA) (<https://www.protectedplanet.net/555785925>).

North Riyadh UNESCO Geopark: In 2025, UNESCO recognized this geopark, which connects the local community in geoconservation (Community, memory, and landscape in North Riyadh UNESCO Global Geopark). It features a range of geosites, including an escarpment, wadi, faults, caves, and fossils (<https://northriyadhgeopark.ncvc.gov.sa/>).

King Khaled Royal Reserve: It is a protected area situated in the northeast of Saudi Arabia. Named after King Khalid bin Abdulaziz Al Saud, the fourth king of Saudi Arabia, the reserve covers over 1,160 square kilometers. It is known for its rich biodiversity and distinctive mountain and desert landscapes. The reserve hosts a variety of plant and animal species, including Arabian oryx, gazelles, wolves, and numerous bird species. It offers opportunities for wildlife watching and nature photography. Visitors can explore the reserve through guided tours and a range of activities such as hiking, camping, and mountain biking. Besides its natural beauty, the King Khaled Royal Reserve also contains archaeological sites, ancient rock art, and remnants of human settlements dating back thousands of years. These historical and cultural features offer valuable insights into the region's rich history.

Imam Abdulaziz bin Mohammed Royal Reserve: The Imam Abdulaziz bin Mohammed Royal Reserve is a protected area situated in the northeast of Riyadh, in the southwestern part of the Dahna Desert. The reserve covers an area of 11,300 square kilometers. It is known for its diverse ecosystems, including valleys, prairies, and desert landscapes such as Rawdat Khuraim, Ghaylanah Valley, and Kasr Al-Muzayr'a. It is home to a wide variety of plants and animals, including several endangered species. The reserve is notable for its proximity to and accessibility from Riyadh, as well as the presence of residential settlements within its boundaries. It also contains numerous archaeological sites and ancient routes (<https://www.iarda.gov.sa/>).

Uruq Bani Ma'arid Protected Area covers the western part of Ar Rub al-Khali and the southern tip of Tuwaiq Mountain, representing the unique aeolian landscape. Its diverse terrain supports various ecosystems and is internationally significant for the reintroduction of iconic desert species, such as the Arabian Oryx (*Oryx leucoryx*) and the Arabian Sand Gazelle (*Gazella marica*). The oryx, which had been extinct in the wild for decades, was reintroduced to this area. The shifting dunes create ideal, well-oxygenated habitats for sand-diving invertebrates and reptiles, while the limestone plateau's deep incised wadis foster rare relict plants. Historically, the region has been used for generations by pastoral, nomadic Bedu communities, who have stayed in the desert (<https://whc.unesco.org/en/list/1699/#:~:text=In%201996%2C%20Uruq%20Bani%20Ma,adequately%20protected%20by%20national%20legislation.>).

Materials and Methods

A thorough literature review has been conducted on the geoheritage research in Saudi Arabia, with particular reference to Tuwaiq Mountain. To support the literature review, a description card has been prepared for Tuwaiq Mountain, providing essential information and photographs (300 dpi). During the field survey, a detailed description was prepared for the following criteria. The photographs have been taken to justify the representativeness, rarity, key locality, and integrity. A detailed literature review has been conducted based on the identification of scientific knowledge categories.

For the geoheritage assessment, the updated document by Brilha et al. (2025) has been followed, where emphasis is given to the "scientific" and "additional" value; however, the qualitative assessment was not clear. Therefore, the author modified and proposed a scoring system ranging from 0 to 1, meaning low to high, for evaluating each criterion, which is inspired by the "scientific" and "additional" value assessments (Reynard 2005; Reynard and Panizza 2005; Reynard et al. 2007). Initial details of the landform are gathered from fieldwork and literature review. The landform with significant scientific, tourism, educational, and additional value is considered, which is part of a basic screening process. For assessing the scientific value, the parameters are: representativeness, rarity, type or key locality, scientific knowledge, and integrity (Table 1).

Table 1
Description of the criteria for the scientific assessment

Criteria	Description	Score
Representativeness (Re)	The geological and geomorphological processes clearly represent the landform and landscapes of the tableland. The fossil records support the depositional environment.	0 = Nil 0.25 = Low: regional context 0.5 = Moderate: at the national level 0.75 = High: regional and national level: 1 = Very High: global level
Rarity (Ra)	Geosite represents an exceptional geological and geomorphological record.	0 = Nil 0.25 = Ubiquitous (low) 0.5 = Can be found regionally (Moderate) 0.75 = Similar features are found nationally 1 = Exclusively endemic
Key locality (KI)	Appreciation of the geological and geomorphological features at the national and global levels e.g. IUGS, UNESCO, IUCN, IAG, ProGEO, or any international organization.	0 = No protection 0.25 = Local level 0.5 = Partially protected 0.75 = National protected area 1 = Appreciation from international organizations.
Scientific knowledge (Sk)	The geosites are documented in the scientific article. It will help in understanding the geological importance of the respective of significance of geoheritage importance of the area.	0 = No published literature 0.25 = Although no published literature, the value can be understood from the field observation. 0.5 = Regional publications 0.75 = National Publications 1 = International Publications
Integrity (In)	The ongoing process of geoconservation status to ensure that the geological and geomorphological features are preserved. Limited degradation risk by any anthropogenic activity. Or, any major potential geohazard and extreme event that is a threat to the key geological features.	0 = Destroyed 0.25 = Close to destruction 0.5 = Key features are partially damaged. 0.75 = Major features are maintaining their integrity, but minor features are damaged 1 = All the major and minor features are maintaining their integrity.

