Climate Change and its Impact on Monumental and Historical Buildings towards Conservation and Documentation Ammon temple, Siwa Oasis, Egypt

Abd El-Aal AK


corresponding author: Abd El-Aal AK, Civil Engineering Department, Faculty of Engineering, Najran University, Najran, Saudi Arabia.

Abstract

Siwa oasis is located in the extreme western part of the Egyptian western desert. There are several archaeological sites in the oasis; the most distinct ones are Alexander the Great temple at Aghormi hill, the Gebel El Mota tomb excavations and Ammon temple. The present study dialed with Ammon temple which suffered due to deterioration and cracks of different kinds and some parts are getting worse as rock falls occur. The causes of deteriorations on the stone material due to climate can be classified as temperature effects, which include air temperature, thermal expansions and solar effect while the atmospheric effects include water and humidity, wind, Rainfall and air pollution. The atmospheric and temperature effects allows causes deteriorations on the stones of Ammon temple are physical and/or mechanical modification crack/fracture, chromatic alteration/stains (taches) erosion/differential erosion, alveolization (efflorescence) scaling and rising damp.

Keywords: Siwa oasis; Ammon temple; Atmospheric effects; Temperature effects; Differential erosion

Introduction

Siwa Oasis is located in the Western Desert of Egypt. The study area is bounded by the zero contour line; laying between latitude 29° 16´ 33˝ and 25° 06´ 32˝ N. and longitudes 25° 48´ 15˝ and 25° 17´ 36˝ E. with a total area of about 408.5 km². Siwa is the largest oasis in Egypt with an approximate area of 1175 km². It is located about 800 km west of Cairo and 300 kilometers inland from the Mediterranean Sea. It is situated in a depression of 20 meters below sea level. It is connected to the other oasis and urban centers through roads and trails as it is the gate to the many Safari trip to the Western Desert as well as a main link between Egypt and Libya. Historically Siwa was on the main trade line between North Africa and Egypt including pilgrimage annual and seasonal trips. The main road leading to it now is Matrouh–Siwa with a length of 306 km (Figure 1).

Siwa Oasis has a length of about 49.9 km and width varying between 0.6 km and 13.33 km.

This paper is targeted to define and assess environmental deterioration consequences due to physical and chemical weathering activities on Ammon temple. The current study is a comprehensive investigation of the chemical and physical properties of the stones building materials of Ammon temple; one of the key World Heritage Sites in Siwa Oasis.

Architecture can be described as the sum of the social; economic; political and cultural developments. The places people live in also live for years. The representatives of architectural heritage each have its own architectural; historical and cultural message have undertaken a social duty to give cultural messages to their environments and future generations. Architecture taking place at the intersection zone of technique and art is the physical and permanent sign of social and economic life culture and national structural culture. The deteriorations on the construction materials have occurred not only because of the years but also mostly due to the environmental factors. One of the most important factors giving shape to the architecture is natural environment and the other is material of construction. The buildings are unfavorably affected from changing natural environment and climate conditions. Climate can be defined as the whole atmospheric events such as rainfall; temperature; wind; pressure and humidity that cause certain damages on the monumental buildings for years. The historical and cultural riches of nations are the values assigning the power; richness and identity of them. Each historical building and cultural value is an expression of accumulation and a bridge from past to present.

Geomorphological Factors

The topographic map indicate that the surface level ranges between – 18 m b.s.l. and zero. The Oasis is bounded in the south by a discontinuous escarpment partly hidden behind a sand sheet cover; whilst the northern edge rises up to (120 m). There are some outlier scattered in Siwa Oasis such as G. Siwa (38 m); G. El kosha; Qaret khamsia; G. El Takrur (88 m) and El Mota [1]. The Oasis is covered by a variety of aeolian sands and sabkhas. The most important landforms in Siwa Oasis are the saline lakes (Birket) e.g.; Zeitun; Aghurmi; Siwa and Maraqi. Around the saline lakes spread marshes; salinas and sabkhas (Figure 2). The cultivated lands (Hatiat) are presents in Siwa; Aghurmi; Khemisa; and Maraqi exist at variable levels from the floor of the Oasis. The difference in elevation between cultivated lands and the lakes controls the depth of the drainage water and consequently plays a vital part in the logging problem and the low lands suitable for the capillary

*Corresponding author: Abd El-Aal AK, Civil Engineering Department, Faculty of Engineering, Najran University, Najran, Saudi Arabia, Tel: +966592375765, E-mail: bahadur.kotlia@gmail.com

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rise of saline water and the concentration of salt crystals in the upper part of the soil profile.

