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ENVIRONMENTAL AND CLIMATIC HAZARDS AND THEIR IMPACTS ON THE CULTURAL HERITAGE OF EL-KHARGA OASIS, WESTERN DESERT, EGYPT

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Abstract:
The archeological sites in El-Kharga oasis represent a tangible cultural heritage of outstanding universal value. Such monuments have suffered environmental and climatic hazards, especially the climate extreme and climate change throughout thousands of years. The current research focuses on determining the deterioration response that has occurred for hundreds of years to the impacts of environmental and climatic hazards in El-Kharga oasis since the Twenty-sixth Dynasty (664 BC) such as the temple of Hibis and beyond many Greek-Roman temples of 13 largest archeological sites (i.e. Umm El Dabadeb, Ain Amur, El-Nadoura, Kasr El-Zayyan, Doush temple, Deir El Monira, Ain El Labkha, Kasr El-Ghawieta, El Gib, Qasr El Somira, Al Tarakwa, El Dabashya and Remains of prehistoric times as in Gebel el-Teir). The current study aims to determine the environmental hazards that affect archaeological sites that represent a tangible cultural heritage in the study area under investigation, to understand and predict the type, nature, and magnitude of environmental hazards that affect the archeological sites in El-Kharga oasis. The fieldwork was accomplished with laboratory tests for some rock samples selected from sites with delegated weathering type and deterioration group of all the archeological sites under investigation. Seventy-one samples have been tested by X-ray diffraction analysis (XRD), polarizing microscopy (PLM), and scanning electron microscopy equipped with an energy-dispersive X-ray analysis system (SEM-EDX). Based on the results of the current study, it has been concluded that most archaeological sites under investigations have reached the categories of severe damage, based on laboratory analyzes and periodic field studies. The present study concluded that there are several potential environmental hazards with significant impact on archaeological areas in El-Kharga oasis include (weathering hazard represents 45%, underground water hazard represents 18%, sand encroachment hazard represents 12%, human-induced hazard represents 15% and climate extremes and climate change hazards represent 10%) of total deterioration ratios, and in some cases, through graffiti.

1. Introduction

Nowadays it has become obvious that in situ conservation of the archaeological heritage is endangered by different environmental hazards such as climate change, erosion, urban sprawl, sand encroachment weathering, and underground water, [1]. These hazards coupled with the anthropogenic interventions [2], increase the decay of archaeological remains. Jointly, the serious damages that most archeological sites have experience in the thousands of years past and the accelerating velocity of urban extending within the latest decades, have made the protection of cultural heritage sites an essential task [3]. El-Kharga oasis has unusually extensive archeological and heritage sites. These sites are very adversely affected by environmental and climatic hazards. Realizing and respecting of the prominence and value of tangible and cultural sites is overwhelmingly unsatisfying [4]. One of the most intractable problems facing those responsible for cultural heritage in El-Kharga is that of environmental and climatic hazards, especially for more than 14 natural and cultural heritage properties in El-Kharga oasis. Recalling all these challenges little is known that El-Kharga oasis monumental sites are considered an important part of our world´s tangible cultural heritage in Egypt. These sites represent cultural heritage and ancient civilizations of outstanding universal value. Naturally occurring processes such as atmospheric, geological, biological, and anthropogenic processes continually threaten monumental sites [5]. Sand and limestones and granites represent the characteristic stone types used for the construction of the Pharaonic monuments in Upper Egypt, and the Greco-Roman monuments in the western desert of Egypt [6]. Since their construction, the temples, castles, forts, and churches have suffered stone weathering. Most monuments in El-Kharga oasis have suffered environmental and climatic hazards. Stones have become the widely used construction material in ancient buildings due to its enormous resistance against natural and environmental conditions when compared to other construction materials [7, 8]. However, stones also wear out and deteriorate in the course of time because of environmental and climatic hazard impacts. Already Herodotus mentions in his history that the stones of the pyramids in Egypt were already deteriorating when he saw them in the 5th century BC [9]. Historical, references to El-Kharga oasis go back as far as the old kingdom, but little evidence remains in El-Kharga today of life in pharaonic times. Throughout its history, El-Kharga oasis considerable to have been the appropriate place to expel undesirable inhabitants or persons signed by rulings from the Nile valley region, because the oasis is 350 km away from the Nile valley, and its temperatures rise with the increase in the frequency of dangerous sandstorms, this fact confirmed by the records dating back to the modern kingdom [10]. The climate in Egypt is substantively arid and hyper-arid, describe by hot, dry summer months, mild winter, and erratic rainfall. Based on Köppen's climate classification, the "extreme desert climate" (BWh) prevails in El-Kharga oasis [11]. The majority of Egypt is covered by the desert, which represents the extremely extended area of severe drought. For at least 4000 years, Egypt has been facing climate conditions, which have impacted archeological sites [12,13]. Hazard is the probability of occurrence within a specific time and within a given area that an event (geotechnical, geological or geomorphological processes) will adversely affect people or the things society values such as the cultural heritage. Throughout history, natural and man-made hazards lead to the destruction of some famous monuments [14]. Interestingly, environmental hazards are a widely used term to describe threats to people and what they value including life, well-being, and heritage by environmental factors [15]. Environmental and climatic hazards in the study area are among the main reasons for the damages suffered by archaeological monuments. There are direct, indirect, and secondary effects from the natural and human hazards which are relatively better investigated in respect to their influence on the cultural heritage in El-Kharga oasis. However, it is also noteworthy that the term cultural heritage was known since antiquity [16]. Also, cultural tangible heritage is the inheritance of tangible artifacts and intangible assign of a group or community that belongs to the past generations, preserved in the present—day and bestowed for the benefit of future generations. [17] Has divided cultural heritage into two categories: tangible and intangible cultural heritage. It is known that tangible cultural heritage is divided into two main categories, which are the movable and immovable tangible heritage. Immovable heritage includes historic buildings, monuments, and archeological sites. While the movable heritage includes paintings, sculptures, furniture, wall paintings. Tangible cultural heritage involves historic places, monuments, artifacts. Intangible cultural heritage symbol to the knowledge, expressions, and skills, in some cases, individuals recognize as part of their cultural heritage [18].

