



DE GRUYTER  
OPEN

DOI 10.1515/pesd-2015-0001

PESD, VOL. 9, no. 1, 2015

## THE CLIMATE AND ITS IMPACTS ON EGYPTIAN CIVILIZED HERITAGE: EI-NADURA TEMPLE IN EL- KHARGA OASIS, WESTERN DESERT OF EGYPT AS A CASE STUDY

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**Key words:** Roman monuments; El- Nadora Temple; Weathering forms; deterioration

**Abstract.** Undoubtedly, El-Kharga Oasis monumental sites are considered an important part of our world's cultural heritage in the South Western Desert of Egypt. These sites are scattered on the floor of the oasis representing ancient civilizations. The Roman stone monuments in Kharga represent cultural heritage of an outstanding universal value. Such those monuments have suffered weathering deterioration. There are various elements which affect the weathering process of stone monuments: climate conditions, shapes of cultural heritages, exposed time periods, terrains, and vegetation around them, etc. Among these, climate conditions are the most significant factor affecting the deterioration Archeological sites in Egypt. El- Kharga Oasis belongs administratively to the New Valley Governorate. It is located in the southern part of the western desert of Egypt, lies between latitudes 22°30'14" and 26°00'00" N, and between 30°27'00" and 30°47'00" E. The area of El Kharga Oasis covers about 7500 square kilometers. Pilot studies were carried out on the EI-Nadura Temple, composed of sandstones originating from the great sand sea. The major objective of this study is to monitor and measure the weathering features and the weathering rate affecting the building stones forming El-Nadura Roman building rocks in cubic cm. To achieve that aims the present study used analysis of climatic data such as annual and seasonal solar radiation, Monthly average number of hours of sunshine, maximum and minimum air temperatures, wind speed, which have obtained from actual field measurements and data Meteorological Authority of El-Kharga station for the period 1941 to 2000 (60 years), and from the period 1941-2050 (110 years) as a long term of temperature data. Several samples were collected and examined by polarizing microscopy (PLM), X-ray diffraction analysis (XRD) and scanning electron microscopy equipped with an energy dispersive X-ray analysis system (SEM-EDX). The results

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were in agreement with the observed values in the study area. The deterioration of El-Nadora temple is above 45 % of original temple (138-161 BC), these deteriorations have occurred not only due to the age of the structures, but also due to the climate elements. It was found that the climate is the most important elements influencing weathering. El-Nadora temple is highly influenced by wind action because it has built on a hill top 180 meter in hyper arid climate and exposed to wind without any obstruction. Finally, El-Nadora Temple has lost about 42.46 % of its original size, and if the rate of deterioration on those rates will disappear the major landmarks, symbols and inscriptions fully in 2150.

### **Introduction**

Throughout the history of mankind natural stones have been widely used as a material for buildings, monuments and art objects. In the course of time, all these natural stones have been affected by several weathering factors. So the interaction between stone materials and natural or anthropogenic weathering factors controls the type and extent of stone deterioration (Fitzner and Heinrichs, 2002). Additionally, Stones cultural heritages exposed to the outside air for the durations from hundreds to thousands of years must have been weathered by Heating and thawing, mechanical weathering, salt crystallization, biological weathering and other factors. Such factors especially climate conditions can cause cracks, exfoliation, discoloration and other forms of deterioration and damage to such cultural heritages.

Generally, The Western Desert covers an area of some 700,000 km<sup>2</sup>, thereby accounting for around two-thirds of Egypt's total land area. This immense desert to the west of the Nile spans the area from the Mediterranean Sea southwards to the Sudanese border. El Kharga is a depression lying with its long axis north and south, bounded on the north and east by a steep escarpment, but open from the south and southwest on which sides the country rises gradually from the floor of the oasis. The extreme length of depression from the northern wall to Jebel Abu Bayan, which for convenience may be regarded as southern limit of the oasis proper is 185 kilometers. Most of expose rocks in the depression belong to the Nubian succession. Rocks exposed in the surrounding escarpment are companion to lower Eocene. Lacustrine deposits and calcareous tufa of probable Pleistocene and recent age are found in the depression.

El-Kharga (the inner in Arabic) is one of seven other depressions scattered within the vast Western Desert of Egypt at about 220 km west of the Nile and about 630 km southwest of Cairo. The southern side of the depression rises gradually until the mean level of the desert. The region is extremely arid as it is a part of the hot and dry Sahara, where descending air coming from equatorial region produce a stable air mass known as the tropical continental region (Beaumont,

1993). The Roman stone monuments in El-Kharga represent cultural heritage of outstanding universal value. All monuments have suffered weathering damage. Stones have become the widely used construction material in ancient buildings due to its enormous resistance against natural condition when compared to other construction materials. However, stones also wear out and deteriorate in the course of time because of climate elements impacts.

The deterioration of the archeological stones has received a special attention of numerous researchers (Gauri and Holdern, 1981; Abel- Tawab and Mahmoud, 1992; Mahmoud, 1995; Soliman, 1997; Fitzner et al, 2002; Cardell et al, 2003; Benavent et al, 2004; Cardell et al, 2008; El Gohary, 2011; Abdel-Aziz, 2012; Marjaneh, 2012; Chan Hee Lee, et al. 2013; Talu, 2014). Guri and Holden (1981) studied the deterioration of the stone of sphinx. The result suggested that the destruction of the sphinx is occurring due to salt crystallization aided by the "ink-bottle" pore systems prevailing in these rocks. Abdel-Tawab and Mahmoud (1992) studied the deterioration of building stones of the old house (20-50 years ago). This study concluded that the rate of weathering for the marly limestone is 68.30 cm<sup>3</sup>/year.

Mahmoud (1995) studied the deterioration of the building stones forming the Greco-Roman wall of Alexandria at two sites. That referenced study concluded that the volume lost of wall over 190 years. The study mentioned that a complex combination of mechanical, chemical and biological factors played an important role in the deterioration of the building stones forming Greco-Roman monuments of Alexandria. Soliman (1997) studied the wind erosion of sedimentary rock monuments in Egypt. The study concluded that the wind erosion is one of the most important factors deteriorating ancient Egyptian monuments.

Mahmoud (2010) studied the weathering products of the sphinx and explained how the body of the sphinx affected by both wind and ground water rise as a capillary action through the cracks. The study calculated the rate of weathering as 0.066 mm/year under arid conditions. Abdel-Aziz, (2012) studied the weathering features affecting the different building stones forming the Greco-Roman building rocks in four areas in Alexandria( Abu Sir Temple, Pompey Pillar, Mustafa Kamal Tombs and El Shatby Tombs). The important study classified the weathering and deterioration features rocks and discussing the causes of these deterioration features, measured the rate of weathering and deterioration of the stones.

Accordingly, there are many types of damages that stones can undergo, These may produce particular deterioration patterns that are then described by specific terms. Given the high number of these patterns, and the fact that this problem is being addressed around the world in different languages, it is important to try to come to a consensus in their use.

