Karst Heritage as a Tourist Attraction: a Case Study in the White Desert National Park, Western Desert, Egypt

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Abstract
Geotourism is a form of maintainable tourism that emphasizes the geoheritage characteristics of a district. Karst landforms are one of the most imperative appealing aspects of the theme of nature-based tourism. The geomorphological regionalization of the karst landforms contributes to a better understanding of Earth’s evolution and provides the necessary provincial knowledge for resource utilization, ecological protection, and general economic improvement. To achieve this goal, an integrated geomorphosites assessment method conveyed by SWOT analysis has been performed in the White Desert National Park (WDNP), Western Desert, Egypt. The paper aims to highlight the geotourism potential of the WDNP and offer strategic plans for identifying geotourist resources to a larger community through geoeducation and geoconservation. The WDNP is covered by Upper Cretaceous-Late Tertiary karstified carbonate successions and fluvioclastic rocks that host an interesting assemblage of diverse karst landforms (geodiversity) and amazing flora (bioturbation mangrove roots) together with fauna (biodiversity), revealing a geological open-air museum. The karst sites, which offer several phenomena with significant lithological, morphological, and paleogeographic features, embrace aesthetic, educational, scientific/scenic, and touristic values that will endure spectators of the geological evolution of this province. The brilliant conspicuousness, scientific excellence, innovative appeal, and distinctiveness of karst geomorphosites involving poljes/uvalas, karst lakes, natural sculptures, mushrooms, inselbergs, towers/bridges, dolines/sinkholes, cones/domes, and speleothems deliberate resources for the progress of geotourism. These landscapes can be considered tools for science and education because they give knowledge about rock/soil types and rock permeability, and paleoenvironmental and paleoclimatic circumstances. Most of their landforms can be used as habitats for endangered bird species, which attract several sightseers, an indicative of ecological significance. This excellent karst geodiversity provides an appreciated tool for geotourism and geopark development that is preferred to raise the local economy for populations and reinforce rural growth in neighboring towns and cities. The paper’s findings reveal a comprehensive base for the improvement, planning, and management of the WDNP in order for it to become a geotourism endpoint. Furthermore, they improve the position of the WDNP in the tourist market and contribute to the local maintainable progress via giving socio-economic assistance to the local community for the advancement of geotourism through geoconservation and sustainability.

Keywords White Desert National Park · Karst landforms · Geotourism · SWOT analysis · Geosite assessment · Sustainable development

Introduction
Visitors worldwide are interested in watching special geological phenomena (Ólafsdóttir and Tverijonaite 2018), which provide assets for geotourism development (Asrat et al. 2012). Geotourism is an internationally evolving educational, monetary, and maintainable expansion style (Ngwira 2015) with substantial comprehensive expansion style (Hose 2011). Tourism’s fascination with geological
lakeshapes has increased promptly over recent decades (Newsome et al. 2012). Its investigations have been welcomed universally due to their scientific, educational, antique, communal, ethnic, and aesthetic values (Pralong 2005; Kubalíková 2013; Štrba et al. 2018; Mucivuna et al. 2019). This style of tourism permits the detection of scarce geological features in the visited regions, together with other natural and human possessions (Mucivuna et al. 2019). The main goal of geotourism, which highlights the Earth’s geological and geomorphological typescripts, forming geosites as tourist attractions, is understanding, improvement, and management, as principal items for the sustainable amplification of geotourism. The latter delivers a chance for business, entrepreneurship, and widespread job prospect for the inhabitants (Newsome et al. 2012; Dowling and Newsome 2018; Tomić et al. 2020).

Geotourism involves an array of tourist interests, from the specialist to the universal guest. Furthermore, it gives monetary, ethnic, and social assistance to both visitors and host inhabitants by demanding proper forecasting and understanding of the benefit and constraints (Ngwira 2015; Gordon 2019). Geotourism needs to be valued by the wider local, general, and global communities by balancing tourism with management that promotes environmental and cultural understanding, obligation, and preservation (Gray 2008; Dowling 2011; Prosser et al. 2011; Gray et al. 2013a, 2013b; Olafsdottir 2019). Geotourism must adhere to five critical principles: geoheritage, preservation, geointerpretation, profits at the indigenous level, and tourist fulfillment (Antić et al. 2019). This has been accomplished through geological visits, the use of geological routes, the perception of scenery, and the requirements for scientific information linking to the geological characteristics for geotourism and practical verification of geotourists, e.g., their favorite destinations, inspirations, and supplies; the difficulties associated with geotourism endpoints; and the positive/negative influences of geotourism on the geographical region and local populations as well as other stakeholders (Panizza and Piccante 1993; Panizza 2001; Panizza and Piccante 2003; Reynard 2004; Reynard and Panizza 2005; Božić and Tomić 2015; Štrba et al. 2018; Tičar et al. 2018; Tomić et al. 2020).

Geoparks are prominent areas with one or more geoheritage sites picked out because of their scientific prominence, scarcity, beauty, or link to geological history, procedures, and ways (Eder and Patzak 2004; Dowling 2011). Geotourism and geoparks have evolved to provide a chance for maintainable regional improvement by lowering the rate of joblessness and immigration, forecasting poverty by involving local residents in geopark activities, and confirming conservation and educational excavations to well-known geosites (Zouros 2007). Geotourism consultants and geopark specialists, for example, have approved various positive strategies for encouraging local participation for economic prosperity, the fortification of natural assets, and sustainable progress (Farsani et al. 2011; Ngwira 2015). Therefore, geotourism requests need to be combined with best practice management to retain and improve the visitor experience while also protecting the resource (Leung et al. 2015).

Geomorphosites are significant landscapes of geomorphological heritage from the viewpoint of tourism, signifying chief resources for geotourism improvement (Reynard 2009; Warowna et al. 2016). A region can be considered a geomorphosite if the landform group and energetic geomorphological processes are capable of attracting tourism (Jelenic 2009). Geomorphosites are surface landscapes with distinct main aesthetic characteristics that form natural monuments that are essential for understanding Earth’s history (Panizza 2001). Coratza and Hoblá (2018) introduced the term geomorphological heritage as a novel division of geomorphology entitled “heritage geomorphology.” Various types of research on geomorphological heritage have been conducted extensively over the last two periods (Reynard et al. 2017; Pica et al. 2017; Migoń and Pijet-Migoń 2017; Clivaz and Reynard 2018; Coratza et al. 2019; Moradi pour et al. 2020; Sinnyovsky et al. 2020; Tahammam et al. 2020). The studies of geomorphological heritage have principally involved the improvement of perceptions and documentation, presenting the prospective geomorphosites for use (scientific, educational, and geotourism attitude), and improvement of inventory and assessment approaches. As a result of its diverse values, geomorphological heritage can be utilized as a national heritage, geopark, or geotourism destinations (Reynard 2008; Dowling and Newsome 2010; Hose 2012; Brilha 2018). The actual preservation and administration of geomorphological heritage require an explanation of its heritage implications in a cohesive style. Karst landscapes are significant topographies of geomorphological heritage, with its geomorphological topographies being observed as the main issue from the standpoint of tourism, creating scenery and attracting tourists (Newsome and Dowling 2018). Karst lands are categorized by extreme scientific, ethnic, ecological, and aesthetic standards, due to the high degree of natural environment (Quaranta 1993; Panizza 2001; Zglobicki and Baran-Zglobicka 2013). They are closely allied with excellent biodiversity. The lands affected by karst phenomena possess a pronounced value in terms of preservation, tourism advancement, and scientific investigation (Van Beynen 2011; Delle Rose et al. 2014; Ruban 2018). Several karst locations are registered as UNESCO World Heritage Sites (Williams 2008). The UNESCO World Natural Heritage List has recorded more than 50 sites for karst geoheritage; however, several regions everywhere in the world have the possibility of being selected as national parks based on their geodiversity, biodiversity, exclusive geomorphology, or valued caves. The karst rocks are associated with the dissolution characteristics of landforms in soluble rocks such as
cavernous carbonates and evaporate through the processes of surface weathering, stream sinking, cave development, and tectonic uplift, resulting in unique morphological and hydrological topography (White 2002; Ford and Williams 2007; Williams 2008; Youssef et al. 2017). The karst dissolution processes and the occurrence of subsurface channels can be used in distinguishing between karst and non-karst systems (Gunn 2004). Tectonics involving networks of fault and fracture networks intensely affects the growth of karst landforms that support the development of karstogenesis.

