JSDSES. **Volume 4**, Issue 1, pp. 29-59 (March, 2025)

Journal of Sustainable Development in Social and Environmental Sciences

Journal Homepage: **https://jsdses.journals.ekb.eg/**

P-ISSN: 2812-6335 E-ISSN: 2812-6343

Weathering and Its Geomorphologic Impact on Heritage Buildings at Mansoura City, Nile Celta, Egypt: A Geomorpho-archaeologic Study

Sherine Sabry Elsebaei[1,*], Sarah Ali Fathy Hamaiel[2]

[1] Department of Geography and Geographic Information Systems, Faculty of Arts, Port Said University, Egypt.
[2] Faculty of Tourism and Hospitality, Mansoura University, Egypt.
[*] *Email address: sherin.sabry@arts.psu.edu.eg*

doi 10.21608/jsdses.2025.347407.1040

ARTICLE HISTORY

Received: 20 -12 -2024
Accepted: 22-1-2025
Published: 1-2-2025

KEYWORDS

Geomorpho-archaeologic
Heritage Buildings
Weathering
Incorrect Restoration
Hydrochemical Analysis

ABSTRACT

Heritage buildings[1] are considered among the most important landmarks of historical and human development in the city of Mansoura. In fact, the city includes many heritage buildings like Dar Ibn Luqman, Al-Shinawi Palace, the Great Mosque of Al-Salih Ayyub, Idris Mosque, and Al-Najjar Mosque, which have recently been subjected to many violations leading to the deterioration of their architectural form, as well as being affected by weathering factors, which is one of the most important damage factors that they face. This led to the spreading of many manifestations of damage such as peeling, efflorescence, disintegration, and disintegration. This study seeks to assess the geomorphological characteristics to better understand the heritage and archaeological place by identifying the historical origins of the monuments, showing their architectural style, analyzing them geographically, studying the geomorphological characteristics and conducting the necessary laboratory analyses. This research explores the most important issues facing archaeological and heritage monuments, such as changing climatic conditions including humidity, drought, and high ground water levels, in addition to wrong restoration processes, population overcrowding, and increased services within the city and the resulting urban sprawl around heritage buildings that made them more vulnerable to destruction and demolition, especially in the Mosques areas. What remains consequently is only a few scattered monuments that are not connected to the urban fabric. Therefore, the study offers a set of solutions to preserve heritage and archaeological monuments, protect them from degradation and destruction, work on their sustainability and benefit as well from them for future generations, and invest in them as culturally important tourist attractions of the city.

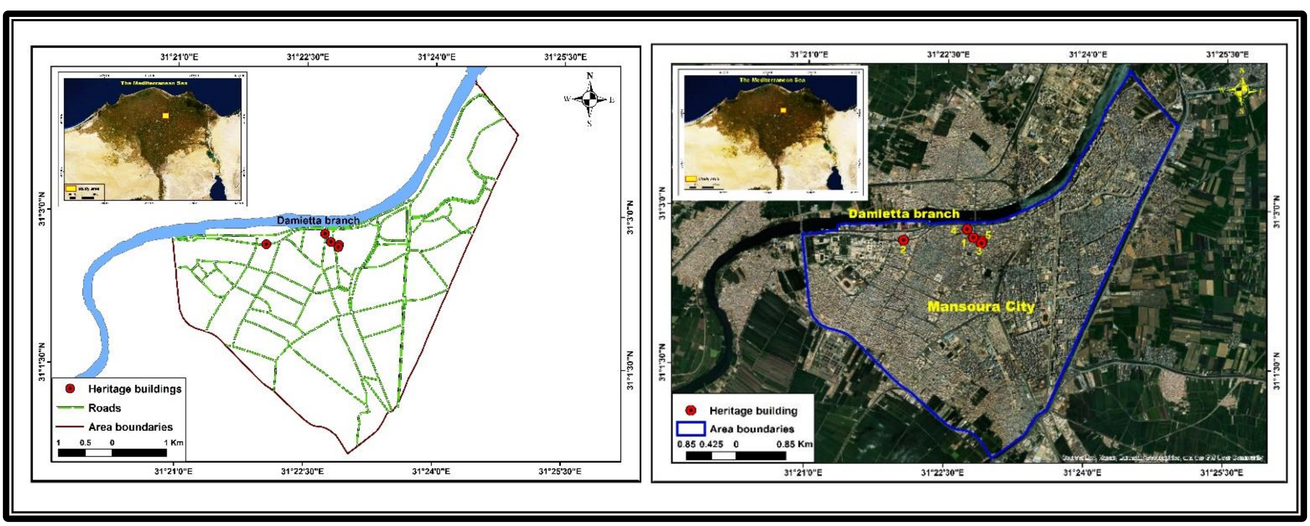
[1] Heritage is the cultural product left behind by previous generations specific to a civilization, while antiquity is everything that is ancient, dating back to a certain era and registered with the Antiquities Authority.

1. Introduction

Weathering processes act on all subaerial materials resulting in partial to complete deterioration of the original form, texture, and composition of such materials. Weathering processes that prevail at a given area are controlled by the agent, environmental parameters e.g. air relative humidity, air temperature, and air pollution level. The deterioration may be physical, chemical or bio-chemical on mega scale or micro-scale (Fitzner & Heinrichs, 2002). The impact of the weathering process is more deleterious if it takes place on an ancient archaeological site that is of historical value and cannot be regained again in its original form (Flatt, 2002). Salt weathering is among the most common and effective weathering processes that were recorded worldwide in all environments (Hall & Hoff, 2007). It has an impact on all building materials including natural stones, red brick, mortars. This includes slight salt efflorescence up to total material fragmentation into rock meal and debris mixed with salt crystals (Smith & McGreevy, 1983; Hall, et al., 2010).