The hydrogeomorphological characteristic of ground water

The underground water system consists of two water bearing units. The first the deepest is the Nubia sandstone aquifer system. Salinity increases downward from 400 ppm to 55000 ppm. The second is the Middle Miocene limestone aquifer; with a salinity ranging between 1500 ppm to 7000 ppm. Uncontrolled irrigation periods cause the pooling feature of the un-seeped quantities in the soil leading to salt accumulation and salt weathering [2].

The depth of soil water ranges also between 0.08 to 2.78 m during winter and from 0.22 to 3.17 m during the summer. The average annual rising in the soil-water of the cultivated low land areas reaches 3.6 cm/ year. The general trend of soil-water movement is towards the natural drainage system from all directions and particularly from the south [3].

The shallow depth of soil-water leads to quick capillary rise of water in the soil profile surface and leads to the concentration of salt crystals thus forming salt flats; salinas and sabkhas due to over evaporation.

Tourism

Siwa oasis commands a great historic interest due to the presence of Romanic monuments such as the temple of Alexander the Great and mountain of the Dead (Gabal El Mawta). It was a center for Roman civilization; which makes it an attractive tourist site. The Temple of Jupiter Ammon is also about one and a half miles east of Siwa. There is also Shali; which is the old City and means in local language the elevated city. The variety of ecosystems in Siwa presents a base for various tourism activities. Briefly; tourist attractions may be loosely categorized into six main categories.

Deteriorations on stone-based construction materials due to climate

Deteriorations mean modification meaning a marked reduction of the material durability and/or static problems for the building.

In Amoun temple; the natural stones have been used as the construction materials of many historical and cultural buildings and monuments. When the atmospheric contaminants join together with the atmospheric factors such as rainfall; smog; humidity; wind; temperature and sun light etc.; they affect the natural stones used for the construction of monumental buildings in various manners and cause damages and deteriorations differing with respect to the type of stones [4]. The intervention decisions about the conservation of stones in historical buildings start with the identification of the present conditions of the buildings. These conditions cover the determination of geological characteristics of the area on which the building was constructed; the climatic conditions; the effects of air pollution and natural disasters as well as the condition of the use of the building during its lifetime and the interventions carried out during this period [5]. The weathering of stone takes place due to chemical; physical; mechanical; and biological processes. Physical weathering breaks stones into smaller pieces. The types of physical weathering also include salt crystallization; freezing-thawing cycles; thermal expansion; and loads; rot pressure of plants and microorganisms; etc [6].

In general; the causes of deteriorations on the stone material due to climate can be classified as “Temperature Effects”; and “Atmospheric Effects”

Temperature Effects

a-Climatic zone

According to the Food and Agriculture Organization (FAO); the climate of Egypt is governed mainly by its location in the north-eastern part of Africa; on the margin of the Sahara; the largest desert in the world. The latitudinal position; between 22° and 32° N; lies in the sub-tropical dry belt; although conditions on the northern coast are ameliorated by the presence of the Mediterranean Sea. Throughout most of the year the hot; dry tropical continental air masses dominate; but during the winter period air masses of both tropical maritime and polar maritime origin make brief incursions into Egypt from the north; and frequently bring rain. Despite the fact that the coast of Egypt is semi-arid; its climate can be considered Mediterranean. The weather is highly seasonal in nature and is strongly related to high-pressure systems that extend towards the North Atlantic; Eurasia and Africa [7,8]. Local and regional climatic conditions have a significant impact on the dispersion of pollutants in the atmosphere. The climate within the project area can be summarized as follows:

• Winter (November to March): a semi-permanent low-pressure
area known as the Cyprus low is usually located over the eastern Mediterranean. It will influence the project area and generate rainstorms. These months are the windiest; with prevailing winds from the north-west and less frequently from the north and north-east.

- Spring (April to May): there is a gradual weakening of the Cyprus low which coincides with the development of a high-pressure ridge over the Mediterranean and a low-pressure zone over the Arabian Peninsula and north-central Sahara. These weaker depressions result in a decrease in the average wind speeds over the Mediterranean. When the depressions are counteracted by strong blasts of polar air; the south-westerly and southerly hot and dry winds (known as Khamasin) become violent; raise air temperature; lower the relative humidity; and transport sand and dust. Summer (May to August): the area is not generally affected by atmospheric depressions; and therefore; rainfall is minimal. Meteorological conditions are relatively stable and prevailing winds are from the northwest and are relatively hot.