In Egypt, the Western Desert (WD) is the major geographic district, covering an area of about 681,000 km² (Fig. 1). The geological and climatic circumstances have prepared the Western Desert (from 200 to 600 m a.s.l) as a province where karst phenomena are plentiful and outstanding. The White Desert National Park (WDNP) is one of the most important karst massifs in the Western Desert (Fig. 1A), which hosts potentially unique karst features and was chosen for this work. There have been no studies that have been interpreted in terms of geotourism or described in terms of environmental significance. Similarly, a geoscience survey in Egypt highlighted the expansion of geoheritage as a geotourism resource, is quite rare in the light of appraising its geosites for geotourism potential. Furthermore, no research has been carried out to identify the geotourism resources and assess them qualitatively through SWOT analysis within the White Desert National Park. The latter was selected because it is characterized by significant properties that have attracted active multi-inhabitants. So, the aim of this paper is to (1) describe diverse landforms of karst morphology for displaying the aesthetic and scientific geological heritage; (2) recognize the strategies for recognizing and inventorying the precise resources for impending geotourism development; (3) record a set of criteria suitable for the assessment of potential geotourist; and (4) evaluate quantitatively and qualitatively the karst sites through SWOT analysis to create the seats for conservation, education, and geotourism.

Fig. 1 A Landsat image showing the location of White Desert National Park. B Geological map of the study territory (Geologic Survey of Egypt 1981). C Geological sketch map of Egypt showing location of Qaret Sheikh Abdallah, Western Desert (Wanas et al. 2009). D Karstified carbonate rocks exposed in the Western Desert (Embabi 2018)
in an appropriate organization mode following the principles of UNESCO Geopark Agenda.

**Methods**

Several quantitative and qualitative procedures have been planned based on presented articles on geotourism, scenic geosite inventory, and evaluation (Pereira et al. 2007; Pereira and Pereira 2010; Vujčić et al. 2011; Fassoulas et al. 2012; Kubalíková 2013; Brilha 2016; Zglobicki et al. 2019). These measures enable recognizing areas of interest, resembling to geological heritage (Reynard and Panizza 2005; Prosser et al. 2006; Reynard and Brilha 2018), offer preservation strategies, analogous to geoparks (Carrión Mero et al. 2018), and provide guidelines for sustainable use, such as geotourism (Reynard et al. 2011). Geosite assessment has been extensively documented as a beneficial tool for the actual improvement, organization, and fortification of geological heritage (Suzuki and Takagi 2018). The four most commonly used techniques (appraisal of the literature, fieldwork, and interpretation of maps together with the elucidation of satellite images) were applied in identifying and inventorying resources for geotourism through field description of karst features based on the scale (macro- (> 10 m) and mesoscale (1 cm–10 m)) (De La Rose 2012). Such site assessment should be focused not only on geodiversity characteristics but also on facets demonstrating the connections between geodiversity, biodiversity, and culture (Kubalíková et al. 2020). The evaluation of karst landforms can deliver valuable understanding for the administration of geomorphological heritage, its advancement, and how to improve protection against destructive human activities.

The inventory and assessment of karst sites for geotourism development were carried out following the criteria of Vujčić et al. (2011) coupled with SWOT analysis. Two main sets were used: Main and Additional ones under indicators and subindicators. Vujčić et al. (2011) offered a composite assessment model that measures scientific/educational (VSE), scenic/aesthetic (VSA), protection (VPr), functional (VFn), and touristic values (VTr). The indicators and sub-indicators used to evaluate geosites deal with not only with themes such as earth sciences but also biodiversity, convenience, and tourist capabilities based on an appraisal of geotourism literature, scenic assessment, and geosite inventory as well as evaluation. The Main value is linked to the intrinsic value of a geosite (the chief purpose for tourists to visit a geosite and its fortification). Five indicators (scientific, educational, scenic, recreational, and protection) which are suplementarily partitioned into twelve subindicators, belong to the Main value (Supplementary Table 1). Regarding Additional value, two indicators (added and functional), which are further subdivided into six subindicators, provide an extra cause for tourists to travel to an appropriate geosite and its visit facilitates (Supplementary Table 2). For each subindicator, a 5-point scale ranging from 0 to 1 was used to rate the impending of geosites, with the geoheritage site attaining a max. of 15 points. The latter that is considered relevant for geotourism development (Kubalíková et al. 2020). The geosite evaluation is a compulsory task for geotourism development and should be made before the improvement of impending geotourism destinations is deliberated upon (Vujčić et al. 2011; Suzuki and Takagi 2018).

**Geological Background**

Karst rocks spread over a wide area of Egypt involving the Eastern and Western Deserts (Fig. 1D; El Aref, et al. 1986; Halliday 2003). Several geoscientific researchers studied the karst rocks on the Bahariya-Farafra terrain (El Aref et al. 1987; 1999; Sokker 1991; Waltham 2001; Brook et al. 2002; Halliday 2003; Kindermann et al. 2006; Moustafa 2007; Wanas et al. 2009; Pickford, et al. 2010; Abdel Tawab 2013; El Aref et al. 2017a,b; Youssef et al. 2017; El Aref et al. 2021). Sixteen fields of karst landform in Bahariya-Farafra Oases have been recorded in WD, Egypt (Fig. 2, El Aref et al. 2017a). Moreover, the latter authors carried out an inventory and assessment of the selected geosites in these areas. Cretaceous–Eocene karstified carbonate successions interrupted by paleo-fossilized karst surfaces that are covered by Quaternary to Recent sediments forming exhumed karsts (e.g., sand dunes, playa deposits, salt lakes), occupy most lands of the Bahariya-Farafrain terrain (Klimchouk and Ford 2000; El Aref et al. 2021). Surficial duricrusts involving calcrite, silcrete, dolocrete, and ferrite characterize the tops of the most karstified carbonate rocks (El Aref et al. 2021). In the WD, enormous karstified carbonate platforms are documented, which are composed of limestone/chalk and shale/clay rhythmic beds in the time period from Upper Cretaceous/Palaeocene to Middle Miocene (Fig. 1B, C). The eastern part of the WD is occupied by the Palaeocene–Eocene rocks, whereas the northern part is represented by the Miocene rocks (Embabi 2018). The structural lines comprising E-W- and N-S-trending faults, fractures, and joints affect these rocks. During the Upper Cretaceous to Late Eocene period, the carbonate rocks were affected by karstic activity, followed by the phases of uplift and tectonic/climate change favoring karstification during the Miocene time (Embabi 2018). Wind and water action coupled with local structures, facilitated the karstification processes. Karst landforms show degraded (erosional) and nondegraded (depositional) characters that are locations of geomorphological interest, which reflects scientific value for reconstructing Earth’s history (Panizza 2001; Clivaz and Reynard 2018).
The WDNP is situated ~45 km from the northern part of El Farafra Oasis, Western Desert, New Valley Governorate between Lat. 27° 39’ 69″ N to 28° 58’ 26″ N and Long. 27° 50’ 35″ E to 29° 12’ 37″ E, covering an area of about 3010 km² (Fig. 1). Its karst landscapes are commonly characterized by closed depressions, surface drainages, and caves. The WDNP was protected to defend the desert ecosystems, karst landforms, and remarkable scenery and erosional features in the carbonate rocks. The sedimentary rocks involving Upper Cretaceous to Late Tertiary carbonate and clastic sediments have been described, belonging to karst and non-karst rocks, respectively (El Aref et al. 2017a). The former includes the carbonate rocks of the El Hefhuf, Khoman Chalk, Tarawan, and Naqb formations (Fms) of the Upper Cretaceous, Palaeocene, and Eocene ages, whereas the latter includes the Bahariya, Dakhla, and Esna Fms of the Upper Cretaceous and Palaeocene ages together with the Quaternary sand dunes. The study area is structurally controlled by NE-SW- and NW–SE-trending faults and folds, which are related to the prevalent dextral wrenching during Upper Cretaceous deformations that are part of the Syrian Arc System (SAS, Sehim 1993, Moustafa et al. 2003). The SAS extends from Syria to Central
Egypt through the Western Desert of Egypt (Guiraud and Bosworth 1997; Guiraud et al. 2005). The structural framework and the related tectonic phases have shaped the surface of karst landforms during karstification processes following the zones of weakness, which facilitate the development of the secondary porosity, permeability, and fractures-controlled solution pathways of the carbonate rocks (El Aref et al. 2017a). In the field, the karst landforms have been described as degraded and non-degraded forms based on their morphology and extension (macro/mesoscale).