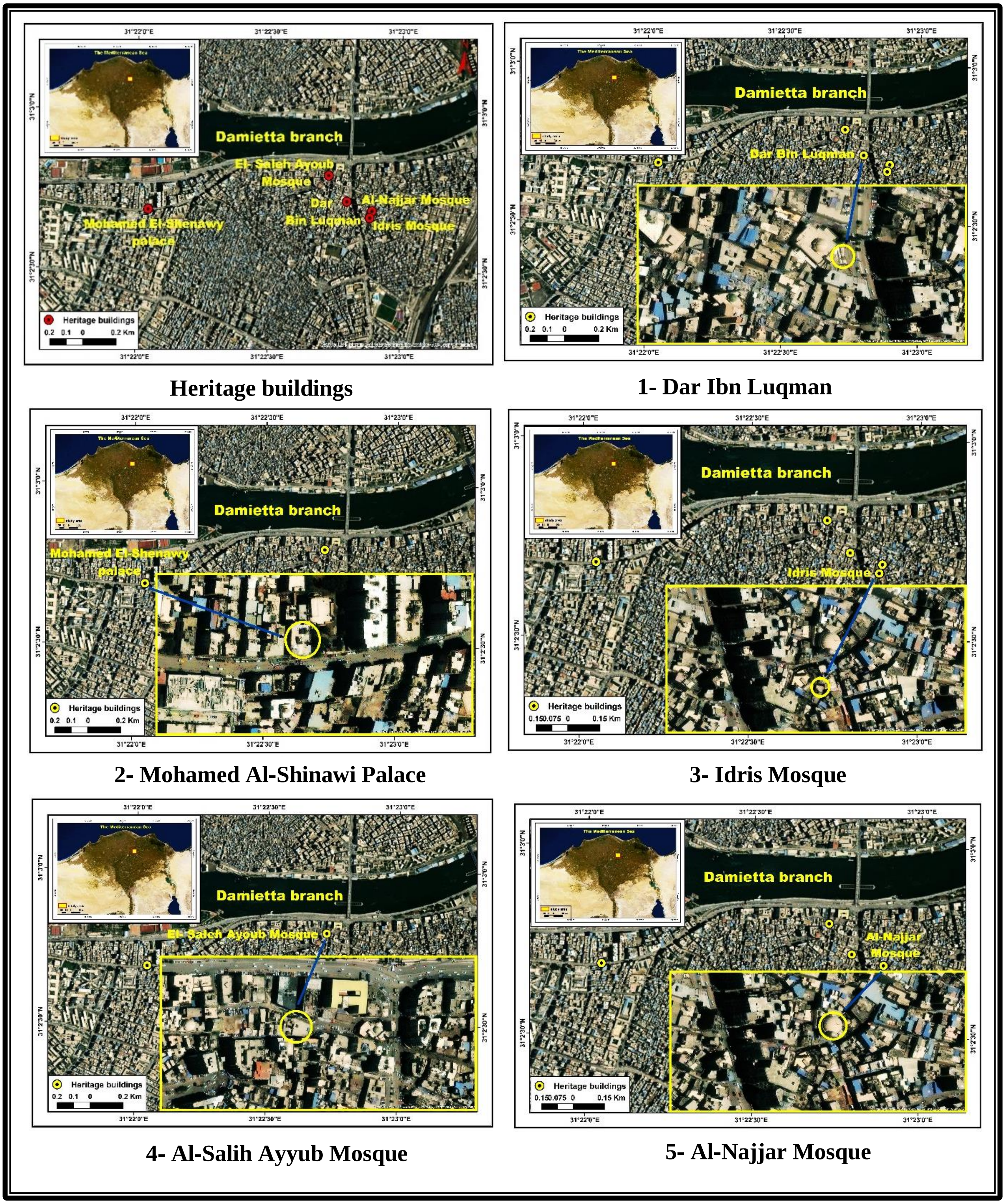
In salt weathering, the salts act on building materials by one of the following mechanisms based on air temperature and relative humidity. These mechanisms are: salt crystallization at dry arid regions where evaporation prevails (Kamh & Azzam, 2008; Kamh, 2009); salt hydration particularly for sulfate salts at humid cold regions where air temperature reaches down to zero and relative humidity reaches up to more than 90% (Rodriguez & Doehne, 1999); or salt thermal expansion at extreme hot dry regions as the Arabian deserts where daily expansion/contraction cycle of the rock and its salt content takes place (Sperling & Cooke, 1985; Smith, et al, 1994; Rudrich, et al, 2011). The weathering processes result in changing the geomorphologic relief of a given stone or building compared with its original form (McGreevy, 1996; McBride, et al., 2004; Benavente, et al., 2007).

The current study had been conducted on some heritage buildings at Mansoura City that lies on the eastern bank of Damietta branch of the Nile Delta. This City lies between latitudes 31˚ 4’ 20″ N and 31˚ 00’45″ N, and longitudes 31˚ 20’ 50″E and 31˚ 25’ 00″ E with a total area around 18 km^2 (Fig.1) and is considered one of the most important touristic cities in Egypt as it has many touristic, archaeological, and heritage buildings. Among these buildings are Mohamed Al-Shinawi Palace, Dar Ibn Luqman, in addition to some ancient mosques such as Idris Mosque, Al-Najjar Mosque, and the Great Mosque of Al-Salih Ayyub (Figs. 1 & 2).



Source: Esri, Maxar, Earthstar Geographics, and the Gis User Communi, Topographic Maps, at a scale of 1:500000, 1986, Using ArcGIS 10.5.