It is important to point out that the same pattern may result from different deterioration mechanisms while any one specific mechanism may result in different types of patterns, depending on the substrate in question. For example, granular disintegration can be the result of chemical attack, frost damage or other processes. Hence in practice, it is generally impossible to deduce the major causes of damage simply by observing the deterioration pattern. Visual observation and documentation serves mainly to attain an overall estimate of the amount and type of damage presents (Michael Steiger et al, 2010).

Deterioration of stone; including building stone and man-made construction materials, exposed to the natural environment occurs through physical, chemical, biological processes in combination or in isolation. It has been estimated that about 30% of stone deterioration is a result of biological activity (Wilimzig, 1996). Weathering forms on stone monuments represent the visible results of weathering processes which are initiated and controlled by interacting weathering factors. The term “weathering forms” is used for visible stone deterioration at mesoscale (cm to m) (Bernd Fitzner, 2012).

Finally, the Deterioration is a complex process affecting by climate and therefore, there are many words that are used to describe it. For example, “weathering” is used for the natural process of rock disintegration by external factors; while “deterioration” implies the impairment of value and use. Thus, rocks weather while stones deteriorate. The difference is that man has intervened in producing and using the stones. Therefore, these two terms are not really equivalent.

### **1 The study Area:**

The area under investigation belongs administratively to the New Valley Governorate. It's located in the southern part of the western desert of Egypt. Its lies between 22°30'14" and 26°00'00" N, and between 30°27'00" and 30°47'00" E. The area covers about 7500 square kilometers. Pilot studies were carried out on the El-Nadura Temple, composed of sandstones originating from the great sand sea.

Accordingly, El-Khaga Oasis is the southern one in this cluster of depressions and represents an important feature in the Western Desert (Fig.1). It is bounded by the Eocene limestone plateau from the east and north, where steep cliffs form a sharp boundary to the depression floor (El-Sankary, 2002). This limestone plateau stretches along Middle and Upper Egypt with an elevation of up to 550 m above the sea level and about 400 m above the depression floor at the study area. However, towards the south and west, the depression floor merges gradually into the Nubia Sandstone open desert. Geomorphologically, the landscape is considered as neither high plateau in the northern and eastern boundaries, or low-

lying depression floor, meanwhile the pediment areas in-between, are considered as badlands (Salman et al. 2010).



Fig.1. Location map of Egypt showing El-Kharga Oasis. (After (Salman et al. 2010.P.343)

### 1.1. El-Nadora temple:

El-Nadora Temple represents an evidence of human history and bridge through which the social customs and experiences passed between the generations. According to the Ministry of archeology in Egypt (unpublished data), the site of El-Nadora consists of two temples. The lower structure uninscribed and its dedication function are thus far unknown (Fig.2A). The main temple is located atop an eminence and its constructed of sand stones, surrounded by mud-brick walls and other structures. A larger Roman temple was constructed in front of an earlier single-room shrine of uncertain date, surviving only as pavement and the bases of walls.

Most of inscription within the Roman temple date to the reign of Antoninus Pius (138-161 BC). The temple appears to have been dedicated to the falcon-headed god Khonsu, a lunar deity, and Re-Horakhty, a solar deity; with Khonsu apparently predominate. The ancient name of the temple is unknown, and the

modern designation El-Nadora may refer to its function as a "look-out" post for the Darb El-Arbain north-south caravan road that connected western Sudan with Upper and Middle Egypt (Fig.2B).



(Fig.2 A.B) Panoramic view of El-Nadora temple zone, (A) lower structure uninscribed and its dedication function are thus far unknown (B) The main temple surrounded by mud-brick walls

## 2. Materials and methods:

The method used in this study was derived from the studies carried out by (Fitzner et al. 1992, Mahmoud, 1995, Fitzner, 2002, Warke et al. 2003, Heinrichs 2004, Talu, 2005, Belmin et al, 2008, Abdel Aziz, 2012, Chan Hee Lee, et al. 2013). These methods were united in order to form an intermediary scale for the weathering rate observed at stone monuments, deterioration features classifications and the correlation between climate conditions and deterioration of El-Nadora Temple. The pre-field studies were the first step of this method including measurements. The identification of chemical, physical and mineralogical properties of stones used in the construction of the walls were taken into consideration in the laboratory studies.

In addition to the above, to achieve the aims of the current study is based on raw climate data, field study, laboratory analysis in order to interpret the scale, pattern of deterioration and weathering process. Furthermore, profound knowledge

of the material properties and the weathering behavior of the natural stones used are necessary, as well as knowledge of weathering factors and weathering processes which initiate and control this weathering behavior. High level of scientific knowledge is an important basis for effective and economic preservation measures.

### **2.1. Climatic data:**

All climate data used in this study is represented by original data, according to unpublished data from Egyptian Meteorological Authority to El-Kharga from 1941 to 2000 and from 1941-2050 as a long term of estimating temperature data only. The climate data consisted of solar radiation, mean monthly and annual records of temperature types (maximum, minimum, absolute), Annual means are the means of all 12 months from a respective year; seasons were defined as follows: winter is the mean through December-January-February; spring through March-April-May; summer through June-July-August; and autumn through September- October-November (Table 1-2). The wind data come in a standard format and represent the annual average of the percent of hourly occurrence of surface wind measured at 10 m height above ground and are arranged into 12 wind speed classes in 12 directions (Table 3) (Hereher, 2010).

### **2.2. Field investigations**

Field work to El-Nadora temple was carried out for four times, from March 2010 to January 2014, its include sample collection, measuring the weathering rate and taking photographs. A total of twenty four fresh and weathered stone samples were collected from El-Nadora temple.

According to (Mahmoud, 1995) and (Abd El-Aziz, 2012) The weathering rate is calculated using the difference between the original volume of stones block and the volume after weathering relative to the age of El-Nadora temple (138 CE). We select some blocks which are not affected by weathering and other blocks which highly weathered. Then we measured the length, width and depth in each block to determine the volume. The volume lost is calculated by the following equation:

Volume lost = original volume – volume after weathering

The rate of weathering calculated by measuring the percentage of decay in stones (volume lost %) through a known age (Mahmoud, 1995).

The percentage of volume lost % = volume lost \ original volume \* 100.

In situ measurements provide complementary quantitative information on stone materials and weathering characteristics. They enable examination of stone structures without any changes due to sampling or removal. During the last decades different measuring methods have been developed, often adapted from other disciplines and modified for application at stone monuments.

### **2.3. Laboratory and statistical analysis**

Twenty four fresh and weathered stones samples have been collected from El-Nadoura temple. These samples were crushed and milled in an agate mortar to avoid contamination and were studied by X-Ray diffraction analysis (XRD) to identify their mineralogy. The samples included the hard rock and the weathered materials. Ten thin sections representing the rock samples of El-Nadoura temple, detailed microscopic examination of the rock thin section were carefully examined under polarizing microscope to determine their texture, mineralogical composition. A JEOL JSM-5300 scanning electron microscopy (SEM). Petrographic examination allowed determining and describing the sandstone minerals, physicochemical alteration, the relation between grains and the state of preservation.