**Karst Phenomena in the White Desert National Park**

The WDNP is one of the areas located in the WD that hosts carbonates and fluviokarst morphologies, resulting from the complex karstification processes. Several shapes of karst landforms have been observed in which certain forms are more far reaching than others.

**Karst Poljes**

The name polje means “field” in Slavic language, whereas it refers to “karst plain” or “karst field” in the English language. Polje is a term used by geomorphologists to denote large fault/fracture-controlled bounded basins with a flat karst floor (Fig. 3A) as Bahariya/Farafra poljes with areas ranging from 980 to 1800 km² (Fig. 2A). Bahariya/Farafra poljes may have originated...
in the Middle to Late Tertiary and been subjected to several climatic iterations. Some poljes are sporadically flooded by floodwaters, which may also be amplified by groundwater rising into impermanent karst lakes on their floors, as has been shown in Bahariya polje (Fig. 2A). The karst lake occupies the northern part of the study area. It covers 2.0 km in length and 0.5 km in width (Fig. 3A, B) and was formed as the result of the collapse of subterranean caves, especially in water-soluble carbonate rocks through karstification processes (Selby 1985). The lake bottom is partially insoluble rocks, leading to the lake formation. The water comes from very short streams derived from the neighboring carbonate landforms through numerous emergences of discharge from aquifers of the depression edges, recognizing several types of hydrological regimes (Embabi 2018). Many authors believe that the creation of many karst lakes occurs occasionally but may return often after heavy rainfall through weakening zones of joints and faults of the district (Waltham et al. 2005; Ali 2019).

**Karst Depressions**

These depressions are recorded in the northern part of Farafra Oasis. They differ in magnitude from a few meters to some kilometers. These depressions denote the most morphological features of the Western Desert, Egypt, occupying large areas (Fig. 2). In the WDNP, they spread over 200 m and involve natural sinkholes. The latter are known as a cenote, sink, swallow hole, Foiba (plural Foibas or Foibe), or doline, and are characteristic of karst landscapes caused by highly fractured carbonate rocks (Figs. 3C, D and 4A, B). They are pure vertical holes/hollows which occur as a noticeable bowl, tabular, or funnel shape 1–2 m wide and 2–10 m in depth (Figs. 3D and 4B). Their walls are white creamy, bedded, hard, compacted, and composed of limestone rocks or pure calcite layers during Eocene period. Most dolines/sinkholes are categorized by the distribution of natural hot springs (Fig. 4C), which have attracted people since Roman times (El Sisi et al. 2002). They result from multi-karstification

![Fig. 4 A Solution doline, internally filled by crustified calcite crystals. Notice the observed honeycomb/tafoni weathering surface. B Swallow hole in calcite-forming hill of semi-circular outline with karst window spectacles. C Doline is covered by fresh hot water, forming springs. D Large flat plain of karst pavement](image-url)
processes aided by wind or tectonic actions (El Aref et al. 1987; 2017a).

**Karst Pavements**

Karst pavements occur as large flat plains having irregular or elongated forms (Fig. 4D). They cover several kilometers in the northern part of El Farafra Oasis (Fig. 2). An array of distinctive karst landforms involving Karren/Lappies created by differential solutions decorate karst pavements (Fig. 5A–C). Karren and Lappies are German and French words, respectively, and both of them refer to small-scale solutional sculpture. They are approximately flat areas, comprising small solution pits, engraved, fluted, and pitted rock pinnacles separated by deep parallel grooves, flutes, and runnels that have several magnitudes from tiny to huge flutes (Fig. 5A, B). The latter are densely clustered and have an elongation or rectangular shape, with diameters ranging from 50 cm to 2 m. Sometimes the top of these grooves are characterized by bowl-shaped hollows (Kamenitza, Fig. 5B).

Most of these flutes develop on steeply sloping rocks affected by wind abrasion. Structural weakness planes (such as joints/fractures) in connection with compacted rocks accelerate the creation of these karst phenomena. When these planes are gradually widened, they produce clefts (grikes, Fig. 5C). Karstification plus wind erosion play a chief role in the development of most of them. The Karren features can be considered a tool for science and education because they give knowledge about the presence/absence of soil, rock permeability, and climatic condition. El Aref et al. (2017a) concluded that solution pits were caused by regular recharge rainwaters coupled with organic acids produced by plants and peat trapped in the sedimentary basins.

Sporadically, the karst pavements are covered by well-rounded siliceous chalky limestone concretions related to paleokarst phenomena, resembling “cannonballs/or melon fields” that are well-known geomorphic structures within the Maastrichtian and Eocene rocks in Kharga, Farafra, Faiyum, and Bahariya Oases in Egypt (Pickford et al. 2010; Plyusnina et al. 2016; Sallam et al. 2018; Khalaf and Abu

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**Fig. 5** A Subvertical parallel runnels/grooves characterizing karstified carbonate rocks. B Bowl-shaped hollow (kamentiza) occupying the top of hilly grooves formed by karstification and wind abrasion.

C Limestone pavement with enlarged joints (grikes). D Mushroom karstified hills comprise irregular-shaped necks and caps displaying a bowl-shaped outline.
El-Kheir 2022). Most of these concretions are hard, compacted, spheroidal, or elliptical in shape as a result of exfoliation weathering and carbonate dissolution, forming onion-skin weathering and nodules on Earth’s surface through weathering processes. These “cannonballs” concretions have an imperative impact because of their wide geologic implications, signifying small-scale microbially induced and chemical heterogeneous in groundwater together with its directions that advanced the host carbonate rocks after the karstification processes (White 1988; Plan 2005; Ford and Williams 2007).

**Mushroom Karst**

The mushroom zone is widely distributed in the El Farafra Oasis, occupying an area of about 244 km$^2$ (Salama et al. 2020). This type of karst comprises vertical short stems with irregular-shaped necks and caps. The latter vary in shape, ranging from bowl to bulbous outline (Figs. 5D and 6A). The necks/caps display characteristic small-scale cavities (Fig. 6B), which host some nests of threatened bird species. The heights of its stems vary from 1 to 5 m. The composition of the stems is mainly soft calcereous sandstone grading to hard siliceous limestone at their caps. Several mushroom landforms have been described in Gabel Qatrani, North Western Desert (Mashaal et al. 2020; Khalaf and Abu El Kheir 2022).

**Inselberg Karst**

Inselberg is a German word that means “island mountain,” similar to that observed in southern Africa in hot/or humid regions. The inselbergs are widely distributed over the floors of the Bahariya/Farafra depressions. They occur in the form of connected to disconnected uneven vertical hilly rocks, resulting in karst inselbergs that rise abruptly from comparatively flat surroundings (Fig. 6C). Their frameworks form tall, upright hills that project sharply from the neighboring peneplains, climbing up to ~2–10 m. These inselbergs consist mainly of greyish-white compacted hard limestone.

![Image](https://example.com/image.png)

**Fig. 6** A Globular/spherical-shaped cap with short stems characterizes mushroom karstified hills. B Solution cavities that are favorite nests for birds portray the caps of mushroom karstified hills. C Connected to disconnected hilly rocks forming karst inselbergs. D Sculpturing carbonates in sphinx-like form. Note pile of carbonate debris at photo front.
rocks that are more resistant to erosion. Some hills are covered by brecciated and collapsed fragments, forming block/boulder-rich breccias with distinguishing cavities/voids. In some localities, the inselbergs display peculiar geomorphological features that resemble Sculptures of birds, turtles, and animals (Figs. 6D and 7A–D) as the result of fluvial erosion by water, differential weathering, and wind sculpturing of chalky limestone beds. Remarkably conserved ancient mangrove plant roots (bioturbation, Fig. 8A) of extreme scientific rank are occasionally observed within the hilly rock sculptures. Another erosional landform besides inselbergs is buttes (Fig. 8B). The latter are applied to disconnected hills of siliceous chalky limestone with steep slopes and flat tops, rising up to \( \sim 5 \) m (Fig. 8C), which are dissected intermittently by deep parallel fracture/joint-controlled gullies and grooves with distinctive bowl-shaped hollows (Kamenitza) at their tops (Fig. 8D). Buttes usually form in arid regions, such as those in Mexico and Monument Valley, Arizona, USA, which represent the most famous butte example in the world. All these geomorphic karst features, such as mushroom, inselberg, and butte landforms, have been recorded in various parts of the Egyptian Deserts (Plyusnina et al. 2016; Sallam et al. 2018; Khalaf and Abu El-Kheir 2022) due to the effect of water and wind erosion when a more resistant cap rock overly soft layers having less sturdy parts (Nenonen et al. 2018). These typical landforms are beautiful, intriguing, and attractive to tourism. They can often provide information about current and past erosional environments.

