



# Geoheritage and Cultural-Religious Heritage of Samalute-Minia Area in North Egypt

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## Abstract

Geodiversity, geoheritage, geoconservation, and geotourism insights are meticulously interrelated. Their investigations are of comprehensive attention worldwide because of their high scientific, educational, scenic, and recreational values. Various new destinations in Egypt have been promoted for the geotourism and abundance in significance geological heritages in which Samalute-Minia Area is one of the most energetic tourist's magnetism. The study area is an imperative geo-cultural province that has significant number of geosites and geotouristic fascinations, demonstrating broad array of distinctive phenomena. The latter are assigned to remarkable geomorphological, volcanological, hydrogeological, quarrying, historical, and cultural landscapes that are deliberated a vital part of the polythematic geopark. All of these sites allow the visitors, sightseers, and indigenous populations to enjoy different aspects of tourism such as religious, antiquities, recreational, safari, or ecological tourism as the root for providing the commitment, education, and pleasure. The goal of the present paper aims to stress the reputation of the geological heritage earmarked by Samalute-Minia Area. A quantitative assessment of geodiversity at the study area was carried out using the Brilha's method (2016) in which the evaluation outputs are labeled for geotourism obligations. A list of eight geosites has been inventoried. Among the principal geosites are (1) geomorphology and karst landforms (GKL), (2) circular structural landforms (CSL), (3) volcanic landforms (VL), (4) riverine landforms (RL), (5) Christian Religion sites (CRS), (6) ancient Egypt monuments (AEM), (7) industrial sites (IS), and (8) hydrogeological aquifers (HA). Quantitative valuation has been revealed that the bunched geosites of GKL, VL, and RL have great scientific and educational value scores, while the geosites of CRS and AEM have high potential touristic use compared to low value for the IS. Regarding the risk evaluation, a high degradation risk is assigned to the sites of AEM, RL, and HA. Severe threats comprising pollution, rapid urbanization, intense degradation of underground water, illegal water pumping, quarrying/excavation, bumpy tourism, and lacking of environmental management are the chief causes for the degradation risk. The lasting five geosites display a moderate to low risk of degradation because there are no extreme observed denudation processes that generate degradation. The protection and geoconservation, increasing the touristic attractiveness, and the socio-economic development for the local community could be proposed in order to decrease the high degradation risk for some geosites. Lastly, the Samalute-Minia Area needs more scientific and potential geoheritage study, improvement in the security circumstances, promotion of the geosites, and strategic implementations as well as regulation constraints for continuous regional development to improve geotourism and geoconservation. The geotourism development would diminish the rate of joblessness and immigration, offer scenarios for dropping poverty through engaging the local inhabitants in tourism activities, and ensure the protection and educational stopovers to well-known geosites.

**Keywords** Geodiversity · Geopark · Geosite assessments · Landscape · Culture · Geotourism

## Introduction

Geoheritage, geoconservation, and geotourism studies have been taken a great interest in the past few years (Nieto 2001; Gray 2004; Croft 2018; Ólafsdóttir 2019; Štrba et al. 2020; Williams et al. 2020; Zgłobicki et al. 2020). Geodiversity is the natural variety of geological (rocks, minerals, and fauna/

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flora), geomorphological, hydrogeological, sedimentological, quarrying, magmatism, tectonic, and soil topographies (Gray 2013). It delivers a diversity of welfares that permit economic improvement and the well-being of societies (Gordon et al. 2012; Kubalíková 2020). Geodiversity gives information about Earth evolution or the science history, resources for manufacture, and possessions for esthetic, educational, and tourist accomplishments (Brocx and Semeniuk 2007; Gordon et al. 2012). The combination of miscellaneous properties between geoheritage and cultural subjects is demonstrated at UNESCO World Heritage. Consequently, knowledge of geodiversity distribution is important for realizing maintainable use of resources and identifying high-priority preservation sectors. Geotourism is a sustainable tourism with a crucial emphasis on sightseeing the Earth's geological and geomorphological features of the landscape, aiming to raise environmental and cultural understanding, obligation, and preservation of geodiversity (Dowling and Newsome 2006; Joyce 2006; Dowling and Newsome 2010; Dowling 2011, 2013; Vlachopoulos and Voudouris 2022). This is realized through clarifications of geological landscapes, use of geotrails, field excursions, and support of geosite centers. Geotourism has enlarged universal as a valuable utensil for stimulating natural and cultural heritage promising local and regional economic improvement during the last decades (Pralong 2005; Anonymous 2017; Kubalíková 2019). The combination of the geotourism knowledge with traditional nature tourism and components of cultural tourism produces a more holistic embrace. In protected regions, the geoconservation community must work to certify the environmental management and conservation in local, national, and international programs for sustainable development (Gordon et al. 2018a; Garcia-Sanchez et al. 2021).

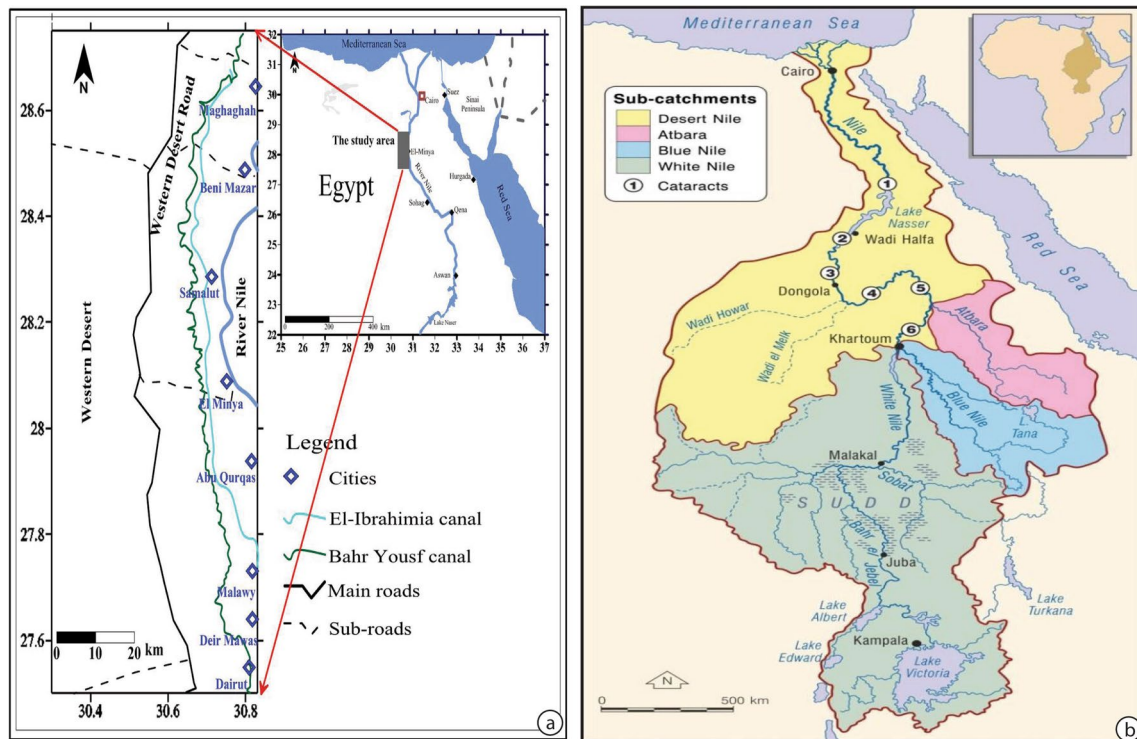
Geoparks are physically defined seats (Brilha 2009; Brilha 2018; Robinson 2019) that are used as utensils for the management of geologically significant terrains and the improvement of rural and local communities in a maintainable mode through geotourism (Zouros 2004; Sánchez-Cortez 2019). Their territories are commonly sheltered broad areas comprising a number of geological heritage sites related to ecological, archeological, historical, or cultural attentiveness, which are tools for science, education, and tourism (Dowling and Newsome 2010; Reynard and Brilha 2017). Geosites/or geotrails are crucial elements of geotourism that can bring a significance knowledge and information about geoheritage principles to visitors and tourists (Gordon and Barron 2013; Gray 2013; Robinson and Hillman 2017). Reynard (2005) described geosites as geological elements that have high scientific, cultural, esthetic, and/or economic values. The study and interpretation of geosites can be established based on magnitude, purpose, character, quality, and weakness (Fuertes-Gutiérrez and Fernández-Martínez 2010). Based on these benchmarks, geosites are

classified as spots, sections, regions, and viewpoints. In fact, the description and protection/assessment of geosites are compulsory prerequisite for geotourism development, geoconservation, and economic profits (Suzuki and Takagi 2018) and should be established before creation of any development for forthcoming geotourism outputs (Vujičić et al. 2011; UNESCO 2012).

Egypt is one of the richest countries in the world in terms of antique artifacts and heritage (Kamrin 2009). Its territories have numerous spectacular geosites with characteristically diverse significance geological elements (Plysnina et al. 2016; Khalaf et al. 2019; Khalaf 2022; Khalaf and El Kheir 2022). The Samalute-Minia Area involves a broad range of geological and cultural phenomena related to geomorphological, tectonic, volcanological, archeological, and historical features. Scarce studies have been published typifying the geoheritage and cultural sites of the examined region and the chances for developing geotourism. For this goal, the region of Samalute-Minia Area in North Egypt has been selected because it has imperative number of geosites and geotouristic fascinations. The main paper's objectives are (i) describe the geoheritage potential of the selected geosites, (ii) evaluate and assess these geosites following the Brilha's method (2016), (iii) highlights on the sites of Christian Religion and ancient Egypt monuments for consciousness, and (vi) recognize the impending threats and put a strategy plan for geoconservation as a best applicant for incorporation in a potential UNESCO Global Geopark.

## Geographical and Geological Background

The study area, around 245 km<sup>2</sup>, is situated in the halfway between Cairo and Luxor as a stretched belt, about 222 km south of Cairo. It is delineated between long. 30° 25' 00" E and 30° 52' 00" E and lat. 27° 40' 00" N and 28° 40' 00" N, covering an area of about 5300 km<sup>2</sup> (Fig. 1a). Samalute-Minia Area is cultivated area that is bounded the Nile River in the east, Bahr Youssef in the west and Assuit and the Beni-Suef governorates in the south and the north, respectively. It is circumscribed by a series of wrench and normal faults striking NW–SE and NE–SW forming horst and graben structures, matching with the trend of Gulf of Suez and Gulf of Aqaba (Said 1962; Youssef 1968; Youssef et al. 2018). The climate in the Samalute-Minia Area is characterized by hot dry summers, rain shortage, and occasionally cold winters. The annual average of temperatures ranges from 21.45 to 38.91 °C in July with a minimum in January (from 5.18 to 19.16 °C). The rainfall annual average values are commonly important (5.3 mm/year) and precipitations are often moderate in winter, ranging from 1950 to 4000 mm/year with the relative annual mean humidity of about 55% (Khalil et al. 2011).