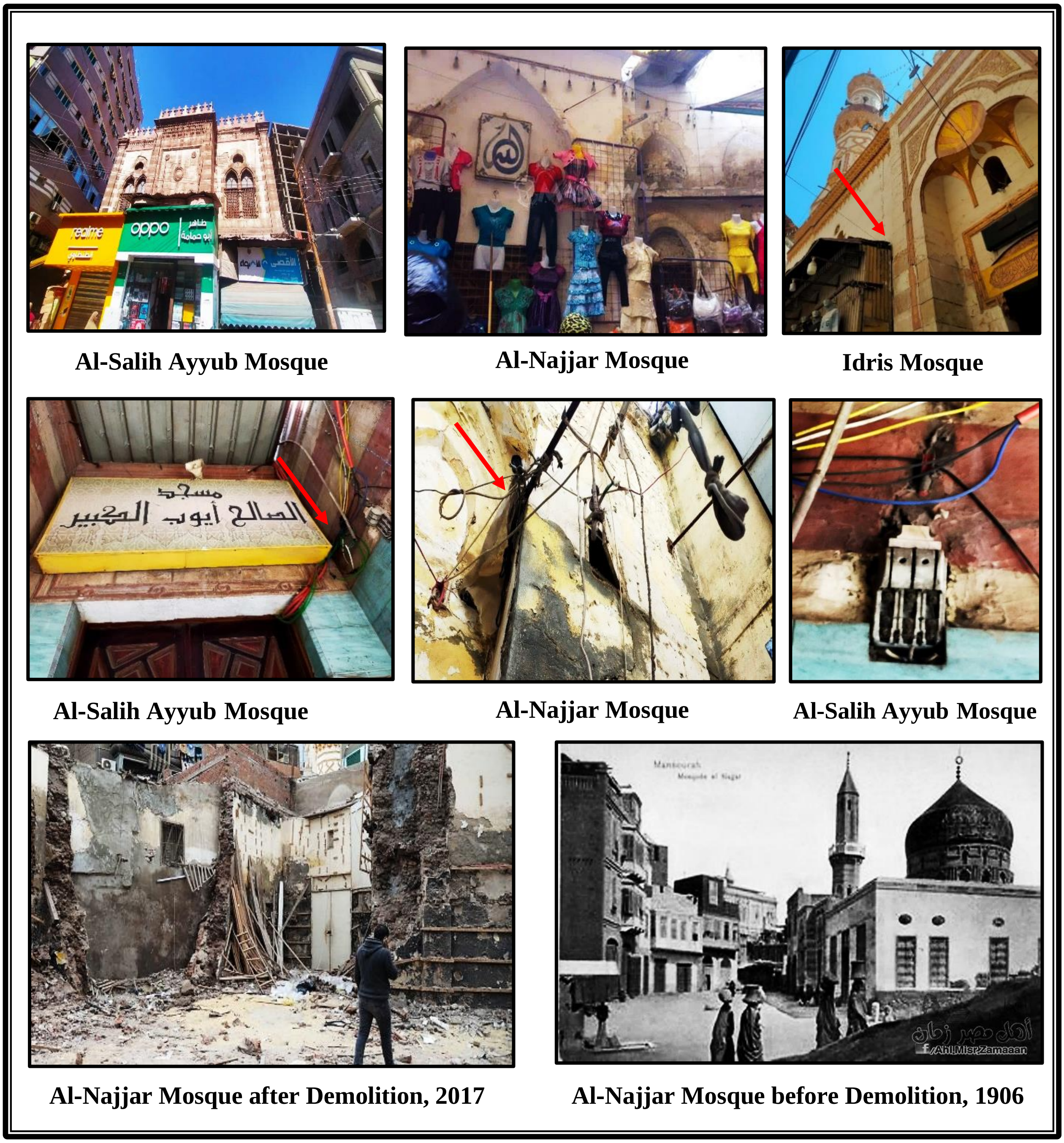
Figure 1. The Geographical Location of the Study Area



Source: Esri, Maxar, Earthstar Geographics, and the Gis User Communi.

Figure 2. Heritage Buildings at Mansoura City

Recently, these heritage buildings suffered deterioration in their external form because of many factors that had interacted together resulting in weathering forms on their building materials including the anthropogenic impact. This is considered one of the most important problems that negatively affect heritage buildings due to the high population density around these buildings, and the resulting acts of demolition, vandalism, and deterioration (Fig. 3).



Al-Salih Ayyub Mosque | **Al-Najjar Mosque** | **Idris Mosque**

Al-Salih Ayyub Mosque | **Al-Najjar Mosque** | **Al-Salih Ayyub Mosque**

Al-Najjar Mosque after Demolition, 2017 | **Al-Najjar Mosque before Demolition, 1906**

Source: Field Study (2024), https://scontent.fcai19-12.fna.fbcdn.net/v/t39

Figure 3. Examples of Human Encroachments on Heritage Buildings in Mansoura City

Human interference with heritage buildings includes incorrect restoration operations, and the demolition of some mosques after decisions to remove them were issued by some concerned authorities due to their exposure to collapse. They were consequently replaced by other buildings, as is the case with the Al-Najjar Mosque, of which only one archaeological wall remains. In addition, there is the urban encroachment on heritage buildings proximity which includes markets encroachment and shops underneath the mosques being rented out to some merchants, as is the case in the Great Mosque of Al-Salih Ayyub that was had shops underneath it rented for the purpose of profit. Moreover, there are many violations and attacks by street vendors which concealed the features of the mosques and their heritage value by exploiting the surroundings and walls of the mosques to display and hang their goods, place commercial signs on them, and randomly exposed electricity wires. Added to this is the deterioration of the infrastructure networks such as water and sewage networks, near surface domestic water that seepage from domestic pipes of buildings around these heritage structures, There is also the accumulation of waste and dust on buildings, which ultimately leads to distorting their architectural form and historical landmarks and thus threatening the cultural and heritage image of the building, as well as renting them from government agencies to perform a function other than the one for which they were created, such as exploiting Al-Shinawi Palace to be a building for the Antiquities Authority in Mansoura City.

The main aim of the current study, considering the above conditions and the historical value of the heritage buildings at Mansoura City, is focused on semi-quantifying the impact of weathering processes, in particular by salts, on five heritage buildings to precise the urgency of their conservation.

The study adopted the **historical approach** to study the historical origins of the phenomenon, its development, and the changes it underwent during different periods of time, and **the descriptive and analytical approach** by describing and analyzing the phenomenon and identifying the factors and processes affecting it and the reasons for its change.

Previous Studies:

Kamh's (2011) study: It is on salt weathering on buildings and monuments in some countries of the world. It dealt with the study of salt weathering as one of the risks to buildings and monuments, with representation of some case studies such as Roman monuments in England, Alexandria, and so on. Then it dealt with the nature of salts, sources of moisture, and geomorphological forms associated with weathering. Salinity and qualitative and quantitative estimation of damage manifestations were also explored.