- Autumn (September to November): season of the year between summer and winter during which temperatures gradually decrease; rainfall is minimal.

**Effects of climate on monumental buildings of Ammon temple**

Climate is the act of all atmospheric events such as rainfall; temperature; wind; air pressure and humidity etc. The traditional architecture in Amoun temple has been formed with natural construction materials such as stone; brick; etc. Therefore; the variations in natural environment and climate conditions in Amoun temple have caused unfavorable effects on architectural buildings during and after the period of May and June. The monumental buildings deteriorated due to the temperature differences of seasons and day-night; capillary movement of water inside the building; salts and other harmful chemicals; air pollution; etc.

**Atmospheric Effects**

**a- Air temperature**

According to the FAO; the mean annual temperatures in Egypt are high and register between 20 and 25°C. Major variations occur between summer and winter temperatures; as well as between coastal and interior locations. Along the coast and project area mean maximum temperatures vary from 18°C to 19°C in January and from 30°C to 31°C in July and August. For monitoring stations at Alexandria; Cairo; Port Said; Minya; Kharga; and Aswan; the mean minimum temperatures show variations from 9°C to 11°C in January and from 21°C to 25°C in July and August (FAO) (Figure 3 and Table 1). Stone has become show variations from 9°C to 11°C in January and from 21°C to 25°C in July and August (FAO) (Figure 3 and Table 1). Stone has become show variations from 9°C to 11°C in January and from 21°C to 25°C in July and August (FAO) (Figure 3 and Table 1). Stone has become show variations from 9°C to 11°C in January and from 21°C to 25°C in July and August (FAO) (Figure 3 and Table 1). Stone has become show variations from 9°C to 11°C in January and from 21°C to 25°C in July and August (FAO) (Figure 3 and Table 1). Stone has become show variations from 9°C to 11°C in January and from 21°C to 25°C in July and August (FAO) (Figure 3 and Table 1).

**Solar effect**

The colors of stones change in the course of time due to the temperature differences between day and night. The faded stone surface takes a matt and pale appearance which is more frequently seen in natural construction stones. Sometimes the color changes occur as vein shaped dark spots.

**Atmospheric effects**

Atmospheric movements and humidity are the unfavorable factors against protection purposes of monumental buildings. Even the stone material is resistant against bad weather conditions; it also goes through deterioration after a certain time period and sometimes disappears. Seriously large damages can occur on soft stones due to the particles carried by winds; and stones can fracture and break into pieces as a result of stresses sourced by temperature differences; freezing thawing and humidity events. The contaminated atmosphere; water and organisms bring about chemical melting on stones; and usually the thin dust layer gets thick by forming a dirty layer on the stones and affects the whole structures of the stones [9]. The atmospheric effects causing the deterioration of stone material used for monuments should be
discussed under separate subtitles of “Water and Humidity”; “Wind”; “Salts” and “Air Pollution”.

**Water and humidity**

Humidity is one of the most important harmful factors against stone-made constructions as for every construction material. Limestone dissolves by the effects of rain water and carbon dioxide. Additionally; the acid rains threatening stones are carried by rain water whose capillary rise inside the building causes harmful effects the construction materials. The soil between groundwater level and earth surface holds water by capillarity where this event is called as “surface water” or “capillary water” that cannot be removed by using any drainage system. The humidity rising up the building can cause serious damages on the structure. At the same time; the salts hold by the building itself can result in florescence and some other effects damaging the chemical and physical structures of the walls (Figure 4 and Table 2).

**Wind**

The seed transport and placement in the cavities and joints of roofs and walls by the help of wind factor sometimes causes to have trees grown on the facades of many neglected historical buildings. This event accelerates the deteriorations on the monumental buildings. Additionally; if wind presents its harmful effects together with sea salts and sands; serious surface weathering will be inevitable on the monumental buildings. Humid structural member involves more or less salt amount that is soluble in their bodies [10]. Water soluble salts are carried by water or any other ways to the pores and cracks of the stones; and as a result of evaporation of water; the remaining salts accumulate on then stone surface and at the capillary cracks of stone.

The existence of water soluble salts in stone buildings causes to have mineralogical and textural deteriorations little by little in the course of time. Furthermore; salt crystallization is another primary effect resulting in deteriorations on the buildings and monuments constructed with limestone [11].

The wind regime is highly uniform throughout the coastal zone of Egypt and is dominated by north-westerly and northerly winds for most of the year. For only a few days during spring; transient changes in this rather stable wind pattern occur; with hot desert wind blowing from the south; southeast or southwest. This wind (Khamasin) often blows as sand storms of hot desert wind covering vast areas of the Egyptian desert; including the Mediterranean coastal area (Figure 5 and Table 2).

