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El-Gendi Fortress: a new military and religious geo-archaeological site, Sinai, Egypt: geomorphological and hydrogeological remarks

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Abstract

El-Gendi Fortress is a unique geo-archaeological site in Sinai, Egypt. It reflects the progress of the Islamic military architecture during Saladin's reign (Salah ad-din al Ayyubi), the founder of the Ayyubid dynasty (1174-1260AD). The fortress's location met two major geo-criteria. One is geographical; it is located on a mound 655 m above sea level (a.s.l) and 152 m above El-Tih El-plateau; this elevation contributes to the exploration of the surrounding areas and provides the fortress with a strong defensive position against the Crusaders' invasions of Egypt (1163–1169 AD). The second is Hydro-geological; it provides exceptional access to both meteoric surface (via barrages) and groundwater (through Sudr spring). The latter is from deep aquifers of the Nubian sandstones (Malha Formation) across the fractured carbonates (Raha and Sudr Formations of Cenomanian to Maastrichtian age). Such water was accumulated since the Pleistocene pluvial age until the fortress' most recent use. The barrages' location upstream of a sub-basin "a" at Wadi Sudr, in a similar direction to the deep ditch side, confirms that the priority of their design is to protect the region from flash flood risks and to store water on a relatively flat-lying land. The study reveals that the fortress' geographical location is used to safeguard the Hajj route in central Sinai and to provide facilities for pilgrims' caravans when they travel from North Africa to Mecca. The study concludes that the fortress should be a part of the Sinai tourism itinerary and promoted globally as a geo-archaeological site for Geo-tourism. In addition, the government should implement a strategy for conserving, rehabilitating, and managing the heritage sites, to improve facilities and increase public awareness of these sites to maximize the outcomes.

Keywords: El-Gendi Fortress, Geo-archaeological site, Islamic Architecture, Sudr Spring, Religious, Flash floods, Barrages, Geo-tourism

Introduction

The Peninsula of Sinai has some distinguished geographical, historical, religious, and geological featured land in the east of Egypt. Demographically, Sinai has a population of approximately 600,000 people on a land area of about 60,000 km². Religiously, the Peninsula of Sinai is a divine blessed land where many prophets have passed and all religions have been met. The Sinai Peninsula has long witnessed many religions and civilizations, which makes it a holy region and the civilizations' cradle. To clarify, the peninsula of Sinai witnesses Islam,

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Christianity, and Judaism. The labels in figures (Fig 3 , 10 Low res) are not readable. Please provide a new figure with legible labels in Vector EPS or tiff / jpeg format with 600 dpi resolution. The figure has changed and uploaded

As for civilization, it is associated with the Nile Valley civilization, as a result, all of the civilizations passing through Sinai, including the Pharaonic, Greek, and Roman. The Pharaohs have abandoned the "Hathor Temple" on Sinai's "Serabit El-Khadim" Mountain [3]. Many antiquities have been left by the Romans in Sahl El-Tinah (El-Tinah Plain), such as Tell El-Farama, which has been landed by the Byzantines in 859–860 [4], the Greeks in 954–955AD [5], and the Crusaders in the 12th Century [5]. Mount Horeb witnesses the proposed Israelite exodus route from Egypt to Canaan, where Moses received the Tablets of the Law, according to the Old Testament [6]. The Christian era has created an architectural icon, Saint Catherine's Monastery, which is the world's oldest active Eastern Orthodox monastery, renowned for its extraordinary holdings of Byzantine art, and designated as a UNESCO World Heritage Site in 2002 [5].

Among the Islamic heritage is the pilgrimage (Haji) route bringing pilgrims from North Africa to Mecca [7]. The Crusaders' invasions (1163–1169 AD) are a series of campaigns launched by the Kingdom of Jerusalem to strengthen its position in the Middle East owing to exploiting Fatimid Egypt's weakness [8]. While the combined Byzantine-Crusader siege of Damietta failed in 1169, Saladin is appointed vizier in Egypt that same year [9, 10]. Saladin, the Egyptian Sultan in 1171, has strengthened the route with several fortresses, the most notable of which is the great citadels of the Pharaoh's Island at Taba and in many other places in Sinai [11]. Furthermore, Sinai is distinguished by its Great Military Road, which dates back to the Pre-dynastic period [12]. The middle road from the Gulf of Suez to the Gulf of Aqaba is added after that era, configuring the presence of the castles, fortresses, and old cities whose ruins are still witnesses on both roads. El-Gendi [13], one of these fortresses, is the subject of the current research (Fig. 1).

Geographically, it is a triangular region in Egypt, interlinking Africa with Asia, and is located between the Red Sea's Gulfs of Suez and Aqaba on the west and east respectively, and the Mediterranean Sea on the north (Fig. 1a). The Gulf of Suez is wider but shallower, having formed within a relatively young but now inactive rift basin about 26 million years ago [1]. It runs for about 300 km north to northwest, ending at the Egyptian City of Suez and the Suez Canal's entrance. Its width ranges from 1 to 32 km. The Gulf of Aqaba, on the other hand, is located on the east of the Sinai Peninsula and on the west of the Arabian Peninsula. Its central area has a maximum depth of 1850 m. The gulf is 24 km wide at its widest

point, extending 160 km north from the Tiran Straits to where Israel meets both Egypt and Jordan (Fig. 1a) [2].

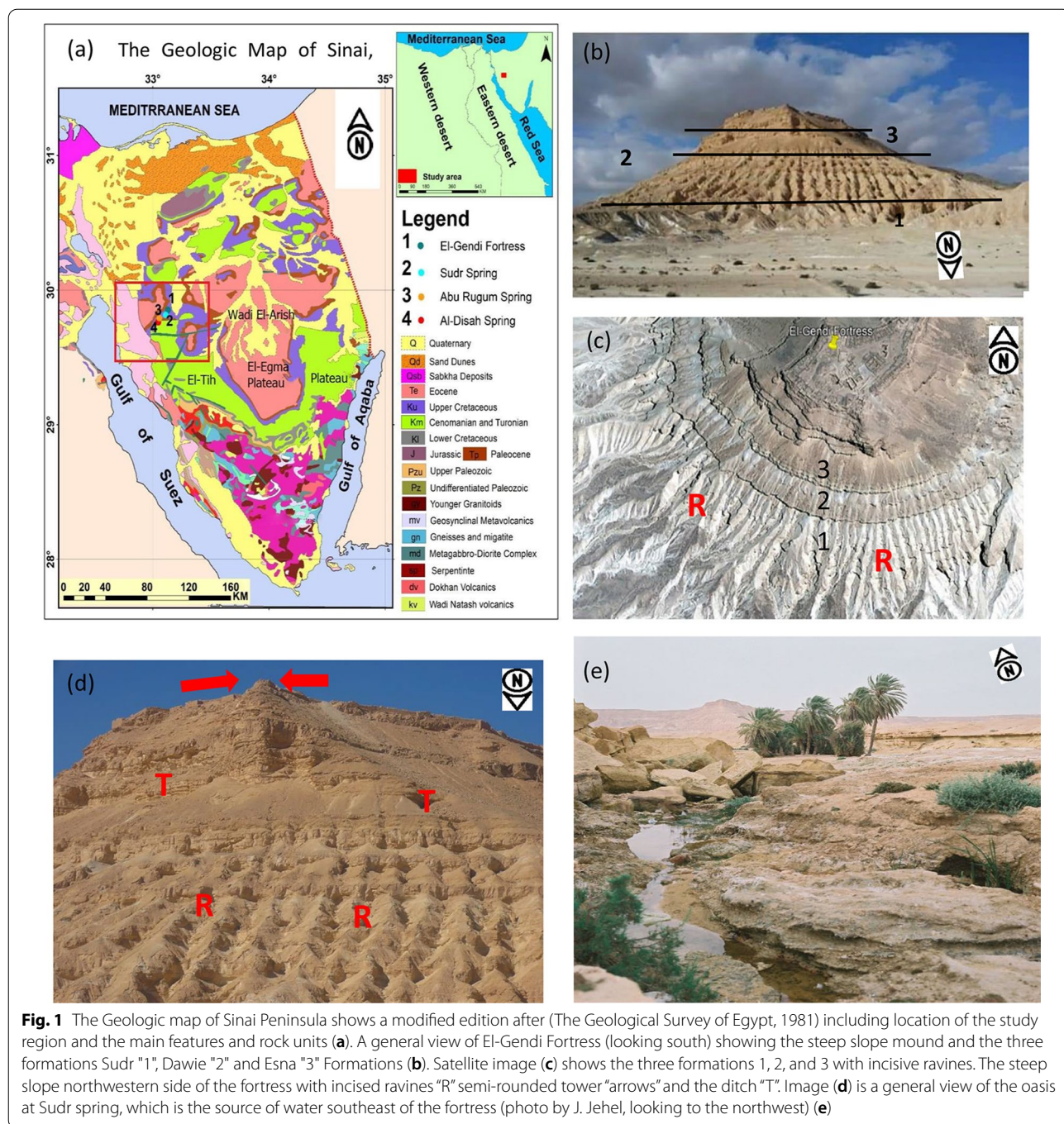
From a tourist viewpoint, Egyptian tourism suffers from some fickleness i.e., the numeral differences of tourists from within and outside Egypt affect tourism revenues, which, in turn, affects Egypt's growth rate [14]. Following a period of terrorism from 2013 to 2017, the Egyptian government intends to broaden its tourism portfolio and incorporate new tourism components as part of its efforts to improve tourism resources and diversify revenue sources. Egypt is holding several conferences to emphasize Sinai's potential as a global center for religious tourism to revive interest in the sacred sites there. To draw in millions of pilgrims and tourists each year, it plans to make use of the region's significance to the three main monotheistic religions [15].