**Fig. 1** Maps for location of the study area and Nile Basin as well as its environs. **a** Site map for the Samalute-Minia Area. **b** Map of the Nile Basin showing the drainage network, major tributary basins, and

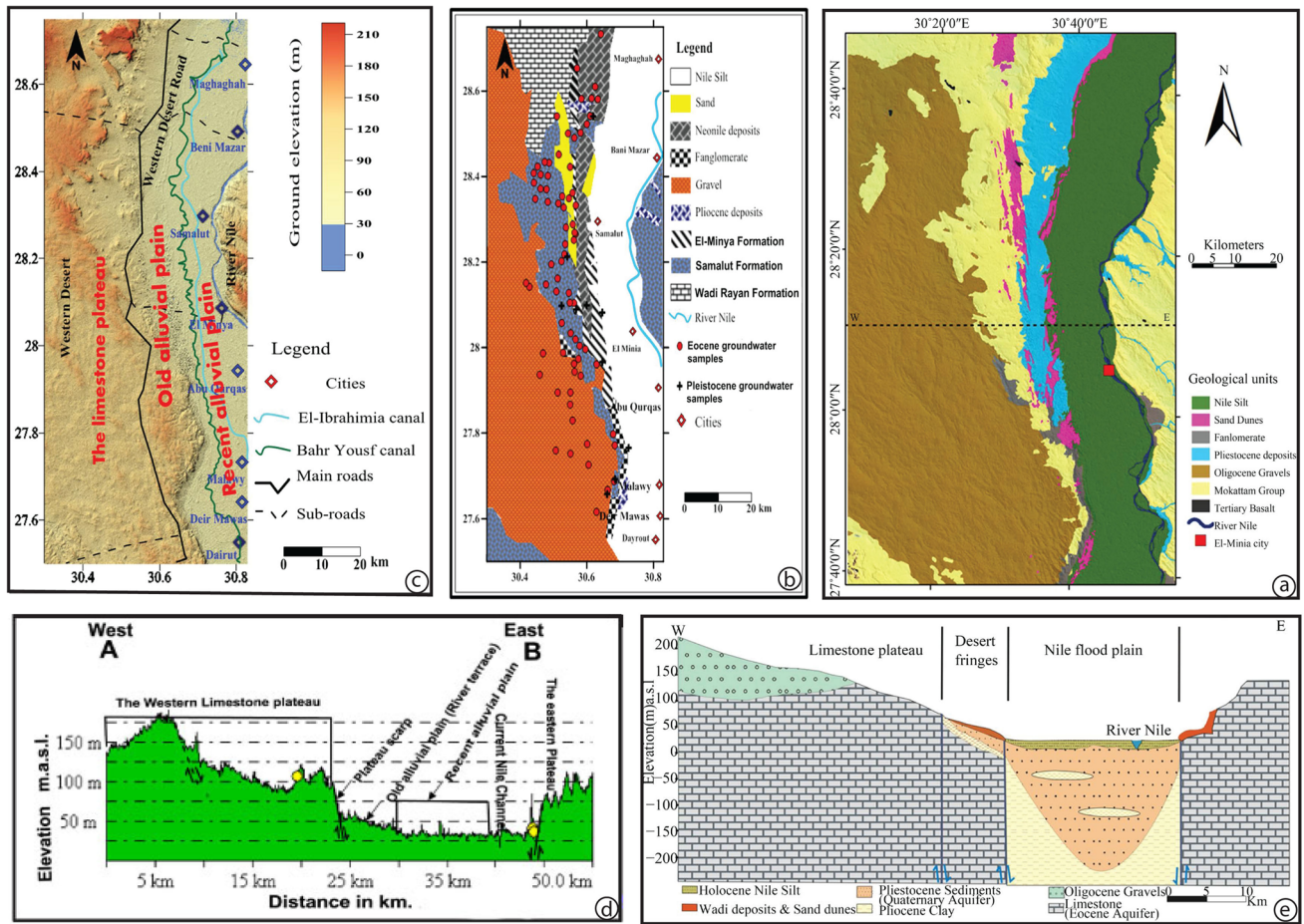
extent of the desert Nile (after Woodward et al. 2015). Lake Victoria in the White Nile headwaters is the largest lake in Africa by area (~60,000 km.<sup>2</sup>)

Several researchers studied geological investigations of the study area (Attia 1954; Said 1962, 1981, 1990; Youssef 1968; Omara et al. 1976, 1977; Boukhary and Abdelmalik 1983; Strougo et al. 1990; EGSMA et al 2005). The examined area is covered by rocks of Middle Eocene to Quaternary age (Fig. 2a, b, Omara et al. 1977; Conoco 1987). This wide range of age reflects the record of diverse lithological rocks fluctuating from carbonate and fluvio-clastic sediments to explosive and effusive volcanoes (Fig. 2b, c). Two formations have been identified for the Eocene carbonate rocks, namely, Minia and Samalute Formation (Fm). Minia Fm is grayish white, silicious, and enriched in fossils like nummulites, pelecypods, echinoderms, and alveolines as well as corals. This Fm is best exposed along Assiut-Minia Area in the Nile Valley, achieving a total thickness of about 35 m. The Samalute Fm, up to 160 m in thickness, overlies Minia Fm along dark siliceous limestone bed (up to 1 m thick). It is fine-grained and comprises snow white chalky highly fossiliferous limestone inundated with *Nummulites gizehensis*, calcareous marls with claystone interbeds, and occasionally light beds of gypsum (Said 1962). The post-Eocene deposits include (1) Oligocene sands and gravels, (2) Miocene volcanoes, and (3) Quaternary alluvial deposits (Said 1981, 1990). The Oligocene and Quaternary deposits occupy an extensive region and are composed of gravel,

sand, and limestone debris of variable size with its maximum thickness up to 200 m especially in the western portion (Said 1981). Tertiary volcanoes are recorded in several locations and form intrusive contact with the carbonate rocks. Holocene deposits are made of Nile silts that represent the cultivated land of Nile Valley with its maximum thickness up to 15 m (Fig. 2e, Said 1981).

**Methods**

Numerous qualitative and quantitative methods have been established to evaluate geodiversity (Serrano and Ruiz-Flano 2007; Gordon et al. 2012; Gray et al. 2013; Hjort et al. 2015; Necheş 2016; Poch et al. 2019; Dias et al. 2021). Eight geosites has been selected, taking into consideration their touristic scientific, educational, cultural, and religious reputation. Their field investigations are carried out in wide geological array fluctuating from geomorphology and volcanology through hydrology and cultural heritage to archeology and quarrying. The scale of the field study for each geosite varies from hundred of meters to several kilometers. The quantitative assessment of the nominated geosites has been done following the Brilha’s method (2016). The issues involved for the evaluation are



**Fig. 2** Geological and topographic maps of the Samalute-Minia Area. **a, b** Geological maps of the study area (Conoco 1987). **c** Geomorphological map of the study area (Said 1981) using digital elevation models (DEM). **d** Topographic profile showing elevation of limestone

plateaus along western and eastern bank of the River Nile. **e** General hydrogeological cross section in El-Minia area (RIGW, Research Institute for Groundwater 1992)

the scientific value (SV), degradation risk (DR), potential educational use (PEU), and potential tourist use (PTU). Seven benchmarks involving representativity, key locality, scientific knowledge, integrity, geological diversity, rarity, and use limitations are used for the assessment of SV with score 0, 1, 2, or 4 points for each criterion. The evaluation of PEU and PTU are based on ten public criteria such as vulnerability, accessibility, use limitations, safety, logistics, density of population, association with scenery, uniqueness, and observation conditions. PTU furthermore comprises three measures involving interpretative potential, economic level, and proximity of recreational areas, while didactic potential and geological diversity are evaluated for PEU. On the contrary, the degradation risk (DR) is highlighted on five criteria involving deterioration of geological elements, proximity to areas/activities with potential to cause degradation, legal protection, accessibility, and density of population with score from 0 to 4 points (Tables 1 and 2).

**Geosites Classification and Landform Description**

Based on the geological characteristics, eight geosites have been described in Samalute-Minia Area. In the latter, some geosites related to the aspects of religious and memorials reflect their importance in tourism and could be used as crucial geotouristic or even maintainable economic profit plans in the future. Therefore, the record of geosites and their geoheritage values will be shown through this article.

**Geosite 1: Geomorphology and Karst Landforms (GKL)**

Geomorphosites are defined as architectural forms with typically esthetic topographies that give significant information about understanding the Earth’s history (Panizza 2001). Geomorphosites and geomorphological sceneries are important features for the geomorphological heritage from the viewpoint of tourism (Reynard 2009). Geomorphosites

**Table 1** Weights for the criteria used for assessment of scientific value, potential touristic use, potential educational use, and degradation risk (adapted from Brilha 2016)

Potential education use		Potential touristic use		Scientific use		Degradation risk	
Criteria	Weight (%)	Criteria	Weight (%)	Criteria	Weight (%)	Criteria	Weight (%)
Vulnerability	10	Vulnerability	10	Representativeness	30	Deterioration of geological elements	35
Accessibility	10	Accessibility	10	Key locality	20	Proximity to areas/ activities with potential to cause degradation	20
Use limitation	5	Use limitation	5	Scientific knowledge	5	Legal protection	20
Safety	10	Safety	10	Integrity	15	Accessibility	15
Logistics	5	Logistics	5	Geological diversity	15	Density of population	10
Density of population	5	Density of population	5	Rarity	15		
Association with other values	5	Association with other values	5	Use limitation	10		
Scenery	5	Scenery	15				
Uniqueness	5	Uniqueness	10				
Observation condition	10	Observation condition	5				
Didactic potential	20	Interpretative potential	10				
Geological diversity	10	Economic level	5				
		Proximity of recreational areas	5				

**Table 2** Classification of scientific value, potential touristic use, potential educational use, and degradation risk into three classes: low, moderate, and high (adapted from Brilha 2016)

Total weighted	Scientific value, potential educational use, and degradation risk
<200	Low
201–300	Moderate
301–400	High

are relief frameworks that have high scientific, cultural, ecological, and esthetic values (Panizza 2001; Joyce 2009; Zgłobicki et al. 2020) that are recorded as UNESCO World Heritage Spots (Panizza 2001; Williams 2008; Newsome and Dowling 2018; Khalaf 2022). The relief of the Samalute-Minia Area is enhanced by plateaus, alluvial fans, and paleokarst landforms. These outcrops are characterized by mature relief, differences in elevation, and large diverse landforms with several gently sloping ridges intermingled with channels and denudation valleys.

The study area shows three geomorphologic units involving the Eocene carbonate plateaus with old (river terraces) and recent alluvial plains (Fig. 2c, Said 1981). The latter display a momentous role in shaping the hydrogeological framework in the Samalute-Minia Area, in which the

plateaus are considered as the watershed regions (Abdel Moneim et al. 2016). The Eocene rocks denote the chief outcrops represented by Samalute and Minia Fm that encircle the eastern and western banks of the River Nile (Said 1981). Their outcrops occur as well-known series of escarpments (Fig. 3a) with characteristic bedding structure (Fig. 3b). The escarpments are steep morphological forms with steep slope and a height of up to 50–150 m (Fig. 1d). Sequence of normal faults along with a lot of dry valleys and gullies dissect these ridges, ensuing in the formation of hilly rocks and depressions as the result of tectonic origin and denudation processes (Fig. 3c). The delivery of interpretive and service amenities allows tourists to see panoramic sights for the Nile’s scenery and gain knowledge about an understanding of the geology and geomorphology of a GKL site (including its involvement to the development of the Earth sciences).

The Eocene carbonate rocks experiencing karst formation are common in the study area. Karst rocks occur as consolidated dissolved or eroded strata (limestone, marl, and chalk) that are momentous sites of the geomorphological heritage. Remarkable karst phenomena involving sinkholes, karst valleys, inselbergs, domes, towers, karst pavements, and karst cavernous features are observed. The sinkholes represent recognizable karst landform that fluctuate in size from a few meters to some kilometers (Fig. 3d). They form bowl or circular-shaped depressions with consistent



**Fig. 3** Geomorphological landforms of the study area. **a** Carbonate escarpment milestones. **b** Even topography with characteristically bedding structure. **c** Series of normal faults crosscut carbonate plateaus. **d** Solution depressions (or sinkholes) with circular outlines. **e** Convex tops and concave bases characterize the dome rocks. **f** Tower

karsts with spine top and broad base. **g** Google Earth image showing large plain karst pavement with characteristic incised karren forms produced by complex dissolutional sculpture processes. **h** Engraved runnels displaying circular, spheroidal, or polygonal shape

inward-oriented dips (Fig. 5a–b) and most of their floors are filled by Quaternary deposits composed of windblown sand and silt. Inselbergs, 5–20 m in height, occur as disconnected vertical conical hilly rocks consisted of grayish to white-colored bedded fossiliferous limestones that are detached by dry valleys. The architecture of dome and tower outlines represents other types of karst landforms (mainly composed of chalky limestones) with convex tops and concave bases and 5 to 10 m in diameter (Fig. 3e). Tower karsts form isolate steep hills detached by dry ravines and vary in shape from triangle to four-sided shape with variation in size from 5 to 10 m in extension (Fig. 3f). Karst pavements have large flat plains consisting of incised karren forms produced by complex dissolutional sculpture processes related to paleo-karst phenomena and wind abrasion (Fig. 3g). Karrens are characterized by densely clustered small solution pits, grooves, flutes, and engraved runnels displaying spheroidal or polygonal shape with fluctuation in their diameters from 1 to 3 m (Figs. 3h, 4a).