Saber's (2012) study: It is on the dangers of salt weathering on archaeological buildings in the city of Cairo. It addressed the factors affecting salt weathering, such as climatic characteristics, faulty restoration, ground water levels, and their major role in damage and corrosion of building materials. The study also relied on Arnold's classification to distinguish four ranges of manifestations of damage in the area, and many techniques were relied upon to determine the manifestations and forms of damage.

Hasan's (2018) study: It is on the dangers of weathering on the Hawara and Lahoun Pyramids in the Fayoum Depression, a study in applied geomorphology that dealt with the factors affecting the activity of salt weathering processes and the characteristics of the rocks used in construction, as well as the manifestations of deterioration and damage resulting from the impact of weathering processes in the region.

Al-Nasiri's (2020) study: It is about the city of Mansoura and the history of its establishment in the era of the Ayyubid Sultans and its victory over the Seventh Crusade. It dealt with the capture of the French King Louis IX, and then talked about the most important archaeological and heritage sites and buildings in the city of Mansoura.

Abdul Maqsoud's (2022) study: It is on the analysis and modeling of geomorphological controls of weathering processes and their impact on archaeological sites in Youssef Al-Siddiq Center, Fayoum Governorate. A study in applied geomorphology that uses geomatics techniques, and deals with the spatial distribution of archaeological sites and their surface determinants. It then deals with the drivers of weathering processes in archaeological sites in the study area and the petrophysical properties of rocks, the spatial distribution of weathering groups and images, and their division into four groups.

Saber and Al-Bana's (2023) study: It is about Sabil Muhammad Ali in Al-Aqqadin, Cairo: A Study in Applied Geomorpho-Archaeology. It dealt with the historical and archaeological characteristics of the Sabil and the characteristics of the building materials used, in addition to the damage factors that affected the stones used in construction. The study ended with identifying the ways and methods of damage to the stones used in building the Sabil of Muhammad Ali and the manifestations of this damage.

Field and laboratory investigations included the following:

- Using a scanning electron microscope (SEM) to identify signs of damage within building materials, studying the microbiological damage that occurs to stones, and X-rays to identify the minerals that make up the rock and determine its degree of resistance to various weathering processes.
- Data collected on the prevailing climatic conditions either in the field or from the closest meteorological station, sampling of weathered building materials of these heritage buildings to be investigated in the laboratory to achieve the aims of this study. Full description and photo-documentation of weathering features noted on the sites under investigation to semi-quantify the damage category of these sites using Fitzner and Heinrichs' (2002) classification. These weathering features will also enable defining the main cause of building deterioration and facilitate defining the laboratory investigations that must be conducted on the collected rock samples.
- Laboratory investigations for mortar and tiny rock samples collected at the sites under investigation have been examined through the following methods to achieve the aim of this study. Petrographic investigation of the rock samples using scanning electron microscope (Scentage-Hitashi-LM2721) to get detailed visual information on the rock's weathering on nano-scale and the crystal form of salts if found within rock pores. For mineralogical identification of this building material, X-ray diffraction for the powder prepared for representative rock and mortar samples have been conducted using X-ray equipment (Scentage-SH-2150). The rock's weathering susceptibility index (WSI) has been investigated for the natural building stone in these sites to find out in a semi-quantitative form the damage category of each of these sites.
- This WSI has been conducted using Mercury Intrusion Porosimetry (MIP) at low and high pressure of mercury injection (13000 mega Pascale and 33000 mega Pascale respectively). The impact of weathering processes at the study area will be checked and reflected as a mirror image in the degradation of petrophysical properties of the building material of the sites under investigation. In other words, the increase in rocks' porosity, water absorption on one hand and the decrease in rock's bulk density on the other hand are the result of weathering impact on the physical properties of building materials. Consequently, these physical properties are measured by immersion method as follows:
- Rock's porosity (Ø) is computed by immersion methods following the method of (2012) using the following equation:

  $$Ø = [(B – A) / V] * 100$$

  Where A is the dry weight (gm) of the tested sample; B is the weight (gm) of the fully water saturated sample; V is the volume of the tested rock sample (cm^3).

  Rock's water absorption (Wa) of the rested rock sample was measured by immersion method following the method of (2002) using the following equations:

  $$Wa = [(B – A)/ A] * 100$$

  Where A is the dry weight (gm) of the tested sample; B is the weight (gm) of the fully water saturated sample.

  While rock's bulk density (σd) was computed for the collected rock samples using the immersion method and equations of (2002) listed as follows:

  $$σd = [W1 / (W2 – (W3\text{-}a))]$$

  Where W1 is the dry weight (gm) of the tested sample; W2 is the weight (gm) of the fully water saturated sample, W3 is the apparent weight (gm) of the rock sample; a is the weight (gm) of the thread used for measuring the apparent weight.

The research topic is addressed as follows:

2. Historical and archaeological characteristics of heritage buildings in Mansoura:

The city of Mansoura is full of many heritage and archaeological buildings of historical and architectural importance, but it does not receive sufficient attention to preserve them and make optimal use of them in the cultural and tourism revitalization of Dakahlia Governorate in general and the city of Mansoura specifically. Therefore, some of these buildings were highlighted due to their distinct heritage, architectural and archaeological importance in Egypt, which are: the Great Mosque of Al-Salih Ayyub, Dar Ibn Luqman, "Mansoura National Museum", Idris Mosque, Al-Najjar Mosque, and the Palace of Al-Shinawi.

2.1. Al-Salih Ayyub Grand Mosque (Al-Mahmudiyah Mosque):

The ancient Al-Salih Ayoub Mosque is located in the city of Mansoura, in the Al-Abbasi area, near Port Said Street. Its establishment dates to the year 1243 AD during the reign of Sultan Al-Salih Nejm al-Din Ayoub, the last Ayyubid ruler in Egypt (Al-Salawi, 2020). It is distinguished by its Ayyubid style and its minaret in the Mamluk style. The mosque still preserves its old form since its inception, except for some old restorations dating back to the "Security Directorate" bombing incident in Dakahlia Governorate in December 2013 AD, where the monument under study lies behind it.