The integration of remote sensing and Geographical Information System (GIS) techniques, with geologic field investigation and archaeological identification, is very interesting in detecting and identifying several geo-archaeological sites in Egypt [16, 17]. In the current study, these tools are integrated to introduce a new important geo-archaeological site at El-Gendi Fortress to global culture and religious tourism. Also, it demonstrates the role of geomorphology and hydrogeology in determining the fortress's location. Moreover, it shows the advancement of the Egyptians in the fields of hydrology and irrigation, in addition to military architecture. Furthermore, it ensures the significance of this fortress as a religious region used for pilgrimage caravan services for over 835 years across the Hajj route. In addition, it highlights El-Gendi Fortress as a new geo-archaeological site added to the cultural materials in Sinai to be included in the Sinai visitor's Agenda.

The study area

El-Gendi Fortress's appellation dates back to G. Wiet (1866) who pronounces it as Sadr (Mu'gam al buldan III, ed. Wiistenfeld, Leipzig, 1866–1873 AD). However, Lyons pronounced it as Sudr (1982) [18]. During the Ottoman Empire (1517–1798 AD), the location has been known as Qallat El-Basha [19, 20]. Later, it is known as Qallat El-Gundi because it is located at the top of a hill that resembles the head of a soldier (Arabic equivalent for Al-Gundi), which has been, consequently, shortened to El-Gendi [21, 22].

Saladin (Salah ad-din al Ayyubi), the founder of the Ayyubid dynasty (1174–1260 AD) intended to overthrow the Shiite Fatimid Caliphate in Cairo (979–1171 AD) and restore Sunnism to Egypt in 1171 AD. Within 1171 AD, the governmental reins have been entrusted to Saladin who has strengthened the country's defenses. In 1183 AD, he ordered the government to restore and



repair two citadels in Egypt; the first of which is Wadi Al-Raha, which disappeared in the meantime. Nonetheless, the second is El-Gendi Fortress, which has been founded before Saladin Era [22]. Saladin has already captured Jerusalem (1187 AD) before the fort's completion [9, 23], which supports the intention to have a religious rule in the fortress.

The current El-Gendi Fortress Lat. 29°51'4.97" N and Long. 33°7'47.36" E (Fig. 1a) locates at the extreme

north-western part of El-Tih plateau, which covers most parts of central Sinai. It is represented by a small, conical (Fig. 1b), steep slope (Fig. 1d) mound [7, 13, 24] that is elevated about 655 m a.s.l., and 152 m above the plateau of El-Tih (Fig. 1b). The Fortress shows a steep slope northward with deeply incisive ravines (Fig. 1c, d). Three springs are detected southward of El-Gendi Fortress; these are Sudr spring, Abu Rugum spring, and El-Disah spring (Figs. 1a, e, 2a). Furthermore, three barrages

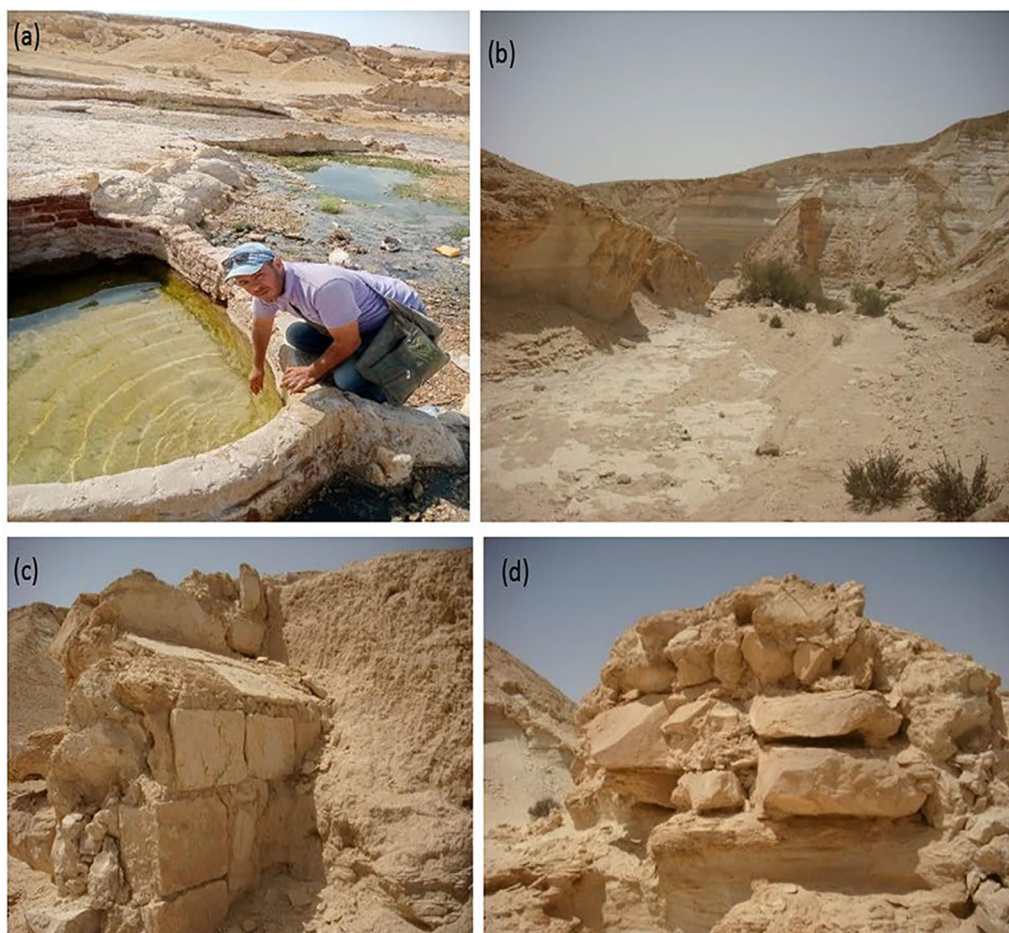


Fig. 2 Sudr spring is the potable drinking water source for El-Gendi Fortress (a). Wadi Kuhayla where the barrage located 1.5 km to the northwest of the fortress (b). Two remnant ruins of the barrage were detected at Wadi 1.5 km northwest of the fortress (c, d)

are constructed along the wadi (possibly called Wadi Kuhayla) to the north of El-Gendi Fortress (Fig. 2b–d), [7, 9].

The current climate in the fortress region follows the Mediterranean system, with most rains-derived forces coming from the northwest quadrant. The average annual rainfall in the desert does not exceed 50 mm. In addition, the boundary between the arid and hyper-arid zones is characterized by the ratio of precipitation to evapotranspiration, which is between 0.03 and 0.2 in the arid zone and less than 0.03 in the hyper-arid zone. Except for the northern coastal strip and the high mountainous region of El-Tieh plateau, this places the entire Sinai in a hyper-arid arid zone [25]. The fortress received potable drinking water from Sudr spring (Figs. 1e, 2a) located 5 km to the south of the fortress, and evidenced by the presence of pottery shards similar to those found in the fortress [26]. The water is transported and stored in large cisterns

(Fig. 7a) dug in the ground [16, 18, 20]. The groundwater of Ras Sudr's water-bearing formations is formed by mixing Ca-HCO₃ recharge water falling El-Tih plateau and pre-existing groundwater, yielding mixed water of the Mg-SO₄ and Mg-Cl types [27]. However, the majority of springs, discovered in this area, draw their water from porous sandstone ranging in thickness from 90 to 150 m [28], dating from the Upper Jurassic to the Lower Cretaceous (Nubian sandstones- Mallha Formation), of hydrologic aquifer properties. Furthermore, it is overlaid by a sequence of Upper Cretaceous carbonates Raha, wata, Matulla, and Sudr, which act as an aquiclude to the underlying Nubian sandstone [28]. These springs are most likely heated by a high heat flow and deep circulation controlled by rift-opening faults [29].

El-Gendi Fortress is selected for the current study because it is one of the most famous signs of religious cultural tourism in South Sinai. Although it is first

situation is reversed in the northern part (Fig. 3b). The two fault zones (Minsherah - Abu Kandu shear zone) and the Themed Fault (Ragabet El-Naam fault created a structural impenetrable passage to Sinai except at a few points known by local Bedouins, who arrange small-scale safari trips for amateurs to enjoy the desert and climb mountains. It is a unique tectonic passage inside the central Sinai used across historical times either as a route of the exodus [39] or through Crusaders' attack, and the Hajj route [9, 18], which has recently been used as a military pass (Mitla pass), (Fig. 3).

The Aqaba trend (N15°–25° E) is third-order predominance, which is prevalent in the southern part, while the E–W trend is predominant in the northern part (related to Mediterranean tectonics) [38]. Such trends of lineaments are based on the detection of a deep and shallow seated structure. On the other hand, the transitional area represents a low-lying graben-like passage that contributes to the underground water of central Sinai [34, 40]. Three major paleolakes are characterized within structurally-controlled depressions. The largest lake occupies an area of at least 337 km² and contained approximately 10.7 km³ of water being filled during pluvial phases [34].

Morphotectonic lineaments, observed on the Sinai Peninsula, are auto-detected from Shuttle Radar Topography Mission 90-m digital elevation model (DEM) and gravity grid data. The analyses of tectonic trends used a DEM lineament shadow (Fig. 2b) to infer the tectonic regimes' relative severity, unravel the prominent structural trends, and demarcate the contribution of various faulting styles that prevail through time [41]. The prominent trends are N50°–60°W, N20°–40°W, N50°–60°E, and N20°–30°E. Nevertheless, the less prominent N–S, E–W, and ENE trends are common (Fig. 3b). The prominence of these trends varies through time. The NW and NE trends show relatively equal abundances in the Precambrian and the Cambrian whereas the prominence of the NW trends prevails from the Carboniferous to the Holocene. Lineaments in all formations are near vertical and on average, about 65% showed as strike-slip, 22% as reverse, and 13% as normal faulting styles (Fig. 3b) [42].

Rock Units

The central Sinai is distinguished by its complicated rock units of the pre-rift succession of El-Tih Plateau east of the Gulf of Suez at Wadi Sudr and Wadi Fieran [28, 43, 44]. The plateau rises from the Mediterranean Sea and stretches more than 200 km to middle of Sinai; it is elevated to about 700 m and ends with the cliff Jabal El-Tih. The succession is composed of a sequence of Cretaceous transgressive Tethys carbonates, clays, marls, and sandstones from Mallha, Raha, Wata, Matulla, Sudr, Dawie, and Esna (Fig. 4). Sudr chalk of

Campanian- Maastrichtian age is used as building blocks; however, the massive dolomitic limestone of Turonian Wata Formation is used both for beams and foundations (Fig. 5).