Scientific Value

For the scientific value assessment, the following criteria have been followed: representativeness (Re), Rarity (Ra), Key locality (KI), Scientific knowledge (Sk), and Integrity (In). The details of the criteria and corresponding scores are explained in Table 1. The score has been divided into 5 classes, where 0 is the minimum, and 1 is the maximum. The summation of the scores of the five (5) criteria is divided by five (5) to get the final score of the scientific value (SV). The SV value will range from 0 to 1.

$$SV = (Re + Ra + KI + Sk + In) / 5$$

Additional Value

The additional value of the site is divided into cultural value (CUL), ecological value (ECO), and aesthetic value (AES) (Table 2). The additional value not only gives a complete analysis of the geosites in terms of ecology, arts, or history, but also examines the possible links between geomorphology and other features of nature or culture. Ecological value considers the geosite's importance for the ecosystem's development, mainly concerning fauna and vegetation. Similar to the scientific value, initially, scores need to be assigned for the ECO, AES, and CUL. The summation of values is divided by 3 (three) to get the final score of the EV of each landform as follows:

Table 2
Description of assessment criteria for the additional value

Criteria	Description	Score
Ecological (ECO)	Any sensitive sites with significant ecological importance, with international significance.	0 = Nil 0.25 = Low 0.5 = Significant at the national level 0.75 = Included in the IUCN Red List, extremely important 1 = Part of the international wildlife/botanical protected area.
Aesthetic (AES)	The beautiful view of the landform and landscape that any international organization recognizes.	0 = Nil 0.25 = Low 0.5 = Important at the national level 0.75 = Popular at the national and international level 1 = Recognised by the international organizations
Cultural (CUL)	Cultural sites associated with the geosites. Description of the sites with international recognition. The significance will be further assessed from the geohistory, religious, culture, and artistic literature.	0 = Nil 0.25 = Low 0.5 = Regional cultural site/significance 0.75 = National and international level cultural significance 1 = Outstanding cultural importance, which is recognized at an international level.

Additional Value (AV) = (ECO + AES+CUL)/3

The final score will fall within the range of 0 to 1. For better interpretation of the score of scientific value and additional value of each key landform, the value is divided into less than 0.25 = low, 0.26–0.5 = moderate, 0.51–0.75 = high, and more than 0.76 = very high.

Result and Discussion

Tuwaiq Mountain offers excellent exposure of the Jurassic limestone sequence, visible in the escarpment's bedding planes, in hillslope processes, and in marine fossils, which hold global significance. Therefore, Tuwaiq Mountain is highly important from scientific, educational, touristic, and other viewpoints.

Landform Diversity of Tableland

The lithology and bedding of the Permian through Neogene sedimentary succession in central Saudi Arabia support the development of a distinctive escarpment landscape. The formation of the cuestas primarily occurred during the Late Miocene but continued into the Early Quaternary. (Rausch et al. 2014).

Tuwaiq Mountain is a cuesta formation with a steep western slope and a gentle eastern slope (Fig. 3A, B). After the formation of the cuesta structure, numerous rills, gullies, and a fluvial network formed, dissecting the entire cuesta structure, which remains as a dried-up fluvial valley network (Fig. 3.C). The transition from a marine-dominated environment to fluvial and aeolian environments is well represented by the large-scale dried-up fluvial valley, marine sedimentary succession, colluvial corals, and fossils (Fig. 3D).

The large-scale tectonic uplift leads to various faults and fractures throughout the Tuwaiq Mountain. Due to its limestone composition, the landform is highly susceptible to erosion and degradation. Moreover, numerous fractures make the landform more friable, which is particularly evident in the

western part of the tableland (Fig. 4.A). Vertical faults significantly contribute to the decay of the rock structure, as clefts extend to form cracks (Fig. 4.B), and the occurrence of rockfalls (Fig. 4.C), often triggered by rainfall. The rectangular rock blocks occupy the gully head, where they are gradually fractured and fill the gully and wadis (Fig. 4.D). The formation and evolution of wadis can be summarized as follows: First, the collapse of the headward part due to rockfall/debris fall leads to the retreat of the wadi head, forming fluvially induced cliffs. The talus slope is mainly comprised of rocks and debris. Second, the side walls of the wadi are decaying due to the slope-wash that leads to the widening of the valley. The rock blocks and debris further disintegrated, fractured, and formed debouches in the floodplain region, resulting in gravel-rich soil. The headward erosion, collapse of the rock block, mass movement (rockfall and debris fall), fluvial scarp retreat, and valley formation are significant geomorphic processes that have global significance in understanding the hill slope processes (Twidale 2000; Sen et al. 2015; Migoń and Kasprzak 2016).

The limestone has developed various geomorphic features, including gully networks characteristic of badland topography, as well as sinkholes, caves, and tunnels formed through erosion (Fig. 5, A, B). The caves are exposed to the surface through a narrow hole. The entire site is not well-protected. The cave tunnel is entirely devoid of sunlight, forming an ambient habitat for the bat species (Fig. 5.C). Due to the weak limestone structure, the rock blocks collapse from the ceiling (Fig. 5.D).

The northern, western, and southern parts of the Tuwaiq Mountain gradually debouch into the sand sea, further supporting the formation of the giant dune structure. The large dunes of Dhahna Sandsea, Jafuah Sandsea, and Rub Al Khali Sandsea gradually cover the eastern and southern parts of the Tuwaiq Mountain. The most notable features are the longitudinal dunes in the Rub Al Khali (Fig. 6A). The limestone exposure is visible in the interdune valley (Fig. 6B). The close-up of the longitudinal dune is characterized by the smooth windward slope, the concave lee-ward side, and the sharp crest (Fig. 6.C). The top of the longitudinal dune exhibits a typical barkhanoid appearance, characterized by rhythmic dune formation. This giant longitudinal dune is formed by the unidirectional wind pattern that shapes the landscape. Along with the dominant wind, eddy formation occurs on the leeward side, resulting in a complex shape for the longitudinal dune.