X-ray diffraction examination of hard weathered samples of El-Nadoura Temple reveals that the surfaces essentially consist of the same mineralogical composition of original hard rocks in addition to gypsum as the main weathered products. The common carbonate minerals detected are calcite and aragonite. Dolomite and quartz are present in minor amount. In addition, altered sandstone weathered samples composed of quartz, microcline, orthoclase, magnetite, kaolinite, halite, anhydrite, gypsum, and illite. Clay minerals are represented mainly by kaolinite and illite dispersed in the sandstone wall reliefs as result of chemical alteration of the feldspar minerals. The results reveal that building stones are mainly composed of subrounded to well-rounded, well-sorted, and medium to coarse-grained quartz. These grains are almost monocrystalline quartz and show grain-supported fabric. These sandstones are considered quartz arenite according to Tucker (1981).

In order to achieve the study objectives, the current study will represent the evidence of the impacts of climate elements on El-Nadoura Temple, by studying the deterioration and its classification features, rate of weathering, and then concludes by highlighting a detailed study of solar radiation, temperature and wind, as the main reason for the deterioration of the stone of El-Nadoura temple.

## **3. Discussion and Results**

### ***3.1. Classifications of the deterioration features at El-Nadoura Temple:***

The classifications of deterioration features observed at stone monuments have been carried out for a few decades using different techniques. These studies developed different frameworks for classification studies, but the systematical classification of weathering features was developed by Fitzner et al. (Fitzner et al. 1992; Fitzner 2002). Heinrichs did the latest study on the assessment of the progress of the weathering forms in 2004 (Heinrichs 2004).

Before 2004, the research studies that were carried out between the years 1994-2000 are listed as follows: the definitions of the weathering forms in 1994,



the evaluations of the weathering forms in 1998 (Fitzner, B. and Heinrichs, K. 1998), the characterizations and ratings of the weathering forms in 1999 (Fitzner, B. and Heinrichs, K. 1999); and finally the litho types and the deteriorations of the cut-stones in 2000 (Heinrichs, K. and Fitzner, B. 2000). After 2004, the research studies propose a visual presentation technique for classification and mapping of weathering forms of stones that in archeological sites, and examined deterioration degrees stone monuments (Talu, 2005), (Belmin et al, 2008), (Abdel Aziz, 2012), (Chan Hee Lee, et al. 2013).

Tab.1. Classification of deterioration features observed at El-Nadara Temple  
(Source: Fitzner, 2002)

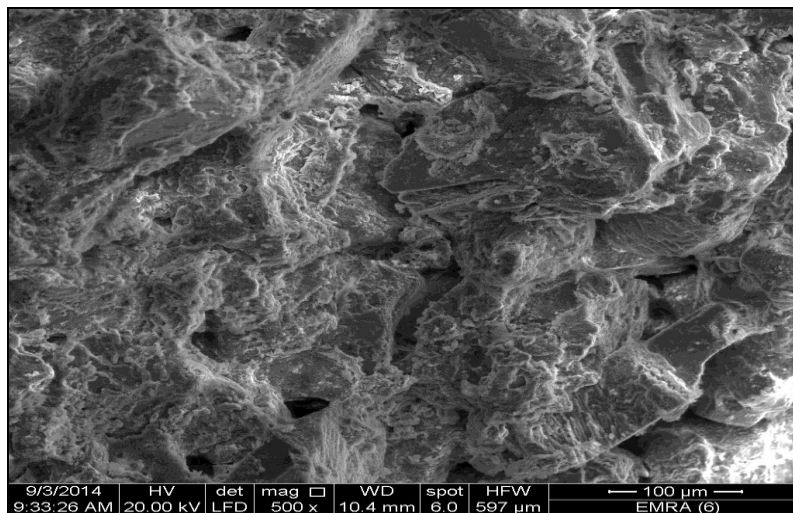
<b>Main groups</b>	<b>Sub-groups</b>
<b>1- Detachment of stone material</b>	Sanding, Flaking, Scaling, Exfoliation, Loose masonry
<b>2-Loss of stone material</b>	Pitting, Alveolar Weathering, Outbreaks, Spalling, Backweathering, Missing insets.
<b>3-Formation of deposits on the stone material</b>	Salt Efflorescence, Surface crust, Microbiological Deterioration, Insect Colonization, Bird dropping, Graffiti, Soiling,
<b>4-Cracking</b>	Fissures, Joint, Fault
<b>5-Structural instability</b>	
<b>6-Collapsed wall</b>	
<b>7-Deterioration of plaster and mortar</b>	Plaster Detachment, Mortar Disintegration, Mortar infestation due to biogenic growth

The deterioration features at El-Nadara Temple have been divided into 7 groups in this study. These groups are: detachment of stone material, loss of stone material, formation of deposits on the stone material, cracking, structural instability, collapsed wall, deterioration of plaster and mortar. These groups are mainly divided into 22 sub-groups (Tab. 1.)

Due to arid climate of El-Nadara Temple many deteriorated features are formed as a result of thermal expansion and contraction where rocks at El-Nadara Temple are exposed to a wide range of temperatures with very hot days and very cold nights. When temperatures changes rapidly, the surface of a rock heat or cools faster than its interior as a result, the surface expands or contracts faster than the interior, the resulting forces may fractures the rocks (Soliman, 1998).

The stone weathering at El-Nadara Temple takes place through chemical, physical, mechanical, and biological, process. Physical weathering breaks stones into smaller pieces. Several features of physical weathering were identified (e.g; salt crystallization, cracks, pitting, and Exfoliation). Salt crystallizations are not common in El-Nadara Temple: where the climate is hyper dry in most of all seasons, with wide range of temperatures with very hot days and very cold night. The low temperature at night, especially near the stones surface is quite often

below the dew point. High temperatures during the days draw the moisture out of pores towards the surface. This water evaporates, with resulting crystallization producing forces adequate to weaken or even disrupt the stone (Fig.3).



(Fig.3) Scanning electron micrograph of deteriorated stones of El-Nadoura Temple showing Crystallization occurs initially in the small and large pores

Cracks are more effective features of weathering resulting either from the effect of mechanical stress due to crystal growth or biological growth (El-Gohary, 2010). Several longitudinal single cracks are observed on the vertical wall of El-Nadoura Temple, cracks are typically several millimeters in width and centimeter in length, due to arid climate and wide range of temperatures with very hot days and very cold nights (Fig.4 A.B).

The thermal expansions do not occur only because of hot weather at afternoon but also freezing process as a result of decreasing of temperature at night, the frozen dew fall in cracks presents a cotter effect, enlarges the cracks and causes to have broken pieces of stones (Abd El-Aziz, 2012). But thermal expansion can also occur in larger zones of the rock itself. The rock surface is more affected by insolation than the deeper part of the rock. Thus, thermal expansion depends on the orientation of exposure of a rock wall (south, west, north, and east) (Fig.5). When this event takes place for several times, the broken upper layers of stones will be observed. Freezing-thawing process has a significant effect on deterioration of stones used at the regions facing with daily and seasonal temperature changes (Yaldiz, 2010).