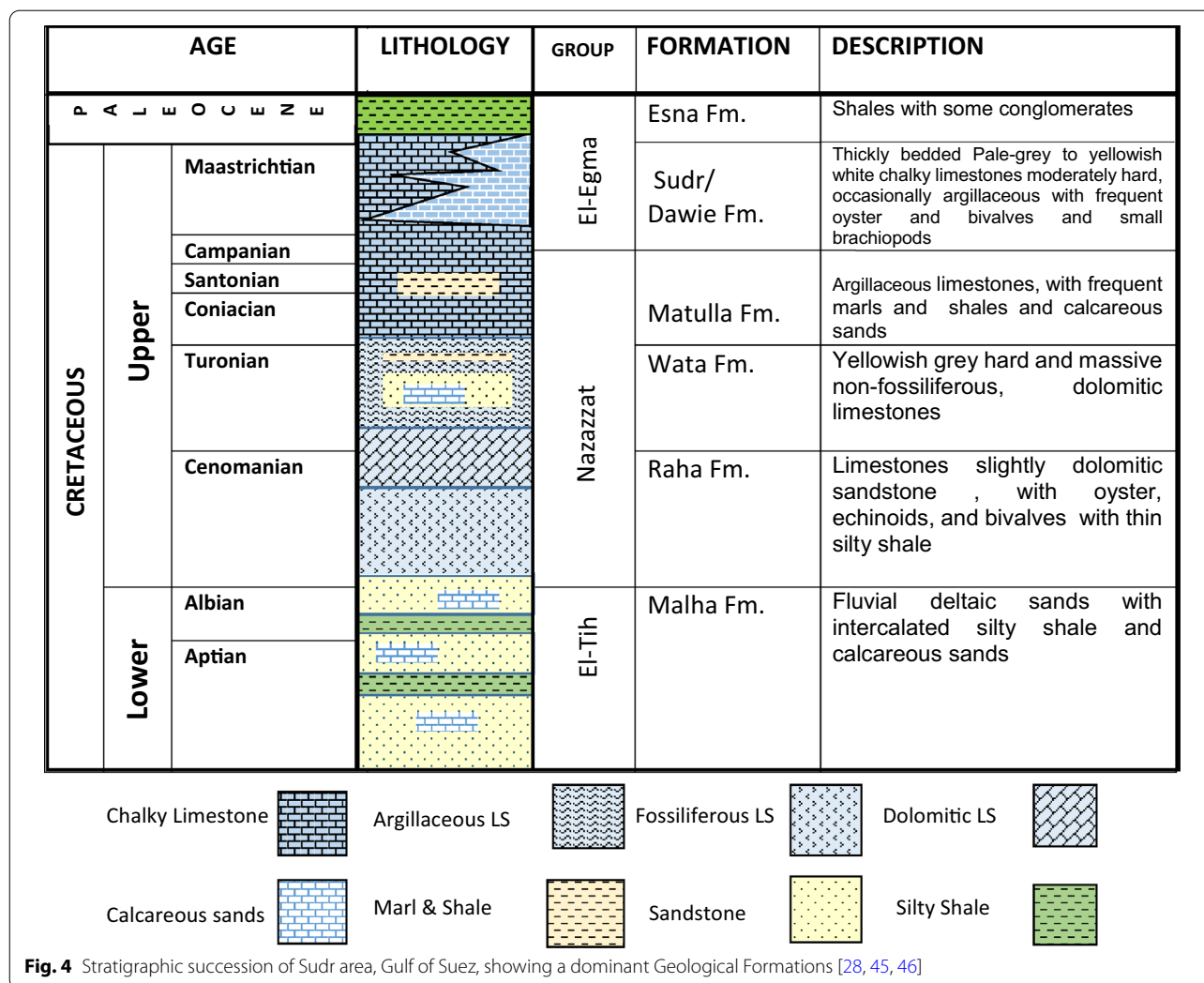
El-Gendi mound is composed of three formations from bottom to top Sudr Formation "1", Dawie Formation "2" and Esna Formation "3" (Fig. 1 b, c) of Campanian-Maastrichtian to Paleocene (Fig. 4). Most of the fortress's building stones are mined from the nearby chalky white limestone of Surd Formation "3" (Figs. 1, b, 5a). However, the massive beige to greyish color dolomitic limestones of Turonian Wata Formation is used both for beams and foundations (Fig. 5b). The cementing materials are composed of Esna shale and Sudr chalk ground, and mixed forming the "mullat" through which the fortress's ground is plated. The lithostratigraphy and microfacies description [28, 45, 46] and age of the formations are summarized in Fig. 4.

Materials and methods

During a short visit to Ras Sudr resort, I was invited to see El-Gendi Fortress to identify the rock sequence upon which the fortress is constructed. Several questions have been raised during this short visit. Some of these questions are patient to how Egyptians allocate the site, select nearby hard rocks for the foundations, grind up other soft rocks, mix them, and make the cementing materials (Arabic Equivalent for mullat) required for construction. Another question includes the fortress's location to water sources, either meteoric or groundwater, the location of barrages to the fortress itself, security, and maintenance. Sixty samples are taken to represent the different rock units constituting the mound; they are examined (Fig. 1b, d). The next stage includes correlating these samples with various rock units and identifying the fortress's rock components and their origin.

Several other data sources are used in the current study to elucidate and validate the results including the global positioning system (GPS). These sources are represented in recording some locations for ground validation. In addition, the geologic map of Egypt Scale 1:2000.000 [47] and Sinai [48] are both used as important sources. Consequently, nine visible/near-infrared (VNIR) and short-wave infrared (SWIR) range from the Landsat-9 scene (Path 175/Row 39, acquired on May 9, 2022), with a resolution of 30 m. Data are downloaded from the US Geological Survey (USGS) websites (<http://glovis.usgs.gov/>; <https://scihub.copernicus.eu/>). Several images from Google Earth with a resolution of 0.5 m (Google Earth program—online program) and SAS Planet are monitored with an accuracy of 0.5 m for the year 2022 (Fig. 5).

The analysis is carried out through a Geographical Information System (GIS) platform configured with a



Remote Sensing System, using ArcGIS 10.3 and ERDAS image processing. Several field trips conduct field verification. Remote sensing (RS) and GIS techniques have proven to be very effective in delineating watershed areas and stream generations [49]. In this study, the Arc hydro tool interfaces in ArcGIS 10.4 software are used to delineate watersheds. ASTER at 90 m is used to delineate Sudr and Bruk basins. Several shape files are generated using DEM ASTER 30 m, and the main sub-basins are extracted using Sudr basin stream generation. Watersheds and stream generations in sub-basin 1 are delineated using the Alos Palsar digital elevation model (DEM) with a resolution of 12.5 m [50, 51].

The Arc hydro tool recognizes the outlets in the DEM and delineates the watershed for each outlet automatically. Streams are created using a variety of tools, including a spatial analyst tool and a data management tool. The results are validated using topo sheets and

Google Earth imagery [52, 53]. There are three main methods for removing geological lineaments from remotely-sensed data: (1) manual elimination [54, 55], (2) semi-automatic extraction [56], and (3) automatic elimination [57–60]. The current study employs automated elimination. Lineaments are extracted so that they can be compared to the extracted structure from other tools. The primary advantage of automated lineament elimination is its ability to provide a method for classifying images, handling quickly-completed operations, and extracting lineaments that are not recognized by human eyes [61].

There are various computer-aided lineament extraction approaches, one of which is the on-edging filtering procedure. The most commonly-used software for automatic lineament elimination is ERDAS, ENVI, and PCI Geomatica. The algorithm line module, in PCI Geomatica software, is used for automatic elimination.

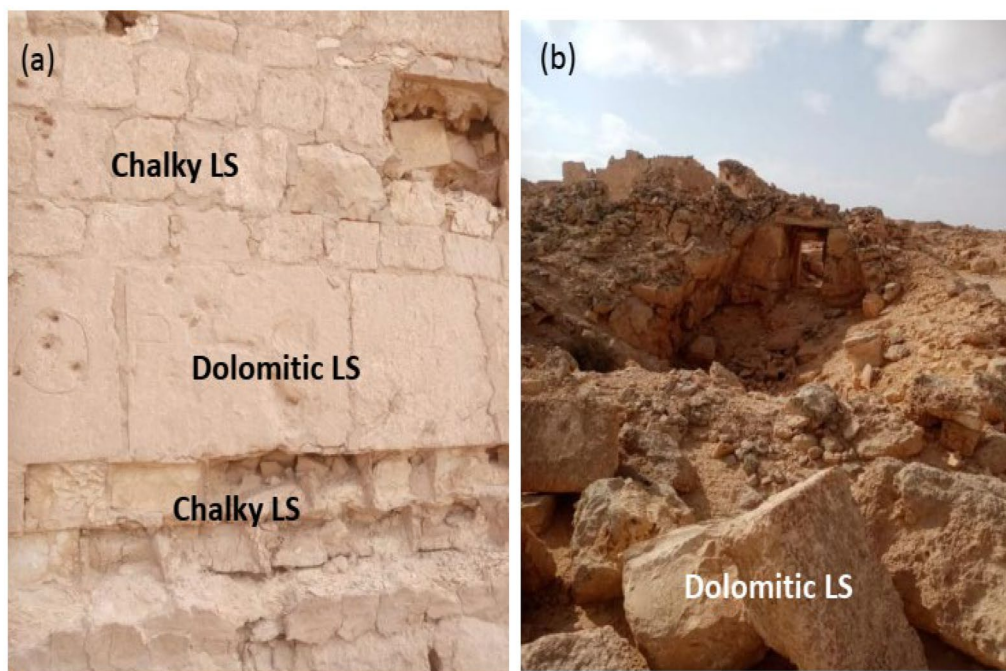


Fig. 5 The wall of El-Gendi Fortress is composed of the nearby Sudr chalk of Campanian- Maastrichtian age, while some support blocks derived from the massive dolomitic limestone of Turonian Wata Formation (a). The entrance of fortress, showing blocks of dolomitic limestone (b)

PCI Geomatica geospatial software aids in reducing subjectivity, saving time, and facilitating comparison and validation with other methods [62]. Principle component analysis (PCA) from LANDSAT-ETM satellite data is extracted automatically, as are hill-shade images extracted from ASTER DEM data 30 m (Fig. 9). To show more data on representative images in DEM, a hill-shade process using 3D analyst tools on ArcGIS software is required. In the first step, the hill-shade process must be performed on DEM data with quadruple value variations of sun azimuth for 0°, 45°, 90°, and 135°; however, the input value of sun altitude is all the same on 45°.