2. Study area

El-Kharga oasis exists in the southwestern of Egypt. It is located between latitudes 22º30'14" and 26º00'00" N, and between longitudes 30º27'00" and 30º47'00" E. covers about 7500 square kilometers, fig. (1). El-Kharga oasis has been an important crossing passage for the caravans through the desert since the 12th dynasty (c.1785-1665 BC). Geologically, the study area is composed of limestone (Lower Eocene) chalk (Palaeocene) as a cap rock for the plateaus, and clastics of shale, clay, sandstone (Cretaceous) forming the floor and the cliff below the escarpment rock. Quaternary fluvial, karst, and Aeolian sediments uncomfortably overlie the bedrocks [19]. The natural discharge of underground water from the Nubian sandstone on the floors of El-Kharga made it possible for prehistoric people to gather, live, and cultivate the famous oases in the huge Kharga-Dakhla Depression. The cultural heritage of both Ancient Egyptian and Greco-Roman has been found in El-Kharga oasis. Furthermore, the evidence indicates that the Kharga oasis has remained home to new settlers and communities from the Nile valley for a long time. The geology of El-Kharga oasis is very well documented in [20-26]. As previously indicated, to achieve its aims, the current study is based on sample collection and preparation, a total of 71 fresh and weathered block samples were collected from fourteen archeological sites temple of Hibis and beyond many Greek-Roman temples of 13 largest archeological sites (i.e. Umm El Dabadeb, Ain Amur, Kasr El-Zayyan, Doush temple, Deir El Monira, Ain El Labkha, Kasr El-Ghawieta, El Gib, Qasr El Somira, Al Tarakwa, El Dabashya and Remains of prehistoric times as in Gebel el-Teir). All the archaeological remains have their own intrinsic value illustrated in fig. (2). However, the archaeological remains earn a high-level value if taken all at once as a living witness of the historical event of El-Kharga oasis. Each site adds significant information to our knowledge of daily life along El-Kharga oasis.

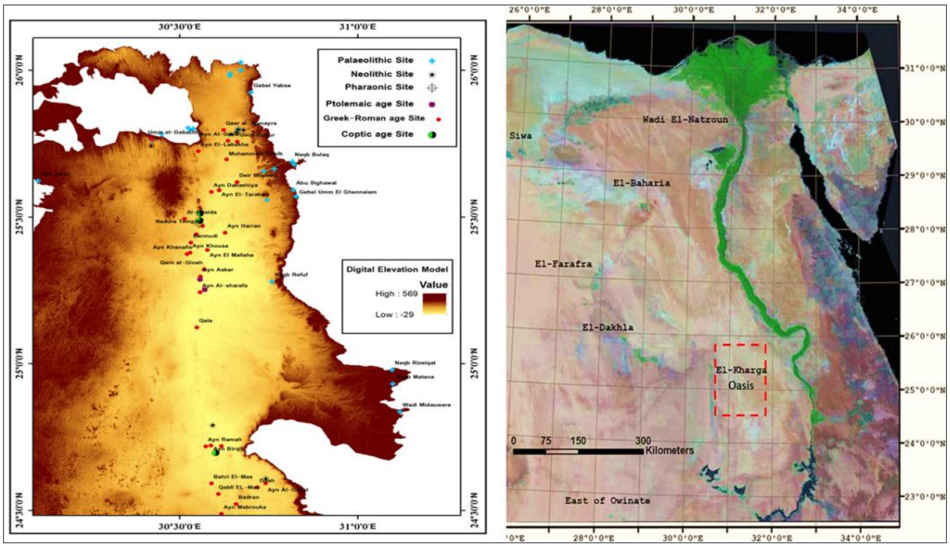


Figure (1) The Location map El-Kharga oasis.

Figure (2) Shows samples of the archeological sites under investigation; **a.** Hibis temple, **b.** Qasr Dush temple, **c.** El-Ghwieta, **d.** Umm El-Dabadeb **e.** Deir El-Monra, **f.** Qasr El-Gib, **g.** Ain Amur, **h.** El-Nadours temple, **i.** Gabel El-tier

3. Material and Methods

To achieve the objectives of the present study, the following analytical techniques and scientific methods have been used to determine all environmental and climatic hazards that have affected the archeological sites, and to understand and predict the type, nature, and magnitude of environmental and climatic hazards that affect the archeological sites in El-Kharga oasis under investigation

3.1. *Condition assessment*

All the weathering forms were recorded along with their dimensions (e.g., width, depth, density, thickness, and length). They were then categorized into five groups following [8] classification, tab. (1). Monitoring and photographing the hazards of groundwater and sand dune encroachment. Through field observations the current study was divided the environmental and climatic hazards that affected the archaeological sites in El-Kharga oasis classified into five categories according to the effect percentage (%), tab. (2). In this regard, the seasonal climate data were specified as follows: winter is the average of December-January-February; spring is the average of March-April-May; summer is the average of June-July-August; and autumn is the average of September-October-November, tab. (3). The winds data are available in a regular format and represent the annual average of hourly occurrence of surface wind measured at 10 m height above ground and are coordinated into twelve wind speed classes in twelve directions. These data were very useful for monitoring the hazards of sand dune encroachment over archaeological sites in El-Kharga oasis.

Table (1) The damage category of the archaeological sites in El-Kharga oasis

Damage category	Damage Category scale
0	No visible damage on the stone's surface, inscriptions and/or paints
1	Very slight weathering on inscriptions and/or paints to less than a 1 mm depth, or less than 5% of the wall side.
2	Slight back weathering on inscriptions and/or paints from a 1–2 mm depth, or 5–10 % of the wall side
3	Moderate weathering on inscriptions only, as paints are totally demolished at this DC, back weathering from a 2–5 mm depth, or 10–25 % of the wall side.
4	Severe weathering on inscriptions and main rock body as back weathering from a 5–10 mm depth, or 25–50 % of the wall side
5	Very severe weathering on inscriptions and main rock body as back weathering is >10 mm, or <50% of the wall side.

Table (2) The environmental and climatic hazards affecting the archaeological sites in El-Kharga oasis

No	The hazards type	The description	%
1	**Weathering hazards**	This type includes group movement (slip, slices, crusts, and pitting), earthquakes, and mining.	45
2	**Groundwater hazards**	This type includes groundwater seepage and ground-water movement	18
3	**Extreme climate and climate change hazards**	This type involves climate extremes and climate fluctuations.	10
4	**Sand dune hazards**	This type includes sand encroachment and rock fall.	12
5	**Human-induced hazards**	This type involves the collapse or failure of infra-structure, civil disturbances, pollution, and fires	15

Table (3) Normal values of climatic elements and its corresponding anomalies during the three distinguished periods (1940-1965, 1965-1990 and 1990-2018) at El-Kharga station.