Fig. 4. A, B. Longitudinal single cracks on the wall of El-Nadira Temple, millimeters in width and centimeter in length, due to arid climate and wide range of temperatures.

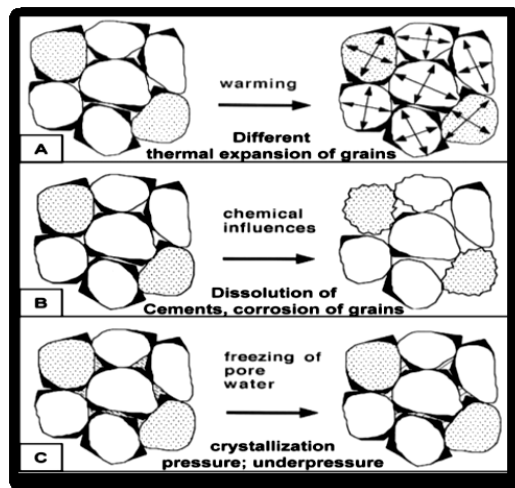


Fig.5. Basic systems deteriorated stones texture in the weathering of rocks. After: Roman Koch, 2008

Pitting is a form of extremely localized corrosion that leads to the creation of small holes in the rocks. This kind of pitting is extremely insidious, as it causes

little loss of wall stones with small effect on its surface, while it damages the deep structures of the monument stones ([sk.wikipedia.org/wiki/Petting](http://sk.wikipedia.org/wiki/Petting)). Pitting is a result from the action of some biological factors (insects and micro-organisms). The feature of the biological deterioration by some animals such as dogs and donkey, as well as some insects such as big ants, are represented by bores (few mm up to cm) into building stone of E-Nadora Temple (Fig.6 A, B), mechanical scratching and acid secretions (Abdel-Tawab and Mahmoud, 1992). Different kinds of organisms can grow using the mineral components of stones and its superficial deposits. The climate elements, especially the wind caused pitting feature of the wall stones of El-Nadora Temple through grains abrasion. Small pits about 0.5mm are noticed on some block facing the prevailing wind, other pits have other modes of origin such effect may increase where holes are developed with final complete destruction of the structure (Fig. 7).

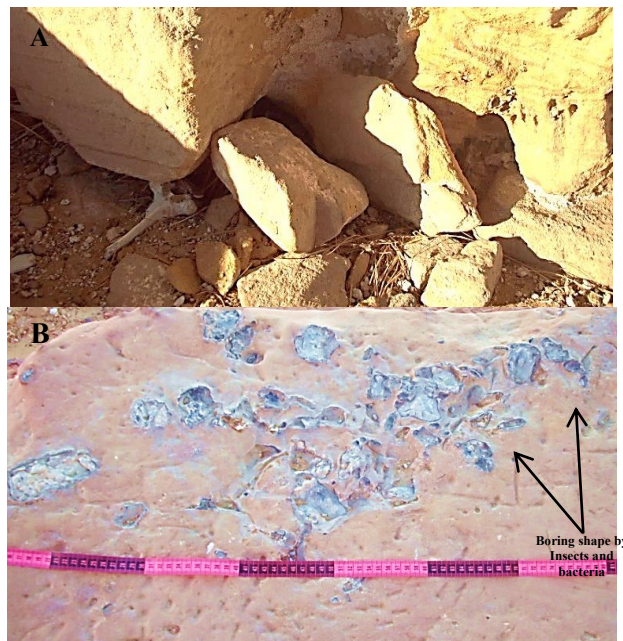


Fig. 6. A. B Biological deterioration at El-Nadora Temple showing boring shape by animals in (A), boring shape by insects, bacteria and fungi effect in (B)

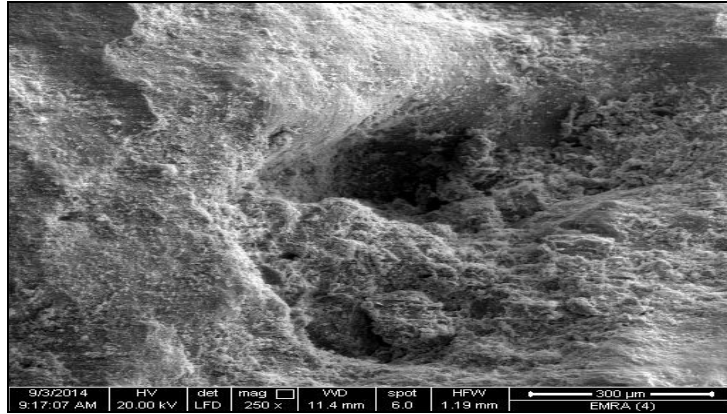


Fig. 7. Scanning electron micrograph of deteriorated stones of El-Nadora Temple showing micro pitting occurs initially in the small pores

According to (El-Gohary, 2010), exfoliation is a type of physical weathering in which the outer layer of a rock surface peel off in flakes and shells. It is caused by the rapid expansion and contraction of the rock surface when subjected to extreme change of temperature. Exfoliation occurs particularly in hot dry climates as a result of thermal expansion, so it can be observed this type of weathering in El-Nadora Temple (Fig.8).

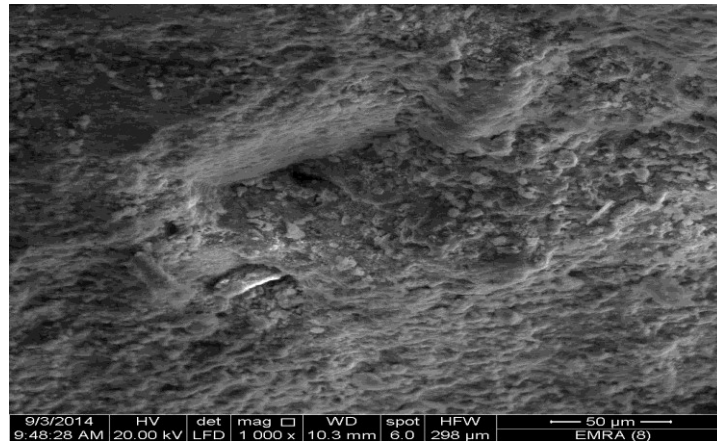


Fig. 8. Scanning electron micrograph of deteriorated stones of El-Nadora Temple Showing micro-exfoliation grains

A complex combination of mechanical, chemical and biological factors played an important role in the deterioration of building stones of El-Nadora temple walls, such as unstable walls (Fig.9). The processes of mechanical deterioration affecting the calcarenit and the aeolianite building stones are boring, abrasion, polishing, scouring, scratching, splitting, fragmentation and rock fall (Fig.10). These processes are reflected by striations, polished surfaces, undulating surface, cracks, fissures and joints and finally rock fall (Mahmoud, 1995).