The images, produced by the hill-shady process, are then overlaid to produce a DEM imagery visible from all azimuth angles [63]. The geomatic software LINE module proves to be a useful algorithm that takes linear elements from an image; in addition, it records the polylines in vector segments utilizing six parameters. The LINE algorithm includes three steps: edge revealing, threshold holding, and curve elimination. This analysis uses the algorithm parameters involved in automated extraction using PCI Geomatica which includes RADI—Radius of filter in pixels, DTHR—Threshold for linking distance, GTHR—Threshold for edge gradient, LTHR—Threshold for curve length, ATHR—Threshold for angular difference, and FTHR—Threshold for line fitting error [62].

The lineament of structural origin is represented as linear ridges, cliffs, valley's aligned segments, or any further distinctive geomorphological manifestation of lineaments. Aerial photographs and satellite images are widely utilized to describe lineaments for various objectives including the description of the tectonic fabrics and geological structures [63].

A digital elevation model is routinely subjected to the aspect function to derive an aspect map (Fig. 11) which is the direction of the greatest rate of change in Z value from each cell in a raster surface. The aspect shows which direction towards the highest rate of value change from one cell to the next is moving in. The values of the output raster will correspond to the aspect's compass direction. The aspect can be thought of as the slope direction. Positive degrees from 0 to 359.9 are used to measure it as it moves clockwise from the North. A value of -1 is given to a cell in the input raster if it is flat and has a zero slope [64]. The aspect identifies the direction of the downslope of the highest rate of change in value from each cell to its neighbors. The values of the output raster is used to represent the aspect's compass direction. (ArcGIS Help Guide 10.4) running the aspect function on the DEM image produces the aspect map. Although it looks to be a grey-scale image, the viewer of the mosaic can alter the symbolism by adding their chromatic imagery using the color function that can be added [65].

Results

The geo-archaeological site

Since 1922, the work of Barthoux [13] more than six Missions have been done either by the French Mission [66] or by the Egyptian Supreme Council of Antiquities in 2021 [9, 16, 17, 66, 67]. The site visits, supported with a satellite image of El-Gendi Fortress (Fig. 6), illustrate that the fortress has an irregular rectangle shape [66, 67]. Its sides range in length between 150–200 m with a total area of 1.5 acres. It is surrounded by a curtain wall of 2 m thick; in addition, its dimensions from the N and NW are surrounded by a deep ditch of 5–6 m wide (Fig. 6; site 11). The fortress is watched through 17 towers of which 13 are rectangular mostly belonging to Sultan El-Adel; and 4 are rounded believed to be for Saladin [67]. 8 towers

on the southern side, 4 towers on the eastern side, and 5 towers on the northern side [22]. The fortress is supported with underneath big cisterns (Fig. 7a).

On the southern facade of the small Mosque, above the door giving access to the city, in situ, a limestone slab represents the text of construction bearing an inscription engraved in relief within two-dovetailed frame [18]. Ten lines, also, are observed in Ayyubid Naskhi, without diacritical dots (Fig. 7b). These cisterns are constructed to store large amounts of water needed for bathing, ablution, and prayer during the (Hajj) pilgrimage, so the fortress is outfitted with several bathrooms (Fig. 7c). Several housing rooms and barracks are built around the curtain's wall for both visitors and soldiers (Fig. 6 site 7; and Fig. 7d).

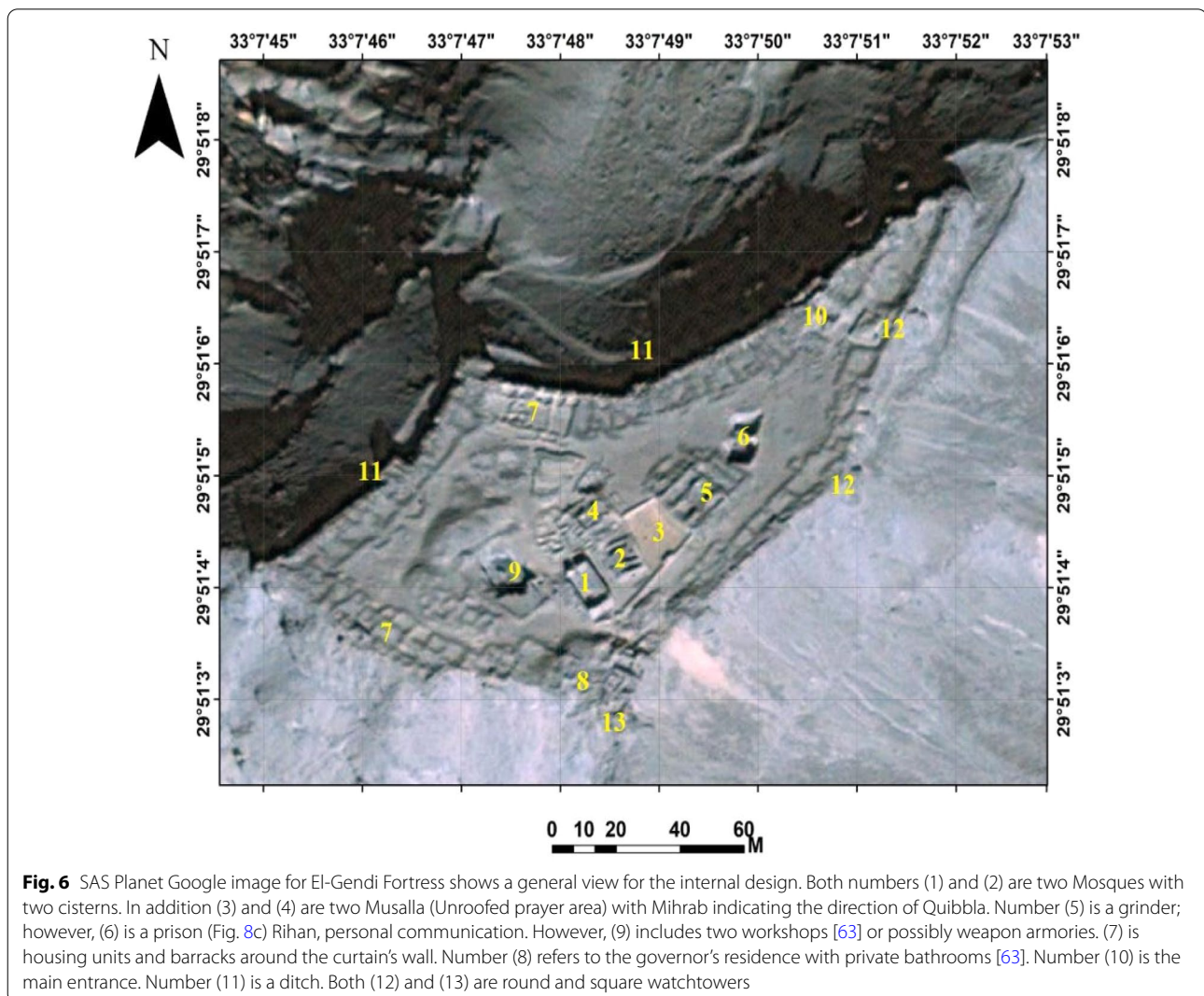




Fig. 7 The grand Mosque with cistern (a) [18], small Mosque cistern with exterior elevation of the Quibbla wall with the text of construction (b) [66], the entrance of the bathrooms (c), and the ruins of barracks (d). The internal design incorporates religious elements which is demonstrated by the presence of four mosques (Fig. 6; sites 1–4), two of which are unroofed "Musalla" (Figs. 6; sites 3–4; 8a), they are always used for crowded worshippers, possibly during Eid. The Mihrab (Fig. 8b) of Fatimid dimensions and ornamentation [66], as well as windows of radial shapes, support the idea that the fortress has been built before Saladin and belonged to the Fatimid Caliphate during the Era of Khalifa Al-Amer (1102–1130 AD), [68]. Shops or weapon armories are discovered (Fig. 6 sites 6, 9) [67], and related to military purposes, however, site 6 is referred to as a prison (Fig. 8c) [21]. Among the renovations made by Saladin is a monumental square external entrance crowned with a limestone arch whose keystone bears an inscription in the name of Allah (Fig. 8d). On the other hand, the inscriptions engraved on the internal entrance show two six-pointed stars (Fig. 8e) that also scatter on walls and ceilings, it is the iconic six-pointed star of Saladin (Fig. 8f) [21, 69, 70]

Basin morphology

Remote sensing images are used to explore the structural lineaments in forming the geomorphology of the study area and the basin's interrelations. The automated lineament map exhibit three prominent trends NW–SE, NE–SW, and N–W with the less prominent N–S, E–W, and ENE trends (Fig. 9).

The basin is subdivided into the Northern part with relatively low structural elements, while the southern and southeastern parts are structurally controlled. These are compatible with the trends of N50°–60°W, N20°–40°W, N50°–60°E, and N20°–30°E [41] (Fig. 3b). The NW–SE and E–W are lineaments associated with the trends of the Gulf of Suez and the Mediterranean. These structures control the shape of the Wadi Sudr basin; they are, also, compatible with the numerous sub-basins.