Climate elements	Normal 1940–2018	Anomalies 1940–1965	1965–1990	1990–2018
Mean temperature (^{o}C)	25.4	-0.85	+0.3	+ 0.4
Minimum temperature (^{o}C)	12	-1.20	- 0.80	- 0.75
Maximum temperature (^{o}C)	41	+ 0.9	+1.45	+1.20
Max Absolute temperature (^{o}C)	52	-	-	-
Min Absolute temperature (^{o}C)	2	-	-	-
Rainfall amount (mm)	14.2	-1.4	-1.2	-.08
Sunshine duration (%)	88.4	+ 1.09	+ 1.02	+1.1
Wind speed (kt)	8.6	+ 0.25	+ 0.30	+ 0.35
Evaporation (mm per day)	10.3	+0.04	+ 0.08	+0.1
Relative humidity (%)	57	+ 2.30	+2.0	+ 2.45
Cloud amount (okra)	1.70	+ 0.25	+ 0.45	+0.5

Egyptian meteorological authority, unpublished data

3.2. *Remote sensing data*

Ten satellite images of Kharga and Baris oasis from the MSS (1972), TM (1987), ETM+ (2018), The Landsat images (MSS, TM, and ETM+) have a UTM projection and (WGS-84) datum. These images have been interpreted to construct surface geological information and climatic maps in the light of the available topographic maps, to monitor the changes detection by comparing satellite images from different dates (1972-2000-2018), to determine the human hazards during these periods. In ENVI V.6.0 Software, the satellite images were present at a scale of 1:50,000. Sand dune movement at each temple was measured in meters in the four satellite images.

3.3. *Laboratory investigations*

A total of seventy-one fresh and weathered stone samples were collected from 14 archeological sites. It has been conducted using teeny rock samples collected at the weath-ered parts, newly reconstructed parts, and remains of the rebuilding (control) rock used at all 14 temples. These investigations included:

A) All samples were shriveled and grind in an agate lute to avert contamination and were interpreted by X-ray diff-raction analysis (XRD). The samples included hard rock and weathered materials, tab. (4).

B) 20 represented samples were selected and were carefully examined by using Scanning electron (SEM) to check their morphological surfaces and define their dominated weathering forms.

Table (4) Properties of the examined monuments, building stones and main hazards types.

Monument	Location	Period	Sample Number	Main Hazards	Hazard degree	Mineral
Hibis temple	El-Kharga	Persian	8 samples SS	Groundwater	dangerous	Felds,+ Qz
El-Ghawieta temple	Paris Oasis	Late period	6 samples SS	Weathering	weak	Felds,+ Qz
El-Zayan temple	Paris Oasis	Roman	6 samples SS	Weathering	weak	Felds,+ Qz
Gabal El-Tier	El-Kharga	Prehistory	6 samples LS	Climate change	very serious	Felds,+ Qz
Umm El Dabadib	NW El-Kharga	Roman	6 samples MB	Human-induced	very serious	Kao.
Ain Amur	NW El-Kharga	Roman	5 samples SS	Human-induced	very serious	Felds,+ Qz
El Nadoura	El-Kharga	Greek-Roman	4 samples SS & MB	Weathering	very serious	Qz + Kao.
Deir El Monira	East El-Kharga	Roman	4 samples MB	Sand dune	weak	Kao.
Ain El Labkha	N W El-Kharga	Greek-Roman	4 samples SS	Sand dune	dangerous	Felds,+ Qz
El Gib	N El-Kharga	Roman	3 samples SS	Sand dune	dangerous	Felds,+ Qz
Qasr El Somira	N El-Kharga	Roman	3 samples SS	Sand dune	dangerous	Felds,+ Qz
Al Tarakwa	East El-Kharga	Roman	3 samples LS	Sand dune	dangerous	Quartz+ kaolinite
Doush temple	Paris Oasis	Roman	5 samples SS	Weathering	weak	Felds,+ Qz
El Dabashiya	East El-Kharga	Roman	3 samples MB	Sand dune	dangerous	Qz + Kao.

SS: *sandstone*; LS**:** *limestone*; **MB** *mud-brick*

4. Results

4.1. *Condition assessment results*

Considering the weathering forms and their dimensions and the damage category have been defined, using [8] damage category scale for all sites under investigation. The detailed conditions assessment of the wea-thering forms (e.g. salt efflorescence, loss of inscriptions, bad restoration, anthropoge-nic impact, cracking, granular disintegration, intersected cracking, loss of stone material, granular disintegration, back weathering, roughening) and measuring its parameters (e.g. thickness, volume, density) have been proceeded to define the damage category of the temples under investigation, Photo-documentation of the various weathering patterns at the Hibis temple's walls have been exemplified and set in fig. (3). Many deterioration forms have been identified and monitored like detachment of enormous flat layers, usually of uniform thickness, following the profile of the rock surface, and deterioration of stone into thin separated layers following the bedding planes of the rock surface. The presence of whitish deposits of loosely attached soluble salts on a surface it happens when water and salt are present within the rock, water evaporates and therefore the salt travels to the surface, and presence of brownish or grayish deposits, not completely hiding the stone surface, it can be the result of an accumulation of dust and mud, or pollutants. Furthermore, the presence of a compact black layer of deposits as a response of contamination influence could affect a thick black crust, which will detach and fall causing the powdering of the stone at Qasr El-Ghwaieta temple, fig. (4). A quick inspection of these weathering forms of Kasr El-Zayyan temple reveals that the presence of loose masonry blocks in a structure, and large cavities in the non-homogeneous stone surface, which is the result of different rates of erosion parts of the stone, missing pieces of stone as well as various sized compact fragments. It occurs due to mechanical stresses, and vandalism due to human influence. As can be seen from there are identifiable fractures in the stones that occur in response to the influence of climate factors or for structural reasons, fig. (5 a, b). The results of field observations have been considered and utilized in the present work as focusing on groundwater hazards and its impacts on Hibis temple as a case study.