**Tower Karst**

Tower karst occurs as isolated bedded hilly chalky limestone rocks with vertical flanks from the depression floor and pedestal rocks, covering an area of about 884 km² (Fig. 2B). Its pedestals vary in size from small to large (1–5 m) and in shape from spherical to rectangular. The tower tops take the form of either spine like, cylindrical, or broad summits of 2 to 15 m in height (Figs. 9A–D). Pits, crevices, and

![Fig. 7 Spectacular sculptures of birds/animals for outstanding karst landforms. A Domestic sheep/lamb-like form. B Turtle-like form. Note remarkable occurrences of mushroom forms with circular outlines. C Chicken fowl-like form beside the mushroom shape. D Sea lion-like form. Note the amazing existence of spectacular sculptures of birds/animals](image)

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solution cavities are common features in tower walls due to the effect of solution sculptures (Fig. 9B–D). Karst towers are separated by dry valleys/gorges (sometimes known as Cockpit karst; Yuan 1984; El Aref et al. 1987; Day 2004; Day and Chenoweth 2004; Zhu et al. 2013) that are distributed between linked or detached permeable carbonate ridges. The dry valleys/gorges are considered fluviokarst, which is defined as a landscape of active stream valleys, dry/blind valleys, and unbalanced drainage systems that do not normally sustain water flows (Selby 1985). Karst gorges vary in size and thickness from one locality to another and are controlled by fracture systems (Fig. 9). The occurrence of these two geomorphological landforms is common in humid environments where high temperature and copious sedimentation deliver favorable conditions for quick and prolonged erosion (Troester 1992). The dry valleys/gorges could be developed as geotouristic attention facts within the prevailing tourist routes (Khalaf and Abu El-Kheir 2022). Tower and cockpit karsts have been described in different parts of the world, like Southeast Asia, Central America, the Caribbean, Jamaica, South China, and North Vietnam (Zhu et al. 2013).

**Bridge Karst**

Bridge karst exhibits astonishing and remarkable karst surface morphologies. The length and width of the bridge karst vary from 5 to 10 m and 0.5 to 5 m, respectively, with a 3–5-m natural arch occupying a distance of about 10 m. Their rock types are composed of the white chalky limestone of the Upper Cretaceous (Fig. 10A, B).

**Dome Karst**

The dome karst spreads over a large area, extending some kilometers. Dome rocks form symmetrical hilly rocks (up to 5 m in diameter and 5 m in height) and involve two rock types: tufa carbonates and chalky limestones. The first is...
greyish white, hard, chalky in composition, and wavy laminated with a stromatolite look (Fig. 10C). In some localities, tufa carbonates are bright grey, porous, dense crystalline, and consist of laminated silt and clay interbedded with carbonate rocks (Fig. 10D). The second are massive, non-porous, hard, grey in color, and composed of disconnected brecciated and collapsed chalky limestone hills, attaining 10 m in height (Figs. 11A, B). Solution channels, cavities, and karst windows are commonly distributed within the dome hills. Remains of open kamenitza characterize the tops of some types (Fig. 11C).

The tufa deposits have been recorded in the Kurkur Oasis, Western Desert (Fig. 1), an indicator of spring-fed streams that previously exhausted the Eocene rocks and precipitated them as hills, terraces, and chutes (Butzer 1964, 1965; Issawi 1968; Ahmed 1996). The stromatolite form of the former domal type reflects relict landscapes that were deposited during the events of intense moisture and improved groundwater discharge that formed in fluviolustrine settings (Keppel et al. 2011; Sallam et al. 2018). Many authors interpreted that such mysterious stromatolites (Reitner 1993) are shaped by nonphotosynthetic organisms or serpulid buildups (McLoughlin et al. 2008; Dupraz et al. 2009). El Aref et al. (1986) recorded algal filaments and moss debris in the Miocene karstified tufa sediments of the Red Sea coastal zone, Egypt. The tufa deposits represent sporadic and peculiar landforms in the geological list, providing critical records of paleoenvironment and paleoclimatic conditions (Ford 2004; Ford and Pedley 2006; Pedley 2009; Capezzuoli et al. 2014) with an amazing view.

**Cuesta Karst**

A type of karst formed on a cuesta is characterized by moderate to high hills or ridges with a gentle slope on one side, attaining a 30–45° dip towards NW and a steep
slope or scarp on the other side (Fig. 11D). Its elevation varies from 2 to 8 m, covering many meters in extension (1–5 m). Such landform is composed mainly of massive chalky limestone of the Upper Cretaceous.

Speleothem Karst

The term “speleothem” is a Greek word that means cave deposits and associated secondary minerals that were precipitated in caves. Its landforms refer to vast quantities of amazing and unique karst shafts/infillings, displaying diverse karst features (e.g., dolines/sinkholes, unroofed karst hills, and numerous remnants of degraded caves) (Figs. 12 and 13), along with clastic sediments and red soils formed by solution/erosion during karst uplifting, degradation, and rejuvenation processes (Emabbi 2018; El Aref et al. 2021). Unroofed/collapsed karst hills can be defined as subsoil karsts that are depicted by several different cave patterns during tectonic uplift with the removal of their cover by erosion (Field 1999). Caves within surface/subsurface Eocene carbonate plateaus are recorded in Bahariya, Farafra, Dakhla, and Kharaga Oases (Fig. 1B). They are well exposed at the NE-striking karst depressions known as Qarat El Sheikh Abdallah (QSA) and Crystal Mountain (CM, Fig. 1C), which have been exhumed in the El Bahariya-Farafra plateau (up to 256 m a.s.l) that encircles these depressions (190–200 m a.s.l, El Aref et al. 2021). The latter authors described the two depressions (QSA and CM) as uvalas, which are demarcated as large (in km scale) karst closed depressions with irregular plan form caused by enhanced erosion along major tectonic zones. Four karst facies forming speleothems, which include marine Khoman white chalk, clast-supported conglomerates, red soils, and bedded limestone/calcite strata, have been described at QSA and CM (Wanas et al. 2009; El Aref et al. 2021; Fig. 12A). The rock facies of Khoman white chalk (Khoman Fm) are of the Upper Cretaceous, while the rock facies of clastic sediments, red soil, and limestone/calcite strata

Fig. 10  A, B Chalky limestone rocks with variations in extension and width, displaying bridge karst morphology. C Symmetrical chalky dome karst with bedding structure and a curvature top, displaying a stromatolitic outline. D Symmetrical laminated siliceous limestone dome karst with a broad curled top.
are of Paleocene (Tarawan Fm), Eocene (Farafra Fm), and Miocene/Oligocene periods (fluvial/Quaternary sediments, El Aref et al. 2021). These karst successions are truncated by three paleokarst surfaces (i.e., chief stratigraphic breaks) involving Upper Cretaceous–Early Paleocene chalk (Kho- man and Tarawan Fms), Paleocene–Early Eocene carbonate (Tarawan and Farafra Fms), and Post-Eocene–Miocene/ Oligocene fluvial and Quaternary sediments (Figs. 12B, C, El Aref et al. 2021). The record of vertebrate fossils in the red soils of the karst carbonate plateau of the El Bahariya- Farafra and limestone excavation in East Beni Suef (Khashm El-Raqaba) dated to the Late Miocene (Pickford, et al. 2006; Wanas et al. 2009, Mein and Pickford 2010; Gunnell et al. 2016).