The contour line connects points having the same elevation (height) above a given level, such as the mean sea level. A contour map is a map that depicts the earth's surface topography, such as heights, hills, mountains, depressions, valleys, and hills, as well as the steepness or gentleness of slopes. It, also, shows the elevation difference between the structural elements. Furthermore, it depicts closely spaced contours at the south and southeast of Wadi Sudr basin (Fig. 10) reflecting the steepness of the wadi which is compared to structurally controlled lineaments (Fig. 9). The surface at the north and northwest has a gentle slope with relatively large spaces and few contour lines (Fig. 10).

The aspect map reflects the slopes in all directions, which is interpreted as rough trains topographic rather than flat without any slope. Aspect directions can be classified on the basis of the slope angle with a descriptive direction. An output aspect raster typically results in several slope direction classes. The aspect map of Wadi Sudr (Fig. 11) shows two major trends one is the SE (112.5–157.5) prevailed at the north and northwest borders of the Wadi, and NW (292.5–337.5) prevailed at the southern part of the Wadi. Other subordinated trends in decreasing order of abundance, are apparent namely W (247.5–292.5), SW (202.5–247.5), S (157.5–202.5), and E (67.5–112.5) (b). These are compatible with the lineament trends (Fig. 9) and closed contours (Fig. 10). There is a mixture of the west (247.5–292.5) and southeast (112.5–157.5) compatible with a series of northeast faults seen in Fig. 11 near the downstream of Wadi Sudr.

The bifurcation index rises, indicating a strong structural control [71]. Simultaneously, as the discharge increases the gradient decreases [72], the velocity increases; in other words, the channel dimensions (width and depth) increase to accommodate the increased discharge. This basin division, clearly, separates Wadi Sudr

basin from Wadi El-Bruk and Wad El-Arish basins. In contrast to what has been stated that [23] Wadi Kuhayla is a tributary of Wadi El-Arish basin. Wadi Sudr basin is made up of deeply incised radial ravines (Fig. 12a, b) that sculpted their way toward the Gulf of Suez during heavy rains. For delineating the drainage pattern and basin at Wadi Sudr, a more high-resolution DEM-30 is used (Fig. 13), revealing more details and showing a more detailed dendritic pattern of the 6th order. According to this DEM, Wadi Sudr basin is divided into nine sub-basins (Fig. 13); three of which (sub-basins 2, 3, 4) are responsible for replenishing the existing springs at Sudr, Abu Rugum, and El-Disah (Fig. 13).

These springs are located on extensive intersected faults; their water is most likely derived from a Jurassic-Lower Cretaceous aquifer of Nubian sandstones Malha Formation [34]. The increases, in the number of sub-basins, reflects the presence of several structural elements, in accordance with the deduced structural elements (Fig. 10), and diversity in rock types [41].

The location of the barrages concerning El-Gendi Fortress is a riddle; both are located in one sub-basin (sub-basin 1 of 5th order) (Fig. 14a, b). This makes us deal with sub-basin "1" as an individual basin (Fig. 14b), and use a DEM 12.5 to separate the smaller basins inside the sub-basin "1" i.e. sub-basin "a" (Fig. 14c) where barrages are located (Fig. 14c).

Satellite images of barrages show that they are allocated along flat-lying land 4 km from the fortress; they are, further, used to store the extra surface water in case of emergency or flash floods. The current study confirms the high-density network of the Wadi Sudr basin and a very complicated network reflecting heavy rains and less recharge rate [49, 73]. The hydrologic drainage network demonstrates ideal radial and dendritic types, with structurally-controlled topography, where the Wadi debouching from the high areas towards the coast.

Discussion

Despite Egypt's long history dating back over 3000 years, only the UNESCO designates seven sites as world cultural heritage sites. These sites are; Abu Mina, Ancient Thebes with its Necropolis, Historic Cairo, Memphis and its Necropolis—the Pyramid region from Giza to Dahshur, and Nubian Monuments from Abu Simbel to Philae, all of which were recorded in 1979, Saint Catherine area was added in 2002 [74] and later Wadi Al-Hitan (Whale Valley) in 2005.

A preliminary list of the properties that each State Party intends to consider for nomination includes an inventory of 34 sites, of which was El-Gendi Fortress in 1994 [30]. The current study seeks to introduce El-Gendi Fortress' geo-archaeological features to the global community of

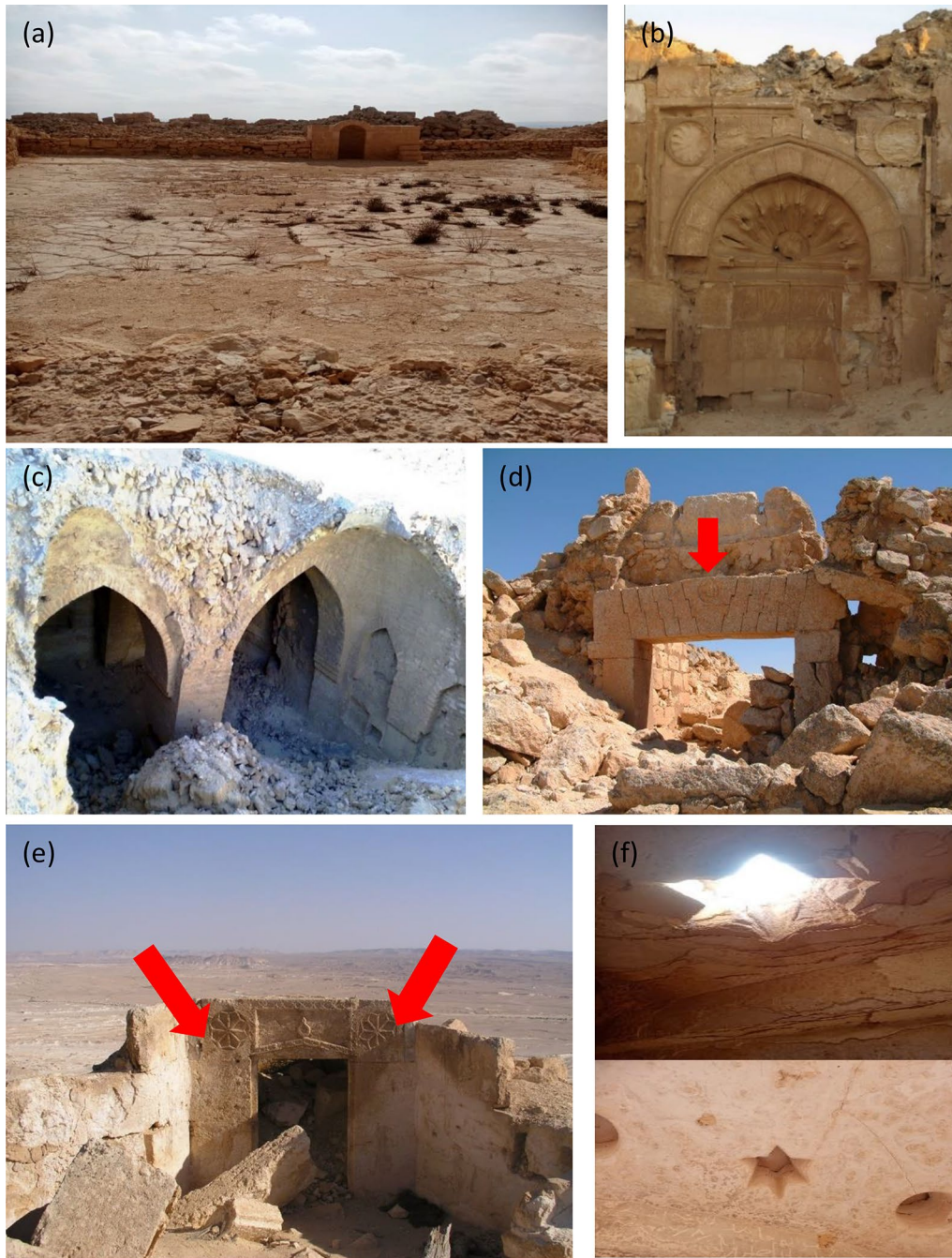
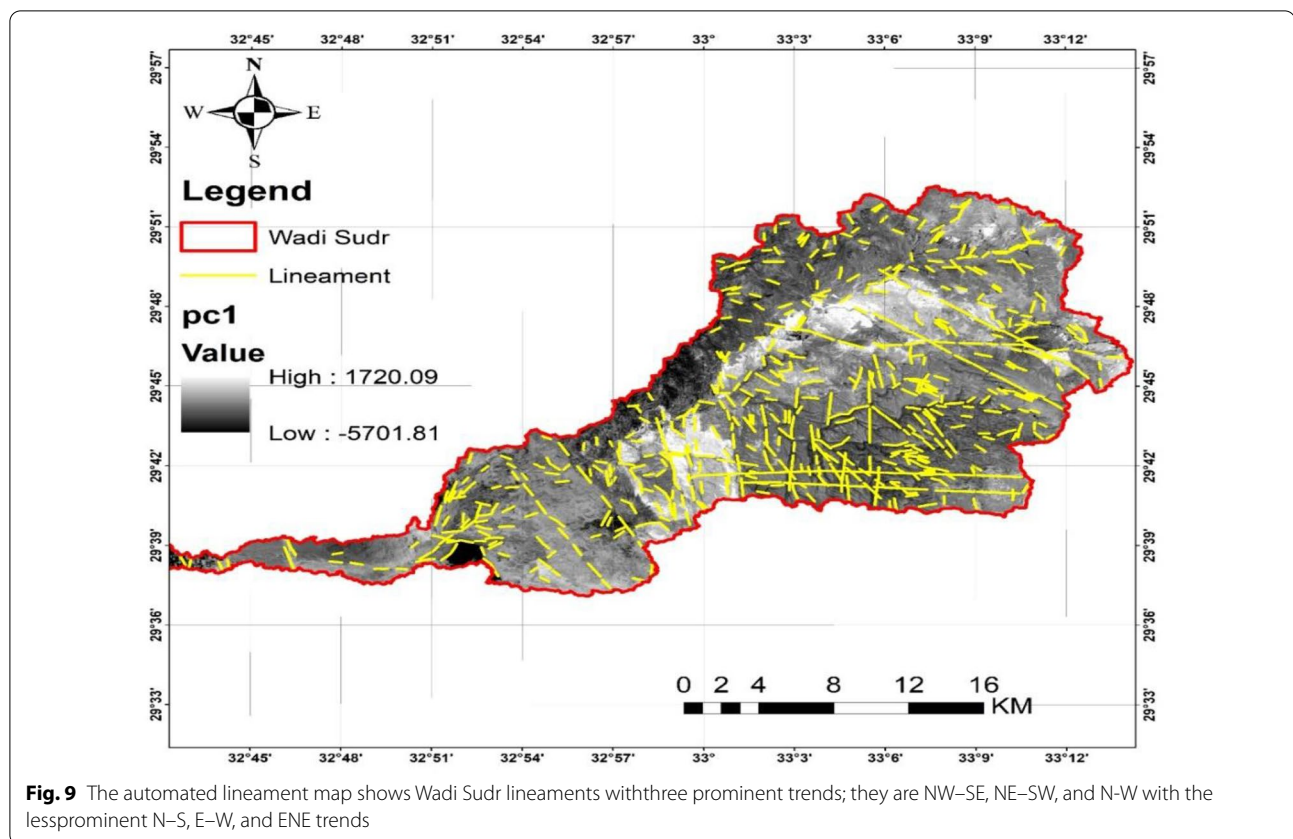