Fig. 9. The presence of structurally unstable walls at El-Nadora Temple as a result of physical weathering (natural causes), or constructional causes



Fig.10. Original Text stone insets that have been lost leading to cavities, with the original stone still in the vicinity



Fig. 11. The disappearance of the texts, symbols, inscriptions as a result of the deterioration caused by physical and chemical weathering

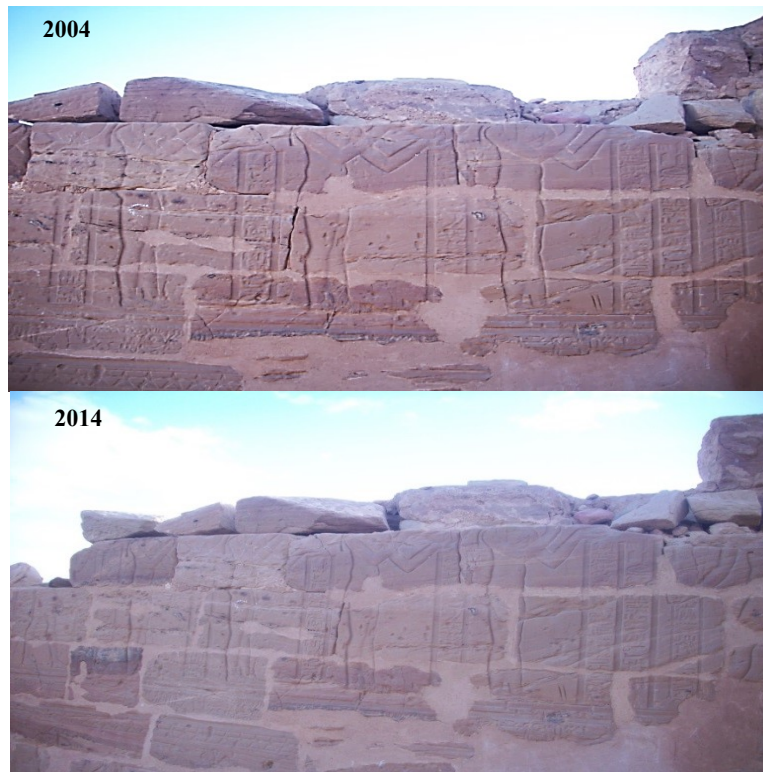


Fig. 12. Progress of clarity of archaeological inscriptions and texts as a result of the deterioration caused by the wind carrying sand between the years 2004-2014



Fig. 13. Disintegration of the mortar used in jointing the stones wall at El-Nadora Temple as result of climate conditions



Fig. 14. Detachment of small, flat, thin pieces of the outer layers (Flaking) of El-Nadora Temple stones

Chemical weathering erodes the stones changing their compositions by chemical reaction. Chemical weathering of the stone takes place through dissolution, hydrolysis and oxidation processes of the stone minerals. Chemical weathering is mostly due to the effects of climate conditions, and caused a lot of deterioration features, such as disappearance of the texts, symbols, inscriptions (Fig.11) and (Fig.12). Disintegration of the mortar used in jointing the stones wall (Fig.13), or flaking the stone (Fig.14). Biological weathering can be described as a



disintegration of stone and stone minerals due to the chemical and/or physical actions of an organism. Action of some organisms changes the stone color or slow down the decay process of stone. Biological weathering takes place by the action plants, animals, fungus, algae, bacteria, lichen etc.

### 3.2. The Rate of weathering:

El-Nadora temple is characterized by hyper arid climate, open area and it is located on a hill top 180 meter, where the amount is exposed to wind effect without any obstruction. Moreover, the temple is characterized by wide range of temperature about 18 c, with hot days and cold nights, these continuous temperature changes caused the cracking and breaking of the stones as a result of material fatigue.

Accordingly, El-Nadora Temple has lost about 42.46 % of its original size, and if the rate of weathering on those rates will disappear major landmarks, symbols and inscriptions fully in 2150 (Table.2). The rate at which weathering processes decompose and break down a solid rock body depends on climate elements and texture of the rocks. Rate of weathering has calculated by measuring the amount of deterioration on rock surfaces of known age (Mahmoud, 1995).

Therefore, the current study takes into consideration the value of the climate oscillations, especially on temperature during the study period 138 B.C to 2014 A.C, by choosing the most appropriate model to Kharga Oasis climate. It is characterized by hyper arid climate, with clearly variability in temperature daily 9-18 c, and on the other side, the lack of clarity of temperature variability on a long-term especially if they are within 0.6-1.5 c.

(Table.2) The rate of weathering of El-Nadora Temple

Block No	Original Volume mm <sup>3</sup>	Volume after weathering mm <sup>3</sup>	Volume lost mm <sup>3</sup>	Volume lost %	Rate of weathering cm <sup>3</sup> /Year
1	37500	21997	15502	41.34	0.72
2	34500	22683	11816	34.25	0.54
3	10920	5307	5612	51.40	1.74
4	8100	4600	3499	43.20	1.62
5	11700	2794	8905	47.12	0.41
6	12000	8618	3381	28.9	0.15
Total	114720	66002	48717	42.46	5.18

The weathering rate is calculated using the difference between the original volume of stones block and the volume after weathering relative to the age of El-Nadora temple (138 BC). By selecting some blocks which are not affected by

weathering and other blocks which highly weathered, then measured the length, width and depth in each block to determine the volume. Therefore, the rate of weathering was measured for six building stone blocks at El-Nadoura Temple which have an age of 2152 Year in 2014. The total weathering rate according to the age of El-Nadoura temple is  $518 \text{ mm}^3$  per year from 138 BC to 2014, and this means that the temple faces a real risk of the elements of the climate (Table.2), (Fig. 15).

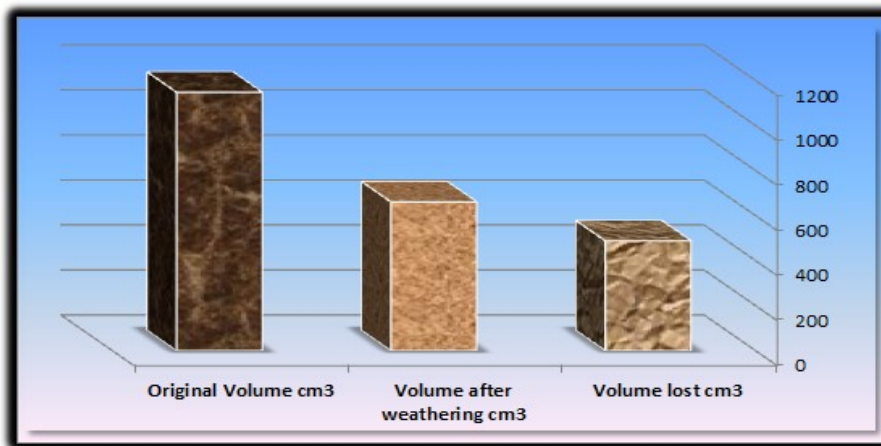


Fig. 15. Average volume of weathering related to total average volume of rock at El-Nadoura temple.

### 3.3. The correlation between climate and deterioration:

Statistical analysis of weathering rates of El-Nadoura temple showed the largest variation according to the climate condition and period of time over which weathering have been active. Precipitation and temperature are the most important factors in climate conditions and the relationship of these two factors determines the weathering process and deterioration features of El-Nadoura stone monuments Temples.