The karst sequences are well categorized by subsidence, tilting, and sagging of the carbonate rocks with unconformable overlying Khoman Fm (Figs. 12B, C). Spherical-shaped hollows (kamenitza) characterize the speleothem deposits (Fig. 12D). Roots of plants/or fossils remains (?) crustified by calcite, form the so-called rootsciles (Perri et al. 2012). They are observed in black limestone (Fig. 12D). This is further supported by the criteria of Wanas et al. (2009), who identified several new faunas involving anurans, soricids, bats, galagids, hystricids and glirids in the speleothem deposits at Qarat Sheikh Abdallah, an indicative of a humid paleoclimatic regime between 11 and 10 Ma, with mean annual rainfall of more than 1200 mm. The record of the faults, joints, fissures, and fractures, acting as the pathways for the water infiltration in the speleothem deposits, facilitates the carbonate dissolution (Figs.11A, 12A, and 13C, D). Such structural patterns trigger the creation of sinkholes/ dolines and collapsed unroofed caves that are filled by coloform crustified calcite layers, forming flowstones that are favorable to form karst phenomena (Figs. 12D and 13). Most of the unroofed caves display remarkable remaining karst architectures like lion’s head or crocodile-like forms (Figs. 14A, B).

Fig. 11 A Symmetrical collapsed dome hills with characteristic solution cavities and fractures/joints. B Symmetrical collapsed isolated dome with a broad pedestal outline. C Collapsed isolated dome and karst window with spine tops and an open kamentiza along its wall.

Notice the observed rubble nature and brecciation affecting the dome hills. D Cuesta-shaped form with moderate to high hills having a gentle slope on one side. Notice the occurrence of solution hollows affecting the carbonate rocks as the result of karstification.
The cave walls are characterized by common cavernous weathering involving honeycomb and tafoni geomorphological phenomena (Figs. 3D, 4A, and 14C). The latter occur as spherical or elliptical cavities/vugs that vary in size from 0.5 to 2 cm. These cavities/vugs may indicate events of ascending water flow and the probable occurrence of hypogene karst systems during the past pluvial periods (Ford and Williams 1989; Williams 2008). The most public speleothem-forming minerals are calcite crystals ((Hill and Forti 1986) that are well exposed at Crystal Mountain, near Qarat El Sheikh Abdalha (Fig. 1C). They form the famous sinter styles such as solution channels (Fig. 14C), dripstones (umbrella-shaped stalactites and stalagmites, Figs. 13B, 14D, and 15A), karst windows or solution channels (Figs. 14B and 15B), and crustified colloform calcite layers forming flowstones (Figs. 15C, D). Calcite crystals in the solution channels/opening and vugs (Fig. 16A) vary in morphology and size from micro- to macrocrystalline crystals (up to 20 cm) and form beds, attaining a few meters in thickness and ~5 m in extension. Sometimes, these crystals have a branching, curved, or spiral shape and may grow in any direction, forming helictite speleothems (Fig. 16B). Stalagmite samples within the speleothems of the intra-Eocene Wadi Sannur cave, Eastern Desert, Egypt, gave a time of less than 200,000 years ago based on uranium–thorium dating (Dabous and Osmond 2000). All the architectures of the crustified calcite crystals would possibly attract the attention of visitors.

The caves, karst towers, and inselbergs are the main nesting habitat for sooty falcons (Fig. 16C) in the Bahariya...
Depression and WDNP, similar to unique cave and karst features that host a set of bird species (Anderson and Ferree 2010). The number of sooty falcon pairs recorded in this National Park ranges from 33 to 101 annually from 2009 to 2013 (Salama et al. 2020). This natural phenomenon encourages geotourism and fascinates a lot of guests.

Results

The outputs of the arithmetic and qualitative evaluation are shown in Tables 1 and 2. Table 2 shows the SWOT analysis established on the evaluation and acts as a center for precise plans of geotourist activities. The indicators and subindicators were earmarked based on an appraisal of geotourism’s literature and scenic/geosite assessments. The results in Table 1 show that the Main values have high scores if compared with those for the Additional values. El Aref et al. (2017b) documented that the WDNP achieved the highest total value and final standing among the inventory and valuation of El Bahariya-Farafra geomorphosites. Karst sites gained more than ten points (Table 1), which can be measured as an appropriate state for geotourism improvement, but these potentials are not completely developed. They have high VSE, particularly in the item of rarity, representativeness, and geological diversity, because chief outcrops are well conserved, signifying intact landforms, and have an assortment of geoscience characteristics (diverse karst geomorphosites, lithological variations, faults/fractures, unconformities, and hydrogeological facets are present). Furthermore, the high scientific values are due to their scarcity and/or the convenience of scientific awareness, which justify the need for management through the evaluation of these sites (Brilha and Reynard 2018). Similarly, the study of specific karst phenomena such as calcite crystals forming the famous sinter forms, such as dripstones (stalactites, stalagmites) and flowstones (colloform crustified calcite layers) observed

Fig. 13 A Collapsed caves (speleothems) that are superimposed conglomerate beds and silt soils forming Miocene/Oligocene fluvial sediments, and both of them lie under bedded sagged limestone beds. B Sagged carbonate beds with typical cavernous surfaces and drapes/curtain structures. C, D Collapsed unroofed caves with sagged structures filled with crustified calcite layers and red soil. Notice that faults controlled the cave borders.
in speleothems at QSA and CM (Figs. 13, 14, and 15), provides information about paleoclimate. The clarification of paleoclimate is of precise scientific interest for guests and visitors because it provides knowledge about the historical strength (amount vs. time), outgassing, pH changes, perseverance of rainfall, temperature variations, rock type, soil carbon sequestration, and the universal atmosphere (Sánchez and Lobo 2018).

The subindicators of scientific and educational values possess a moderate to high level. The geomorphological landforms are vital for the understanding of the improvement of the WDNP. Initially, the rarity of the karst landforms is high because of the presence of unique landscapes that are highly developed tourist endpoints. Karst Lake, wind sculpture landforms, speleothems, Karren/Lappies karst, and stromatolite-like tufa denote some of the rare karst wonders in the WDNP. The former may be considered natural conditions for swimming (Figs. 3A, B), which is a real terminus for nature-based tourism. It owns high appealing and amusing value, which could be better endorsed to inspire entertaining activities. The whole karst topography, as well as the sites’ high aesthetic eminence, represent highly superfluous values. Furthermore, most of these karst features have moderate to high values of representativity because they form well-exposed appearances like mushrooms, inselbergs, and bridge/tower karsts, but others have low values of representativity, e.g., speleothem karsts (or degraded caves). With respect to viewpoints, surface, and surrounding landscape, karst sites have the highest VSA, like the natural sculptures or speleothem deposits, which gain an assured level of aesthetic and visual value, like Crystal Mountain. On the other hand, some Main values attain the lowest score (e.g., items II.4, II.5, II.6., II.8., Table 1) because the WDNP spreads over a small region having little awareness of geoscientific subjects and interpretation level.

Karst sites are sheltered on a national level and are recorded on the list of protected regions of the Egyptian Environmental Affairs Agency. The White Desert National
Park has been listed as an IUCN category II-National Park since 2002 (Ministerial Decree No. 2219/2002) for administration purposes (Fig. 16D). Protection value attains a high score for karst sites, which allows visits of enormous tourist groups without triggering substantial destruction to the ecosystem. Regarding VFn, the karst sites get a high mark, especially in the case of accessibility and proximity of the main road network (Fig. 1B). This is notable because an international main asphalt highway passes through the WDNP, joining the Bahariya and Farafra Oases together with a dense network of desert paths (Fig. 1B). By contrast, anthropogenic values achieve a low score.