Fig. 8 The unroofed Musalla (a), the Mihrab of the grand Mosque (b) [63], and the prison (c) [64, 66]. The external main entrance of the fortress whose keystone bears an inscription in the name of Allah “arrow” (d) [70]. The inscriptions engraved on the internal entrance “arrows” (e) [70], and the six-pointed star of Saladin scattered on walls and ceilings (f) [69]

heritage and geo-tourism enthusiasts, considered as a religious heritage site involved in the Sinai tourism itinerary [18, 20, 24].

Several pieces of evidence, reinforcing the religious aspect of the fortress, are the presence of Mosques

with the characteristic of Fatimid Mihrab style, the cisterns and, bathrooms for pilgrim’s bathing and ablution (Fig. 7a–c), unroofed Musalla (Fig. 8a) for crowds of worshipers during Eid or on their way to Hajj [23, 24]. In addition to Islamic ornamentations such as that



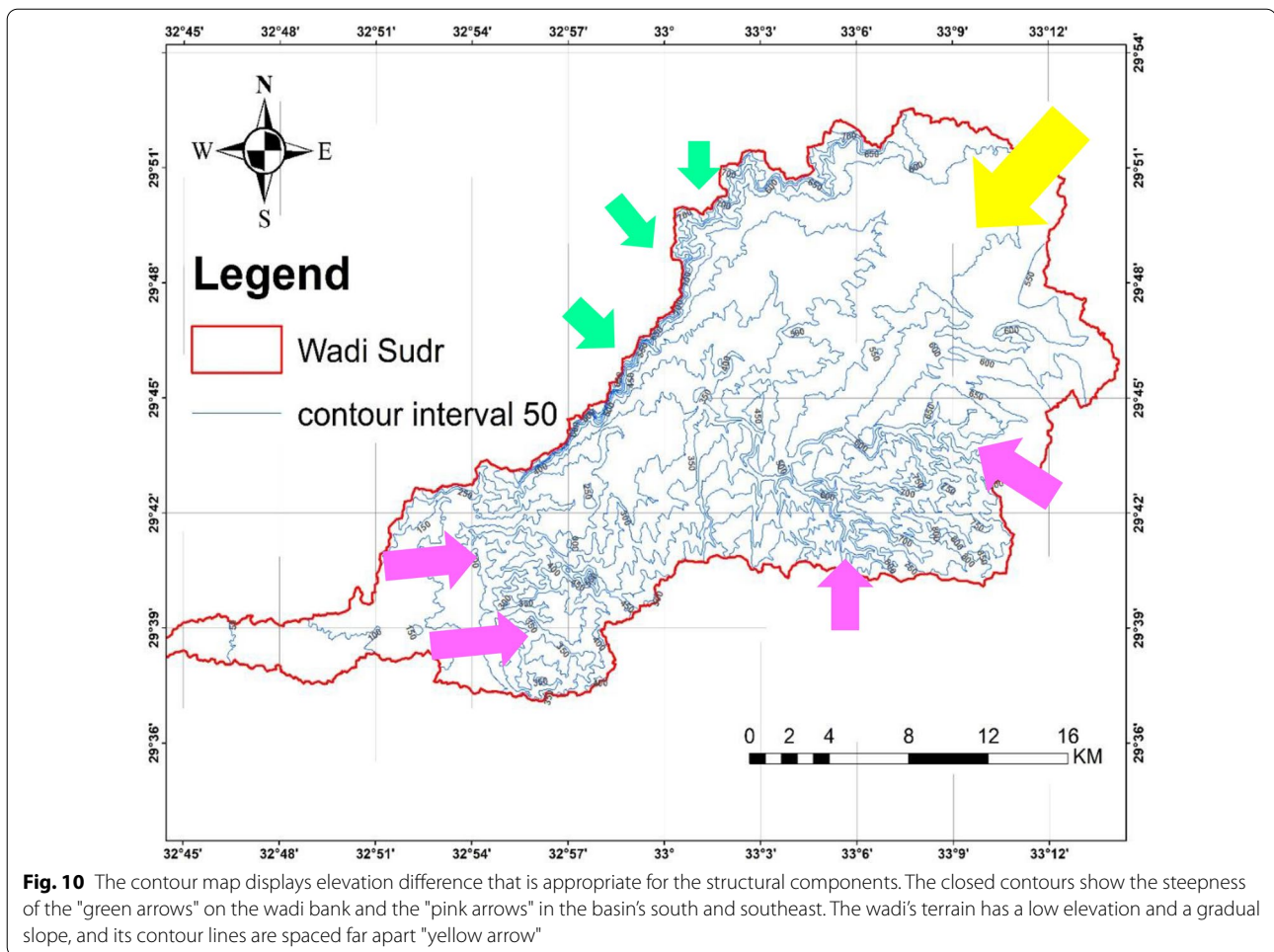
of Mihrab (Fig. 8b), the external entrance with key-stone and the six-pointed star of Saladin engraved on the internal entrance bear an inscription in the name of Allah (Fig. 8d-f), [66, 67, 69]. The Egyptians are accustomed to immortalizing legends by engraving their icons on official palaces. On the other hand, the fortress's military architecture aspects include watch-towers (Fig. 1d), weapon armoires, soldier barracks, and a prison (Figs. 6, 7d, 8c).

The location of the fortress reflects the Egyptians' awareness of several advanced sciences such as architecture and water resource management. The selected fortress's location, on a high mound, allows for exploring the surroundings, giving it a strong defensive position with a commanding view of the lower areas (Fig. 1b, c) [7, 9, 18, 20, 24]. It, also, provides an exceptional access to fresh water from underground and surface sources through Sudr spring (Fig. 2a) and barrages respectively (Fig. 2b-d). The presence of pottery shards, near the spring similar to those found in the fortress, supports this source [26, 66].

The current climate, in the fortress region, follows the Mediterranean system, with most rains-derived forces coming from the northwest quadrante [25], with an average annual rainfall of 50 mm. During the

Pleistocene, the climate has been more humid, with heavy meteoric waters charging the Nubian sandstone aquifer [28, 76]. This water can reach shallower environments through the shallow young structural elements of the limestone plateau, and the deep old structural elements of the Nubian sandstones [37] to Mallha Formation, which has been identified as a potential source of such springs east of the Gulf of Suez [77, 78]. Nonetheless, the geomorphology of the deeply incised ravines reveals that the study region experiences heavy rains (Fig. 1c, d), [79-81] extending beyond the Pleistocene to the time when the fortress was in work. These heavy rains caused flash floods that threaten the fortress and enforced the construction of the barrages.

The presence of the three barrages (Figs. 2b-d, 14d) barring waters at the upstream watershed sub-basin "a" near the fortress, supports the presence of flash floods [75] while the fortress was in work (Fig. 14b, c) [26, 66, 67, 70] supports the concept that El-Gendi Fortress is subjected to recent periods of heavy rains. This prompted those in charge of the fortress to focus on water resource management to reduce flood risks. This confirms that the barrages and the ditch primary roles are to protect the fortress from flash flood