Assessment of Scientific and Additional Value

This section evaluates the various landforms and geological features using a scientific score (Table 3) and the potential linkages of the geosites to ecology, culture, and aesthetics (tourism) (Table 4). Tuwaiq Mountain includes scarps, gullies, mesas, buttes, pinnacles, fossils, faults, cuestas, caves, and dunes. Several protected areas have been designated nationally and internationally throughout Tuwaiq Mountain; thus, the aesthetic value is high. Several such important sites are recognized in the North Riyadh UGGp for geotourism. Many national parks have been established in Tuwaiq Mountain, which is part of the UNESCO World Heritage Site. Therefore, ecological value is also very significant for the various landforms. The network of gullies serves as an important cultural site for the plantation, agriculture, and old settlement. Many such places have been transformed into tourist spots in the North Riyadh UGGp.

Table 3
Description of the scientific importance of Tuwaiq Mountain.

Landform Diversity	IUCN Theme	Representativeness	Rarity	Type or key locality	Scientific knowledge	Integrity
Scarp	Erosional System	High representativeness due to clear representation of scarps, geomorphic processes, and easy-to-collect specimen samples	A 120 km stretch of Jurassic limestone is the sole representation.	National protected areas and UNESCO geopark	Sen et al. (2023)b, (2024)d	All the landforms are safe.
Gully (Wadi) Network	Erosional System	High representation	A similar wadi structure cannot be found in other part of the country.	National protected areas, parks and UNESCO geopark	Sen et al. (2023)b, (2024)d	Integrity is maintained
Mesa	Erosional System	Global example for understanding how it forms after detaching from the main tableland.	Similar landforms are documented in NEOM, AlUla	National protected areas, parks and UNESCO geopark	Sen et al. (2023)b, (2024)d	Integrity is maintained
Butte	Erosional System	Global example of the weathering along the vertical fractures and forming the isolated rock unit.	Well documented in Hishmah Desert, NEOM	National protected areas, parks and UNESCO geopark	Sen et al. (2023)b, (2024)d	Integrity is maintained
Pinnacle	Erosional System	Sore representation in the Tuwaiq Mountain, which is not documented in any other part of Saudi Arabia.	Documented in Hishmah Desert, NEOM	National protected areas, parks and UNESCO geopark	Sen et al. (2023)b, (2024)d;	Integrity is maintained
Cave	Cave and Karst System	Regional Significance, multiple in the Tuwaiq Mountain	Can be found in another part of the country. For example Jabal Al Qarah.	Limited protection. Part of the National protected areas	Sen et al. (2024)a; (2024)d	Integrity is maintained partially.
Faults	Tectonic System	Can be found in the road-cut section	Available in other part of the country	UNESCO geopark	Sen et al. (2023)b, (2024)d;	Integrity is maintained
Cuesta	Erosional System	Global example of landform evolution and hosting other landforms like mesa-butte-pinnacle-gravel plain.	Unique in this region	National protected areas and UNESCO geopark	Sen et al. (2023)b, (2024)d;	Integrity is maintained
Sand Dune	Dessert and semi-desert system	Global example to see a longitudinal dune	Unique in this region	UNESCO heritage site	Sen et al. (2024)a	Integrity is maintained
Fossil	History of planet Earth and the evolution of life	High representativeness of marine fossils	Unique in this region	UNESCO geopark	El-hedeny, (2012); Hewaidy et al. 2017; Tawfik et al. (2016)	Integrity is maintained

Table 4
Description of the additional features associated with Tuwaiq Mountain

Landforms	Ecological (National and international protection status)	Aesthetics (Appreciation from an international organization)	Cultural
Escarpment	The protected areas in this region are the Tuwaiq Reserve	North Riyadh UGGp	Various national tourist spots have been constructed.
Gully (Wadi) Network	The protected areas in this region are the Tuwaiq Reserve (National Protected Area).	North Riyadh UGGp	Important for the plantation, agricultural practices, various historical structures, and the castle.
Mesa	Tuwaiq Reserve	North Riyadh UGGp	-
Butte	Tuwaiq Reserve	North Riyadh UGGp	-
Pinnacle	Part of Qidiyadh Development project	-	-
Cave	Tuwaiq Reserve	Tuwaiq Reserve (IUCN WDPA nomination)	-
Fault	-	North Riyadh UGGp, Tuwaiq Reserve (IUCN WDPA nomination)	Geotourism Site
Cuesta	Tuwaiq Reserve	-	Local tourist spot
Sand Dune	Urug Bani Muaarid (UNESCO Protected Site)	-	-
Fossil	-	North Riyadh UGGp	Geotourism Site

In terms of representativeness, all assignments received a score of 1 (Table 5). Because all the key sites are part of the national park, protected wildlife areas, and a UNESCO Global Geopark, they are directly and indirectly involved. However, many regions with similar scores are not protected. Although a high scientific score is assigned, it may not guarantee the complete implementation of geoconservation. The present study, along with the supporting evidence from previous literature, indicates the importance of the geoheritage value of the scarp, cuesta, and wadi spread across the Tuwaiq Mountain. Jurassic fossils distributed throughout the Tuwaiq Mountain are significant earth materials for explaining the region's dynamics; therefore, the score of this geological heritage is 1. Except for the cave (score: 0.5), all the key landforms score a high geoheritage value (Table 5).

Table 5
Assessment of the scientific value, Saudi Arabia. The scientific value ranges from 0 to 1, which is assessed based on the five criteria.