The asphalt and desert roads have provided an appropriate situation to visit the geomorphological heritage and improve both geotourism and educational activities in this region. Bahariya and Farafra Oases can provide solid, quality accommodation facilities, providing a visitor center for devious travel periods. The karst sites get a low score of VTr because there is not enough existence of tourism infrastructure, interpretive panels, and publicity activities together with a lacking of tour guide facilities and organized excursions. The WDNP has no sufficient tourist substructure and amenities to identify and comprehend its landscape. Particularly notable is the lack of guide (lighting), dull pathways, signal marks, trails, and planned excursions for visits. Tourists are self-initiative when they visit these karst sites. There are no interpretive panels that explain the diverse karst landforms, and they are completely absent. The closeness of the karst sites in relation to the Research Center received a lower rating. Thus, visitors do not obtain useful information to understand each karst geomorphosite. Furthermore, the scientific awareness of the karst phenomena has not been adequately established. The same conclusions are reached by El Aref et al. (2017a), who concluded that adequate infrastructure and qualified staffs are lacking in education and interpretation. The additional studies on scientific clarification of the karst phenomena in the fields of geography and tourism are few if compared with several national publications about karst themes (Antić and Tomić 2020). When

![Fig. 15 A Close-up view of unroofed stalagmites (dripstone). B Folded and tilted solution channel forming a karst window that is filled with crustified calcite. C, D Colloform crustified calcite layers](image)

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these weaknesses/or deficiencies are overcome, other factors of tourism enhancement can be realized.

There are other subindicators of scenic/aesthetic values which should be evaluated. Viewpoints are imperative because they give an attractive view to visitors. General discernibility of landforms is possible. Most parts of the karsts are beautifully attractive to tourists, e.g., the karst nests for bird species. The karst subject has a dazzling theme that achieves a high level in many scientific and non-scientific publications. The karst geomorphological processes permit a high to a moderate level that can be simply elucidated to a public visitor. Due to the lack of tourism development in the WDNP, the preference and the annual quantity of planned visits are valued with the lowest scores. The tourism development in the deserts could have a positive influence on indigenous and provincial tourism and economic advance if this central deficiency is overwhelmed. It is required to focus on investment plans and improvement schemes through advertising and administrative construction. After evaluating the functional values, it can be decided that all karsts maintain acceptable advanced situations that are significant for tourism development. A comprehensive plan study in the WDNP is compulsorily deliberated in order to diminish the breakdown outputs, which have a great influence on the local residents and infrastructure, with the priority aim of tourism growth.

SWOT Analysis

The SWOT analysis (Dony 2017) is a framework used to facilitate a realistic, fact-based, data-driven look at the strengths coupled with weaknesses of an organization, initiatives, or within its industry and evaluate a company/organization’s competitive position to develop strategic planning (Table 2). It assesses internal and external factors as well as current and future potential. The organization needs to keep the analysis accurate by avoiding pre-conceived beliefs or grey areas (ill-defined situations) and instead focusing on real-life contexts. Companies should use it as a guide
Table 1 Numerical assessment of karst sites in White Desert National Park, Western Desert, Egypt

| Indicators/subindicators                                      | Description                                                                 | Score |
|---------------------------------------------------------------|-----------------------------------------------------------------------------|-------|
| Main indicators/subindicators                                 |                                                                             |       |
| I. Integrity and current status                               | The quality of being sincere                                               | 0.75  |
| II. Scientific/Educational value                              |                                                                             |       |
| II.1. Rarity                                                  | Number of closest identical sites                                          | 0.75  |
| II.2. Representativeness                                     | Well-exposed classic characteristics of the site due to its good quality    | 0.75  |
| II.3. Diversity of the Earth science features                 | Assortment of natural phenomena like stratigraphy, geomorphology, fauna,   | 1.00  |
|                                                               | rocks/minerals, hydrology, etc                                              |       |
| II.4. Knowledge on geoscientific issues                       | Number of written papers in journals, presentations, and other publications | 0.5   |
| II.5. Level of interpretation                                | Understanding of geological and geomorphologic phenomena                   | 0.5   |
| II.6. Paleogeographical significance                         | Interpretation of paleogeography and climate change                        | 0.25  |
| II.7. Ecological value                                       | The development of diverse ecosystems                                       | 0.75  |
| II.8. Cultural value                                         | The great attendance of karst heritage in the WDNP culture, appearing in   | 0.25  |
|                                                               | novels, stories, legends, and different artistic representations             |       |
| II.9. Historical aspect                                      | Past history of cave karst                                                  | 0.25  |
| III. Scenic/Aesthetic                                        |                                                                             |       |
| III.1. Viewpoints                                            | Number of viewpoints accessible by pedestrian pathways                    | 0.75  |
| III.2. Surface                                                | Whole surface of the site. Each site is considered in quantitative relation to the others | 0     |
| III.3. Surrounding landscape and nature                      | Panoramic view quality, presence of water and vegetation, absence of human-induced deterioration, vicinity of an urban area | 0.75  |
| III.4. Environmental fitting of sites (aesthetic value)      | Level of contrast to nature, a contrast of colors, the appearance of shapes, etc | 1.00  |
| IV. Protection                                               |                                                                             |       |
| IV.1. Current condition (protection status)                  | Current state of the geosite                                               | 1.00  |
| IV.2. Protection level                                       | Protection by local or regional groups, national government, international organizations, etc | 0.75  |
| IV.3. Vulnerability (damages and threats)                    | Vulnerability level of the geosite                                          | 0.50  |
| Additional indicators/subindicators                          |                                                                             |       |
| I. Functional values                                         |                                                                             |       |
| I.1. Accessibility                                            | Possibilities of approaching the site                                       | 0.75  |
| I.2. Security                                                 | Safety sides of visitors                                                    |       |
| I.3. Site context                                             | The principal attractive landscapes of the national park                    | 1.00  |
| I.4. Additional anthropogenic values                         | Number of additional anthropogenic values in the radius of 5 km            | 0.25  |
| I.5. Vicinity of emissive centers                            | Closeness of emissive centers                                              |       |
| I.6. Vicinity of the important road network                  | Closeness of important road networks within a radius of 20 km              | 1.00  |
| I.7. Additional functional values                            | Parking lots, gas stations, mechanics, etc                                  | 0.5   |
| II. Tourist values                                           |                                                                             |       |
| II.1. Promotion                                              | Level and number of promotional resources                                  | 0     |
| II.2. Interpretative panels                                 | Interpretative characteristics of text and graphics, material quality, size, fitting to surroundings, etc | 0.25  |
| II.3. Number of visitors                                     | Annual number of visitors                                                  | 0     |
| II.4. Tourism infrastructure                                 | Level of additional infrastructure for tourists (pedestrian pathways, resting places, garbage cans, toilets, etc.) | 0     |
| II.5. Tour guide service                                     | If existing, expertise level, knowledge of foreign language(s), interpretative skills, etc | 0.25  |
| II.6. Hostelry service                                       | Hostelry service close to geosite                                           | 0.25  |
| II.7. Restaurant service                                     | Restaurant service close to geosite                                         | 0.25  |
| III. Conservation values                                     |                                                                             |       |
| III.1. Legislative protection                                | Lawmaking for protection                                                   | 0.5   |
| III.2. Current threats                                       | Present-day intimidations/terrorizations of geosite                         | 0.75  |
| Total value                                                  |                                                                             | 15    |

Sources: Vujičić et al. (2011), Reynard et al. (2016), and Román et al. (2020)
and not necessarily as a prescription. The SWOT analysis has already been used by many researchers (Kubalíková and Kirchner 2013, 2016; Boukhchim et al. 2018; Carrión Mero et al. 2018; Ateş and Ateş 2019), which represents a vital step in the assessment of geosites because it (1) provides assessment view about strengths, weaknesses, opportunities, and threats; (2) serves as a root for grouping of these characteristics into other scheduling brochures/booklets and the provincial development policies or site management; and (3) gives comprehensible vision about geodiversity and geoheritage concept for the broader community, consultants, management, and other organizations. The SWOT analysis serves as a foundation for geotourist and geoeducational event applications, providing an explanation for applying precise preservation measures (both natural and cultural) to certain locations (Kubalíková et al. 2020). These sites can then be confirmed as protected areas and should be incorporated into the planning strategies.