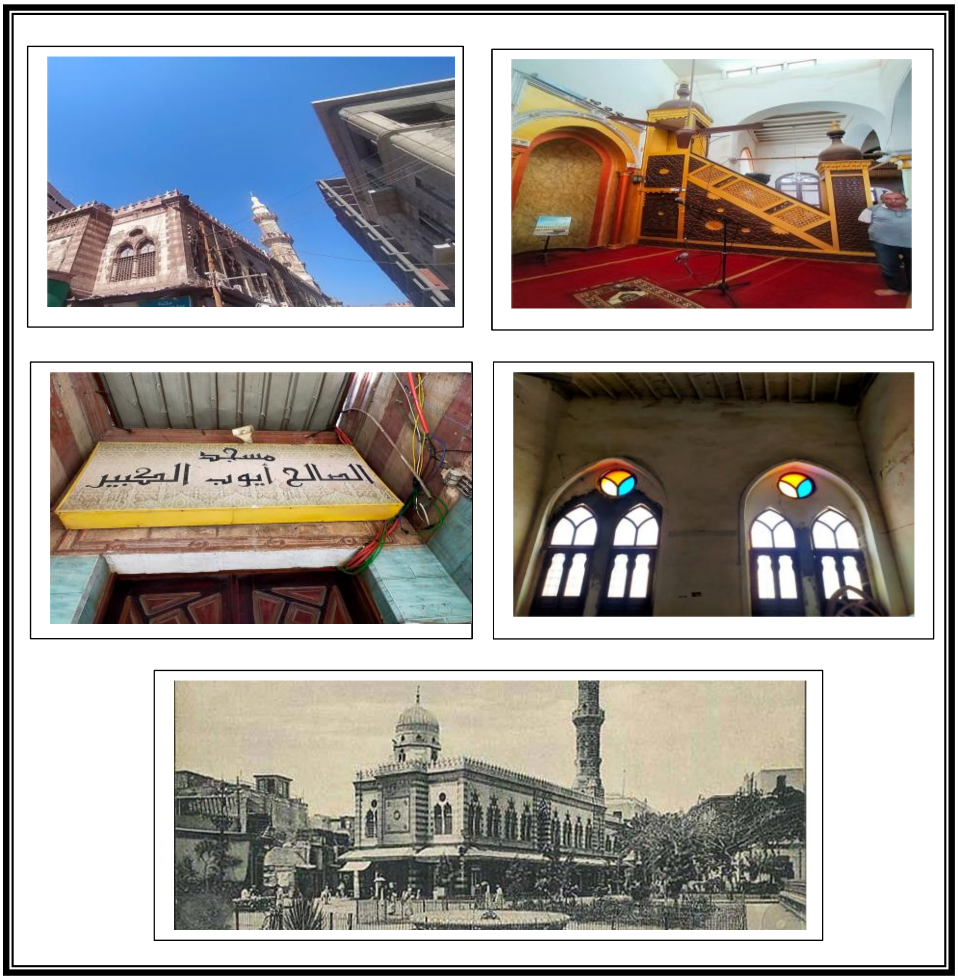
The mosque consists of two floors. The first floor includes a large bathroom and a prayer hall over the corridors of the three entrances to the mosque, which are topped with muqarnas decoration. There is a wooden staircase that ascends to the second floor of the mosque to reach the men's and women's prayer rooms, the room of the imam of the mosque, and the entrance to the minaret (Fig. 4). We find aspects of Ayyubid architecture in the mosque, where they relied on carved stone of large dimensions to decorate the facade of the mosque, and the ceilings are supported by vaults, the appearance of muqarnas on the facades of the mosque, with the colors of the stones interchanging in the facades. The mosque also contains lamps and chandeliers dating back to the date of its construction, in addition to the presence of the wooden pulpit and distinctive decorations (Fikri, 2008, pp. 77-80) The most important feature of the mosque is the Mamluk-style minaret, as one can ascend to it through a door on the second floor in the women's prayer room, leading to a wooden staircase through which one can ascend to its balcony. The minaret is similar in its architecture to the minaret of the Ali Al-Farra Mosque on Al-Bahr Street, branching off from Claude Bey Street in Cairo (Abu Ajila, 2021). In the past, there was a pond of water next to the mosque that was used to move from the mosque to Dar Ibn Luqman via wooden river boats. The Nile River also passed near the mosque and Dar Ibn Luqman at the beginning of the construction of the city of Mansoura and its heritage streets[2].

2.2. Dar Ibn Luqman:

Dar Ibn Luqman, "Mansoura National Museum," is located in the middle of Port Said Street. The founding of the house dates back to the founding of the city of Mansoura in 616 AH/1219 AD, when King Al-Kamil ordered ships loaded with tiles and stone to be brought to establish it. The city was a small island surrounded by water called "The Roses Island". The house was established at that time on the shore of the Nile, but we note that the Nile is currently far by a distance of 500 meters. The house is attributed at the time to the judge of the city, Fakhr al-Din Ibrahim Ibn Luqman, the writer of the Diwan al-Insha during the reign of King al-Salih Najm al-Din Ayyub (Al-Nasiri, 2020, pp. 42-43).

The house was transformed into the Mansoura National Museum in 1997 due to its historical importance, as king Louis the nineteenth, the leader of the Seventh Crusade, was imprisoned there after his capture in the Battle of Fariskur in Muharram 648 Hijri (Fig. 5), and King Louis was taken away in shackles (Al-Nuwairi, 1992, 29/ p.356). Transforming the house into a national museum was achieved in commemoration of the victories of Egypt and its army that took place in the Dakahlia

[2] Field visit of the researchers to mosque patrons and the mosque guard.



Source: Field Study (2024), https://Images.App.goo.gL/RnjvjpglPT92LtMb6

Figure 4. Description of Al-Salih Ayyub Mosque

Source: Field Study (2024).