The carbonate plateaus display noticeable cavernous weathering. The latter is defined as solitary hollows or pseudo-regular structures of cavities detached by walls on the rocks surface. Rock shelters, tafoni, and honeycomb architectures are examples (Fig. 4b–h). Rock shelters (or large tafoni) are described as cavities with diameters in the range of decimeters to meters (Viles 2001, Fig. 4c–d). They are characterized by concave inner surfaces displaying circular or elliptical or oval frameworks that are parallel to bedding planes with vugs of up to 5 m and hollows up to 1–2 m (Fig. 4e–f). Alveoli weathering is small-scale cavernous structures with diameters of the cavities in the range of millimeters/or centimeters to decimeters (Viles 2001; McBride and Picard 2004), which coalesce in clusters, forming honeycombs. The latter occur as amalgamated closed spaced hollows that fluctuate in diameters from centimeters to decimeters (5–10 cm) with near-circular shapes representing sponge structure (Fig. 4g–h). Moreover, there are plentiful sculptured elongated channel-like indentations (Fig. 4c, g) and enlarged vertical and horizontal linear karstified joints (Fig. 4h) characterized these plateaus. Tafoni and honeycombs represent the most enigmatic and puzzling geomorphological phenomena (Klimchouk 2017). The latter can be deliberated an important utensil for science and education because they give information about paleo-hydrogeological history and origin through complex processes of weathering like eolian deflation, frost action, chemical weathering, and biological decay that are formed by ghost rock phenomena and hypogenic karstification (Dushevsky 1987; Dushevsky et al. 1979; Dushevsky and Kuznetsov 1991; Turkington 2004). The conception of ghost rock karstification is created by chemical erosion processes involving chemical denudation and dissolution-driven conduit development (Covington et al. 2022). Carbonate rocks are dissolved by

carbonic acids in which meteoric water/or groundwater dissolves CO<sub>2</sub> within the atmosphere/soil and transmits CO<sub>2</sub> descending into the rocks within the vadose zone, thawing carbonate minerals along joints and bedding planes (Vergari and Quinif 1997; Vergari 1998; Bruxelles et al. 2009; Quinif and Bruxelles 2011). This latter stage is followed by elimination of the altered rock forming the ghost rock, similar to deliberated phenomena in France, Italy, UK, and Hungary (Klimchouk 2017).

## Geosite 2: Circular Structural Landforms (CSL)

Circular structures are conspicuous geomorphological topographies on Earth's surface that are resulted from diverse geological events such as meteorite impact, volcanic craters, evaporite diapirs, karst dissolution sinkholes, dilational faulting, periclinal folds, or magma rise-related. Moreover, magma-water interactions producing maar diatreme, karst subsurface dissolutions, earthquakes, and mud volcanoes may form circular structures (Lucia 1995; Tuttle 2005; White and Ross 2011; Bentivenga et al. 2017; Mazzini and Etiope 2017). These structures exist in diverse rock types and numerous geological environments over wide age period. The mechanisms for their formation and discrimination between them are dispute and subject of discussion (Vendeville and Jackson 1992; Stewart 1999; Wyrick et al. 2004; Levy et al. 2010; Sori et al. 2017).

In Samalute-Minia Area, a large number of concentric structures outcrop in the carbonate and volcanic rocks (Fig. 5a–g). Eocene carbonate beds display conspicuous geomorphological circular structures which range from some to several meters in width and may be related to dissolution collapses sinkholes (Figs. 3d, 5a–b, Ford 2004) or occasionally hydrothermal fluid expulsion or extraction processes such as karstic collapse (Loucks 1999, 2007). The configuration of the joints and faults acts as channels or passages for water flow that across rock borders, resulting in an approximately ring subsidence arrays of dissolution in limestone terrains (Klimchouk et al. 2012). Many authors believe that hypogenic karst related with discharge regimes of flow systems was common during the Oligocene time because Egypt's climate was wet and rained, whereas a lot of rivers were recorded in wide, low-lying surfaces (Bown and Kraus 1988; Rasmussen et al. 2001; Holmes et al. 2010).

A network of isolated or stacked ring syncline folds at a scale of several hundreds of meters, with relatively steep limb dips (Fig. 5c–f) characterize Eocene carbonates. Tewksbury et al. (2017) interpreted these ring structures as low-lying steeply double plunging, disharmonic syncline folds at a scale of tens to hundreds of meters that are observed on aerial images (Fig. 5c–e). These syncline folds attain many meters in width, ranging in height from 100 to 350 m with a consistent northeasterly dip of roughly 3–6°



**Fig. 4** Diverse karst landforms. **a** Densely clustered small solution pits, grooves, and flutes. **b** karst cavernous topographies in carbonate rocks. **c, d** Rock shelters (or large tafoni) characterize limestone rocks. **e, f** Tafone framework shows circular or elliptical forms that are parallel to bedding with characteristically vugs/cavities. **g, h** Centim-

eter- to decimeter-scale closed spaced hollows forming honeycomb morphology with near-circular shapes representing sponge outline. Note the observed sculptured elongated channel like indentations and enlarged vertical and horizontal linear karstified joints (furrows/grooves) cut these plateaus



(Tewksbury et al. 2017). The latter authors concluded that these structures are reliable with the ideal geometry of small syn-depositional sag basins formed above cave collapses in karst systems (Loucks 1999, 2007), analogous to circular structures outcropping in the sedimentary basins of Saudi Arabia (Stewart 2015). A set of joint arrays striking WSW-ESE crosscut the syncline folds via the uplift throughout the rifting of Red Sea in Miocene period (Issawi et al. 2009; Bosworth et al. 2015). The occurrence of abundant sag structures provides concrete support to dissolution collapses, highlighting the karstic nature of the carbonate rocks (Mukhopadhyay et al. 1996; Youssef et al. 2017). Hypogene speleogenesis could yield collapse and coalesce paleokarst with sag of superimposing limestone rocks at many meters to several kilometers during millions of years (Klimchouk et al. 2016), analogous to topographies in the Ellenburger Group, West Texas, USA (Loucks et al. 2004; McDonnell et al. 2007). The volcanic crater with an approximately circular depression and a bowl-shaped feature is peculiar and remarkable ring structure recorded in the Neogene volcanoes at the study area (Fig. 5g). This crater has steep wall that is stretched along a north–northwest trend with 20–30 m in width and depth up to 5–10 m. The site of the volcanic crater is a significant geological feature to guests and tourists because it highlights on the volcano summit, representing an outlet for producing volcanic gasses and molten lava during collapse activities. Furthermore, its situations comprise a composite interaction between magma assemblages, pressure build-up, explosive outbreaks, and the deposition of tephra.

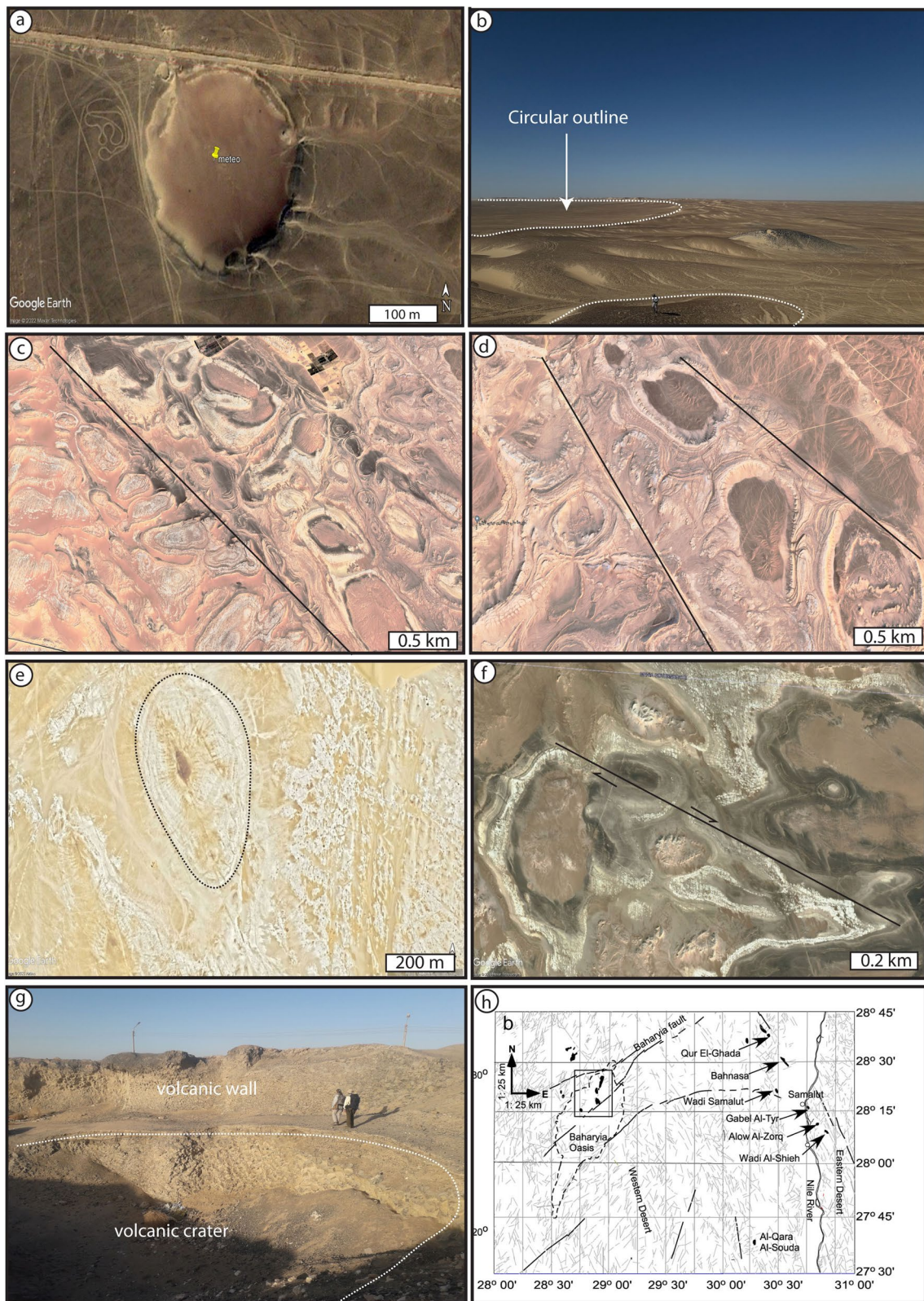
### Geosite 3: Volcanic Landforms (VL)

Volcanism and its spectacular landscapes can attract universal community about the forces of nature (Nemeth et al. 2017b). Volcanism has created demoralizing natural cataclysms through human history and its civilizations. The volcanic characteristics related to diverse morphologies and eruption processes are stimulating and commonly widespread attractions for visitors and geotourists (Lopes 2005; Erfurt-Cooper 2011, 2014). Several scientific publications on volcanic provinces are usually related with developed concepts to establish volcanic geoparks at different scales (Csillag et al. 2004; Moufti et al. 2013; Moufti and Németh 2013; Nemeth et al. 2017a; Szepesi et al. 2017). A lot of global UNESCO Geoparks ([www.globalgeopark.org](http://www.globalgeopark.org)) and volcanic geoheritage habitations are becoming recognized, such as parks in Germany, Hungary, Slovakia, Spain, Iceland, and other countries in the European Geopark Network ([www.europeangeoparks.org](http://www.europeangeoparks.org)). Geoconservation and geoeducation developments are progressively predominant in several volcanic fields distributed on the Earth's surface (Bitschene and Schueller 2011; Erfurt-Cooper 2011, 2014). Such developments are related not only to visiting volcanic

heritage sites with its remarkable landforms, but also emphasis on scientific research to understanding the Earth evolution. A complete database of potential geosites should be collected through diverse scientific and educational agendas under the umbrella of regional and global geoparks (Joyce 2010) in order to facilitate protection of volcanic geoheritage. It is necessary to take positive volcanic impacts (like geothermal resources, raw materials, and fertile soils) into account when speaking about volcanic geoheritage (Gravis et al. 2017; Kelley et al. 2019; Khalaf et al. 2019).