Figure (3) Shows different weathering forms at Hibis temple; **a.** loss of inscriptions, damping, bad restoration, **b.** anthropogenic impact, cracking, granular disintegration, **c.** salt efflorescence, contamination, loss of inscriptions and bad restoration, **d.** some damage categories affected sandstone of El-Ghwieta temple, **e.** & **f.** some damage categories affected sandstone of El-Zayan temple

4.1.1. Effects of underground water

The relationship between the structures of El-Kharga oasis, the groundwater supply, and the present-day habitation and the past—occupied archaeological sites is clearly examined. Groundwater springs are restricted to the fault traces located in the middle lowest parts of the depression. Also, along with these faulted areas, the Nubia sandstone blocks are dislocated, emerging upward, forming raised hillocks [19]. The archaeological sites restrict these hillocks due to their rocky terrain allowing the foundation of such big buildings. In addition to the strategic their high position which helps temples and garrison buildings to be constructed [11]. Unexpectedly, most temples in El-Kharga were constructed on such a suitable hard sandstone ground. At the same time, the unique temple of Hibis was built on unsuitable shale fine ground in a relatively depressed. In recent years, this unsuitable ground does not support the temple foundations especially in case of high subterranean water table conditions that cause differential swelling. The temple under investigation is of a great value, for that, we have focused on it as a historic structure built 2600 years ago at good environment that became recently aggressive (through the fluctuation of the groundwater level upward and downward, as a result of the sharp changes in temperature, and the weathering of salt resulting from the danger of water. Underground, as well as human influences) affecting its building stones including its inscriptions that reveal part of history that we did not live [27]. The unique temple site is established on bedrock contains a weak rock layer of shale beds reach more than 14 m in depth. These shale layers characterized by highly expandable rocks as its clay content (mainly smectite) experiences swelling upon moistening from the groundwater seepage. Hibis temple site is surrounded by dense agriculture, which represents a double risk threat to the stability of the temple basis. The source of water seepage beneath is partly from an agricultural return flow, which affects the shallow groundwater table. The temple was severely damaged after 1823; it was restored by Émile Baraize. Unfortunately, the rising groundwater has weakened the foundations. The Metropolitan Museum's work at El-Kharga established a precedent for the study, fig. (4-a, b). The Continuous Partial Immersion at Hot and Cool Temperature (CPI-HT/CPI-CT) regimes had been conducted to imitate the climatic conditions dominating at El-Kharga oasis. The regime cycle is 24 h altering among HT (Temp. more than 40 ^{o}C and relative humidity less than 10%) and CT (Temp. down to zero ^{o}C and relative humidity less than 10%) every 12 h, and the stone bars are continuously partially immersed in 0.5 M sodium sulfate salt solution. The test has been extended to 30 cycles i.e. 30 days taking into consideration weighting and documenting the sample every 2 cycles to record the underground water effects over test progress. At the end of the test, the weight loss has been computed. The durability class and value of the original construction rock, reconstruction rocks, and the control rock samples has been determined using Barry diagram (1991) [27]. The extensive use of groundwater for domestic and irrigation purposes from natural springs and deep wells during successive periods led to the present-day lowering in the static levels to tens of meters below the oasis floor. To clarify this further, the frequency of climate change impacts on El-Kharga oasis has extended to the present-day climate and it can be observed that such impacts have been increased. In particular, the risk of groundwater fluctuation, and the accumulation of weathering forms on the walls of Hibis temple.

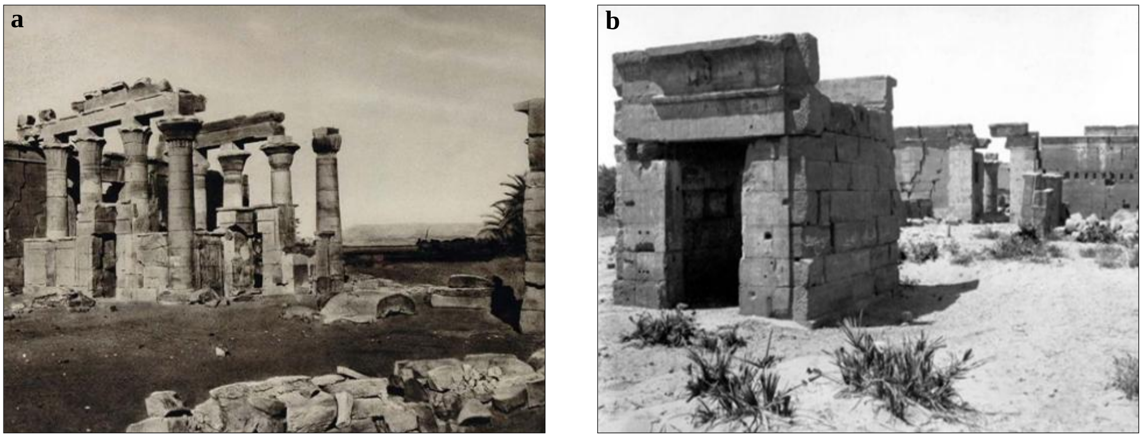


Figure (4) Shows **a.** & **b.** underground hazards affecting Hibis temple 1823(http://www.metmuseum.org).

4.1.2.Effects of climate conditions

A rock art represents ancient Egyptians who had painted a large boat preparing for a hunting mission in prehistory Gabal El Tier, and this indicates that the current desert environment was a rainier environment in the past, and petrified trees existed during wet periods, fig. (5-a, b). In contrast, termination shows the depletion of the aquifer during several centuries when the exploitation of the non renewable groundwater resources represented the adaptation strategy of the Neolithic population. In addition, about 3000 years ago aridity had been increasing for 3000 years, which was expressed in sand dune reactivation and migration further south in the Western desert of Egypt [28]. According to Köppen's climate classification, Egypt experiences the "hot desert climate type" (BWh) in the southern and central parts of the country and the "hot steppe climate type" (BSh) along the coast. El-Kharga oasis is one of the driest regions on the earth's surface, where the solar radiation is mightily evaporating over 200 times the amount of rainfall. The air temperatures range from 51 °C in summer months to 15 °C in the winter months and possibility evapotranspiration is as high as 5 mm/d. To illustrate this further, the climate of El-Kharga oasis is determined by the influence of many factors, the most important of which are: the geographic location, wind belts, air pressure, and great sand seas. Specifically, the regions between the ITCZ and the subtropical highs are dominated by the trade winds. Wind speed head for low in August; it increases gradually in November to February and reaches a peak from spring season (March to May) causing massive dust storms famously known as "El-Khamasin". It has greatly affected the archaeological sites in El-Kharga oasis, this type of local wind has the potential to fill in entire ancient villages and cities, or at least to demolish walls and cause serious damage to inscriptions, writings, and the rock arts. In El-Kharga oasis, the summer temperatures are extremely hot, the mean summer temperature is 32.2 °C and 24.2 °C, 41.2 °C to the minimum and maximum temperature, respectively. Moreover, the temperatures of the spring and autumn seasons reach 33.2 °C and 34.1 °C, respectively. These high-temperature values have a great effect on mechanical weathering of the walls of ancient temples. The mean annual temperature ranges were computed at study stations, showing the highest ranges (e.g. minimum range of 13.2 °C in winter and 17.3 °C in spring), with southward the values of the mean annual temperature ranges rise to a maximum value of 16.5 °C at spring and 18.4 °C in the summer. According to the record of the absolute temperature, it can be observed that May and June months were recorded 50.3 °C at (1/6/1961) and 49.4 °C at (30/5/1998) respectively, fig. (5-c, d). Accordingly, the archeological sites subjected to direct solar radiation, daily, seasonal, and annual variations and changes in air temperatures and relative humidity, where air temperature reaches up to 47 °C during days' time of summer months (June-July-August) and hauls down to about 14 °C during nights time during the same months and varies from less than 5 °C during nights time during the winter months.