Figure 5. Description of Dar Ibn Luqman

2.3. Sheikh Idris Al-Hanawi Mosque:

It is one of the ancient mosques in the city of Mansoura, where its construction dates back to the year 577 AH. The mosque is distinguished by being built in the style of Ayyubid mosques and schools, as it begins with the entrance, which leads to a path surrounded by a number of rooms on both sides, then an iwan for prayer, and stone carved with large dimensions was relied upon to decorate it. The facade of the mosque, the ceilings are supported by vaults, the appearance of muqarnas on the facades of the mosque, the exchange of colors of stones in the facades (Fikri, 2008, pp. 77-80) It is also distinguished by its minaret, which resembles the minaret of the Great Mosque of Salih Ayyub, known as the Mahmoudiya Mosque, as one can ascend to it from a door near the main entrance of the mosque and its staircase is made of carved stone, and muqarnas adorn its balconies (Fig. 6).

2.4. Al-Najjar Mosque:

The construction of Al-Najjar Mosque dates back to the year 566 AH / 1170 AD. It was built by the devotee Muhammad Al-Najjar, for whom the mosque was named. It is located in the Al-Khawajat Market area in Mansoura, off Port Said Street. A shrine was erected for the devotee Muhammad Al-Najjar, and he was buried in it inside the mosque. A birthday celebration was held annually, and the mosque was distinguished by its inclined minaret, which resembled the Tower of Pisa, but it is currently demolished: the entire mosque and shrine. In fact, only part of the entrance and gate remains (Supreme Council of Antiquities, unpublished excavation reports, 2024), (Fig. 7).

2.5. El-Shinawi Palace:

It is located on Al-Gomhouria Street in the city of Mansoura, and its construction dates back to the year 1920 AD/1925 AD. It was built for its owner, Mohamed Al-Shinawi, son of the late Muhammad Pasha Al-Shennawi, Ibn Aql, one of the notables of Mansoura and a member of the Wafd Party in Mansoura (Al-Rafi'i, 1929, p. 429), where the palace was given the name "House of the Nation". All party meetings were held in it in Mansoura, and the leader Saad Zaghloul, Mustafa El Nahhas, and the artist Mohamed Abdel Wahhab resided there at times. King Farouk also stayed there. The palace received Badawi Bey Hamouda, Minister of Justice and President of the Constitutional Court, Prince Abdel Moneim, a member of the royal family, and Mohamed Pasha Al-Noqrashi. It was designed in the style of the Italian European Renaissance. Mohamed Bey El-Shinaiy brought Italian engineers and artists to build his palace in the city of Mansoura. The palace also obtained a certificate from Italian President Mussolini in the year 1350 AH/1931 AD stating that it was the only palace in the East that was built in the Italian style (Shehata, 2002, pp. 117-130).

The total area of the palace is about one acre, and the buildings occupy 441 square meters. The palace consists of a basement, a ground floor, and a first floor. In the middle of the palace is a garden containing tennis courts, a billiard room in the basement, rare trees, and a heritage fountain in the background of the palace. The palace's view of the Nile River was in the past, before the heirs sold a large part of it for the establishment of an investment project. The palace also contained a roofed trellis made of Doric-style columns. It was probably intended for playing and holding dance parties. It had two entrances, a main entrance and an entrance for servants. Manual aluminium shutters and mats were used in the palace windows to close the windows and balconies (Shehata, 2002, pp. 117-130), (Fig. 8).

Source: Field Study (2024).

Figure 6. Description of Idris Mosque

Source: Field Study (2024)

Figure 7. Description of Al-Najjar Mosque

Source: Field Study (2024)

Figure 8. Description of Al-Shinawi Palace

3. Factors affecting the weathering process in heritage buildings in Mansoura City:

Heritage buildings in the city of Mansoura are exposed to many geomorphological hazards resulting from weathering processes, which deteriorate the building material, leading to a change in their architectural form and metal composition. This is due to their being affected by many factors such as climatic conditions and high ground water levels, in addition to negative human interactions such as faulty restoration operations. Together, these factors work to increase the activity of the weathering process in its various forms, whether mechanical or chemical weathering, or both. Mechanical weathering works to break up rocks into smaller materials, while chemical weathering works to change the mineral composition of rocks.

Salt weathering is one of the most influential weathering processes that affects heritage buildings as it combines the properties of mechanical, chemical, and biological weathering together (Smith, 2009). Therefore, it is one of the most important processes that damage building materials and destroy structures of various types, as it results in corrosion of the building foundations, peeling of the wall surfaces, rust and corrosion of the iron fences, and an increase in their size, which results in the occurrence of great pressures that lead to the disintegration of the concrete layers. In addition to the widening of cracks and joints resulting from the crystalline growth of salts inside the pores of the rock, or the thermal expansion of salt crystals, which occurs when the temperature increases, the salts expand and their size increases. This in turn leads to the disintegration of the surface layer and the exposure of archaeological buildings to collapse, and (salt hydration) through saturation. Salt crystals are exposed to excess moisture in the atmosphere, causing these crystals to expand and increase in size by a rate that may reach 0.5% such as sodium carbonate, and thus pressures are exerted on the cracks and grains of the rock, leading to its flaking and weathering (Mahsoub, 2004, p. 118).

The effect of salt weathering on archaeological buildings is two-fold: the first is chemical and leads to the transformation of the original mineral components of the walls into minerals with new chemical properties that differ in their composition and crystalline form in a complex chemical process known as Chemical Decomposition, and the second is physical-mechanical and leads to what is known as the efflorescence process whether on the external surfaces or between and inside the pores in what is known as hidden blooming. The growth of salt crystals creates stresses at the boundaries of the external joints and on the rock grains, which leads to granular disintegration (Saber, 2012, p. 1).
Among the factors affecting the weathering process in Mansoura City are the following:

3.1. Climatic conditions:

Climatic characteristics play an important role in influencing the archaeological and heritage buildings in Mansoura, especially their role in the deterioration of the stones used in construction. During the field study periods, it was observed that these buildings were exposed to weathering activity, especially salt weathering, which is linked to several factors. Among them: high temperatures, especially in the summer, the amount of water that is rich in salts (sewage, groundwater) and the humidity level. So, it is recommended to maintain it on a regular basis.