Landforms	Representativeness (Re)	Rarity (Ra)	Type or key locality (KI)	Scientific knowledge (Sk)	Integrity (In)	Scientific Value (SV) (Re + Ra+KI + Sk+In)/5
Escarpment	1	1	1	1	1	1
Gully	1	1	1	1	1	1
Mesa	1	1	1	1	1	1
Butte	1	1	1	1	1	1
Pinnacle	1	1	1	1	1	1
Fossil	1	1	1	1	0.75	0.95
Fault	1	1	1	1	1	1
Cuesta	1	1	1	1	0.75	0.95
Cave	1	0	1	0	0.5	0.5
Sand Dune	1	0.75	1	0.75	1	0.9

Cave structures in Tuwaiq Mountain are open to the general public, who camp inside the caves, causing potential damage to the cave ecosystem and structure. Therefore, there is a risk of degradation of this geoheritage site; however, the integrity is high (1), and representativeness is less because several parts are damaged due to anthropogenic interference. The ceiling and wall are highly weathered and have received limited attention for their paleogeographic importance; therefore, paleogeographic importance is nil (0).

Since most caves are essential habitats for bat species, however, limited scientific evidence exists on this topic. During the survey, bats were observed, indicating a need for further investigation and protection of the natural environment. The geological sites also hold additional value through ecological, aesthetic, and cultural factors, which further contribute to the overall significance of each geological feature. The escarpment provides natural shelter and habitat for various birds and land animals, enhancing its ecological importance. Additionally, the impressive view of the scarp boosts the site's aesthetic appeal. As a result, the ecological and aesthetic values of the scarp are rated 1 (Table 6). However, the cultural significance of these geological features is considerably lower, leading to an overall score of 0.6. The gully network offers important habitat for diverse plant and animal species, giving this geomorphic unit significant ecological value. Similarly, the Jurassic limestone rocks and valley structure increase its appeal to tourists, assigning an aesthetic value of 1. Furthermore, the presence of historical buildings, monuments, and traces of Arab civilization in this region confers a cultural value of 1, resulting in a total score of 1. This indicates that this geomorphic unit merits attention for geoconservation. The mesa and butte are different landform scales that hold geoscientific importance, but their ecological and cultural significance is minimal. Their distinctive flat-topped shapes have aesthetic value even for non-geoscientists. Of particular interest, the pinnacle is formed at a more advanced stage of landform development, and some, such as those part of the Qiddiya Project (<https://qiddiya.com/>), have cultural value enhanced to 1. Growing awareness of fossil conservation, emphasized by geoeducation efforts of the North Riyadh UGGp, has made locals aware of abundant fossils throughout Tuwaiq Mountain. Moreover, the international significance of marine fossils and colluvial coral structures grants an aesthetic value of 1. Cuesta landforms possess ecological importance because many fauna species prefer to inhabit this rocky terrain. The exposed limestone increases tourism appeal, leading to an overall score of 0.6. The giant dune in the southern part of Tuwaiq Mountain is part of the UNESCO World Heritage site, important for its ecological role and its mesmerizing, unique view. Given its UNESCO recognition and national importance, this dune has an added value score of 1.

Landforms	Ecological (ECOL)	Aesthetic (AEST)	Cultural (CUL)	Additional Value (ECOL+AEST + CUL)/3
Escarpment	1	1	0	0.6
Gully Network	1	1	1	1
Mesa	0	1	0	0.33
Butte	0	1	0	0.33
Pinnacle	0	1	1	0.6
Fossil	0	1	0	0.33
Fault	0	1	0	0.33
Cuesta	1	1	0	0.6
Cave	1	1	0	0.6
Sand Dune	1	1	1	1

Geoconservation: Challenges and Possibilities

Despite strong support from the local community and the National Center for Vegetation Cover and Combating Desertification, not all geoheritage sites in Saudi Arabia have been fully explored; as a result, many potential sites remain overlooked and underrated. Several common risk factors need to be addressed to protect the country's unique geoheritage. First, according to Saudi Arabia's Vision 2030, rapid urbanization is progressing across the country, including the expansion of Riyadh City. Therefore, establishing a national geoconservation policy for preserving Saudi Arabia's geomorphological and geological heritage is crucial. Although the National Center for Environmental Compliance (NCEC) conducts Environmental Impact Assessments (EIA), a specific geoconservation policy is still lacking. Second, community awareness of the conservation of geomorphological and geological heritage remains limited. While the Salma UGGp (Sen et al. 2026) and the North Riyadh UGGp (Turki et al. 2025) actively promote a bottom-up approach to geoconservation and geoeducation, a comprehensive strategy for natural heritage conservation is lacking in the areas surrounding the geoparks. Third, geoheritage should be recognized within protected areas, national parks, and cultural heritage sites. The most effective approach is to develop educational signage for geosites or regions, especially to explain geomorphological and geological features and, most importantly, their significance.

Tuwaiq Mountain holds significant scientific value due to its unique landforms and fossils. Additionally, various protected areas and conservation projects aimed at safeguarding flora, fauna, and habitats further enhance its overall importance (Fig. 7). By directly protecting the landscape from human-related degradation, as seen in other limestone formations worldwide. Moreover, it will help promote the conservation of the region's geological, geomorphological, and ecological resources.

Conclusion

Linking to the historical legacy for the explanation of the tableland and its associated landforms and landscape, especially pointing out the research in Europe and Australia (see Duszyński et al. 2019), the spectacular Jurassic Tableland Tuwaiq Mountain in Saudi Arabia is a global example. The terminology, Tuwaiq Mountain, is similar to the tableland mountain or scarpland, which comprises the horizontal bedding of the Jurassic Succession. Further, Tuwaiq Mountain represents an ideal relationship between the weathering process and landform development, such as mesas, buttes, pinnacles, and towering rock pillars. Two types of scarps. Firstly, the main scarp is oriented in the N-S direction, while the second scarp is developed due to fluvial processes triggered by rainfall. The scarp retreat, slope wash, and valley formation lead to the majestic dried-up fluvial valley network (wadis) that dissect the entire tableland.