**Deteriorations due to air pollution**

Air pollution is also one of the most significant factors affecting the construction material of stone. Besides the considerable deteriorating effects of gas and ion solutions carried to the surface of the buildings by

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**Figure 4:** Illustrate the average humidity (%). Data in Siwa measured over a period of 30 years.

**Figure 5:** (A) Distribution of Annual normal of Wind Speeds (m./sec) Illustrate the average.). (B wind speed (km/h). Data in Siwa measured over a period of 30 years.

| Months | Average Relative Humidity | Average Wind Speed km/h | Average Precipitation mm |
|--------|--------------------------|-------------------------|-------------------------|
| JAN    | 55.5                     | 12.2                    | 3.1                     |
| Feb    | 49.8                     | 14.0                    | 1.4                     |
| Mar    | 44.2                     | 14.8                    | 2.1                     |
| Apr    | 37.0                     | 14.8                    | 1.2                     |
| May    | 34.7                     | 13.3                    | 0.2                     |
| Jun    | 33.8                     | 12.2                    | ---                     |
| Jul    | 39.5                     | 11.9                    | ---                     |
| Aug    | 42.1                     | 11.2                    | 0.1                     |
| Sep    | 44.0                     | 10.1                    | 0.1                     |
| Oct    | 48.4                     | 9.7                     | 0.4                     |
| Nov    | 55.5                     | 9.4                     | 1.9                     |
| Dec    | 57.2                     | 11.2                    | 1.8                     |
| Annual | 45.1                     | 12.1                    | 12.3                    |

Table 2: Average Relative Humidity, Average Wind Speed (km/h) and Average Precipitation (mm) in Siwa Oasis.
the help of rain water; the atmosphere movements; wind; rainfall and snow cause weathering on the outer surfaces of stones [9]. Chemical weathering erodes the stones changing their compositions by chemical reactions such as dissolution; hydrolysis and oxidation processes of the stone minerals. Chemical weathering is mostly due to the effects of air pollution [5]. The meteorological factors such as wind; relative humidity; fog; sun light and solar radiation cause to have faded stones. The existence of dense or loose air pollution considerably depends on the position and

Rainfall

According to FAO; the rainy season is the winter period from October to May when the depressions follow their southern tracks over the Mediterranean region. Most of the precipitation is associated with the warm and cold fronts of these systems. Many of the fronts are weak by the time they reach Egypt and rainfall is light and showery. Rainy periods usually last for one to four days. Over most of the interior of Egypt it is not unusual for a year to pass without any precipitation at all being recorded. Throughout Egypt rainfall reveals considerable variability over time and space. Figures 6, 7 and Table 2 present the mean annual precipitation in Egypt (mm.y⁻¹) as well as the annual number of precipitation days.

Types of deteriorations

Atmospheric and temperature effects allows causes deteriorations on the stone material due to climatic changes; the following are the main types of observed deteriorations in Ammon temple in Siwa Oasis:

Physical and/or mechanical modification Crack; fracture: Physical and/or mechanical modification cracks are physical separation of layers; plates; sheets following the bedding planes extension of laminated stones (sedimentary) (Figure 8A). Easily formed when laminated stones are posed with their stratification parallel to the exposed surface. This phenomenon supported by the presence of soluble salts; micro-organisms; and by cycles of freeze/thaw cycles. It takes place in zones more or less exposed to water supplies. Discontinuity which separates macroscopically one part of the stone of another; with or without relative displacement of the two parts. It can be limited at the stone surface or can affect the in depth vertically or horizontally (Figures 8B and 8C).

Chromatic alteration/Stains (taches): Chromatic alteration/Stains (taches) generally correlated with alien materials like: rust; copper salts; organic substances; painting; and varnish. This phenomenon does not strictly depend on exposure conditions of water supplies. The original color of a material changes because of processes like; water penetration (more or less permanent colored stains); exposure to sunlight (fading) and formation of metallic oxide in the structure but not because of a deposit. Chromatic alteration doesn’t depend on exposure conditions to water supplies.