The analysis of Table 1 and Figure 9 indicates the following:

Temperature Degree and Evaporation: Temperatures affect ancient buildings due to the daily and seasonal changes that occur to them, which results in expansion and contraction of the rock. Therefore, they are a source of pressure inside the monument and cause cracks in some architectural parts and thus their collapse. Temperature varies within the region during the seasons of the year and throughout its months. The average annual temperature in the study area is 21.8°C. The winter months record the lowest temperature rates, reaching 13.8°C on average, especially January, which is one of the lowest temperature months with an average of 13°C, which led to a decrease in evaporation rates to reach 3.5 mm on average. The temperature begins to rise slightly during the months. In the spring, the region is exposed to the influence of hot depressions, while in the summer, the temperature increases to 28.3°C, 28.9°C, and 27.9°C during the months of "June, July, and August," respectively, so it is one of the seasons with the highest temperatures, and this increase is accompanied by an increase in the evaporation processes with an average of 8 mm. Thus, it led to the rapid evaporation of salt solutions and their gradual crystallization inside the walls, causing damage.

Table 1. Some Climatic Characteristics of Mansoura City

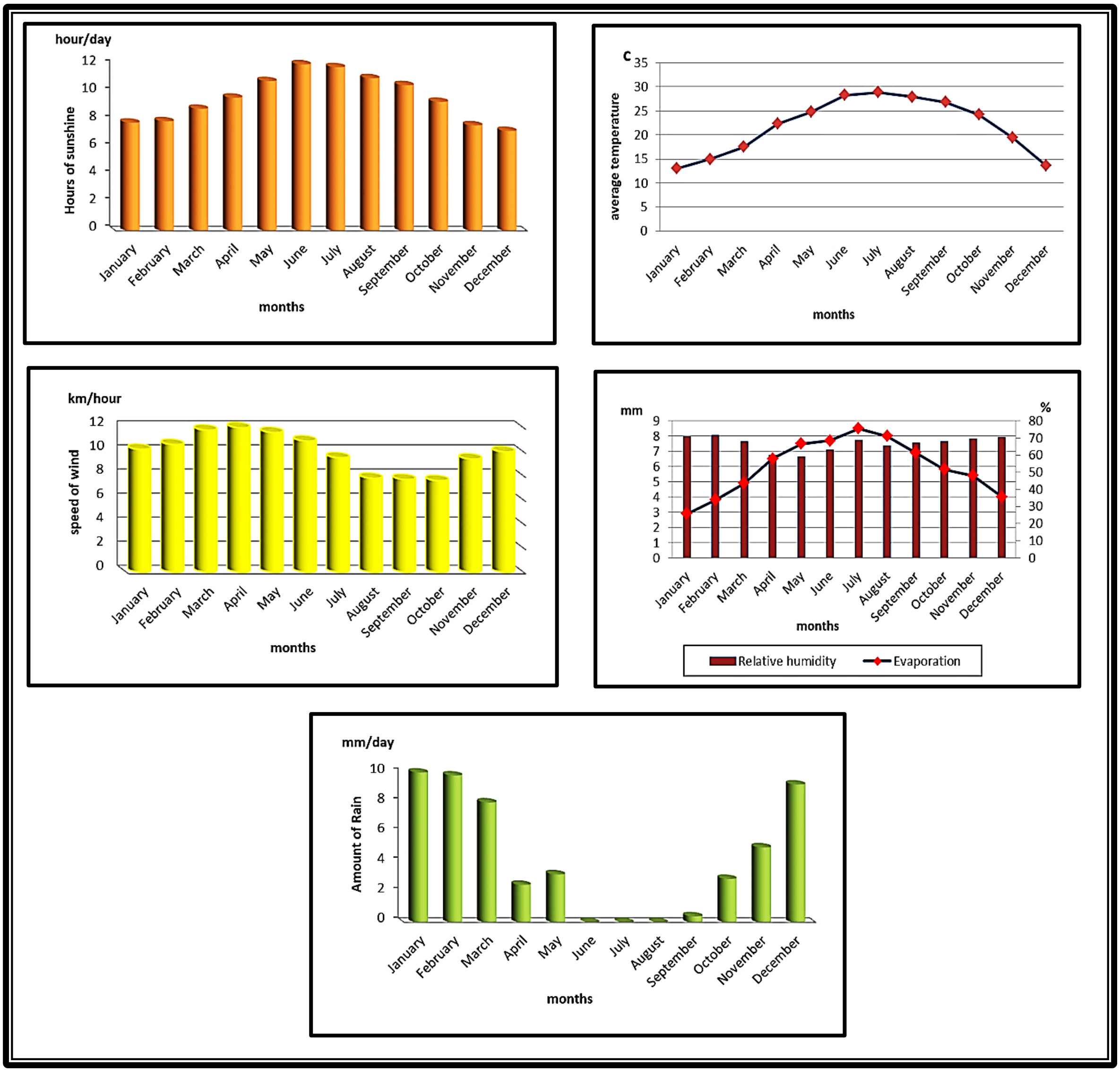
The Month	Hours of Sunshine (Hour/day)	Temperature (C)	Amount of Rain (mm/day)	Evaporation (mm/day)	Relative humidity (%)	Speed Wind (Km/hour)
January	7.8	13	10.3	2.9	70.6	10.2
February	7.9	15	9.2	3.8	71.6	10.6
March	8.8	17.5	8	4.9	68	11.8
April	9.6	22.3	2.5	6.5	59.7	12
May	10.8	24.8	3.2	7.5	58.8	11.6
June	12	28.3	Zero	7.7	62.9	10.9
July	11.8	28.9	Zero	8.5	68.7	9.5
August	11	27.9	Zero	8	65.6	7.8
September	10.5	26.8	0.4	6.9	66.9	7.7
October	9.3	24.2	2.9	5.8	68	7.6
November	7.6	19.4	5	5.4	69.7	9.4
December	7.2	13.6	9.8	4	70.4	10
Anuual Average	9.5	21.8	51.3	6	66.7	9.9

Source: The Egyptian Meteorological Authority, Unpublished Data (1980-2022).