Neogene volcanic activities in Egypt are short-lived monogenetic subaerial mafic volcanoes that were formed in continental intraplate settings during the Red Sea rifting in Oligocene–Miocene period (Khalaf et al. 2019; Khalaf and Sano 2020; Khalaf et al. 2021). In Egypt, several sites involving Cairo-Suez District, Sinai Peninsula, River Nile, and Western Desert are occupied by the Tertiary rift-related volcanoes. The latter form various landforms varying from explosive scoria cones through effusive lava flows to subvolcanic sills and dikes intrusions, in which their age of eruption is restricted between 27 and 20 Ma (Williams and Small 1984; Baldrige et al. 1991; Khalaf and Sano 2020). These volcanoes are well exposed in many localities within Samalut-Minia Area, such as Bahnasa, Wadis Samalut and Al-Shieh, Gabal Al-Tyr, Al-Qara Al-Souda, Qur El-Ghada, and Alow Al-Zorq (Fig. 5h). Meneisy and Kreuzer (1974) proposed 23–28 Ma for the eruption of basaltic rocks at Wadi Samalut based on K/Ar age. Morphologically, explosive scoria cones and effusive lava flows have been identified. Most of these volcanoes are buried under loss sand dunes.

The scoria cones occur as disconnected edifices with semi-circular basis and convex-upward surface having explosive craters (Fig. 6a–c). Their architectures comprise reddish-colored pyroclastic deposits (tephra) at the base followed by superimposing black-colored lava flows along unconformity surface (US, Fig. 6b–c). The pyroclastics, 5–10 m thick, are matrix-to clast-support framework, fine to medium-grained size composed of normal to inverse graded deposits with irregular shapes and different sized juvenile clasts ranging from fine lapilli to blocks and bombs grain size. Planar low-angle cross bedding and dune bedding structures (Fig. 6c) have been described in these deposits. The latter are inferred as pyroclastic surges and fallouts formed via phreatomagmatism eruptive style at moderate to high discharge rates in wet environmental setting (water-magma interaction, Zimanowski et al. 1997; Valentine and Gregg 2008; Ross et al. 2011). The overlying lavas are massive, jointed, blocky, and brecciated flows (Fig. 6d). Colluvial, talus, and ravine have been observed at the top of the lava as the result of erosion processes (Fig. 6e). The whole design of the scoria cones was interpreted as volatiles-rich composite edifice whereas hydromagmatic or phreatomagmatic explosive phases began at the commencement of the



volcanic eruption followed later by extrusion of lava flows that create attractive volcanic landscapes (Carmona et al. 2011; Chako-Tchamabé et al. 2016).

Lava flows occur either as rock caps overlying pyroclastics (Fig. 6b–c) or as discrete rocks. They are massive, aphyric, black in color, with rough and blocky brecciated

**Fig. 5** Framework of circular structures. **a** Google Earth image showing sinkhole depression in Eocene carbonate rocks. **b** Concentric circular structure in low lands related to dissolution collapses sinkholes. **c, d** Google Earth images showing grid of oval sag synclines and concentric bedded ridges. **e** Close-up view showing doubly plunging syncline characterize chalky limestone illustrated on Google Earth image. **f** Concentric circular structures crosscut by normal faults observed in chalky limestone and overlying Quaternary deposits. **g** Circular with bowl-shaped feature of volcanic crater. **h** Location map showing the distribution of Neogene volcanoes in Samalute-Minia Area

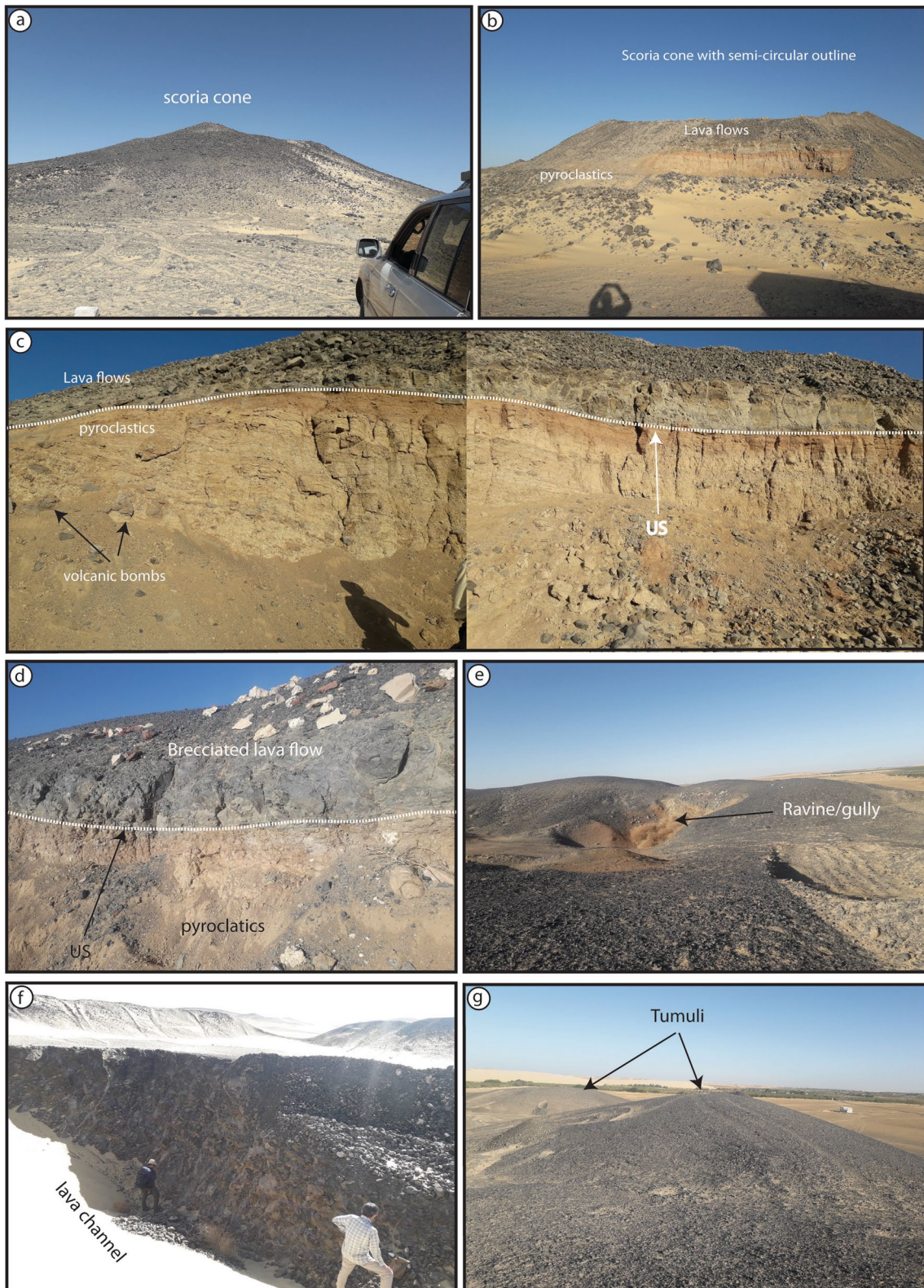
surface portraying subaerial AA'-Pahoehoe lava type. Lava channels, lava rise, tumuli, and pressure ridges are common landforms characterizing lava flows (Figs. 6f–g, 7a–b). The vertical columnar joints involving colonnades at the base and entablatures at the top with hexagonal regular polygons are peculiar geological phenomena which categorize the lava flows (Fig. 7c–e) due to quenching or cooling of the lavas. This geosite considers a dazzling and recreational place to the international volcanology community and sightseers, highlighting high scientific and educational values which allow the visitors to know more about the volcanic eruptions located in the Egyptian Territory during Red Sea rifting. It gives also significance scientific info about the development of cooling history of the volcanoes through cooling-induced shrinkage (Fig. 7e–f), resulting in cooling and solidification of columnas after lava stagnation. Such cooling process is derived from an interaction of lava-underground water that causes pressurized steam within the vadose zone resulting in decrease the water table (Moore 2019). Moreover, the record of phreatomagmatism phase (Fig. 6b–c) via water-magma interaction suggests predominant groundwater availability (Kereszturi et al. 2012), emphasizing the role of the substrate hydrogeological circumstances in the development of the phreatomagmatic eruptions and cooling history of the lava flows. Finally, the presence of composite polyphase feeding system composed of explosive to effusive rocks make the geoheritage, geotouristic, or geoeducational value of the VL site (G3) enormously high.

#### Geosite 4: Riverine Landforms (RL)

The Nile River represents one tenth of the African continent and the longest waterway on the Earth's surface (>6500 km, Woodward et al. 2015; Fielding et al. 2018). It is a chief north-flowing river in northeastern Africa and spreads over different territories involving the Equatorial lakes plateau of the White Nile headwaters, the volcanic highlands of Ethiopia, the Sahara Desert, and the huge delta at the mouth of Mediterranean Sea (Fig. 1b). Nile Basin involves five major regions that have dissimilar structural and geological styles (Said 1981). The prevailing terrains of the Nile Basin are the

Equatorial lake highland in the White Nile; the swamp lands of South Sudan; the Ethiopian Highlands forming the headwaters of the Blue Nile and the Atbara with deep gorges; the desert Nile with rocky cataracts and alluvial fans in the arid lands of Sudan and Egypt; and the Egyptian district comprising delta, lagoons, and grid of irrigation channels (Fig. 8a). The whole catchment area of the Nile is around 3.3 million km<sup>2</sup>, in which the desert Nile of Sudan and Egypt occupies one third of this catchment area (Said 1981). The Nile Basin represents different climatic regimes that vary from Equatorial in the East Africa plateaus to hyperarid in the desert stretches of northern Sudan and Egypt (Thompson 1965; Griffiths 1972; Buckel 1996; Leroux 2001).

River Nile denotes enormous deep bedrock canyon (Fig. 8b) that extends from ca. 570 m below sea level at Cairo to about 170 m at Aswan (Chumakov 1968), achieving 1100 km long and 1900 m deep if compared with the Grand Canyon of the Colorado River (Le Pichon et al. 2005). The main water resources are derived from River Nile along with Ibrahimia and Bahr Youssef canals (Fig. 1a) in which the length of River Nile attains 147 km in Samalute-Minia Area. The region of Nile Valley and Delta resides about 4% of Egyptian landform and hosts most of the populations. It has received a great responsiveness from researchers because its lands comprise energetic industrial and profitable towns, main tourism centers, and refreshment areas (Said 1990). The famous Greek historian Herodotus shortened the reputation of the river to the Egyptians by saying "Egypt is the gift of the Nile." Agriculture activities are widespread in the study area and represent about 63% of the entire agricultural property, due to the presence of fertile alluvial soils, plentiful water, and good irrigation system (Zeydan 2005; Mabrouk et al. 2013). The elevation level of the cultivated lands that bound the river banks fluctuates from 25 to 80 m (Omara et al. 1977). The territories of the River Nile hold esthetic, educational, scientific/scenic, and archeological aspects that attract most of the academics, visitors, and sightseers. Their imperative ranks attribute to its wonderful mosaic geomorphological and landscape values (Fig. 8c–f), outstanding ancient history, progressive civilizations in the ancient world, and prospects for leisure supplies. This is confirmed by the fact that the Nile Basin comprises a vast range of ecosystems (Rzoska 1976) which has played a central role in the development of the philosophies diversity (Wendorf et al. 1976; Welsby 2001; Shaw 2003; Spencer et al. 2017). Furthermore, River Nile has an extraordinary impending for scientific/educational uses as it gives significance information about its evolutionary tectonic history starting from initial catchment formed by the Pan-African Orogeny (Kröner and Stern 2004) to uplift during opening of the Red Sea in the Neogene Era (Ebinger 2005;



Bosworth et al. 2005). In addition, the Nile Valley has a lot of cultural and historical sites and wondrous monuments as well as cathedrals, churches, and monasteries (Fig. 8c)

throughout Egyptian history initiated from the Pharaonic to Ptolemaic and Greco-Roman Period (Shaw 2004; Ramsey et al. 2010).