Several papers have mentioned the use of protracted SWOT analysis for geoheritage and geopark areas (Carrión Mero et al. 2018; Ateş and Ateş 2019). However, its use is not public in geotourism research (Kubalíková et al. 2020). The White Desert is already a national geopark with an incomplete infrastructure that is located midway between Bahariya and Farafra Oases (Fig. 1B). It is easy to reach this National Park through general and local roads by minibusses to the park entrance, giving an appropriate conveyance and high accessibility. The SWOT analysis has proved that the WDNP can be considered a composite region for the progress of geotourism actions and making exact geotourist outputs (a geopath). Furthermore, it shows that the study area has undergone the effect of a positive or negative influence on karst geoheritage (Table 2). Concerning positive creativeness, the WDNP has a well-prepared zonation map of karst landforms (El Aref et al. 2017a). The White Desert has a substantial number of natural geoheritage landscapes with abundant exceptional features. The latter has international prominence and geotouristic attractions which can be appreciated within the forthcoming UNESCO Global Geopark. Moreover, most of the karst morphologies can be used as nests for threatened bird species, e.g., sooty falcon, which fascinates a lot of tourists and visitors. All these positive impacts have allowed us to declare the White Desert a national park in 2002. In order to establish the WDNP as an ambitious Universal Geopark, a series of steps should be planned to protect the geoheritage sites. Regarding the negative influence, the karst geoheritages lie under the condition of degradation (water/wind erosion and degradation hazards) and deprivation, owing to the lack of actual

### Table 2: SWOT analysis of the karst sites of geotourist interest

| SWOT       | Remarks                                                                 |
|------------|-------------------------------------------------------------------------|
| Strengths  | The attendance of zonation map of karst landforms                       |
|            | Close to main roads and Bahariya/Farafra cities                        |
|            | The WDNP has been declared a protected area in 2002                    |
|            | High scientific and educational values                                  |
|            | Features of amusing or tourism consequences (e.g., karst lake, tower/bridge karst, sculptures of birds, turtles, and animals, etc.) |
|            | Nest for endangered bird species, e.g., sooty falcon, signifying a close link between karst landform and biological diversity |
| Opportunities | Interpretation of links between karst landforms and biological diversity |
|            | Infrastructures are available                                           |
|            | Good public convenience                                                 |
|            | The conceptual cooperation between universities and research institutions should be initiated in the field of geodiversity, ecosystem, and geotourism |
| Weaknesses | No training courses/or programs for attendants and local inhabitants as official guides for karst sites |
|            | The absence of public awareness and educational materials for visitors |
|            | Lack of brochures, panels, and guidebooks                               |
|            | The educational recreational and tourist potential of geomorphosite phenomena are not recognized by the public |
|            | The development plan for geotourism is not involved in the development strategies |
| Threats    | Erosion and degradation hazards (wind action, climate change, natural catastrophes) |
|            | An increase of urban areas close to protected expanses, resulting in changes in hydrological regimes which may destroy natural landforms |
|            | Lack of finance for the advancement of geodiversity and geotourism outputs |
|            | The development of the geotourism concept is still misunderstood         |
|            | Lack of interest in geodiversity and geoheritage on the part of authorities and the public in the future |
|            | The bad performance of local inhabitants or visitors leads to intimidation of the study area |

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strategies of geoconservation and fortification. There are no systematic training courses/or programs for employees and tour guides in the protected natural areas. Moreover, there is no communication with the stakeholder team of well-known universal geoparks. Local residents are not conscious of the meaning and appreciation of geoheritage. They also have low intelligence and awareness of environmental conservation. All the geoheritage sites lack educational materials, instructional signs, and geological interpretations. As commended by Martin-Duque et al. (2012) in those circumstances whereas the impact of human action enlarge the welfares and improve the endorsement to geoheritage, the subsequent equilibrium should be measured as positive and well-matched with geoconservation.

Discussion

Assessment Significance of Karst Sites for Geotourism Development

All natural heritage landscapes have been recorded in the region of the WDNP. These denote surface karst features, springs, valleys/gorges, and other geomorphological phenomena. The diverse, exceptional, and pretty karst landforms of the WDNP resulted from numerous paleo-karstification processes during the Cretaceous-Oligocene/Miocene paleo-topographic evolution of the tropical paleoclimate (El Aref et al. 2021) along with wind or tectonic actions (Said 1960; 1962). They have a high impeding for geotourism improvement, scientific/educational uses, and promotion of geological and geomorphological heritage, as has been shown in other studies (Migoń and Pijet-Migoń 2016; Szepesi et al. 2017). Regarding scientific, scenic, and recreational values, the karst sites receive high scores, which reveal that these sites are currently the most appropriate for tourism activities. The latter has the possibility to convert the WDNP into tourism destinations and can meaningfully add to scarcity improvement in various portions of the evolving world like Egypt (Newsome and Dowling 2006). Furthermore, the development of geotourism undertakings can aid to discover auxiliary reserves of income for the societies existing adjacent to these fascinations (Khalaf and Abu El-Kheir 2022). The record of new karst sites and their proper development can add to dispersed visitors’ span of stay in the area. Besides evaluating the geosites for geotourism growth, indicators related to biodiversity were incorporated for a broad understanding of the environment and maintainable improvement. This is reinforced by the concept of Schrodt et al. (2019), which say that “a universal approach that identifies the reliability of the biotic constituents of ecosystems is the most actual way to report comprehensive environmental challenges.”

Guests traveling to geosites need to know the geological and geomorphological landscapes as well as the phenomena linked to biodiversity and culture as declared in the description of the geotourism designation. Some of the karst sites are unique biological habitats, indicative of their ecological significance, like the development of an amazing flora (bioturbation by mangrove roots) and fossil remains (Figs. 8A and 12D) that add supplementary enthusiasm for itinerants to visit these sites. Wanas et al. (2009) recorded endemic faunal species including anurans, snakes, soricids, bats, galagids, hystricids, and glirids in speleothem karst at Qaret El Sheikh Abdalha (Fig. 1C), providing evidence of a humid palaeoclimatic nature during karstic geomorphological processes. Moreover, the karst landforms have uniform environmental situations for nesting and breeding of migratory birds (e.g., sooty falcon, Fig. 16D). Nests for endangered bird species, e.g., sooty falcon, signify a close relationship between karst landform and biological diversity (Salama et al. 2020), justifying their ecological importance. The fortification of bird species depends on the protection of their territories. Without acceptable preservation actions, these nests may become fragile sites and will perhaps result in the extermination of the wild bird inhabitants, which are dynamic homelands for them (McGrady et al. 2010). The protection of biodiversity and increasing information about its value is a vital introductory stage towards the sustainable growth of geotourism, especially ecotourism. Hence, the existence of miscellaneous geological/geomorphological and biological features having scientific, educational, scenic, and ecological impact could assist in attracting tourists with diverse interests. An understanding of these ecosystems is required to advance and justify their administration in order to reserve them against environmental threats.

The karst sites have a deprived quality of informative panels (site description, fluent explanation, clarifications of processes and miracles, the level of protection). Info sheets, signs, and panels should deliver guests precious knowledge and fascinating proof that increase the entire interpretation picture (Fig. 17). The latter aids the visitors in comprehending the routes and geological wonders in order to understand the site’s surroundings. Normally, info sheets offer knowledge on the length and duration of the walking path, difficulties, and additional distinct topographies. In the absence of an assistant, interpretive panels reduce complicated natural processes and deliver expressive information about the geosite, the length of the tourist pathway, documentation, and cautions, and simplify the program of guests. Geotourists are typically individuals who know little about geological and geomorphological phenomena, so a well-organized explanation model (Fig. 17) is required to comprehend complex events (Crane and Fletcher 2016).

The instructive data about the geoheritage of karst sites are inadequate because the funds required for advertising actions
are very restricted. So it is necessary to take advantage of the desirability, inclusive attention region, and low charge of marketing via electronic media. The latter mainly refers to the use of Internet promotion and advertising actions that represent one of the key elements in marketing policies (Bratić et al. 2020). Supplementary improvement of geotourism should be centered on the Geographical Information System’s (GIS) usage and mobile presentations (Marinoni 2004), which embody one of the cleverest and the most effective means to bring geotourism nearer to a comprehensive audience (Filocamo et al. 2020). The development and management of geotourism is considered an intricate job (Newsome and Dowling 2018). The vanishing of the negative influences on tourism through geoconservation groups is the main goal of geotourism (Gray 2008). Sustainability is one of the principal purposes of geotourism, which should increase through the enlarged consciousness of visitors and the indigenous community about the prominence of conserving the geological heritage. This action has been done through geological teaching and understanding (Newsome and Dowling 2006). Geoconservation signposts how much people accept their responsibility to natural wonders and their strategies to preserve geosites, geodiversity, geological processes, and their fluctuations (Sharples 2002; Hose
2005; Schutte 2009). It is likewise vital that the growth of tourism improvement is made in a justifiable style to ensure continuous economic advantage from tourism in the region. The so-called speleo-tourism, associated with ecotourism and adventure tourism, should develop as activities that add to the protection of the karst heritage by producing revenue and increasing the value accredited to the local populations (Sánchez and Lobo 2018).