Chromatic alterations due to local oxidation of iron and black to brownish red in color (Figures 9A and 9B). The Natural modifications of the building stones surface are normal in outdoor environment and the quite uniform very thin layer which sticks to the substrate from which it is chemically different (enriched in iron/clay minerals and/or in biogenous calcium oxalates)

Mechanical Weathering is processes that break a rock or mineral into smaller pieces without altering its composition. These are actions or things that break down Earth materials due to frost wedging; thermal expansion and contraction; mechanical exfoliation; abrasion by wind; water or gravity; freezing/thawing and plant growth; (Figures 10A and 10B). Chemical Weathering is processes that change the chemical composition of rocks and minerals due to dissolving (dissolution); oxidation and hydrolysis.

Dissolving (dissolution) commonly caused by water; often containing acid from dissolved carbon dioxide; will dissolve minerals from a rock body leaving cavities in the rock. These cavities may generate sinkholes or cave features such as stalactites and stalagmites.

A - Erosion/Differential erosion: In the present study; the erosion of variable intensity on various sectors of the material due to the inhomogeneity of the stone material and takes place in zones exposed to more or less direct water supplies (and to wind); (Figure 10C).

Alveolization: Alveolization appears mainly on very porous materials as formation of cavities (alveoles) of variable shapes and sizes (cells; lines; often centimeter size) and also appears on the surfaces
exposed to strong winds where the crystallization of salts occurs underneath the surface; eroding it gradually. Takes place also in zones exposed to direct water supplies (and wind). Two types of Alveolization

1- **Subflorescence**: accumulation of salt crystals just under the external surface of building stones. They are harmful; the pressure exerted by crystals can cause damages

2- **Efflorescence**: any visible salt deposit on the surface of the building stones and caused by the salt concentration and precipitation in the water evaporation zones (Figures 11A and 11B).

*Modification by stone decoherence/Scaling*: Detachment of stone layers (scales) parallel to the stone surface BUT not following any stone structure. These layers have a homogeneous thickness from a few millimeters to a few centimeters. Takes place in zones exposed to direct water supplies; (Figures 12A and 12B).

*Modification linked to water supplies/Rising damp*

Rising damp is caused by water absorption by capillarity from the ground at the base of walls or from a surface of retention. The Moisture goes through the walls; wets the internal and external surfaces where a horizontally limited stain is visible. It takes place in zones where water supplies from the wall bases (or from a surface of retention) are important. The material surface shows wet spots or zones of different color; generally darker. It can be caused for example by the penetration of water (by rising damp) and/or by the hygroscopic behavior of salt (Figure 13A-13C).
Summary and Conclusion

Siwa Oasis is located in the Western Desert of Egypt. The study area is bounded by the zero contour line; laying between latitude 29° 16´ 33˝ and 25°06´ 32˝ N. and longitudes 25° 48´ 15˝ and 25° 17´ 36˝ E. with a total area of about 408.5 km². Siwa is the largest oasis in Egypt with an approximate area of 1175 km². It is located about 800 km west of Cairo and 300 kilometers inland from the Mediterranean Sea. Siwa oasis commands a great historic interest due to the presence of Romanc monuments such as the temple of Alexander the Great and mountain of the Dead [Gabal El Mawta]. It was a center for Roman civilization; which makes it an attractive tourist site. The Temple of Jupiter Ammon is also about one and a half miles east of Siwa. There is also Shali; which is the old City and means in local language the elevated city.

They have been constructed using stone i.e. natural construction materials that today serious deteriorations are observed on them. These deteriorations have occurred not only because of the age of the structures but also mostly due to the environmental conditions and factors. Climate can be defined as the entire atmospheric events such as rainfall; temperature; wind; pressure and humidity that cause certain damages on the monumental buildings in the course of time.

Living four different seasons in Siwa cause some problems against monumental buildings. Consequently; the deteriorations related to climate conditions on the monumental buildings in Siwa present regional differences and occur due to temperature differences between seasons and day night; the capillary movement of water within the structural members of the building; the weathering effects of rain water; salts and various chemicals existing in water; particles carried by winds and air pollution. But regional temperature and precipitation caused by a team consisting of differences in structure translate it to different aspects of corruption that have been observed.

Atmospheric and temperature effects allows causes deteriorations on the stone material due to climatic changes; the following are the main types of observed deteriorations in Ammon temple in Siwa Oases; physical and/or mechanical modification crack; fracture; chromatic alteration/stains (taches); chemical and/or mechanical weathering; alveolization which includes subflorescence; accumulation of salt crystals just under the external surface of building stones. they are harmful; the pressure exerted by crystals can cause damages and efflorescence: any visible salt deposit on the surface of the building stones and caused by the salt concentration and precipitation in the water evaporation zones; modification by stone decoherence / scaling and modification linked to water supplies / rising damp

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