Assessment of Tuwaiq Mountain can serve as a valuable reference for understanding how to implement geoconservation through description card preparation and assessment. In addition to the UNESCO Global Geopark and UNESCO Cultural Heritage, as well as various national protected areas. Geoconservation is crucial for preserving landforms of significant scientific, biodiversity, historical, and cultural value. Tuwaiq Mountain, with its distinctive display of the Tableland's evolution from initial formation through stages such as mesa, butte, pinnacles, rock pedestal, and gravel plain, holds international significance for both scholars and tourists. Additionally, the flora and fauna in the wadi area of Tuwaiq Mountain are crucial for maintaining the ecosystem of this landscape.

One of the key strengths is the high representation, integrity, and scientific evidence that demonstrate the importance of the conservation approach. Failing to adopt geoconservation will result in the loss of this unique landscape on Earth. Therefore, the present study recommends a holistic conservation approach for the Tuwaiq Mountain, with the active collaboration of all national and international protected areas and community involvement. Also, urbanization and industrialization in the Tuwaiq Mountain are recommended for a geoheritage assessment and geomonitoring to protect the geosites during major construction. Finally, it can be concluded that geoconservation is not only for the geological heritage conservation, but also for the protection of additional heritage like ecological, cultural, historical, and beyond.

Declarations

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Author Contribution

Subhajit Sen is the has conducted the extensive survey, geoheritage assessment, and manuscript preparation.

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All the data are available with author.

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Figures

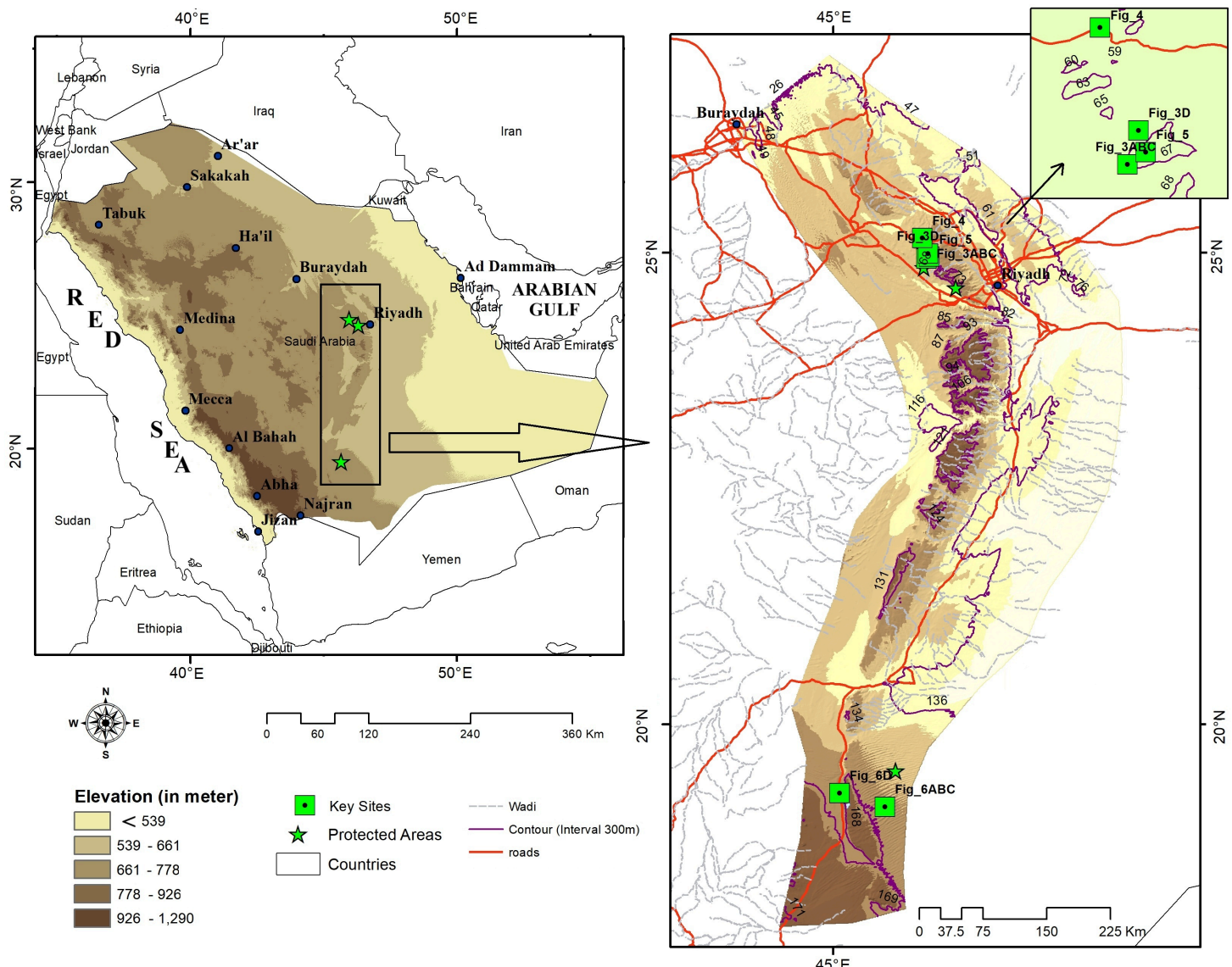


Figure 1

Location of the Tuwaiq Mountain in the central part of Saudi Arabia.