**Fig. 6** Volcanic landforms. **a** Solitary scoria cone with convex upward surface. **b** Scoria cone with semi-circular outline composed of explosive pyroclastics at the base followed by lava flows. **c** Close-up view of scoria cone showing unconformity surface (US) separating pyroclastics at the base from the overlying massive lava flows. Note bedding and cross bedding with normal to inverse graded bedding characterize the pyroclastic beds. **d** Brecciated lava flows dissected by joint sets superimposing reddish-colored bedded pyroclastic deposits. **e** Ravines/gullies crosscut the volcanic edifice. **f** Lava channel formed due to erosional processes. **g** Tumuli with low, dome-like mounds as the product of lava thickness and magmatic overpressure within its flow interiors

### Geosite 5: Christian Religion Sites (CRS)

Egypt has tourism destinations since the Pharaonic era, where diverse portfolios of tourism like recreational, cultural, eco-, religious, health, and gastro-tourism have been recognized (Gyr 2010). Religious tourism related with pilgrimage journeys have chiefly been implemented as part of cultural tourism since Egypt hosts various Islamic, Christian, and Jewish archeological spots. The journey of the Holy Family (HF) to Egypt is a spinning stage in the forthcoming of cultural and heritage tourism in Egypt which is one of the greatest celebratory and powerful value for the Egyptian Coptic Church (Gabra et al. 2012; Kupelian 2020; Abed and Abouzied 2021). Researchers assigned the historical visit of the HF in Egypt to twenty-five stopping points across eight governorates beginning from Rafah in Sinai to Qusiah in Assiut (Fig. 9a) with a total distance of 3500 km for 3 years and 6 months (Saleh et al 2019; Abed and Abuzied 2021). Egyptians and Christians from all over the world deliberated the HF's track as the longest pilgrimage route (Rodrigues and Lay 2012; Egyptian Ministry of Tourism and Antiquities 2020; Abed and Abouzied 2021). Many memorials such as churches, monasteries, and Coptic icons (Fig. 9c) have been recorded for the trip of HF to Egypt after being victimized from the Romans at the beginning of the first century (Saleh et al. 2019; Abed and Abouzied 2021). The most important archeological sites documented for the path of Holy Family are the Virgin Mary Tree in Matariya, the Church of St Sergius in Old Cairo, the Monasteries of Wadi Al-Natroun, Al-Adaweya Virgin's Church at Maadi (Fig. 8c), the Church of the Virgin Mary at Gabal Al-Tair in Minia, and the Al-Muharrag Monastery in Assiut (Ali 2013; Holy Family in Egypt 2018). Gabal El-Tair, roughly 250 km south of Cairo, is one of the most important sites and spots for the HF trail (Fig. 9b, Elzek and Alfy 2017; Kupelian 2020). It is called Birds Mountain or Gabal El-Kaf (or Palm Mountain), due to the traveling birds which came yearly and established on its foot. On cliff top of the Gabal Al-Tair, there is Monastery and Church of the Virgin Mary of fourth century with delightful vision of the Nile Valley along with wide

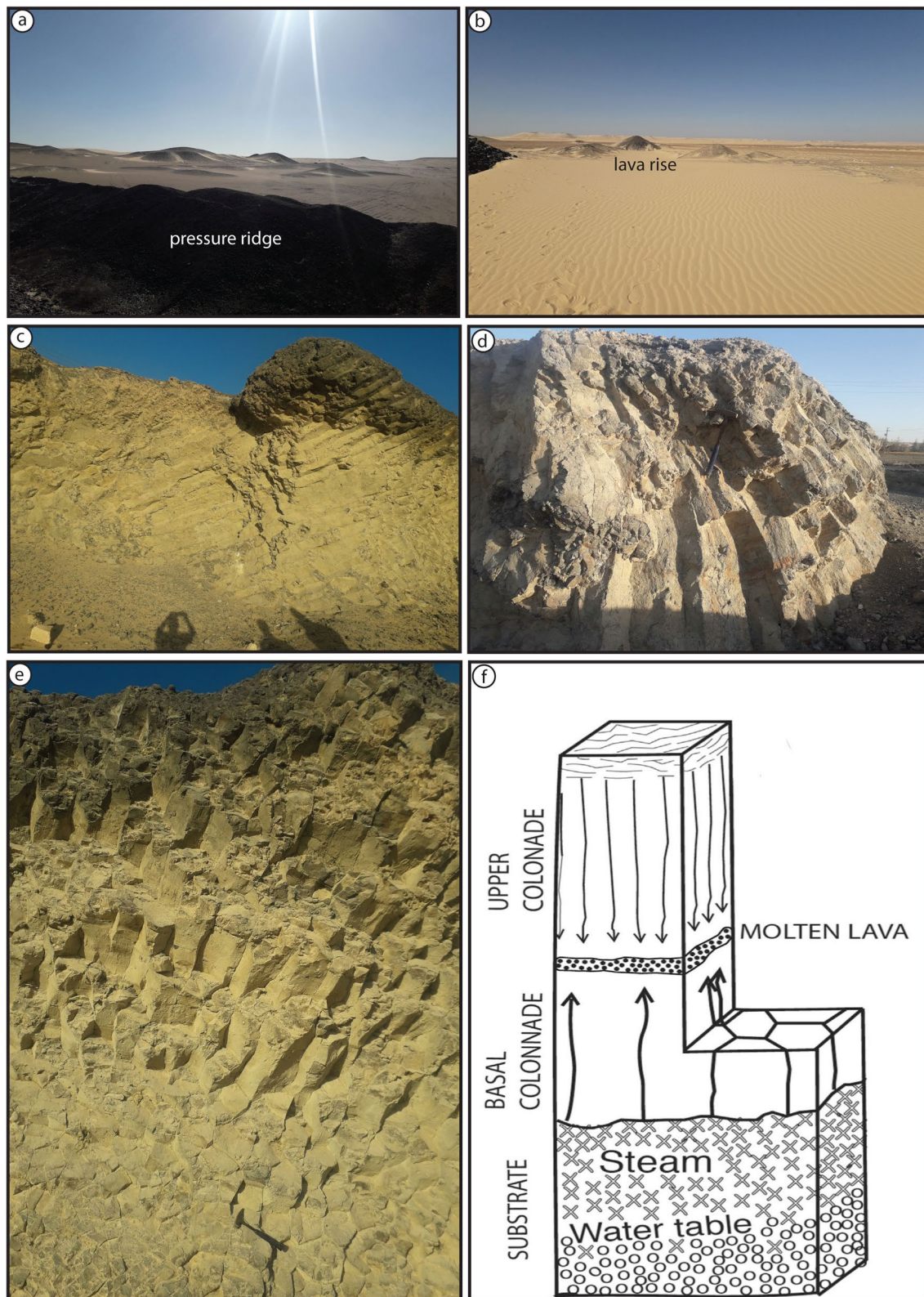
cultivated green pitches, palms, and luxurious plantations on the Nile banks (Figs. 8d, 9b).

The Church of the Virgin Mary at Gabal Al-Tair (Fig. 9b, d) is the only church built inside the mountain in which the Holy Family passed through this area and stayed in its cave (or grotto) for 3 days since more than 2000 years (Fig. 9e–f, Elzek and Alfy 2017). In 328 AD, Queen Helena, mother of Roman Emperor, decided to use the remains of the cave temple and the neighboring area into construction the Virgin Mary Church according to the architectural style of Orthodox churches during her visit to Gabal El Tair (Egyptian Tourism Authority 2020). The church nave is maintained by 12 rock-hewn pillars in the cloister, altars, and sculpted by the architectural Orthodox icons on the walls (Fig. 10). The HF then left Gabal Al-Tair and went towards Dairout and Al-Qosia, Meir and then to the site of the Al-Muharrag Monastery and Mount Dronka in Assiut (Fig. 9a). The latter holds the oldest altar in Egypt. In Assiut, Holy Family stayed for 6 months, in which this last stop is longer than any other locations of HF spent in Egypt before their returning to Palestine home (Abed and Abouzied 2021).

### Geosite 6: Ancient Egypt Monuments (AEM)

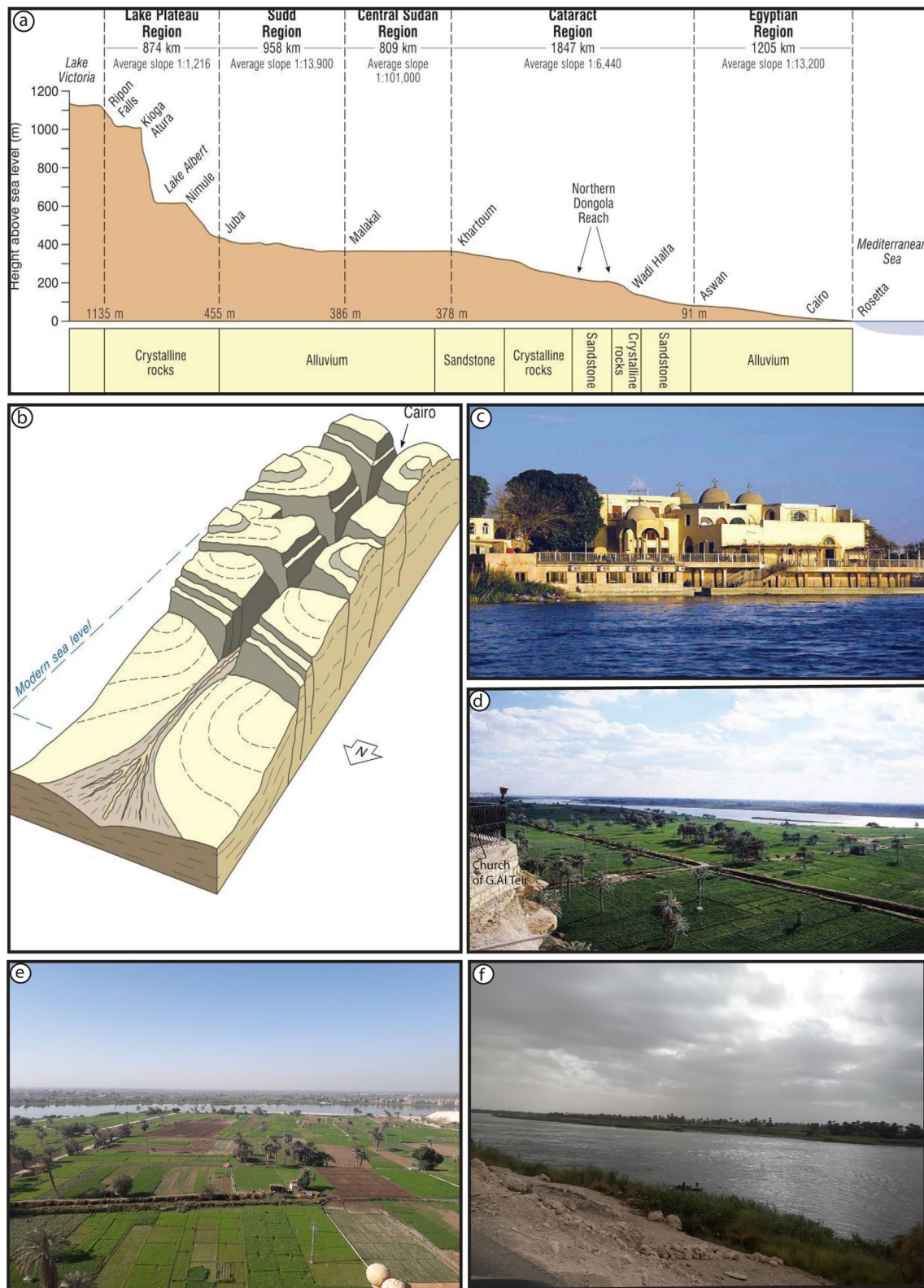
Beni Hassan and Tell El Amerana sites of Minia City are one of the most well-known ancient archeological locations in Egypt. Numerous remnants (monuments, tombs, and temples) were discovered during the excavations piloted in the nineteenth century by various international archeological crews. The latter offered a sporadic catalog that the ancient Egyptians had a great gratefulness for life in which old Egyptian's culture revealed all types of delighted accomplishments. Their walls are ornamented with gorgeously coated prospects and portraying activities of daily life such as grooming performs and games, funeral art, and utensils used for agriculture, hunting skills, military activities, and building industries. The broad range of these activities provide a hint about daily life in ancient Egyptian civilization that was exaggerated by the nature, especially the Nile and an understanding of how people in the past used these objects from illustrated scenes in tombs, temples, and written accounts.