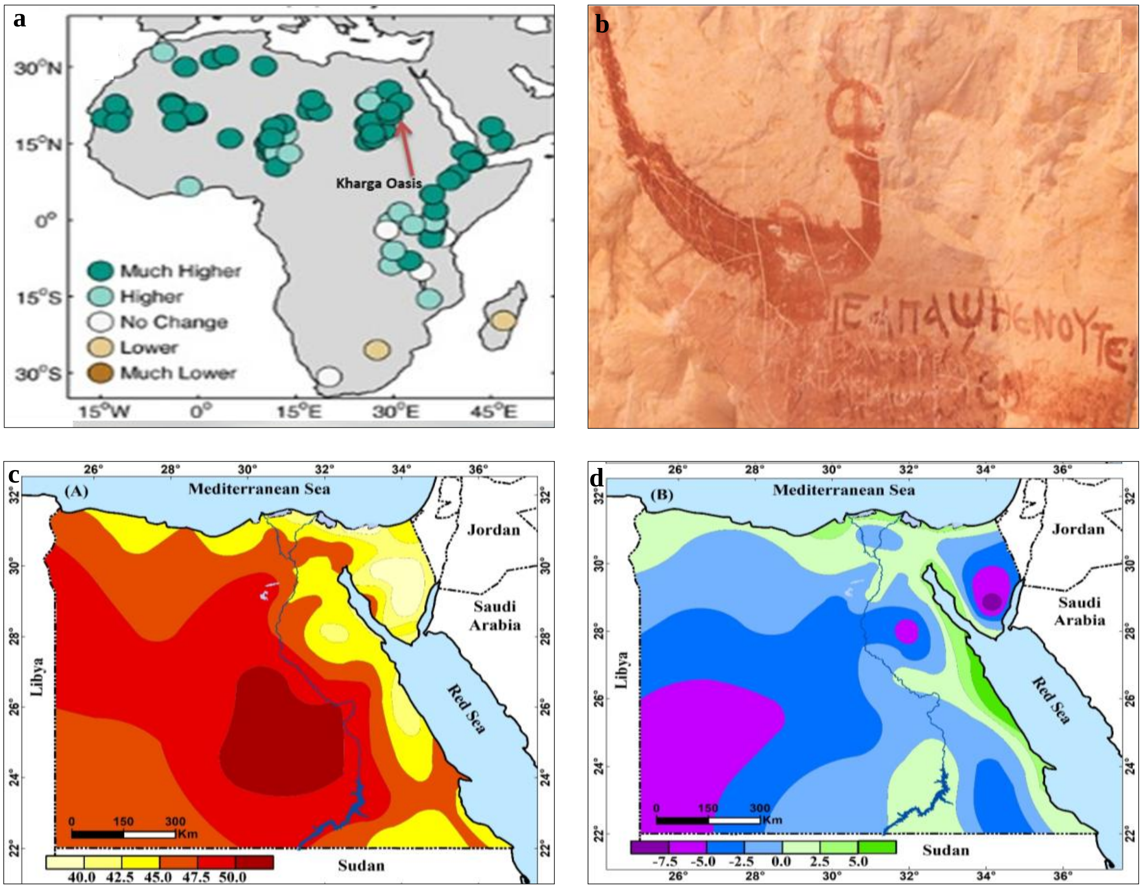


Figure (5) Shows **a.** & **b.** evidences of paleoclimate change in El-Kharga oasis, Shows **c.** & **d.** absolute maximum temperatures (°C) in June and Absolute minimum temperature (°C) in January (based on the Egyptian Meteorological Authority data)

4.1.2.1. *Temperature impacts*

The temperature varies considerably, especially in summer; when they may range from 7 °C at night, to 52 °C during the day. While the winter temperatures in deserts do not fluctuate so wildly, they can be as low as 0 °C at night, and as high as 25 °C during the day. Kharga oasis recorded the highest temperature in the Egyptian air temperature record, on the ninth of June 1961. Therefore, the temperature has a great effect on the stones of the archaeological areas, as the repeated heating and cooling of the stone will ultimately lead to its deterioration over time. As an outcome thermal residual degree that may keep in the stone once it returns to the "normal" temperature. The extending degree of rocks results from those of the minerals present in them induced by temperature changes. Thus, sandstone has high expansion values because of the presence of quartz, white marble and limestone reflect that of calcite or dolomite, and slates that of clays and micas, since it has been metamorphosed muddy rocks such as mudstone. Hence, the temperature is most significant climate elements affecting the walls of the temples by losing of stone material parallel to the stone surface or profile, detachment of small, flat, thin pieces of the outer layers of the stone or rock surface, presence of small cavities in the inhomogeneous stone surface, which is the result of different rates of erosion of discrete parts of stone and fracture in the rock, with one side displaced relative to the other.

4.1.2.2. *Humidity impacts*

The relative humidity varies from about 76% during night's time during the winter months (December-January-February) and hauls down to less than 20% during days' time of the same months and varies from about 57% during night's time during the summer months (December-January-February) and hauls down to less than 14% during days' time of the same months in El-Kharga oasis. It is considered high humidity is one of the most important harmful factors affecting stones formed monuments for every construction material. The humidity raising the building can cause serious damages to the structure. At the same time, the salts hold by the building itself can result in inflorescence and some other effects damaging the chemical and physical structures of the walls. Increasing relative humidity motivates microbiological deterioration and led to the presence of living or decayed microorganisms such as algae, lichens, moss, and fungi on the stone surface, sometimes get feeding by the metal found in the scree or stone. Also, the disintegration of the mortar used in jointing the stone wall. Eroded parts of the soft stone surface regularly washed by rain or underground water seepage and missed the wall color, text, and graph, fig. (6).