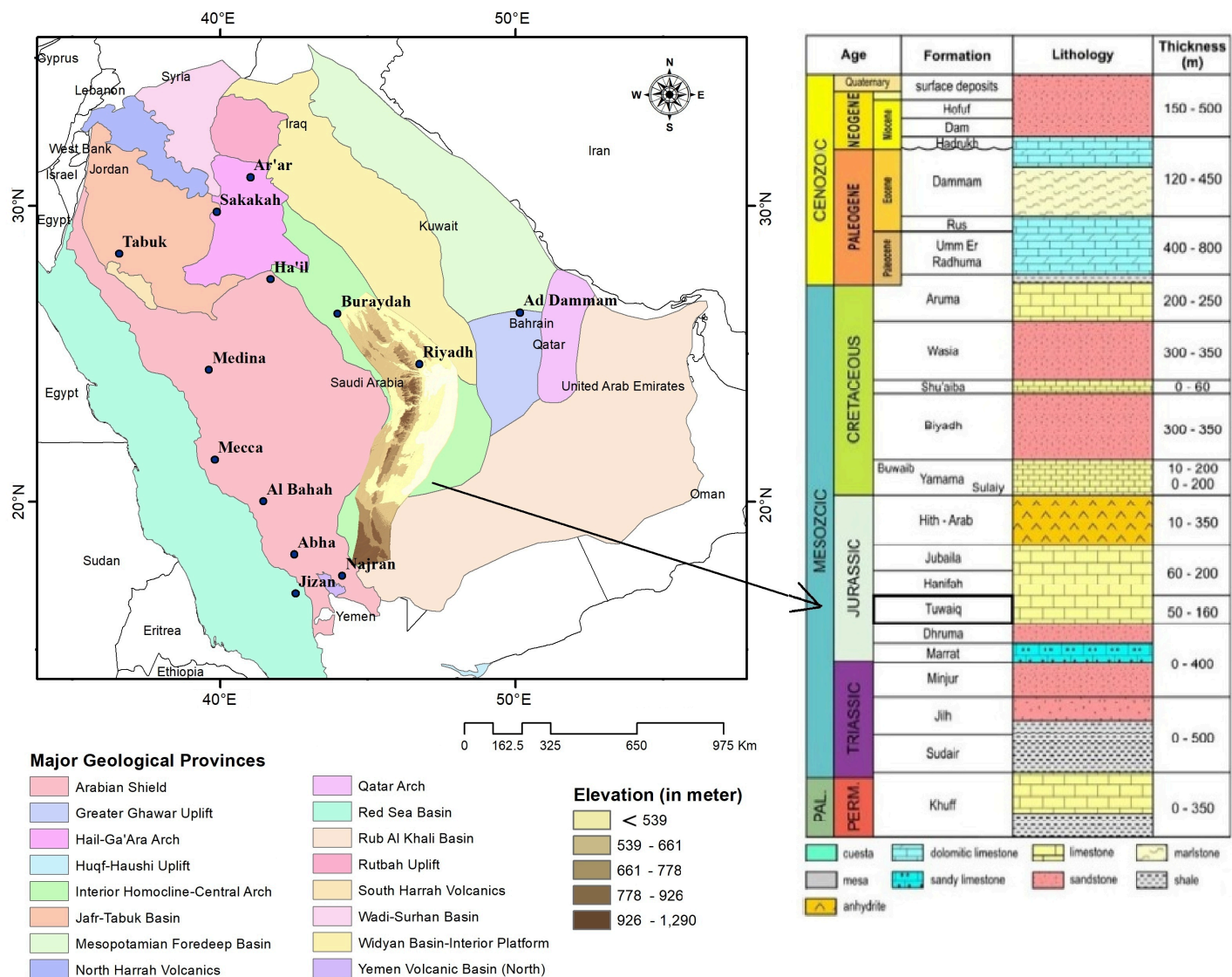


Figure 2

Geological Provinces of Saudi Arabia indicate that Tuwaiq Mountain is located in the Central Arc, which comprises Jurassic Limestone (extracted from Powers et al. 1966, Rausch et al. 2014).



Figure 3

A view of the Tuwaiq Mountain. (A) Scarp with exposure of the Jurassic succession, located in the western cliff of the cuesta. (B) Flat-top cuesta and scarp edge of the scarp. Additionally, several of the wadi networks are located in the foothills of the cuesta. (C) Close view of the cascading waterfall and seasonal pond in the wadi (fluvial valley). (D) Representative photograph of the marine fossil (extracted from Sen et al. 2023b).



Figure 4

Stage of the valley form-process. (A) The headward part of the fluvial valley (wadi) collapses due to mechanical weathering. (C) The cracks are extended and disintegrate the rock blocks, leading to rockfall. (D) Detached boulders and debris filling the wadi were transported down to the gravel plain (Photo by Subhajit Sen).