**Beni Hassan Cemetery** Beni Hasan, 20 km south Minia, is a small town and involves a large significance number of combs and tombs engraved into the limestone cliffs (Fig. 11a) that are exposed along the east bank of Nile, demonstrating excellent viewpoint over the Nile Valley (Fig. 11b). The cemetery of Beni Hassan is situated in one of the most fertile areas that includes the most impressive and well preserved tombs of Middle Kingdom (Wilkinson 2003; Kamrin 2009). The tombs are located in two distinct



**Fig. 7** Volcanic landforms and joint patterns. **a** Elongated massive strip of pressure ridge. **b** Lava rise morphology consisting of lava accumulations with low-lying small cones. **c, d** Vertical colonnade joints with regular hexagonal outlines characterize the lava flows. **e** Master columns extending up from base of lava flows. **f** Cooling-

induced shrinkage that form master columnar joints after lava stagnation. The top and bottom of columns initiate to cool and coagulate. Such cooling process is derived from interaction of lava-underground water that cause pressurized steam within the vadose zone resulting in decrease the water table (Moore 2019)



**Fig. 8** The characters of the riverine landforms. **a** Long profile of the Nile from the White Nile headwaters to the Mediterranean Sea (after Said 1994). Note that the Blue Nile and Atbara are not shown. **b** Schematic reconstruction of the Nile Canyon showing the main channel and tributary gorges cut by the Egyptian Nile drainage dur-

ing the Late Miocene (Messinian) salinity crisis (Said 1981). **c** The historic Al-Adaweya church at Maadi as one reputation and peaceful spot of Holy Family sites during her visit to Egypt. **d, e, f** Cultivated lands bound the river banks that create the most distinctive model for attracting visitors and tourists



**Fig. 9** Christian Religion sites. **a** Map of the journey of the Holy Family in Egypt (Egyptian Ministry of Tourism and Antiquities, 2020). **b** The view from the top of Jabal al-Tayr’s Christian complex. **c** Contemporary icon of the Holy Family’s journey depicting the Holy

Family traveling to Egypt, photo Church of the Holy Virgin, Maadi, Cairo (Kupelian 2020). **d** The rock-hewn Monastery and Church of the Virgin Mary at Gabal Al Tair, Minia. **e, f** Ancient cave which Holy Family secreted for three days at Gabal El Tair





**Fig. 10** The architecture features inside Virgin Mary Church at Gabal El Tair. **a** Ancient altar that exist inside the cave. **b** Model showing the daily life inside the church in ancient time. **c** The Virgin Mary Church's entrance showing its old design. **d** The rock-hewn pillars and walls with wood roof inside the Virgin Mary Church. **e** Engraved

column that represents one of the Virgin Mary Church's pillars. **f** An icon showing Virgin Mary carrying the infant Jesus. **g** The veil of sanctuary of the Virgin Mary Church. **h** The crypt of Virgin Mary Church



**Fig. 11** Detailed investigation showing past daily life at tombs at Beni Hassan. **a** The main entrance of tombs. **b** View of the Nile Valley from the upper cemetery at Beni Hassan. **c** Exterior of Beni Hassan tombs. Note the presence of alveolar and honeycomb weathering in **a** and **c** which represent great problem for monuments. **d** Khety and his

wife. Note Barbers and wild animal hunting in upper part of photo, Tomb of Khety. **e** Fishing with a spear, Tomb of Khety. **f** Wrestlers in different position, Tomb of Khety. **g** Pilgrimage trip to Abydos, Tomb of Khety. **h** Wrestlers in different position and military trainings, Tomb of Khety

areas, namely, lower and upper tombs (Fig. 11c). The first contain 800 catacombs in period from the first intermediate period (7th to 10th dynasty, c.2181–2055 BC) to Middle Kingdom (11th to 13th dynasty, c.2055–1650 BC) but Late Old Kingdom (3rd to 6th dynasty, c.2686–2181 BC) tombs have also been recorded (Porter and Moss 1968; Kamrin 2009; Bommas 2012). During 7th to 10th dynasty, Egypt suffered state of faintness and political dissection. However, Egypt recovered its unity, economic prosperity, and observed an agricultural and artistic stimulation during 11th to 13th dynasty. The second include 39 tombs that were dated to the 11th to 12th dynasties of Middle Kingdom (ca. 2055–1795 BC, Kamrin 2009), in which four tombs are available to the community. The vestiges of these tombs are sign to the ancient Egyptian architecture skills. Khety (BH17), Baqet III (BH15, dating to 11th dynasty), Khnumhotep I (BH14), Khnumhotep II (BH3), and Amenemhat (BH2, dating to 12th dynasty of the Middle Kingdom) are examples of Beni Hassan's tombs (Porter and Moss 1968; Silverman et al. 2006; Parcak 2019).

**Tomb of Khety** Khety, son of Baqet, was the governor of the 6th upper Egyptian province. His tomb consists of a forecourt and a room with two rows of three columns and lotus capitals. Its walls are decorated with scenes of fowling and the papyrus harvest, wild animal hunting, wrestling in various position and military trainings, and industrial sections of spinning, weaving, and wine making process (Fig. 11d–f). Moreover, scenes of men playing board games and young women juggling and performing acrobatics along with listening to music and perform different sports (Fig. 11g–h).

**Tomb of Baqet III (no.15)** This tomb belongs to Baqet III, the son of Remushen, both of whom were governors of Menat-Khufu (Modern Minia) during the 16th Dynasty XI of Middle Kingdom (c.2055–1956 BC, Allen 2000). Its walls are also ornamented with scenes daily life like hunting, barbers, sandal makers, goldsmiths, pinners, and weavers as well as gathering papyrus. In addition, 220 pairs of wrestlers and besieged fortress, tax collection, and fishing were recorded (Fig. 12a–b).

**Tomb of Amenemhet (no.2)** Amenemhat held his position for around 25 years, during the reign of the great king Senusret (c.1965–1920 BC, Bommas 2012). His tomb has some of the finest decoration of all the tombs at Beni Hassan (Fig. 12c–h). Its wall-paintings include scenes activities of daily life such as agriculture, fishing, hunting, and fowling. Military activities and memorial burials with offering-bringers and butchers as well as the practicing of various crafts and professions including carpentry, sandal making, pottery, and the production of bows and arrows have been observed.

**Tomb of Khnumhotep II (no.3)** Khnumhotep II was overseer of the Eastern Desert under kings Amenemhat II and Senusret II (c.1911–1870 BC) in the Middle Kingdom. Khnumhotep's life is recorded in 222 columns. The tomb of Khnumhotep II (BH 3) attracts the most attention in Beni Hasan due to its bright colors and excitement of the polychrome. The tomb wall shows fishing and fowling in the marshes with funeral rituals, boat processions, and bringing funeral gifts. In the north wall, a delegation of 37 sector comprises men, women, and children dressed in beautiful, colorful clothing bringing eye-paint to Khnumhotep.

**Tell El-Amarna** Tell El-Amarna site lies about 58 km south of El Minia on the east bank of the Nile River. In 1330 BC, Amarna (Ancient Akhenaten) was Egyptian's capital (Pfeiffer 1963). This area represents a graceful archeological site (Fig. 13a) and contains the tombs of Akhetaton's city built by the Pharaoh Akhenaten (son of Amenhotep III and Queen Tiye, and husband of Queen Nefertiti) in the Late Eighteenth Dynasty (c. 1353 BC, Silverman et al. 2006; Muller 2013; Norwich and John 2014). The 18th Dynasty (known as New Kingdom of Egypt) prolonged the period from 1550/1549 to 1292 BC, in which the ancient Egypt attained the peak of its power. Most of the well-known pharaohs governed Egypt during 18th Dynasty such Tutankhamun, Hatshepsut (c. 1479 BC–1458 BC), and Akhenaten (c. 1353–1336 BC) with his Great Royal Wife, Nefertiti (Allen 2000; Ramsey et al 2010; Muller 2013). The king Akhenaten (Fig. 13b) marked an important turning point in the Royal Egyptian history because his name changed from Amenhotep V to Akhenaten and the multi-gods' system of ancient Egypt united into one god, Aten during his period (sun god, Fig. 13d–e). The city of Akhenaten, 12 km, is a plain park, detached from the Nile Valley by a band of palm trees and has the ruins of Aton Great Temples (Fig. 13a), palace and Royal family tomb made of mud brick. It is one of the most dreamy residences because of its stillness and the peaceful beauty, which attract a lot of foreigners and visitors. In Royal tomb, Akhenaten, Nefertiti, and Prince Meketaten were buried in separate chambers. After Akhenaten death, the Royal tomb was opened and its contents had been partly transferred to Luxor for reburial in the Valley of the Kings. Besides, there are two other tombs named north and south tombs. The north tombs are among the most impressive monuments at Amarna sites which contain unique evidence for Akhenaten's prospects. The latter involve scenes of temple and palace life as well as Hymns to the Aten, reveling the creative influences of the sun god. North Ahme's tomb conserves brilliant illustrations of daily life, artists, musicians, grids, and outlines, screening the introductory stages taken to organize the wall reliefs (Fig. 13c, f–g). The latter photographs are proved that the ancient Egyptians had



a great love of music (Fig. 13c) which played an important role in life from the earliest time during civil and religious life like rituals, feasts, festivals, and banquets. The southern

tombs situated at the other end of the historical site of Tell El-Amarna are less attractive for tourism if compared with the northern ones.

◀**Fig. 12** Detailed examination showing past daily life at tombs of Baqet III, Amenemhet, and Khnumhotep II tombs at Beni Hassan. **a** Wrestlers during fighting training, Baqet III tomb. **b** Various crafts involving hunting animals, fishing, and offerings, Baqet III tomb. **c** Interior view of the Amenemhet cemetery. **d** Amenemhet shrine, Amenemhet cemetery. **e** Statue of Amenemhet, his wife, and his mother, Amenemhet cemetery. **f** Various scenes activities of daily life such as hunting, butchers, and memorial burials with offering-bringers, Amenemhet cemetery. **g** Hieroglyphics telling about various depictions during ancient record and the lotus flowers which represent the power of the sun, creation, rebirth, and regeneration. Note memorial burials with offering-bringers at the photo margin, Amenemhet cemetery. **h** Khnumhotep fowling (hunting, shooting), Khnumhotep tomb

### Geosite 7: Industrial Sites (IS)

Carbonate strata of Middle Eocene exposed via El Mina and Samalute Fm extend along the east and west side of Samalute-Minia Area (Said 1981). Snow white fossils-rich limestone rocks are main lithofacies of the carbonate strata. The study area deliberates as one of the world's biggest and highest grade carbonate because of high contents of Cao which fluctuate from 98.20 to 99.00 wt% and its brightness oscillate from 94.28 to 95.39% (Abdelaal et al. 2017), signifying high brightness, purities, and whiteness. A lot of excavating channels and quarries within the limestone plateaus are established in the study area, representing an economic geosite of mining (Fig. 14a). The carbonate properties are an appropriate testimony for diverse industrial uses such as paints, paper, plastics, food and pharmaceuticals, cement production, ceramics, rubber, construction/architecture, adhesives, and sealants. Moreover, the limestone applications are very important industrial materials in the environment like flue gas desulfurization, or drinking water and waste water treatment (Chatterjee et al. 2006). Egypt is an important manufacturer of cement, in which the yearly production is 55 Mt (Wagdi and Fathi 2023) that is transferred to several Mediterranean and Middle East countries. On the basis of all, the rank of the geosite seems to be universal.

### Geosite 8: Hydrogeological Aquifers (HA)

Groundwater aquifers along with Nile River represent a substantial part of the whole water resources used for domestic and irrigation resolutions, particularly in arid regions (Keesari et al. 2014). Egypt signifies one of the nations which suffers water deficiency as the result of high inhabitants progress, water pollution, asymmetrical spreading of water resources, climate deviations, and construction of projects in the Nile River basin like Grand Ethiopian Renaissance Dam (GERD) in Ethiopia (Tesfa 2013; GERD fact sheet 2014). Most of the water resources in Egypt are derived from the Nile River (97%) and 3% of groundwater, flash floods, recycled drainage water, and seawater desalination

(RIGW/IWACO 1989; RIGW 1992; Sultan et al. 2000). In El Minia area, two main aquifers are recorded in Quaternary floodplains and Eocene limestones. The first comprises thick sand, clay, and gravel beds, covering a wide areas in Nile Valley (Fig. 2e), while the second is made up of white snow fossils-rich limestone rocks (Samalute Fm), occupying the eastern and western banks of the study area (Rawy et al., 2020,201). The Quaternary silty clay deposit vary from 5 to 20 m in thickness (RIGW/IWACO 1989), while water depth in the Eocene limestones declines from 200 m below the Nile to a few meters towards the desert fringes. The Quaternary and Eocene aquifers are recharged from the penetration of the agricultural water, the leakage from Ibrahimia and Bahr Youssef channels (Fig. 1a), and the Nile River (Sultan et al. 2000). Local karstification enhances the water infiltration after irrigation (agricultural wastes) into the aquifer system. The water salinity indicates fresh to brackish water in the Eocene limestone aquifers, while fresh water in post-Eocene aquifers (Reda et al. 2017). In general, the carbonate aquifers are a vital module of the comprehensive water supply (Ford and Williams 2007; Keesari et al. 2014; Worthington 2015). Thus, this geosite along with River Nile is an important water source to the economies, supporting agriculture and fishing.