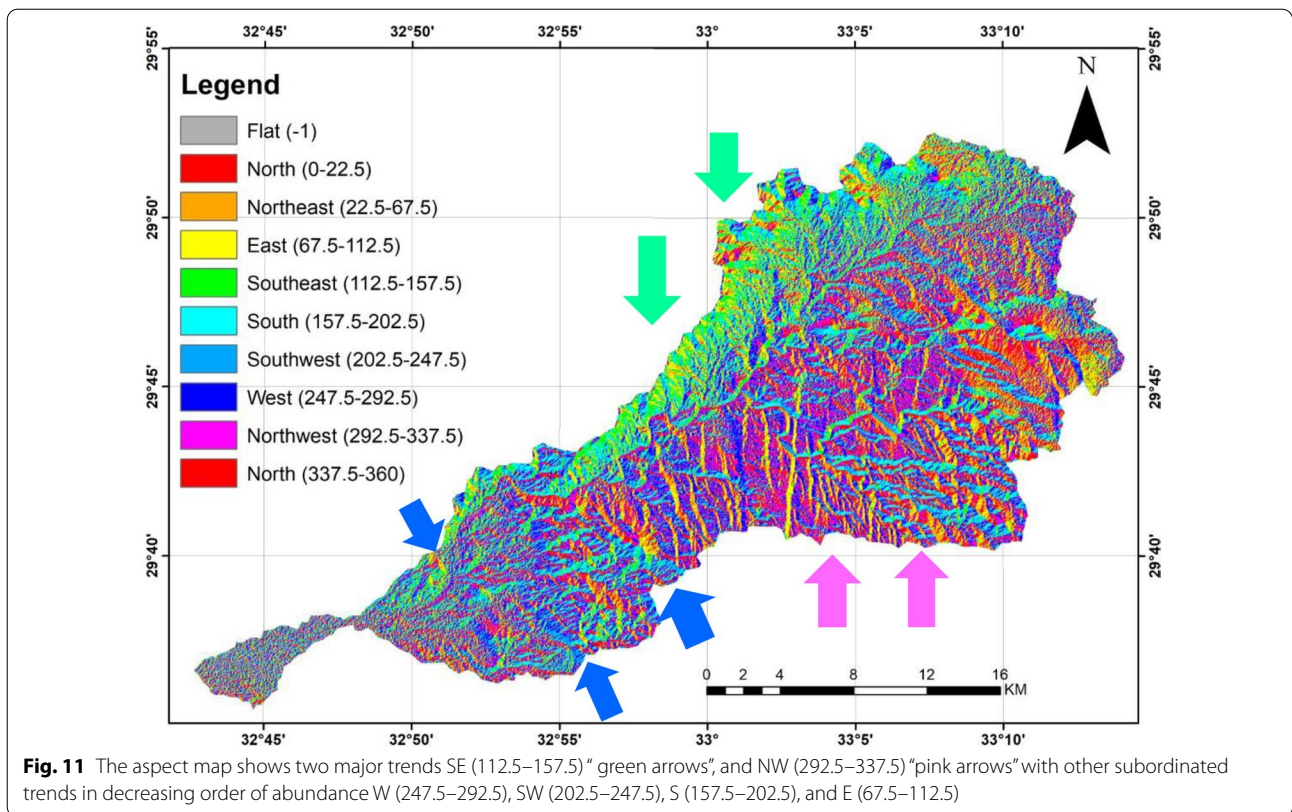
risks and land sliding that may have occurred at any time. i.e., the fortress is built on a mound composed of chalky limestone and shale. This conclusion contradicts most of the previous studies assuming that the ditch is excavated for defensive purposes [7, 9, 18, 19, 66, 67, 79]. This may be acceptable if the ditch is drilled in an easily accessible location. However, its current location may rebut the defensive purpose.

At the end of the current study, it is critical to discuss El-Gendi Fortress as a geo-archaeological site in the frame of conservation and heritage management issues in order to be included in the tourism portfolio of religious and military significance. The conservation of the archaeological site is a critical issue for extending the life of the site because it provides future generations with a sense of continuity and identity in a rapidly-changing world [82, 83]. Heritage management, on the other hand, is a developing field concerned with identifying, protecting, and stewarding cultural heritage in the public interest [84]. Cultural heritage management entails striking a balance

between developing the tourism industry, generating revenue, and preserving the physical integrity of sites during promoting and celebrating their educational, historic, and cultural values [85, 86].

Despite Egypt's care of heritage sites, still the majority of these sites suffer from a lack of services; even some of them are not documented on Egypt's archaeological map [87]. Egypt should, therefore, focus more on accelerating the addition of new cultural sites to UNESCO's list. Opportunities for better management of these sites may arise from using the prestige included in the world Heritage List (WHL) to draw more tourists and exploit mitigation strategies to minimize the negative effects of numerous threats on the other hand [88, 89].

The government needs to focus more on the initiatives and plans associated with the preservation and development of the Egyptian heritage sites. It, also, needs to play a significant role in raising public awareness of this process, particularly for the private sector and for non-governmental organizations that can



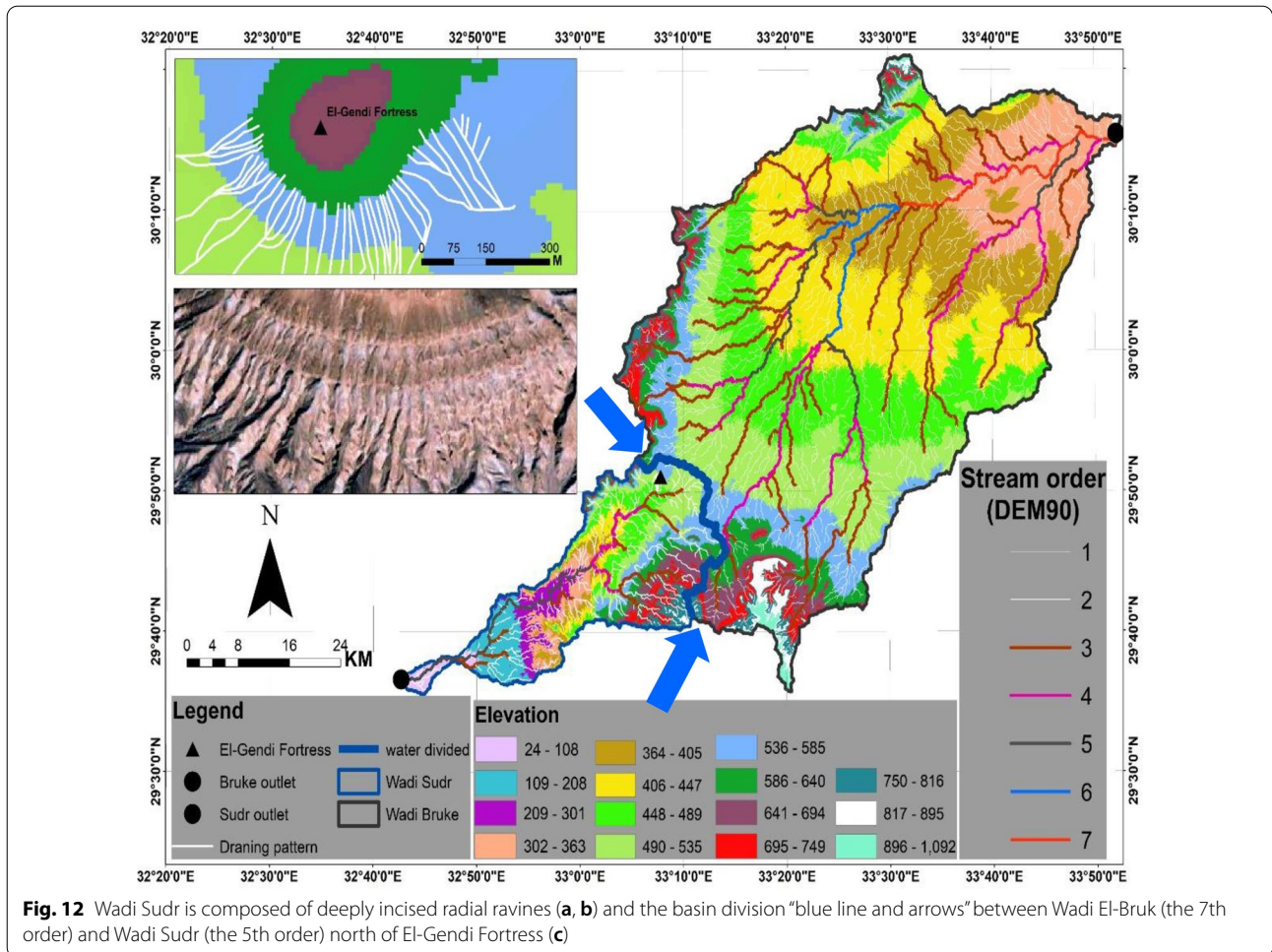
participate in these initiatives [90]. A regional restoration and rehabilitation plan should be implemented concurrently along with a plan of infrastructure development, such as road extension supported by security and police centers, emergency treatment facilities, restaurants, and hotels. In addition, a plan of heritage management includes inventory and recording, interpretation, visitor management, social education, organizational and administrative structure, legislation, financial management, monitoring, and reviewing [88].

Additional activities of conservation, rehabilitation, and management at El-Gendi Fortress should be considered. The construction of two roads to connect Nekhel and Ras Sudr Cities to the fortress should be regarded through building a road with ascending steps to the mound. Furthermore, planning a cultural sound and light historical show should be implemented to configure the history of the passage from the Jewish Exodus, and the Crusades, and catering to pilgrim caravans travelling from North Africa. Finally, the government should set up some events for entertainment and recreation, such as safaris across El-Tih plateau from El-Gendi Fortress to Dahab.

Conclusions

The current study concludes that El-Gendi Fortress demonstrate some features owing to its location: religious, military, geomorphological, geographical, and hydrological. Religiously, the fortress reveals that it has been built during the Fatimid Caliphate through an archaeological viewpoint, most probably during the Era of Khalifa Al-Amer (1102–1130 AD). This is confirmed by the presence of Fatimid Mihrab with characteristic ornamentation. In addition, the fortress has been renovated during Saladin with the addition of a monumental square external entrance crowned with a limestone arch whose keystone bears an inscription in the name of Allah, the engraved on the internal entrance show two six-pointed stars scattered on walls, and ceilings. The presence of an unroofed Musalla and several bathrooms suggest that huge caravans of pilgrims and crowds of worshipers have been accustomed to travelling from North Africa to Mecca during Hajj and Eid prayer. On the other hand, the presence of watchtowers, weapon armories, soldier barracks, and a prison supports military purposes.