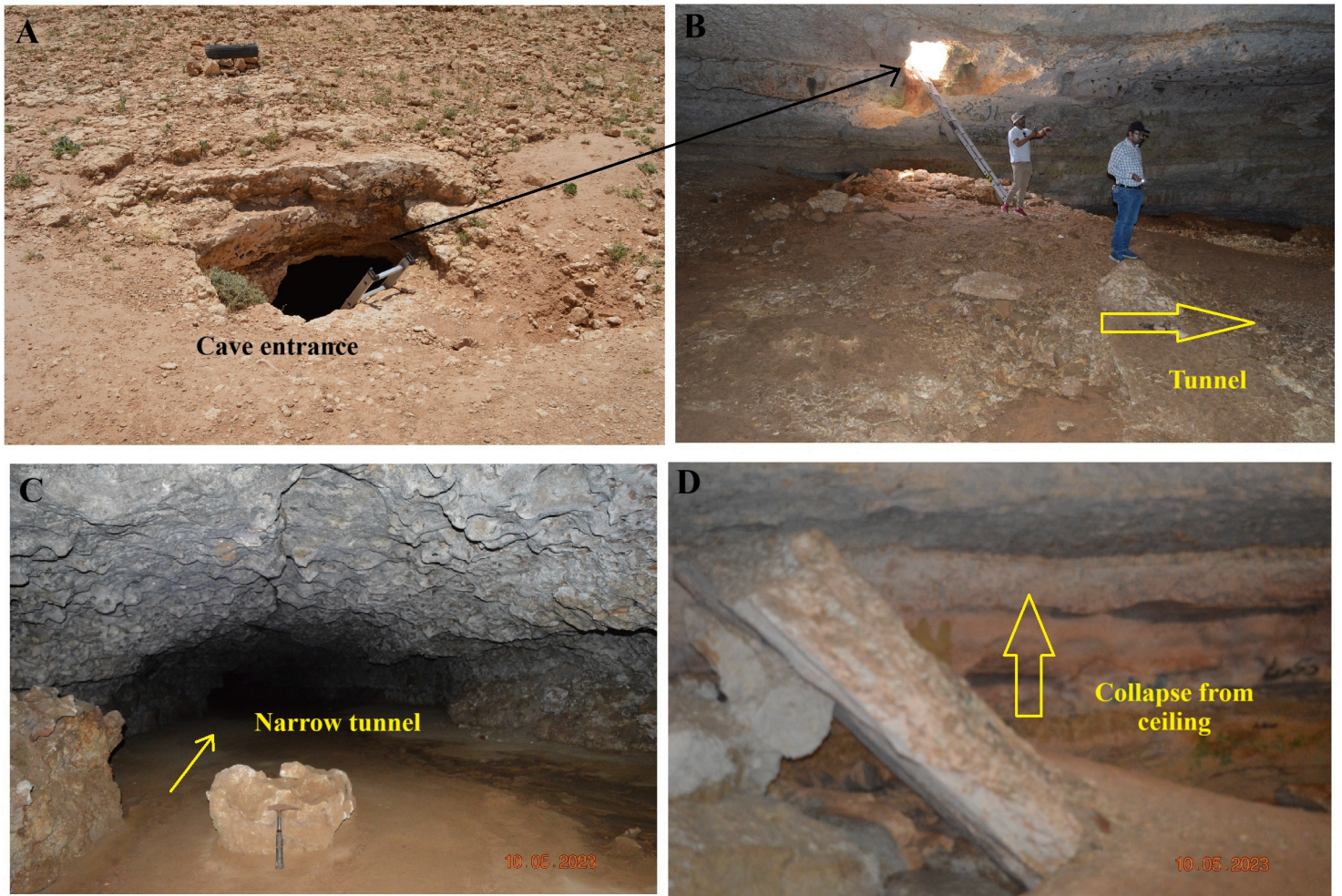


Figure 5

(A) Narrow opening of the cave followed by the broad cave chamber (B), which is extended towards a linear tunnel (C). Cave chambers are enlarged due to the collapse of rock blocks from the ceiling, a typical mechanical weathering process of the Karst landform (Photos by Subhajit Sen).