## Discussion

All the selected geosites are categorized by substantial scientific and touristic values, expressive geoeducational potential and high esthetic values related to the gorgeous geological landscapes and diverse hydrological and historical aspects along with economic excavation. The discussion of the geosites assessment and their consequences has been clarified below with approvals to decrease the negative impacts of the geosites and rise the ultimate ranking of potentials in forthcoming assessments.

The assessment of scientific value, degradation risk, potential educational use, and potential tourist use for the nominated geosites along with the scores for each criterion are shown in Table 3 and Fig. 15. The consequences show that the first six geosites involving VL, GKL, CSL, RL, AEM, and CRS gain high scientific value. The latter geosites have scores of 350, 330, 320, 310, and 305, respectively. The geosite that has moderate scientific value is HA with score 280, while site of IS has low score (<200). Regarding the potential touristic use, geosites for AEM, CRS, and RL reach high potential tourist use with a score of 380, 350, and 330 points, respectively, because these geosites are well-known touristic destinations and lie within urban areas, signifying global reputation. In the other hand, geosites of VL, GKL, and CSL have moderate potential tourist use with scores fluctuating from 300 to 250 points, while geosites of HA



and IS with scores of 120 and 80 reflect low touristic value. Their moderate and low touristic ranks are owing to their situations in rural areas whereas no mobile communication

is available. Similarly, most of the geosites of VL, RL, GKL, CSL, AEM, CRL, and IS have high potential educational use with score variation from 320 to 302 but the remaining last

**Fig. 13** Detailed investigation of Tell El-Amarna tombs. **a** Sketch map showing Akhetaton's city at Tell El-Amarna (Egyptian Ministry of Tourism and Antiquities 2020). **b** The king Akhenaton, Civilization Museum, Alfustate, Cairo. Insert photo showing architecture of the Akhetaton period as represented in a tomb wall-painting from Tell El-Amarna. **c** Musicians play music during rituals, feasts, festivals, and banquets. **d, e** King Akhenaten, Queen Nofreterti, and one of their daughters offering libations to the sun disk. **f, g** Activities of daily life for ancient Egyptian like preparing of military wars and offer bringers

geosite (hydrogeologic aquifers site) has moderate potential educational use (~300). The accessibility through the main asphaltic trails, no boundaries of use (no fees for entrance) and no difficulties that obstruct the remarking of the geological features are the main causes for gaining the best scores for nearly all the geosites. Furthermore, the educational programs of schools and universities include themes related to geology, hydrology, history, and archeology. Besides, the direct observations of all the geological elements (like rocks, sedimentary structures, fossils, and quarrying systems) through volcanic and quarrying sites allow the visitors to get information about the Earth evolution. Concerning the degradation risk assessment, geosites of river landforms, industrial sites, ancient Egypt monuments, and hydrogeological aquifers have a high risk with a score of 330 to 305 and its weighting is 35%. But, geosites of volcanic landforms, geomorphology and karst landforms, and circular structure landforms have a moderate risk ranging from 300 to 201 and the last geosite (path of Holy Family) has a low risk of degradation. The high risk for the RL, IS, AEM, and HA geosites is due to extensive effect of contamination, exploitation/excavating, waste water, and urbanization. Nevertheless, these geosites especially RL and AEM have high potential tourist and educational together with a high scientific value.

### Potential of Geosites

In general, high scientific value characterizes most of the geosites in the Samalute-Minia Area. Geosites of VL, GKL, CSL, and RL have a high scientific value connected with geodiversity related to lithological and structural variations along with wide diversity of ecology. GKL and CSL geosites provide obvious preservation sites of geomorphological and circular structural landforms that give an idea about different geological events, aiming to understanding the Earth's evolution. Geosite of volcanic landforms (G3) is one of the most descriptive spots of multi-phases of volcanic rejuvenation composed of explosive scoria cones and lava flows, analogous to the scoria cones elsewhere in the comprehensive regional setting like Marssous's scoria cone in Bahariya Oasis, Western Desert, Egypt; Al Haruj volcanic region, Libya; and the Al-Duaythah scoria cone, Saudi Arabia (Khalaf and Sano 2020; Khalaf et al. 2021). It offers

scientific knowledge to visitors about how these volcanoes developed in a volcanology context and the importance of water role in the creation of phreatomagmatic explosive phase (magma-water interaction), transferring to eruption of AA'-Pahoehoe lava flows lava (Khalaf et al. 2019, 2021). Furthermore, information about thermal gradient-controlling cooling system, in which the joints tiers are caused from filtration of meteoric water and the underlying groundwater-rich substrate resulting in modification of isotherms (Budkewitsch and Robin 1994; Lyle 2000; Moore 2019). The improved scientific research on active and dormant volcanic regions is generally associated with broadening of beliefs to form volcanic geoparks at many scales (Moufti and Németh 2013; Migon and Pijet-Migon 2017; Khalaf et al. 2019). In the other hand, the geosite of River Nile (G4) is one of the longest rivers in the world and is characterized by its significant ancient history, unique climatic setting, ecological diversity, and long hydrologic record, highlighting the history and communication between the society and nature (Fielding et al. 2018). The hydrogeological behavior of the river reflects the evolution stage for remarkable civilization whose historical events and amazing monuments are recorded along the Nile banks throughout the long Egyptian history initiated from the Pharaonic to the Ptolemaic and the Greco-Roman Era (Wendorf et al. 1976; Said 1990). These geosites have been published in several scientific periodicals (Fielding et al. 2018; Khalaf et al. 2019; Khalaf 2022), while the remaining four geosites have low value because there is no enough knowledge or awareness available for these geosites. Journals in scientific periodicals and membership in international proceedings may facilitate scientific knowledge. Brilha (2016) commented that the scarcity of scientific pamphlets does not show that the geosites have no scientific knowledge because these geosites may have been lately exposed or a few researchers are not studied them or committed to Earth science educations.

Regarding the tourist potential, geosites of AEM, CRS, and RL have the best score because these geosites are situated in urban areas and have been recognized as tourist destinations in Samalute-Minia Area. The latter geosites permit the guests to get valuable info about the archeological and heritage sites, Christian memorials and locations along the HF path. There are no borders of use with no complications that create challenging the observing of these geosites for the visitors and guests because of their existences a few kilometers from cafes and guesthouses and near the main asphaltic roads. The Holy Family's vacation in Egypt (Holy trail) has great historical, religious, and cultural consequence for Egyptians which made Egypt as one of the most blessed Christian midpoints in the world and gave the Egyptian Coptic Church a distinctive situation among other Christian churches (Rodrigues and Lay 2012). The description of Holy paths as a sanctioned pilgrimage site was recommended by



**Fig. 14** Economic and risk values in the study area. **a** Open cast quarrying in limestone rocks. **b, c** Extreme deprivation for antiquities as the consequence of the effect of underground water at Tell Amarna locations. **d** Guide map for antiquities in Egypt (Egypt’s Minister of

Culture and Tourism 2020). **e** Illustrative guides and informative texts at Tell El-Amarna. **f** Holy Family hotel, restaurant, and souvenir shop has been established at Gabal El Tair church



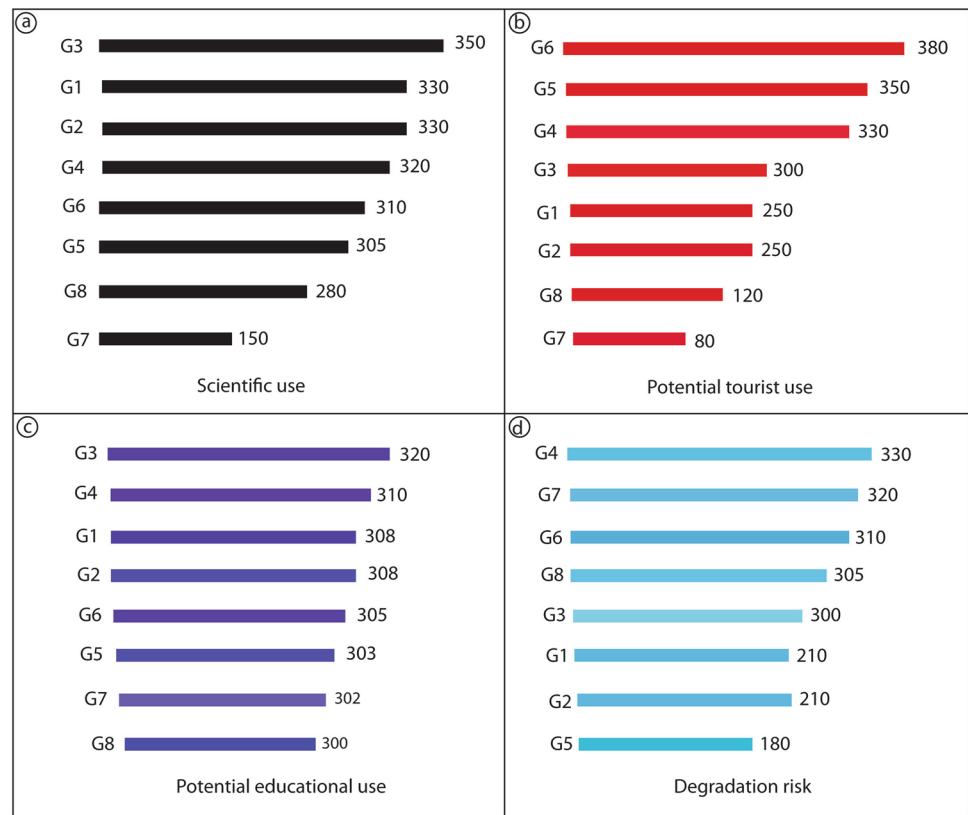
**Table 3** Score of the quantitative assessment criteria of the investigated geosites: SV scientific value, DR degradation risk, PEU potential educational use, and PTU potential touristic use

Assessment of scientific value, degradation risk, and potential educational/touristic use	Geosites							
	G1	G2	G3	G4	G5	G6	G7	G8
Selected geosites								
Representativeness	4	4	4	4	4	4	4	4
Key location	3	4	3	4	4	3	4	4
Scientific knowledge	4	3	3	4	3	4	3	3
Integrity	3	3	3	4	3	3	3	3
Geological diversity (SV)	4	4	4	3	2	3	3	3
Rarity	3	4	3	4	4	4	4	3
Use limitation (SV)	0	0	0	0	2	2	0	0
Vulnerability	2	2	3	2	4	2	2	2
Accessibility	4	4	4	4	4	4	4	4
Use limitations (PEU and PTU)	0	0	0	0	2	2	0	0
Safety	2	2	3	4	4	3	2	2
Logistics								
Population density	2	2	3	4	4	4	2	4
Association with other values	4	4	4	4	3	3	2	2
Scenery	2	4	4	4	2	3	3	2
Uniqueness								
Observation conditions								
Interpretative potential	4	4	3	4	3	4	4	4
Economic level	2	2	2	4	4	4	4	2
Proximity of recreational areas	2	2	2	4	3	3	2	2
Didactic potential	3	3	3	4	4	4	2	2
Geological diversity (PEU)	3	3	3	3	2	3	2	3
Deterioration of geological elements	2	2	2	3	3	3	3	3
Proximity to areas/activities with potential to cause degradation	2	2	2	4	3	4	2	3
Legal protection	0	0	0	3	3	3	0	0