Figure (6) Shows the humidity impacts on the walls of archeological sites under investigation

4.1.1.1. *Wind impacts*

The spring season (March to May) in El-Kharga oasis is characterized by strong winds, moderately high temperatures, and low relative humidity. For the summer season (June to August) is characterized by high temperature, low relative humidity, and moderate wind speeds over El-Kharga oasis. For the autumn season (September to November) differs from spring with higher values in temperature and relative humidity, and wind events leading to dust storms. The interaction of wind with monuments manifests itself various patterns, thorough: differential weathering; scratching, and undercutting. Aeolian weathering is manifested in all parts of limestone and sandstone formed most temples under investigation, where that sandstone and limestone are low hard and easily eroded due to speed of the wind. It can also be noticed that this analysis is consistent with the sand dunes hazards on the archeological sites in the study area. The impacts of wind and the consequent encroachment of sand dunes hazards are highly shown on all building stones (temples, cemeteries, and castles) in El-Kharga oasis. The wind blows from the north-northwest direction with moving capacity to drift sand dunes from the North, which is a common phenomenon encroaching upon archeological sites; particularly, which have been built on a hilltop 100-140 m. in hyper-arid climate and exposed to the wind without any obstruction such as Al Tarakwa, Ain El Gib, Qasr El Somira and Umm El Dabadeb, fig. (7).

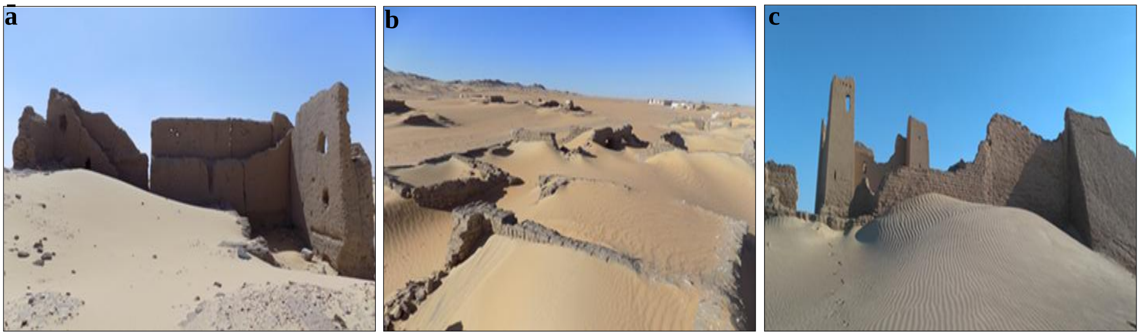


Figure (7) Shows the wind impacts on the archeological sites under investigation

4.2. *Remote sensing results*

Remote sensing has been used successfully in monitoring the sand dune movement. Three sets of sand dunes were selected at El-Kharga and Baris oasis for measuring dune encroachment over the archeological sites human induced hazards using Landsat satellite images. The results of remote sensing data in the current study have been considered as focusing on monitoring the hazards of sand dune encroachment and human-induced hazards on the archaeological sites.

4.2.1. Sand dune hazards

The sand dune hazards in El-Kharga oasis have been treated by some authors; the following is a brief for some important results in their studies [29] measured the diameters of the sand dunes and their rate of movement at El-Kharga oasis, based on two series of aerial photographs more than 16 years apart. He concluded that the rate of movement of the sand dunes depends mainly on the size of the dune and the amount of moisture in the surroundings. In his statistical work on barchans sand dunes of El-Kharga oasis, Southern Peru and California [30] provide that there is a linear relationship and a high degree of association among barchans shape dimensions. He also analyzed quantitatively the dunes profiles with respect to slope angle, slope form and dunes size [31] estimated the average annual movement of 100 m for barchans dunes in El-Kharga oasis. [32] studied the impact of some environmental factors on development in El-Kharga oasis, they used in this study both aerial photos and Landsat images and they revealed a soil deflation annual rate between 2 cm and 2.5 cm. The study also deals with sand movement in the depression. It becomes clear that the dunes are moving southwards by a rate of 30-40 m/year. These two factors indicate that there is a delicate balance between deflation, encroachment of sand moving bodies and the drop of the underground water table in El-Kharga since at least Roman times. It is evident from this study that the sand dunes form a real hazard on the monumental sites. It is evident also that the sand movement rate of these dunes is of 30-40 m/year. The hazard of the moving sands from the huge sand dunes belt to the north most archeological sites is very clear. In this archeological site, the sands derived from great sand seas from the North started to accumulate over most of the temple under investigation, fig. (7).

4.2.2. Human-induced hazards

Oasis of El-Kharga is wealthy of tangible cultural heritage that recorded from the prehistoric past during the several stages of world civilization. Nowadays, such archaeological sites all over El-Kharga oasis are confronting one of the biggest threats. Human-induced hazards not only have caused losses of hundreds of thousands of human lives but have also adversely affected many important cultural heritage sites around the world by causing decay, fractional damage, totally destroy, or the loss of heritage and cultural value. Human-induced hazards represent a real potential threat to these sites in the future. The deterioration or destruction of tangible cultural heritage sites in El-Kharga oasis constitutes a harmful loss to humanity as such sites represent unique and irreplaceable properties of great value to mankind's legacy. Most tangible cultural heritage sites in El-Kharga oasis are threatened by human-induced hazards. The cultural heritage site of Ain Amour, El Labkha and Umm El Dabadeb, are examples. It has been the site of a Greek colony and Roman city. The site was inhabited since prehistoric times. Subsequently, the present archaeological sites are suffering looting before and during the 25th Egyptian evolution. The sites continue to be in peril by the threat of conflict in the region, as well as to the potential impact of mining and cement industries, such as vibrations. Looting and wanton destruction of El-Kharga's tangible cultural heritage have been widespread because the archaeological sites are unprotected and spread over large areas, the vast number of sites in El-Kharga makes this an impossible task at every site. During the field study 2018, skulls from El Trakwa and El Dabashya showing what can happen to ancestors when a site is looted. A quick inspection of many field studies reveals that looting and wanton destruction of El-Kharga's tangible cultural heritage have been widespread, because the archaeological sites are unprotected and spread over large areas, the vast number of sites in El-Kharga makes this an impossible task at every site. During the field study 2018, skulls from El Trakwa and El Dabashya showing what can happen to ancestors when a site is looted. Also, it can be observed that the temples in Ain Amour, Umm El Dabadeb and Dabashya have been destroyed by using heavy construction equipment such as a loader, fig. (8).