This is well-matched with the concept of Wartiti et al. (2008), which says that geoheritage sites have to be accurately achieved to create jobs and novel economic doings, especially in districts lacking few sources of income. The karst geological landscapes labeled in this work are appreciated and fascinating for geotourism. The demonstration of the evaluation outcomes of the main and additional values (Table 1) could help in comprehending the grade of the geosites and ranking them for maintainable geotourism progress. Such a presentation of outcomes could be connected to a suitable entire tourism improvement, promotion, and administration strategy that improve maintainable development (Vujčić et al. 2011). Thus, superiority in the advertising and improvement of necessary services and infrastructure could be given to the karst sites, representing principal urgency in geotourism growth.

Certain itineraries can provide satisfactory convenience to geomorphological heritage and should be taken into consideration for handling tourists and geotouristic uses through sustainable geotourism development. The WDNP can be held liable for the administration of these ways in order to improve the administration of guests and, consequently, enhance the protection of geomorphological heritage and, lastly, maintainable improvement of geotourism. Organizing geo-interpretation conveniences and facilities at the visited geosites is one of these ways. In Africa, geology is “ignored in guidebooks and by excursion operators, and most tourists obtain little knowledge about the geology of the visited regions,” as has been observed by Thomas and Asrat (2018). As a consequence, impending geotourism improvements should be made to offer sufficient familiarity, such as scientific and instructive magnitude, about the geosites for tourists. Tourism infrastructure, monitoring visitors, stakeholders in management, and the development of education from dissimilar facets, providing interpretive facilities are also involved. To increase the number of visitors to the WDNP, it is vital to increase tourism services and entertainment activities like cave surveys, trekking, climbing, paragliding, camping, and biking. Guests can also enjoy watching birds and their nests. Along with these geotouristic activities, tourists can also make excursions and ecotours to local communities such as Bahariya/Farafra oases to gain knowledge about human–environment interaction. The Bahariya/Farafra oases were confirmed under law number 102/1983 in the context of sheltered regions in Egypt (Fig. 1).

The Bahariya/Farafra Territory is one of the most hyper-arid deserts in the world with the scarcest rainfall rate during the last 7000 years (El Aref et al. 2021). The natural environs occupying this territory have significant geoheritage sites, achieving very high rankings for tourism destinations, such as geological and geomorphological fascinations, as well as cultural and historical sites that are very gorgeous and attractive situations for tourists and guests. Plentiful natural landscapes in these areas are detected, such as surface karst landforms, hot freshwater springs, volcanic landforms, iron mineralizations, palm trees, palaeontological localities like the Cenomanian Dinosaur site in Bahariya Oasis, and sand dunes, along with Black Desert consisting of black cone hills (El Aref et al. 2006; Plysmina et al. 2016; Khalaf et al. 2019). In addition, indigenous anniversaries, old-fashioned houses, ancient roads, temples, and caves, together with Safari journeys and camping, add attractions to the visitors in these areas, which establish an innovative style for geotourism that can be managed by overseas and indigenous tourists. These outstanding geological landscapes reinforce that the WDNP and its surrounding areas are a central province for geotourism improvement and have a favorable circumstance to develop as Global Geopark, which would become the territory’s model tourist destination. The consequences of several numerous studies have revealed (Gray et al. 2013a, b; Kot 2017) that the multiplicity of landscapes like the WDNP and its neighboring places have an excessive potential to offer different geosystem amenities. However, it is imperative to incorporate the outcomes of geodiversity and biodiversity investigations (Gray 2018; Brilha et al. 2018; Zarnetske et al. 2019) for the promotion of geosystem facilities, geomorphological heritages, and administration along with preservation objectives of the WDNP.

The other way is by constructing awareness for the indigenous populations about geotourism and the reputation of geosites. Creating an approach to how the general public can benefit from geotourism is likewise imperative. This marks its potential to acquire community assistance in protecting geosites, building local inhabitants—guest dealings, and developing maintainable geotourism. Karst sites in the WDNP are influenced by natural and anthropogenic processes, including contamination, gravel quarrying, urbanization, soil erosion, and degradation hazards (wind action, climate change, natural catastrophes). The preparation and implementation of a legislative agenda and management design for the geosites are portions of the resolution in solving these difficulties for conservation, geosite protection, and sustainable geotourism improvement. Supplementary studies are required to develop profitable and maintainable tourism, such as geological and geomorphological mapping, analysis of geological and environmental susceptibility, and comprehensive evaluation of the substantial topographies that outline the region’s geoheritage. Preparing combined geoheritage maps, explanatory panel diagrams (Fig. 17), and identifying promising sites for
understanding the different karst landforms and their environment complications in the WDNP along with its surroundings are mandatory for geotourism, inventors, managers, and liable organizations (Reynard et al. 2016; Melelli et al. 2017). The sustainable tourism administration strategy of the region for long-term economic profit is active in ensuring that geological topographies are preserved, protected, and applied. It is expected that this research will deliver crucial information for emerging geotourism strategy, design, and administration as well as emphasize the capacities of the WDNP and its surroundings for establishing a Global Geopark. All of these steps can be officially used as an actual tool to advance the protection of geological features in the Western Desert. A geopark is credible to motivate pronounced attentiveness among the visitors and the residents to learn more about geology and, therefore, help in propagating geosciences. It will also support the privilege that tourism can be sustainably advanced by making use of prevailing natural topographies without excessive assets and with minimum damage to the environment.

Conclusion

Egypt has several protected areas with geoheritage, geodiversity, and biodiversity, as evidenced by the number of initiatives and resources implementations. The WDNP that lies in Bahariya-Farafra halfway links to one of these sheltered regions in the WD. This manuscript presents the evaluation of geomorphological karst landscapes as a potential geotourism in the WDNP. The latter has many different types of karst features due to its diversity in geologic and climatic regimes. Miscellaneous fluvial and karstic landforms together with rock types, faults/fractures, unconformity surfaces, and dry valleys/gorges are only part of the geomorphodiversity of the WDNP and its surroundings, which needs distinctive awareness for geotourism advancement, management, and scientific/educational uses. In fact, the various karst features can play a vital role in endorsing the attractiveness, scientific, educational, and aesthetic value of geomorphological heritage and its better understanding. The results of geomorphosite assessments signpost that the analyzed karst sites maintain generous geotourism potential for creating the WDNP a geotourism purpose or world heritage and geopark. However, there are many actions for the enhancement of additional functional values, tourist infrastructure, interpretative panels, visitor centers, authorized tour guide amenities, and interpretative boards that permit geological and geomorphological topographies to be presented to tourists. Policy strategies together with the participation of the local inhabitants must be applied in order to exploit the total use of tourism as possible, leading to provincial economic development and highlighting the site of the WDNP in the tourist market. In order for the karst geomorphosites to have a positive economic influence, promotional activities should be upgraded and prolonged to the national level, as well as the organization of websites comprising more geosite information, better demonstration at tourism carnivals, more informative and imaginative brochures, and sketch maps as a guide for tourist excursions. Furthermore, organizing collaborative workshops and education for tourists with dissimilar objectives would meaningfully enhance tourists’ awareness of maintainable improvement and the importance of the karst geosites as geodocumentation and geointerpretation, which are vital tasks in the confirmation of geotourism and its development. The collaboration of universities, research institutions, and the design of geotourism programs through the application of effective realism will aid not only to facilitate the broadcasting and knowledge of appreciated karst geomorphological heritage but also contribute definitively to the sustainable development of rustic areas as well as to the active participation of local communities in this development. All of these enhancements will improve tourism infrastructure as well as the resident economy and community participation, together with an advance in the awareness of the indigenous inhabitants and authorities regarding the requirement for maintainable use and organization of geoheritage. With an attitude that integrates the organization of geotourism and its administration (comprising collaboration between community and secluded divisions), a number of positive influences could be proposed in the future.

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Declarations

Competing Interests The author declares no competing interests.

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