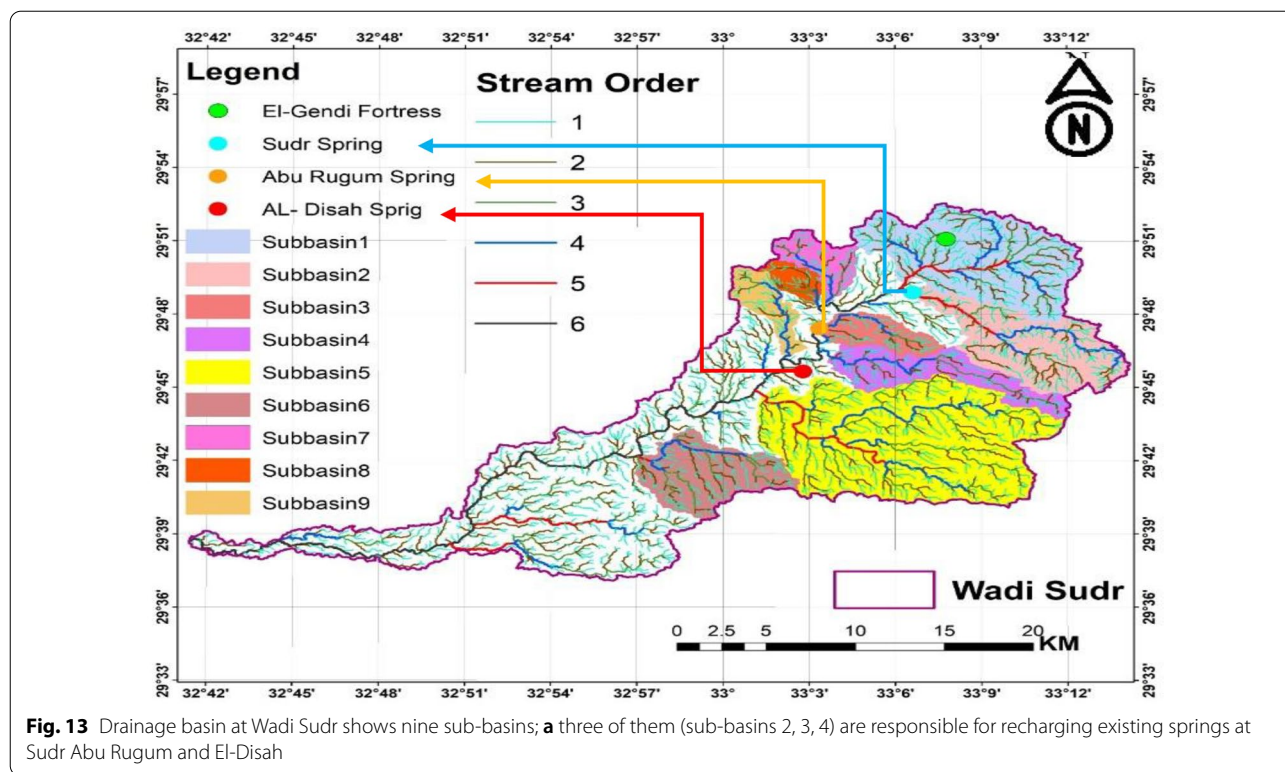
The fortress indicates the progress of Egyptians in several aspects of science. Geographically, the location of



the fortress on a mound of 655 m elevation (a.s.l), with a ditch of 5-6 m depth at the northern side contributes to exploring the surrounding areas and providing the fortress with a strong defensive position. Architecturally, the building materials, used in the fortress’s construction have been selected from the nearby region identifying the knowledge of the rock types, hardness, and cementing material created from these rock units. Geomorphologically, the position of the fortress secures the storage and management of water resources either as ground or as surface water through the Sudr spring or the surface storage behind the barrages.

Remote sensing study along the Wadi Sudr basin confirms that it is structurally controlled, with lineaments

having a W–E trend of the Mediterranean Sea and the NW–SE of the Gulf of Suez rifting. Such old structures affect the deep aquifer of the Nubian sandstones, while the young structures influencing the overlaid carbonates, and bringing the water to the surface, as seen in Sudr spring. Wadi Sudr basin includes nine sub-basins, where sub-basin 1, in turn, is subdivided into smaller subbasins, of which one has located nearby the fortress “sub-basin a”. The large numbers of sub-basins and high-density drainage order denote structurally controlled basins and heavy rains with low discharges. The presence of barrages, at the upstream to the northwest of the fortress conflicting with the usual downstream position, suggests that the barrages were built for water



storage in flat-lying land, to protect the fortress from flash flood risks, which is confirmed by the presence of the ditch on the same side. The hydrologic drainage network exhibits ideal radial and dendritic types, with structurally controlled topography, where the wadi debouches from the high areas towards the coast. This indicates that the climate was rainy in recent times when the fortress was functioning.

Archeologically, El-Gendi Fortress is a distinguished geo-archaeological site in Sinai that should be promoted on a global scale for those interested in geological heritage and geo-tourism. As the case in most fortresses, it is an Egyptian approach to build border fortifications for protection purposes. Most fortresses are damaged; nonetheless, two famous fortresses are still witnesses at the isthmus of Suez and Aqaba: El-Gendi Fortress and Pharaoh’s island respectively. Although Pharaoh’s Island becomes well-known owing

to its proximity to Taba and reclamation through political and military conflicts, El-Gendi Fortress is unnoticed despite its old military importance in overlooking the Gulf of Suez and the passage road, which identifies the religious significance of El-Gendi Fortress, considered the ancient Hajj route.

The study recommends some effective strategies to configure the diverse roles of the geo-archaeological sites such as El-Gendi Fortress. Instantly, implementing a national strategy for the conservation, rehabilitation, and management of heritage sites begins with the registration of new cultural sites to the UNESCO list. Thereupon, there are some improvements of facilities and an increase in public awareness of these sites. Accordingly, El-Gendi Fortress is involved as part of the Sinai tourism itinerary and is promoted globally as a geo-archaeological site for geo-tourism, therefore, more tourists will be attracted.

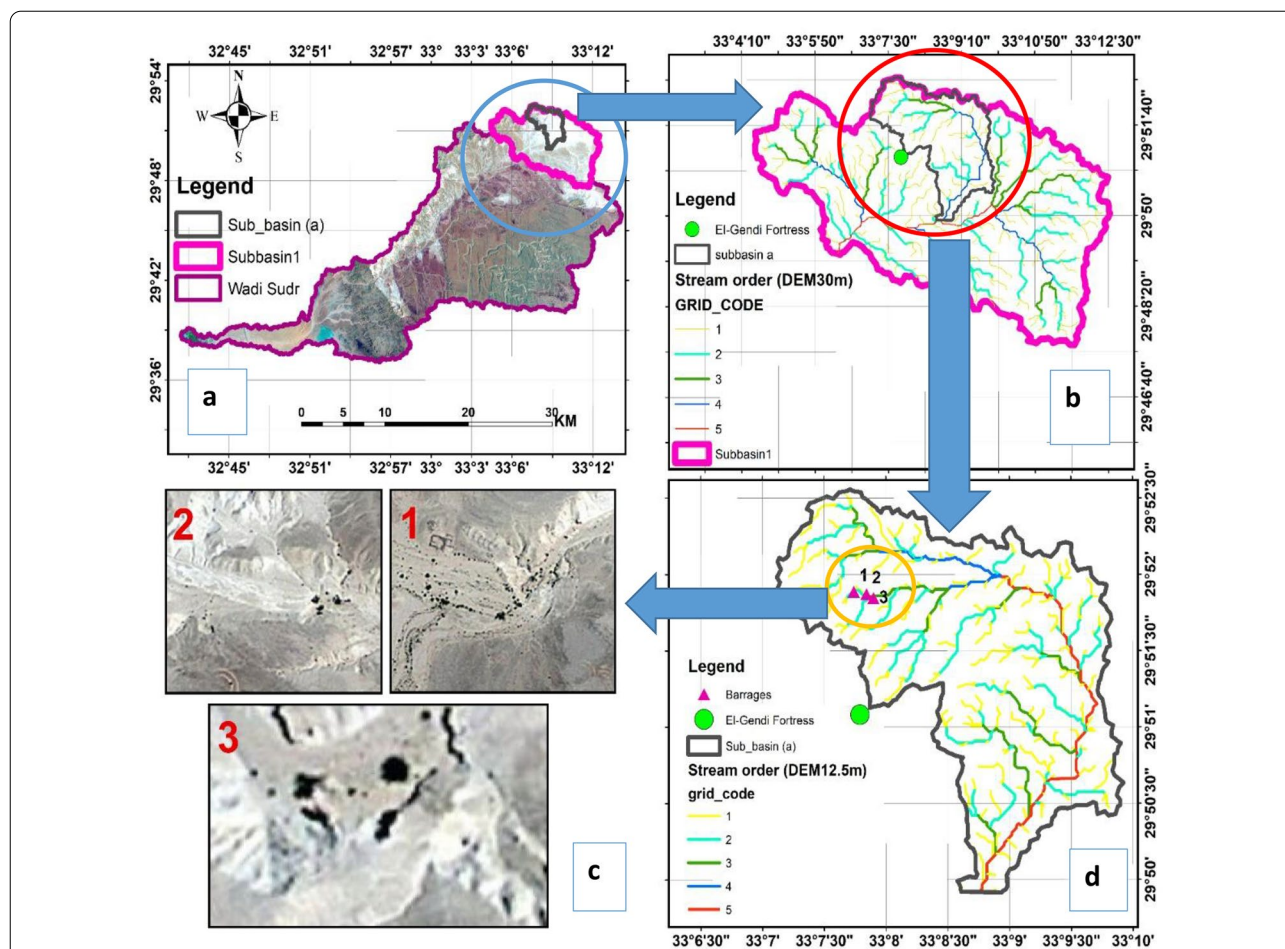


Fig. 14 Drainage basins of Wadi Sudr is deduced through using DEM-30 (a) showing the 5th order drainage pattern with the location of the fortress at the basin division (b). The upstream of the 5th order tertiary basin of a DEM 12.5 (c). The satellite images shows the locations of the barrages (d) in a flat-lying land “pink arrows”

Abbreviation

DEM: Digital elevation model, a.s.l. above sea level.

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Author contributions

HE-A puts the concept, writes the paper and is the correspondence author finally he joined the field work. TE-E is responsible for the archaeological data. MT is responsible for the Remote Sensing Data processing and interpretation. All authors read and approved the final manuscript.

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Availability of data and materials

The data is collected from field work and photographing, published work, Archaeological reports and Remote sensing image The data were downloaded from US Geological Survey (USGS) websites (<http://glavis.usgs.gov/>; <https://scihub.copernicus.eu/>). (3) Several images for the studied area from Google Earth with resolution 0.5 m (Google Earth program – online program) and from SAS Planet with accuracy 0.5 m for year 2022.

Declarations

Ethics approval and consent to participate

Not Applicable.

Consent for publication

Not applicable.

Competing interests

Not applicable no conflict of Interest.

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