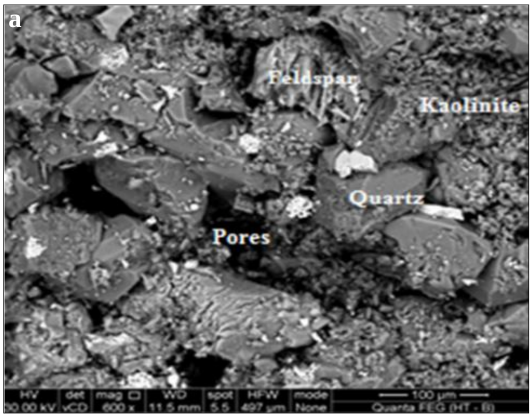

Figure (8) The Human-induced hazards on the archeological sites under investigation

4.3. *Laboratory investigations results*

Laboratory results have been considered in the present work as focusing on the weathering hazards. Evidently, most of the archeological sites under investigation had suffered from weathering hazards, to illustrate this further, the current study focused just on two archeological sites in El-Kharga oasis (Hibis temple, Kasr El-Ghawieta temple and Kasr El-Zayyan temple) to diagnostic the weathering hazards as a case study. It has been conducted for small size samples collected at the parts presenting weathering at Hibis temple, Qasr El-Ghawieta temple and Qasr El-Zayyan using scanning electron microscope (*SEM*). Noticeable difference in weathering forms and intensity has been noted from one site to the other for grain-scale size. Quartz and kaolinite are the main components of the constructional rock of these sites in addition to K-feldspar can also be noted. The weathering on micro-scale has been observed as micro-cracks of different forms (e.g. Parallel, interconnected, Y-shaped, single crack), pitting at different deeps and intensities; fragmentation of quartz grains, particularly in parts of intense interconnected micro-cracks; removal of cement materials resulting in weakening of rock's strength and higher limits of rock's porosity; kaolinite deformation and leaching or removal by weathering from rock pores; and interconnections of these pores. All these weathering forms can be specified regarding the constructional rock at each site under investigation as follows agree with Ismael & Kamh [26].

4.3.1. Hibis Temple

It has been indicated that the constructional rock is sandstone which is mainly of an arkosic texture with sub-rounded to sub-angular moderately sorted quartz grains. For more illustration on the matrix (almost clays) kind and weathering factor on micro-scale of the rock's composition [33], SEM has been used pointed out kaolinite as a rock matrix almost for the reconstruction and restoration, and also the construction sandstone, fig. (9-a). The dissolution of quartz grains as K-feldspar has been noted within the field of examination particularly for the weathered reconstruction rock. The constructional rock of this temple is sandstone with an arkosic texture that is texturally mature, almost composed of quartz with rare clay (Kaolinite) content. The same has been noted for re-constructional rock but with noticeable kaolinite content as could be seen in fig. (9-b).



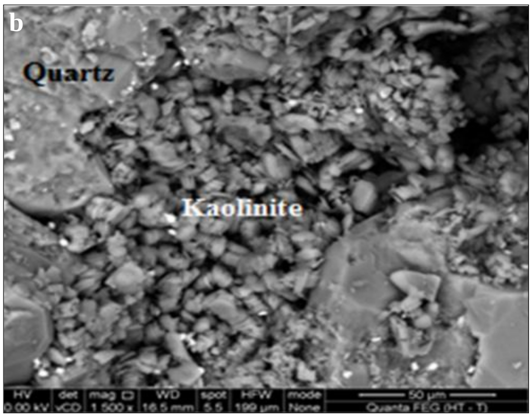
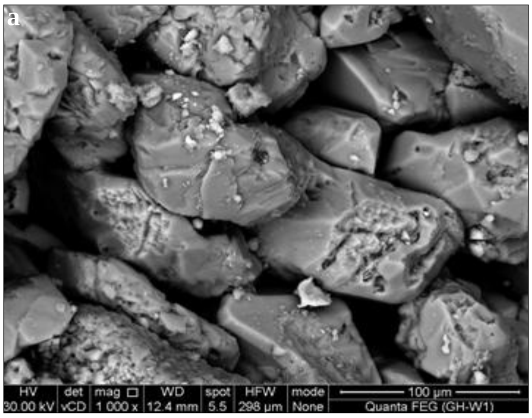


Figure (9) Shows SEM micrographs presenting deterioration of rock's **a.** components for the re-construction sandstone used, **b.** kaolinite as a matrix for the sandstone used at Hibis Temple

4.3.2. Kasr El- Ghawieta Temple

Sampling has been notified with the weathered stone of this temple to diagnostic the weathering on micro-scale; add to pores properties using SEM. The construction rock presents physical weathering noted as pitting on quartz grains that almost resulted from wind carrying sand in desert dry lands. The big pitting is roughly hollow of cement or matrix and is connected, fig. (10-a). The presence of kaolinite was determined as a matrix within the pores of the pits and fissures. Some parts of these facies have interconnected micro-cracks that increase physical weathering, fig. (10-b).



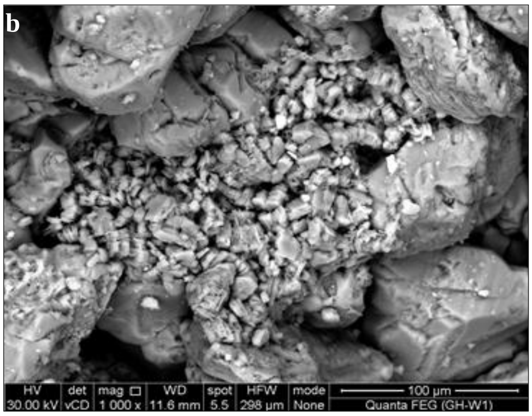


Figure (10) Shows SEM micrographs presenting some kaolinite as matrix within some pores

4.3.3. Kasr El-Zayyan temple

This site presents weathering with different intensities, then sampling has considered different parts of this site then, four samples representing this weathering have been examined in detail using the SEM. The samples indicated intense pitting and micro-cracks, clear interconnected pores, micro-grooves, brain loops on quartz grains can be noted all indicating physical weathering on this rock, fig. (11-a). While the other samples of the same site indicated silica grains with micro-cracks and damage in the matrix. Silica grains are severely dissected and fragmented into micro- and Nanoparticles in size, fig. (11-b).