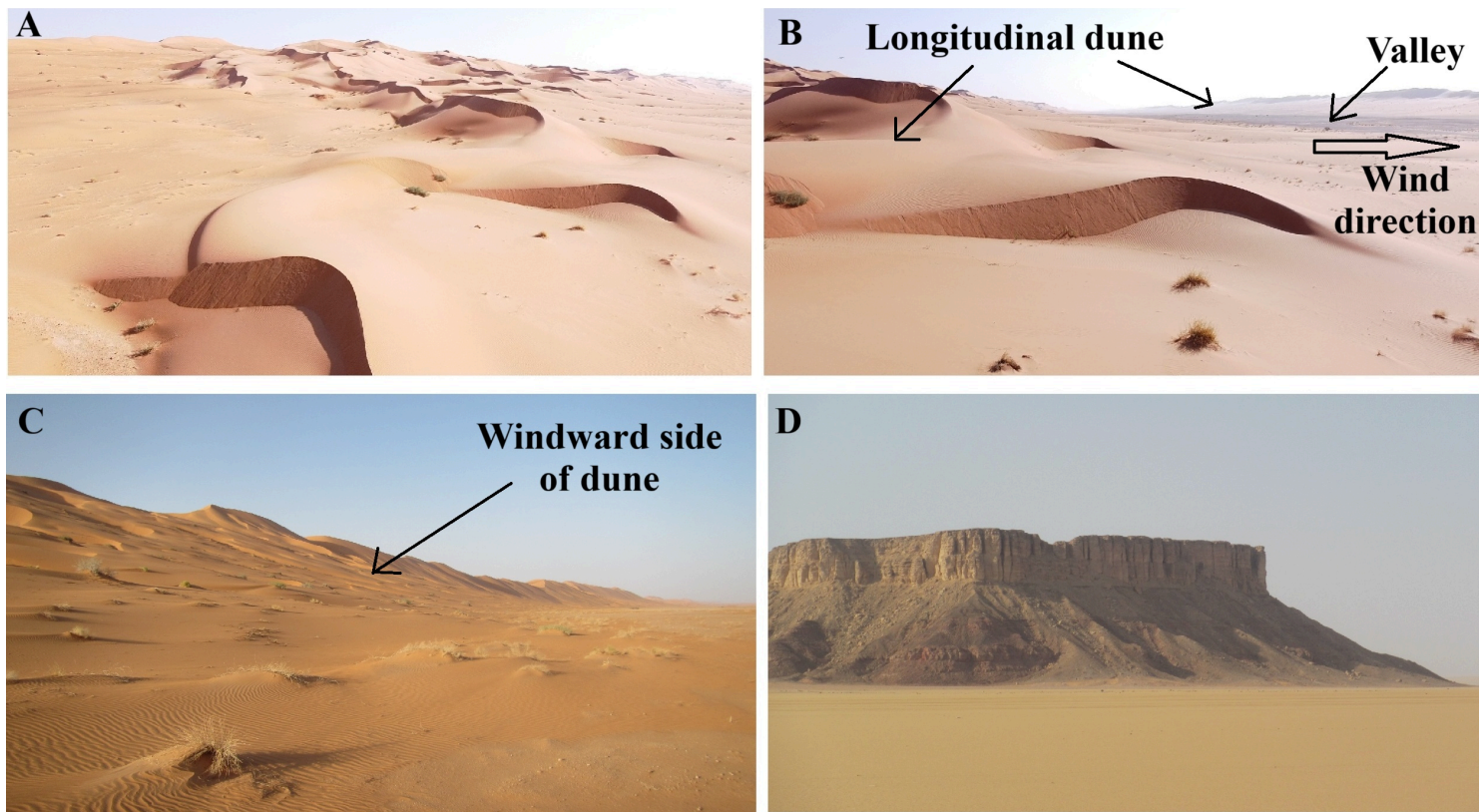
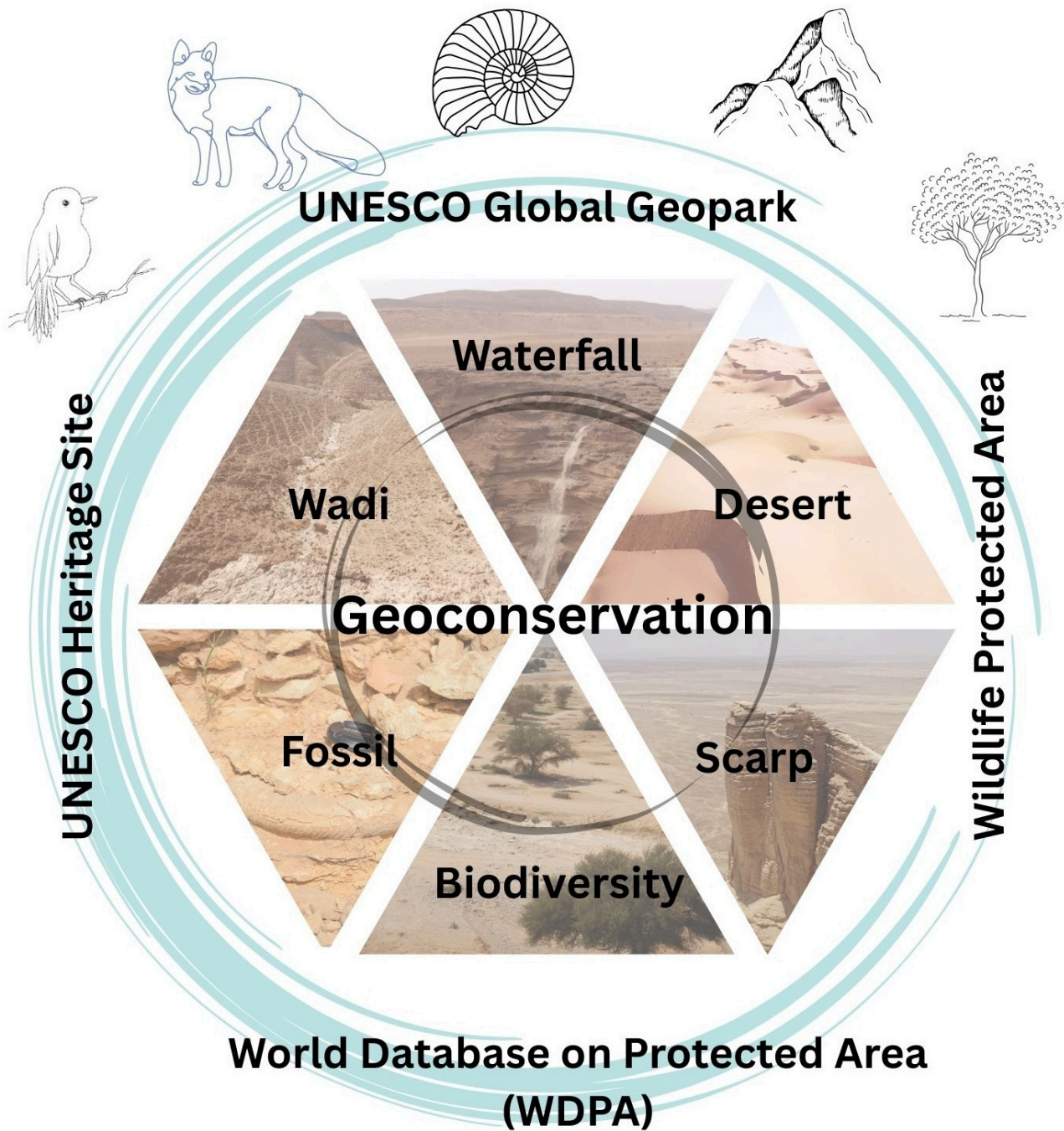


Figure 6

A key landform in the western part of Rub ' al Khali is a longitudinal dune (A) that covers the top surface of the cuesta. Such a parallel longitudinal dune formed due to unidirectional wind through the valley (B), as an inter-dune linear valley. (C) Close-up of the windward side, with asymmetric ripples. (D) The southern tip of the escarpment forms a cliff and talus. Dune formed in the crest of the cuesta (Photos by Subhajit Sen).



Tuwaiq provides a holistic conservation approach for biodiversity and geodiversity.

Figure 7

The conceptual diagram shows the geodiversity and biodiversity of the Tuwaiq, which overlap with international and national protected areas.