In order to examine the influence of climate conditions on cultural heritages, this study applied the correlation diagram of climate conditions and weathering designed by Fookes et al. (1971). Using the data collected for the last 60 years on mean temperatures and precipitations. As a result, the regions influenced by El-Kharga climate conditions are classified into three groups: strong deterioration, moderate deterioration and very slightly deterioration (Fig.16).

It was postulated that this finding was caused by different physical, biological and chemical weathering in the environments of El-Kharga oasis. Thus, properties of climate conditions especially temperature and Precipitation were synthesized for

analysis. Under climatic conditions and topography in El-Kharga Oasis, decomposition and disintegration take place simultaneously and it is difficult to separate the direct effects of the two processes. Their relative importance is very much a function of the climate (Peliter, 1950; Thomas, 1974; Fookes, 1991). In hyper arid region, deterioration of the building stone is far more effective than disintegration.

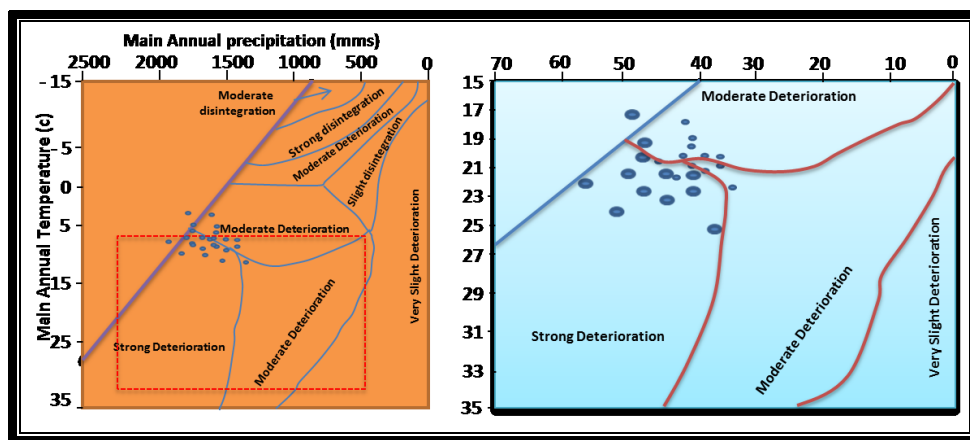


Fig.16. Correlation diagram between climate and Deterioration affecting El-Nadira Temple Modified after Fookes et al., 1971

### 3.4. Climate conditions:

Climate conditions are the most significant factor affecting the weathering process. To preserve a stone cultural heritage for a long time, it is necessary to examine how the rock is weathered, based on the climate condition at El-Kharga Oasis. Generally, climate in Egypt is commonly described as arid and semi-arid, characterized by hot, dry summers, moderate winters and erratic rainfall. According to Koeppen's climate classification, Egypt experiences the 'hot desert climate type' (BWh) in the southern and central parts of the country and the 'hot steppes climate type' (BSh) along the coast. Most parts of Egypt are occupied by the Sahara desert, which represents the most extensive area of severe aridity on globe (Domroes et al, 2005).

El-Kharga region is the driest on the earth's surface, where the incident solar radiation is capable of evaporating over 200 times the amount of precipitation (Henning and Flohn, 1977). Temperatures range from 52°C in summer to 15°C in winter and potential evapotranspiration is as high as 5 mm/d (Hereher et al, 2014). Wind blows from the north-northwest direction with moving capacity to drift sand

dunes, which is a common phenomenon encroaching upon farmlands, roads and settlements in the depression.

Additionally, the Climate of El-Kharga Oasis is largely determined by the interaction of the location, Air pressure and wind belts and great sand seas. As from a global perspective, the sun's mean angle is highest, on average at the equator and then becomes progressively lower polewards, mean temperatures gradually decrease with increasing latitude in Western desert. The air pressure distribution which is responsible of the wind patterns affects the annual temperature and precipitation. Wind is produced by the differences in the air pressure and the weather systems, such as weather fronts and storms controlled by wind patterns.

**The solar radiation.** Solar radiation is the main source of heat in the atmosphere; it directly affects all the elements of climate, which represents the pattern different forms of the amount of radiation received by different parts of the Earth's surface. According to the analysis of (Table. 2); the annual rates of the solar radiation Increased in the study area within the Western desert, its about ( 24.5 MJ / m<sup>2</sup> day) in El-Kharaga station , and about ( 24.8 MJ / m<sup>2</sup> / day) in El-Dakhla station. The reason is due to the dry air, the scarcity of vegetation, clarity of the sky and a few clouds.

**Seasonal averages of solar radiation :** The solar radiation reaches the study area as little as possible in the winter, and increase this rate gradually, its about (18.5 MJ / m<sup>2</sup> / day) in El-Kharga station, and about (19 MJ / m<sup>2</sup> / day) in El-Dakhla station. In Spring, the sun is moving outwardly from the Tropic zone , heading north towards the equator , leading to increase the amount of the solar radiation during the spring, where the amount of solar radiation at El-Kharga station is ( 27.5 MJ / m<sup>2</sup> / day) , while in El-Dakhla station is (27.6 MJ / m<sup>2</sup> / day). The amount of solar radiation during the summer doubles that record during the winter. Where the amount of solar radiation at El-Kharag station about (29.7 MJ / m<sup>2</sup> / day) in summer. The sun movement to the south during the autumn, this movement reduce the amount of solar radiation to all parts of the study area, it's about ( 22.3 MJ / m<sup>2</sup> / day).

(Tab.3. Annual, seasonal rates of solar radiation in the study area (1941-2012).

Station	Jan	Feb	march	April	May	June	July	Aug	Sept	Oct	Nov	Des	Annual mean
El-Kharga	17.7	21	24.6	28	29.8	30.4	30.1	28.8	26.0	22.3	18.6	16.9	24.5
El-DaKhla	17.7	20.9	24.6	28.2	29.8	30.2	30.4	29.0	26.1	22.3	18.6	16.9	25.3

The source: Egyptian metrological authority, unpublished data

**Monthly average number of hours of sunshine.** December is the most months of the year drop in the number of hours of sunshine with an average of approximately (9.3 hours / day) in the study area . Increase the number of sunshine hours gradually during the months of spring. In March there will be a slight increase resulting from exposure to the region of desert depressions and they happen under high pressure belt coupled atmosphere net. The number of sunshine hours increasing in the month of May average range (6/10 to 6/11 hours / day) in the study area. This increase is due to a decline in the amount of drag and increase the length of the day. The rising rates of the number of hours the solar brightness in the summer months of July to record a substantial rise in the solar brightness be recorded (12.2 hours / day) in the study area . And shows a clear reduction in the monthly averages for the number of hours of sunshine during the months of autumn, The reason is due to the existence of a state of instability in the air and exposed the region to the vagaries of weather caused by exposure area of depressions air, where the recorded station outflows (10 hours / day in September, compared to 9.4 hours / day in December) Table.4.