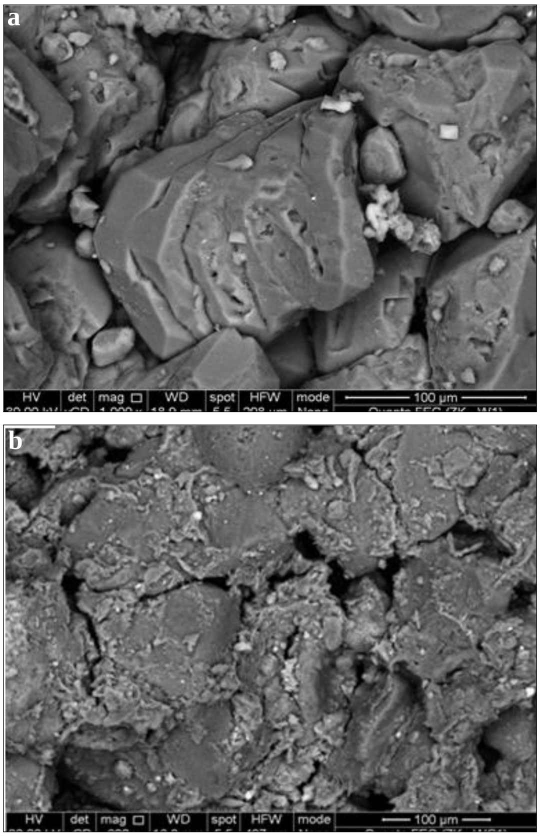


Figure (11) Shows SEM micrograph **a.** present angular inter-connected pores, micro-grooves, brain loops on quartz grains, **b.** presenting silica grains are severely dissected and fragmented into micro and Nano particles

5. Discussion

SEM and XRD results revealed that the construction rock of the temples is sandstone composed of almost quartz grains with some kaolinite and feldspar. All of these components present physical weathering indicated by micro-cracks, fragmentation into nano-sized grains, kaolinite deformation and feldspar micro-texture. Noteworthy, variations in weathering rate and intensity have been indicated from the SEM interpreting results and have been numerically expressed on measuring the properties of the stones formed the archeological sites e.g. geotechnical properties. Based on SEM investigation, it is difficult to rank damage category of these sites as all of their facies present physical weathering facilitated by the presence of kaolinite and feldspar as a component of this arenite sandstone. The pore system of these facies is almost inter-connected particularly for Qasr El-Zayyan and Kasr El-Ghawieta temples, for example. According to the hazards of underground water, the results revealed that the Hibis temple is undergoing many problems, columns began to tilt, cracks appeared on the walls, and salts seeped through the porous stones that threaten the temple with total collapse. Specifically, a quick inspection of all damage to most of the archeological sites in El-Kharga revealed that the climate is by nature a rather complex theme. The climate in the area under investigation is mostly hot during the day surface temperature reach (50.3 °C), and windy at night (140 km/hr.). Most of the archaeological sites in the Kharga oasis reached a category of severe damage based on field investigations and laboratory studies. It was also found that many of the environmental measures already measured have a significant impact on the archaeological areas in the Kharga, and these risks represent different proportions (weather risks 45%, the risk of groundwater 18%, the risk of crawl on sand 12%, risks caused by man 15% and represent extreme climate hazards and climate change (10%) of overall degradation rates, in some cases through graffiti. The impact of each type of environmental risk on archaeological sites in the Kharga oasis cannot be separated, because all these risks do not work alone. Through field studies, it could be noticed that there are different weathering forms and damage categories affecting the stones of most archeological under investigation temples which could be attributed essentially to weathering hazards and vandalism caused by surface destruction. And other minor effects resulted from the effect of condensation and graffiti. The severity of these patterns is mainly due to eleven of deterioration mechanisms. All these mechanisms led to the presence of some deterioration patterns which could be summarized according to some specialists [34-39] as following:

*) *Weathering out dependent on the stone structure*
*) *Back weathering*
*) *Detachment of stone material*
*) *Loss of stone material*
*) *Formation of deposits on the stone material*
*) *Microbiological deterioration*
*) *Cracking*
*) *Deterioration of plaster and mortar*
*) *Relief due to anthropogenic impact*
*) *Break out due to constructional cause*
*) *Efflorescences symptom*
*) *Presence of light-colored crust tracing the surface.*

6. Conclusion

The current study was concluded that Egypt is rich in cultural heritage that can be traced from the remote prehistoric past through the various stages of world civilization. It has been clarified that all archeological sites in El Kharga oasis have been exposed to aggressive deterioration factors mainly due to environmental hazards. Also, the current study demonstrated that the preservation of our tangible cultural heritage in El-Kharga is constantly endangered by the inevitable action of environmental hazards. Although stone is one of the most durable building materials, in the course of time, it can be severely damaged by climate change and weathering processes. A very accurate deterioration diagnosis is in demand to ensure the archeological sites' constructional and aesthetic safety. This can be accomplished by correctly identifying both the causes of weathering processes and climate change impacts. El-Kharga and the small southern oases form a unique containing precious evidence of the environmental changes that shaped the Western desert. The geomorphological and geological characteristics have been described as the voluntary migration of the population or their forced expulsion from the Nile valley to the Kharga in the heart of the Western desert. The roots of these long sequence dates are back to the Pleistocene, and continue into the Holocene, and had a deep impact on the human evolution and occupation of the area. The prominent impact of the environment and its hazards in El-Kharga oasis establish a dual role: witness in itself of environmental and climate change, and scenario of 12,000 years of human evolution, as an inevitable consequence of these environmental hazards. It was confirmed that all monumental sandstones in El-Kharga oasis have suffered serious damage factors due to natural weathering and anthropogenic activity. These factors affected the rock arts from the wall paintings and led to pillar breaking. The action and interaction between the environmental hazards and the monumental sites in El-Kharga oasis are clear. The weathering forms are a serious hazard to most of the reported monumental sites. The groundwater hazards are rather clear caused salt weathering at many archeological sites due to its presence in a relatively low topographic level in El-Kharga depression. It was concluded that the environmental hazards have common effects and interact with each other, and it may be difficult to establish a boundary between their effects and the degree of severity to the archaeological areas in the Kharga oasis. It was found that the human risks to the archaeological areas in Kharga are constantly increasing due to the lack of insurance of these sprawling archaeological sites. Finally, the looting of finite cultural heritage is not the way to bring about social change and improve the standard of life, for theft goes against all Islamic and Christian principles and also Egyptian law. The results of this work can advance our knowledge of the role of environmental and climatic hazards and their impacts on the archeological sites in El-Kharga, giving insights into their possible ramifications for different archaeological, tourism, and environmental and economic sectors in El-Kharga oasis.

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