Vatican Pope Francis during his visit to Egypt in April 2017, whereas he declared Egypt as an official Roman Catholic pilgrimage destination (Elzek and Alfy 2017; Egyptian Ministry of Tourism and Antiquities 2020; Abed and Abouzied 2021). The whole region is extremely engulfed by large number of churches and monasteries such as Monastery of the great Saint Abu Fana Monks, Lahore monastery, Dahr El Barsha, Church of Great Martyr Mina Kom El Mahrs, Saint Abu Skhairoun Coptic Orthodox Church. The presence of the Christian and Coptic milestones in the study area attracts mostly Christian tourists and adventurers to participate in religious activities, e.g., Church of the Holy Virgin at Gabal El Tair (G5). The development of the HF trail is directed to serve 2.4 billion Christian pilgrims worldwide as well as other traditional sightseers (Gabra et al. 2012; Elzek and Alfy 2017). Geosite of AEM (G6) represents archeological sites which preserves valuable information on ancient Egyptian history to comprehend the past human behavior in terms of the development of ancient civilizations through the analysis of ancient texts, artifacts, and architecture. Monumental arts and architectures as well as secluded tombs (Beni Hassan and Tel

El Amarana sites) in which their walls are decorated by paintings and/or reliefs, are considered an important discipline for studying the culture of ancient Egyptians (such as funerary beliefs). In addition, cemetery of Tuna El-Gabal, which is famous for its extensive catacombs (Late Period, 688–332 BC) along with hundreds of Greco-Roman tombs (332 BC–364 AD), was documented in El Minia Governorate (Shaaban 2018). Thus, the historical sites of Egypt with emphasis on the Samalute-Minia Area provide scientific and educational information about the archeological and heritage places in Pharaonic (e.g., Beni Hassan & Tell El-Amarna), Greco-Roman (e.g., Tuna El Gabal), and Islamic periods (El-Beltagui 2011), representing an extreme historical reputation and great impact on tourism. Geosite of riverine landforms (G4) is fitting touristic site for guests to see the wealth of archeological treasures and cultural attractions as well as enjoy fishing, and swimming together with sighted migratory birds and wonderful cultivated lands on river banks. The lasting five geosites show moderate to low touristic potential use as most of them are situated in rural areas and accessible only through desert trails without mobile coverage. Therefore, these criteria got

**Fig. 15** Quantitative assessment of **a** scientific value, **b** potential tourist use, **c** potential educational use, and **d** degradation risk of Samalute-Minia's geosites following Brilha's method (2016)



the low score especially for geosites of VL, CSL, GKL, IS, and HA.

Referring to the potential educational use, almost all the geosites are the best scored because there is availability to trace these sites along with no difficulties that prevent the detection of the geological phenomena, ancient monuments/tombs and religious visits. Most of the subjects related to these geosites are studied in numerous academic disciplines, in which Egyptology (the study of ancient Egypt) is one of these disciplines that is of interest to biblical and classical researchers. Similarly, geosites of VL, RL, GKL, and CSL permit visitors and guests to get information about the Earth history through direct observation of sedimentary and volcanic rocks, geological structures, and fossils along with hydrogeological landscape (RL and HA sites). The latter refer to hydrodiversity and biodiversity (surface water and groundwater) and may be part of geoheritage (Winter et al. 1998; Simić 2011; Cruz et al. 2014; Lazzarini 2015). On the opposite side, the industrial site (G7) has moderate educational potential as the result of destruction of geological features through quarrying/excavation.

### Geosites Risks

The outcomes of the degradation risk evaluation display that RL, IS, AEM, and HA geosites have a high risk, in which pollution has negative influence on soil and water resources.

River Nile and water aquifers show high risk of deprivation because there is a lot of contaminated sources that affect soil, surface water, and groundwater through leakage and percolation of waste impurities at depth. Examples of these reasons are domestic sewage, oil spills, aquifer salinization, waterlogging, urbanization, and waste water from industries and agriculture. Illegal water pumping reveals a disorganization of unique specialists to impose environmental guideline and protect hydrodiversity. Hence, all these factors in addition to population growth, asymmetrical circulation of water resources, and climate changes cause shortage in water supplies in Egypt (El-Rawy et al. 2021). Most of the monuments and tombs at Beni Hassan and Tel El Amnerna are affected by intense degradation (Fig. 14b–c) as the result of negative impact of underground water, hazards, and alveolar weathering processes (Fig. 11a–c). Siedel (2010) declared that cavernous weathering represents a famous problem for building stones and monuments. An increase of urban areas close to these sites produces also fluctuations in hydrological regime which may distort and abolish natural landforms of memorials and development of sinkholes (Figs. 3d, 5a–b). The latter and groundwater flooding cause severe hazards in carbonate karstic landscapes and substantial economic losses in thickly populated areas that are related to human activities via water extraction and land improvement (De Waele et al. 2011; Gutiérrez et al. 2014). The human activities can hasten sinkhole development through dropping of

the water table, change of recharge into karst depressions, or creation of water table oscillations (Waltham 2008; Parise et al. 2015). With rapid urbanization, geodiversity topographies are gradually demolished due to the lack of urban or environmental design taking into account the values of geodiversity. Another damaging activity of major importance in the local context is open surface quarrying/or excavation (G7) which cause degradation of geological landforms with some geomorphological variations on the landscapes that create misrepresentation of paleoenvironmental information (Kirkwood and Antita 1995; Gray 2013; Periferakis 2021). Furthermore, there are no systematic training courses/or agendas for local inhabitants, no tour guides, and no communication with the sponsor group concerned with tourism industry in the sheltered and touristic regions. Besides, the absence of special desires supplies, feeble marketing labors and advertising utensils, hospitality facilities offered and scarcity of food and beverage amenities generate barriers in pilgrim sites for HF (Abed and Abouzied 2021). Nevertheless, these geosites (VL, AEM, and HA) have high to moderate potential scientific, educational, and touristic use. So, conservation and management measures should be implemented for these sites. The remaining four sites have moderate risk value because most of their landforms are preserved. However, erosion and wind action produce sustained exploitation and obliteration for some of the geological and geomorphological architecture like denudation of volcanic and karst geoheritages.

### Geoconservation Perceptions

Geoconservation areas and geoparks are the perfect pathways to attract visitor's attention if they are well designed through the planning of an advanced plan. In order to develop geopark, the proposal strategy should involve three main modules involving the protection and the conservation, infrastructural development for tourism, and socio-economic sustainability for the local community (Carcavilla et al. 2009; Farsani et al. 2011; Gordon 2018; Gordon et al. 2018b; Crofts et al. 2021). The Egyptian government has established a number of principal strategies for geoconservation in order to avoid an increasing of threats and protect the elements of geodiversity and potential geosites as well as improve these sites as tourist magnetisms. Constructing of natural parks and distinctive regions of environmental protection should be required to decline the effect of any human action that has excessive negative impacts on geodiversity (Reynard and Britha 2017; Gravis et al. 2020). These ventures aim to preserve the religious and cultural heritage, renovate infrastructure of the touristic and archeological sites, and enhance inferior regions and humanities in the Delta and Upper Egypt via creation of job opportunities. A lot of developments around the religion and antiquities

sites, churches, and monasteries have been created by the Ministry of Tourism and Antiquities in cooperation with Egypt's Coptic Church such as establishment of descriptive guides (informative texts, Fig. 14e), thematic/or geographic and sketch maps (Fig. 13a) at historical sites (like G6) and guiding signposts as well as calendars of religious symbols along the roads and squares. Infrastructure amenities (hotels, restaurants, bazars, and souvenir shops) around the Gabal El Tair church and other path sites are settled to help and fascinate visitors from all over the world (Fig. 14f), permitting relocation the Holy Family path as a world-wide tourism destination. In addition, there are some open-air galleries/museums observed in the study area like Mallawi National Museum constructed in 1963 in El Minia City which has Pharaonic, Romanic, and Grecian antiquities that can be used as tools for tourism, teaching, scientific researches, and economic improvement in a rural areas.

In spite of these positive impacts, there are some deficiencies need to be conserved. Didactic materials such as pamphlets, training, and educational and interpretative activities (like brochures, guide books, and path cards) should be advanced and available at religious and touristic sites, where geological phenomena features are observed. Appropriate activities of explanation and education could attract more visitors, particularly for persons who do not have excessive information of geology and other analogous themes (Hose 2000; 2005). Explanatory approaches are achieved either through interpretive form (e.g., information signs, panels, geotrails, and guided tours) or interpretive facilities (e.g., visitor centers and museums, Hose 2005) along with preparation of lectures, interactive and video presentations as well as laboratories. Furthermore, guided tours/excursions, workshops (e.g., simulated geological phenomena, ancient Egyptian civilization, and River Nile), or multi-media presentations should be organized to the investigated sites. In such a framework, the geoeducation influence for community consciousness about the geodiversity importance seems as a support, hopeful way in any evolving region as geoeducation is one of the goals of UNESCO's Geopark strategies. The guests and community should be able to see and hear about several scientific proofs not only about geological phenomena and environmental problems, but also about archeological and cultural history and the time period in which these geosites involved.

Similarly, an increase in scientific, business, and local governance collaboration could be proposed in order to enhance the low value of research, education, and tourism items as well as decrease the high degradation risk for some geosites. In December 2022, Egypt's Minister of Culture announced Egypt's success in recording the folder of Holy Family's Voyage on the representative List of the UNESCO Society as well as preparing a guide map for Egyptian vestiges (Fig. 14d). Besides, Egyptian government began in

solving the pollution problems by carried out some plans like recycling of the industrial water, water treatment processes, and severe enforcing of the already existing environmental laws along with sensitization of the populations (Kirkwood and Anti 1995; Jabbra 1998; Gawad 2009). Together with these advanced movements, there are many work strategies that should be recommended regarding the improvement of religious and monuments tourism such as (i) raise the capability of the touristic sites especially the places which suffer extreme deprivation as the consequence of underground water as Tell El-Amerna locations (Fig. 14b–c); (ii) improve the quality of hospitality services and safety edifices and protection around sites; (iii) a lot of hotels and restaurants should be established beside those sites to improve scarcity of food and beverage amenities; and (iv) an increase of advertising efforts, documentation, announcement, and digital marketing of the major touristic objects. Finally, the Brilha's method should be improved to the framework of each geopark because not all benchmarks cannot be applied due to geosites position in countryside regions or lack of their detailed studies and all these factors affect the concluding scoring of the geosite potential. Accordingly, before evaluation, the researchers should obtain the info for each geosite compared to previous studies gained by other investigators which lead to facilitate geosciences education and the geodiversity importance in land-use planning.

## Conclusion

The Samalute-Minia Area involves discontinuing places and distinctive geosites which allow the visitors to get information about the diverse geological elements (geodiversity/hydrodiversity) and cultural/religious heritage. These sites are characterized by remarkable geomorphological, volcanological, hydrogeological, quarrying, historical, and cultural topographies that can be allowed this region to be appropriate for its development as a UNESCO Global polythematic Geopark. The geosites evaluation following Brilha's method (2016) are proved that the geosites of Samalute-Minia Area have scientific, educational, and touristic potential use. Geosites for ancient Egypt monuments, Holy Family trails, and riverine landforms fascinate the local and foreign visitors international, due to their high touristic potential, accessibility, and lack of both barriers and limitations of use. In the case of scientific value, geosites of volcanic, geomorphology/karst, circular structural, and riverine landforms are gorgeous for scientific research because of their high geodiversity related to lithological and structural variations along with the developed ecological diversity. However, geosites of River Nile, quarrying, and archeology have a high risk of degradation due to the high pollution, denudation of the geological phenomena, and groundwater effects. The high

educational potential categorized almost all the selected geosites as the result of their multiplicity in geological elements, convenience, and the absence of borders of use. Impending geoheritage need studies and public/private organizations' decisions or executions in Samalute-Minia Area to improve geotourism and geoconservation, which might take into deliberation the UNESCO strategies to create geopark. So, preservation plans following the Brilha's scheme should be done to reduce the weakness and the negative impacts of the selected geosites as well as facilitate the establishment of the geopark. In order to create the geopark in the study area, action plans should be carried out like improving geosites, protection and management, infrastructural improvement for tourism, better security conditions, developing inter-institutional cooperation, and the socio-economic development for the local community.

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## Declarations

**Conflict of Interest** The author declares no competing interests.

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