(Table.5) Monthly average number of hours of sunshine in the study area (1961-2012)

Station	Jan	Feb	march	April	May	June	July	Aug	Sept	Oct	Nov	Des
El-Kharga	9.4	9.7	10.4	10.5	11.6	12.3	12.4	12.6	12	11.2	10.3	9
El-DaKhla	9.3	10	10.3	10.5	10.7	11.4	12	12.4	12.2	10.9	10	9.1

The source: Egyptian metrological authority, unpublished data

**Temperature:** The Climate is by nature a rather complex theme, because of the manifold earth atmosphere interaction which considerably varies over space and time and finally creates a specific type of climate at a particular location (DOMRÖS and GONGBING, 1988) (Attia El-Tantawi, 2005). The climate in the area under investigation is mostly hot during the day (50.3 °C), and windy at night (140 km/hr). The temperature is vary 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. Egypt's official heat record is 50.3°C measured by British colonial officials at El-Kharga Oasis on June 9, 1961 would be Egypt's national heat record. The study area is part of the most hyper arid region in the world. There is essentially no precipitation. Winds are predominantly from the north. The temperature ranges from 5 C to 26 C in winter and from 26 C to 45 C in summer. The study area is characterized by tropical arid climate. The maximum day time temperature fluctuates within a wide range, reaching up to 45–52 C in summer months, meanwhile in winter, the minimum temperature may drop to as low as zero at night.

Kharga Oasis is known as the driest area in the Western Sahara and probably the driest region on Earth (Kehl and Bronkamm, 1993). Wind speed tends to be low in August; it increases progressively in November to January and reaches a peak from March to May causing dust storms famously known as "El-Khamasin". The annual mean value of relative humidity is about 39%. Generally, the atmospheric precipitation as rainfall is extremely scarce and insignificant (1 mm/year) (salman, 2010).

In the study area, climate is continental with very hot summer and extreme daily temperature ranges. Air is very dry, large daily temperature fluctuations occur and the potential evapotranspiration is high (NOBLE and GITAY, 1995). The desert climate type in El-Kharga Oasis is distinguished by high mean annual temperature, El-Kharga station (27.3 °C), El-Dakhla station (26.4 °C), and by erratic annual rainfall, El-Kharga (1.1 mm), El-Dakhla (9.0 mm)). Summers temperatures are extremely hot, mean summer temperature are 33.6 and 34.1 °C at El-Kharga and El-Dakhla, respectively.

**The Wind.** El-Nadora temple is highly influenced by wind action because it has built on a hill top 180 meter in hyper arid climate and exposed to wind without any obstruction. Wind is the most important factors of weathering and deterioration of El-Nadora temple stones especially if it carried with sand particles of high hardness. The impacts of wind are highly shown on the building stones at the arid climate like El-Nadora temple. Globally, the subtropical high-pressure belts centered near 30 degrees north and south latitude is responsible for many of the world's deserts. The regions between the ITCZ and the sub-tropical highs are dominated by the trade winds. The mid- latitudes are mostly situated between the subtropical highs and the sub-polar lows and are within the westerly wind belt. In the equatorial zone there is a permanent belt of low pressure due to heating and strong convection currents. North and south of this belt, subtropical highs are formed in belts of descending air masses, going farther polewards (MARTYN, 1992).

According to (soliman, 1998) the interaction of wind with sedimentary rock monuments manifest itself several forms, including: scratching; differential weathering; undercutting and shaping. Aeolian differential weathering is manifested in all parts of sand and lime stone formed El-Nadora temple, where that sand and lime stone are less hard and easily eroded due to speed of the wind. According to (Abdel-Aziz, 2012) an increasing in wind velocity may affect the deterioration of building stone in other way. Higher velocity of wind (up to 140 km/hr) accompanied by sand and dust from the great sand sea can increase the air temperature suddenly about 20 °C within two hours and consequently the degree of weathering can be increased.

**Temperature variability:** Climate of the past 2152 years (El-Nadora Temple constructed 138 B.C) has undergone a warm period during the middle ages (1150-1350 A.D.) followed by a cold period known as the ‘little ice age’ (1500-1850 A.D) and a warming trend was set from 1880 until the late 1930s and early 1940s (Fig.17) (Mgely, 1984). Recent climate analyses for the last 1000 years over the northern hemisphere indicate that the magnitude of 20th century warming is likely to have been the largest of any century during this period. In addition, the 1990s were experienced as the warmest decade of the millennium.

It is clearly identified that the 20th century was the warmest century during the past 1000 years; it was also shown that warming pronouncedly occurred over two periods, 1910-1945 and 1976-2000. The 1990s were experienced as the warmest decade while 1998 was the warmest individual year during instrumental records (HOUGHTON, et al., 2001).

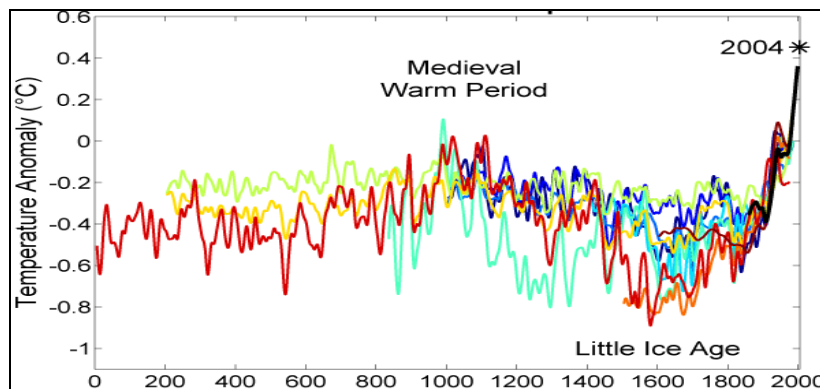


Fig.17 Global surface air temperature change since 2000 years  
(After Mgely, 1984)

Global surface air temperature has clearly risen over the last 150 years, it is virtually agreed that a generally increasing trend in global surface air temperature has occurred over the 20th century; annual global air surface temperatures warmed by 0.62 °C over 1901- 1997 (JONES, et al., 1999: 196). IPCC Third Assessment Report, 2001 and several studies objectively identified the worldwide behavior of temperature changes in the three periods; 1910-1945 (first warming period), 1946-1975 (period of little temperature changes), and 1976-2000 (the warmest period) (El-Tantawi et al 2005). In the last decades tremendous scientific efforts from wide discipline, especially from the climatologist have been done to understand and to reveal the nature, causes and consequences of the rapid warming that occurred particularly in the last few decades of the 20th century. The established of the

Intergovernmental Panel for Climatic Changes (IPCC) was devoted to these purposes under the auspices of WMO and UNEP. Over both the last 140 years and 100 years, the best estimate is that the global average surface temperature has increased by  $0.6 \pm 0.2\text{°C}$  (IPCC, 2001).

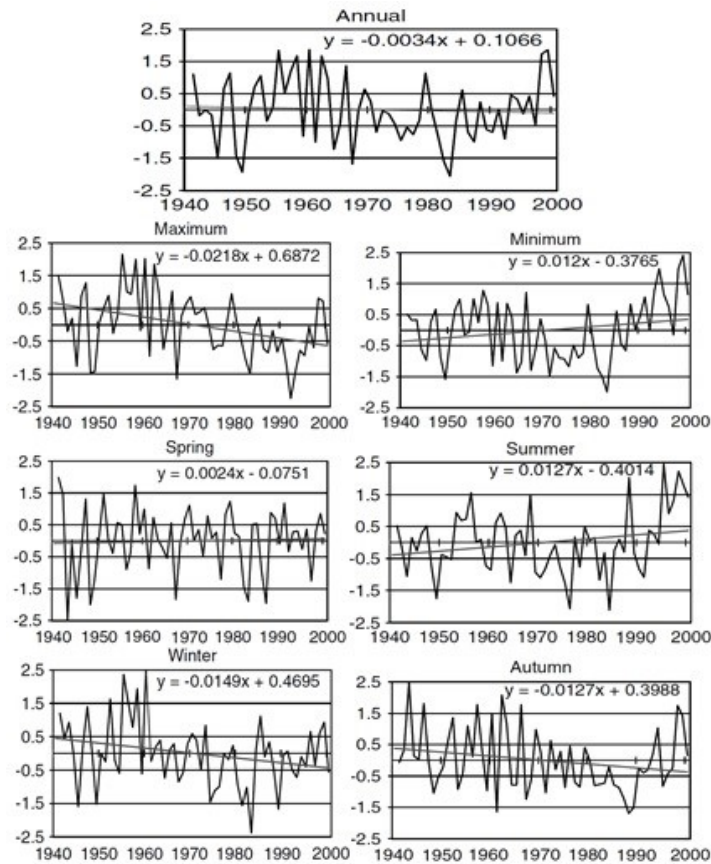


Fig. 18. Recent temperature trends for all Egypt from 1941 to 2000 (mean of annual, maximum, minimum, summer, winter, spring and autumn) based on principal component analysis After: M. DOMROES AND A. EL-TANTAWI, 2005

Among the most important parameters used for monitoring climate change is surface temperature (Comiso, 2006). Temperature data of Egypt consist of gridded data for the period 1901-2000. The data was taken from Climatic Research Unit, University of East Anglia. The correlation coefficient was used to test the strength of the temperature relationships with time (1901-2000). Linear trend was used to



understand the temperature trends throughout the 20th century. Trends are very important in climate research and usually estimated using simple linear regression (Hannachi, 2007).

According to the least-squares method and the Mann–Kendall test for trend, trends of the mean annual Temperature were positive at El-Kharga alone in all seasons. The annual temperature trend record  $+ 0.16$  C/decade at El- Kharga due to the high interannual temperature variability, were shown to be significant at the 0.001 level, The trends at El- Kharga, however, were above the global warming trend for the corresponding time series from 1941 to 2000. For the mean maximum temperatures trend was negative at El- Kharga, and positive for the mean minimum temperature.

The trend behavior for both periods Over the period 1941–2000, increasing trends are observed for the minimum, summer and spring temperatures, and decreasing trends for annual, maximum, winter and autumn temperatures have been computed (Fig. 18). Compared with the global temperature trend after Jones et al. (1999) that were calculated as a positive trend at  $0.06$  C/decade, for Egypt a negative trend at a rate of  $-0.03$  C/decade was computed.

### Conclusion

The weathering of stone monuments which represent the cultural heritages are depending on their climate conditions. The main deterioration factors at El-Nadira Temple it seems to have been high temperature, low precipitation levels, wind speed and repeated heating and cooling. Thus, different properties of weathering in each region have to be considered in designing the way of the conservation of the stone cultural heritages. El-Nadira Temple has lost about 42.46 % of its original size, and if the rate of weathering on those rates will disappear major landmarks, symbols and inscriptions fully in 2150.

The total weathering rate according to the age of El-Nadira temple is  $518$  mm<sup>3</sup> per year from 138 BC to 2014, and this means that the temple faces a real risk of the elements of the climate. The stone materials of El-Nadira temple have been deteriorated due to temperature difference and solar effects. The absolute temperature in E-Kharga Oasis during the hottest months (july-August) reaches up to  $51$ C. The absolute temperature in E-Kharga Oasis during the coldest months (December-February) about  $2$  C, and potential evapotranspiration is as high as  $5$  mm/d.

El-Nadira temple is highly influenced by wind action because it has built on a hill top  $180$  meter in hyper arid climate and exposed to wind without any obstruction. Wind is the most important factors of weathering and deterioration of El-Nadira temple stones especially if it carried with sand particles of high hardness. Considering the influence of climate conditions on stone monuments at

El-Nadora Temple, the deteriorations are classified into strong decomposition, moderate decomposition and moderate decomposition according to the correlation between temperature and precipitation.

The deterioration features at El-Nadora Temple have been divided into 7 groups in this study. These groups are: detachment of stone material, loss of stone material, formation of deposits on the stone material, cracking, structural instability, collapsed wall, deterioration of plaster and mortar. These groups are mainly divided into 22 sub-groups. Due to arid climate of El-Nadora Temple many deteriorated features are formed as a result of thermal expansion and contraction where rocks at El-Nadora Temple are exposed to a wide range of temperatures with very hot days and very cold nights. When temperatures changes rapidly, the surface of a rock heat or cools faster than its interior as a result, the surface expands or contracts faster than the interior, the resulting forces may fractures the rocks.

The thermal expansions do not occur only because of hot weather at afternoon but also freezing process as a result of decreasing of temperature at night, the frozen dew fall in cracks presents a cotter effect, enlarges the cracks and causes to have broken pieces of stones.

The total porosity in El-Nadora temple rocks ranges between 27-29.3%. The main type of porosity has been observed is primary intergranular porosity. The percent of cement ranges between 19-32 %. Many types of cement are observed isopachous rime and equant mosaic cement.

The microscopic examination of several thin sections revealed that the sandstone consists mainly of quartz (main component), rock fragments, feldspars (microcline and plagioclase), calcite, hematite, micas, clay and heavy minerals. Quartz grains occur as turbid color, fine to medium grained and vary from angular to subrounded grains. It was affected by mechanical breakage and chemical process which produced micro-fractures and cleavages dissecting the quartz grains into several subindividual grains.

#### ***Recommendations***

- El-Nadora Temple represents an evidence of human history and bridge through which the social customs and experiences passed between the generations. It was necessary to revive the past and move the pulse through the restoration and rehabilitation of it, so as to restore it glory.

- The interventions to be carried out in El-Nadora Temple must be based on scientific principles of conservation and must aim at preserving their aesthetic and historic documental value. In this sense, use of original materials is the basic approach.

- Intervention decisions for the conservation of El-Nadora Temple must start with the identification of the present and past climate conditions. In addition, cover

finding out the geological and geomorphological characteristics of the area upon which the structure was constructed.

- Using the modern technology for preserving the temple rocks, such as using suitable resins, safe chemical injected materials and suitable cleaning methods where appropriate.

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