Rain: The total annual rainfall at Mansoura station is 51.3 mm. The months of the year with the highest recorded amount of rainfall are the winter months, where the amount of rain falling on the study area during the month of January reached 10.3 mm, which is the highest percentage recorded, and 9.8 mm during the month of December and 9.2 mm during the month of February, which contributes to the stones retaining water for a long time, as the interaction of rainwater with carbon dioxide present in the atmosphere results in its conversion to carbonic acid, which in turn converts calcium carbonate ($CaCo_3$) present in limestone or building materials turns into calcium bicarbonate ($Ca(HCo_3)$) which is soluble in water and then crystallizes on the roofs of buildings, leading to their weakening and disintegration. While the amount of rain falling on the region decreases during the spring and fall months, it is almost non-existent during the summer months.

Relative humidity: Relative humidity is one of the most important climatic factors that causes severe damage to a heritage or archaeological building. Its source in the study area is rain, water vapor, subsurface water, and sewage, and in most cases, it acts as an activating factor for damage processes. This appears in the joint product between heat and humidity, as humidification and drying with heat lead to damage to stones and the possibility of crystallization or hydration of salts (Ahmed, et al., 2021, p. 43). The annual average relative humidity in the study area is 66.7%, and it reaches its highest value during the winter months, ranging between 70.4% and 71.4%, while its lowest value is during the spring months, with an average of 62.1%. Accordingly, increasing relative humidity levels within the building materials of archaeological buildings causes them to crack and collapse faster.

Wind: The annual average wind speed in the study area is 9.9 km/hour, and the maximum average wind speed reached 11.8 km/hour during the month of March, while the lowest average wind speed reached 7.6 km/hour during the month of October. It becomes clear that increasing wind speed increases the rates of the drying of the wet surface layers of the archaeological buildings which leads to the gradual activity of salt crystallization processes inside the walls. The speed of the wind also causes the weak parts of the ancient building to sculpt and collapse, especially the old minarets in mosques.

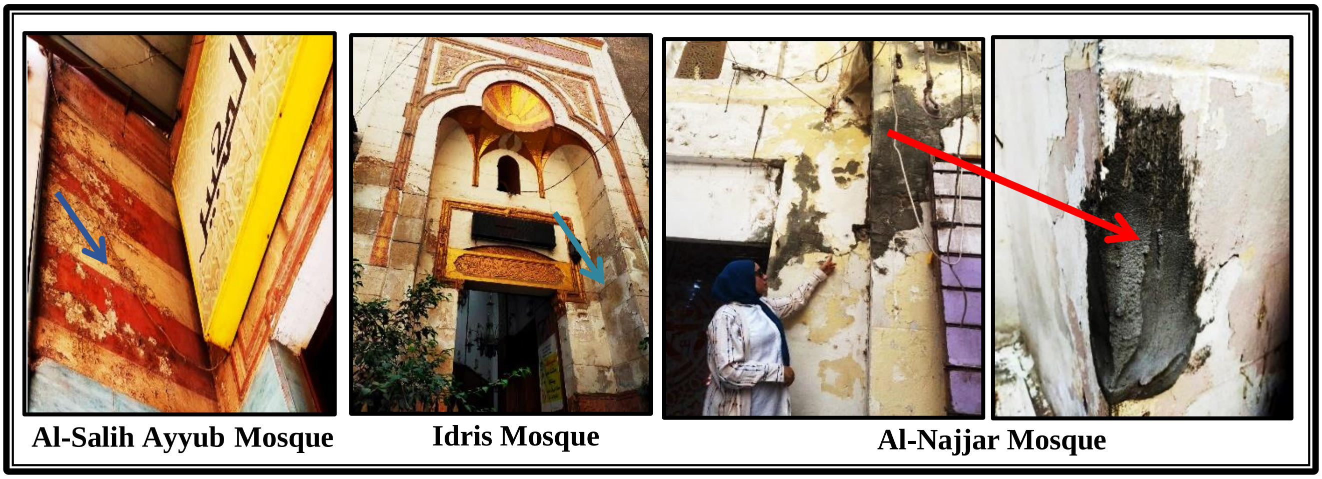


Source: Adapted from Table 3.

Figure 9. Some Climatic Characteristics of Mansoura City

3.2. Incorrect Restoration:

Incorrect restoration is one of the dangers to which archaeological buildings are exposed, as it usually includes restoring the building's exterior structure while making some modifications to the ceilings, windows, doors, and floors (Fig. 10) to restore the antiquity to its original state, but it was observed that large parts of the antiquity become distorted due to reliance on invalid building materials, weak and inconsistent stones, disproportionate colour paint, and inappropriate layers of cement placed on the damaged areas of the archaeological building, which gives a distorted shape to the building, and leads to concrete damage due to the combination of sulfur with cement aluminate in the presence of water, causing chemical reactions that result in salt crystals of a larger size than its constituent elements, in addition to the lack of proper maintenance of sewage networks, and reliance on companies that do not specialize in restoration with the low skill of the restorers. All these factors caused a rise in humidity and an increase in salts, which led in turn to the damage and deterioration of the facades of heritage buildings.

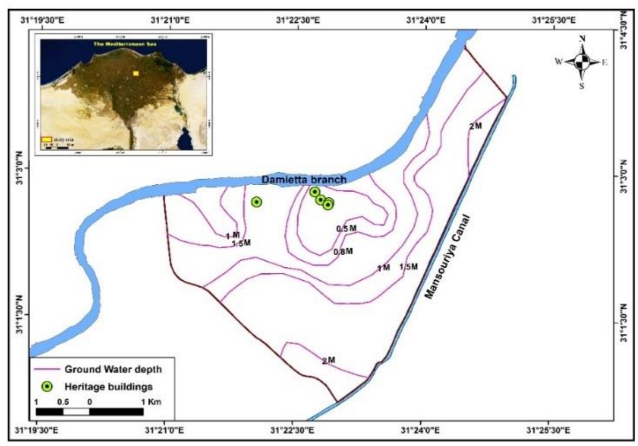


Source: Field Study (2024).

Figure 10. Manifestations of Faulty Restoration in Heritage Buildings of Mansoura City

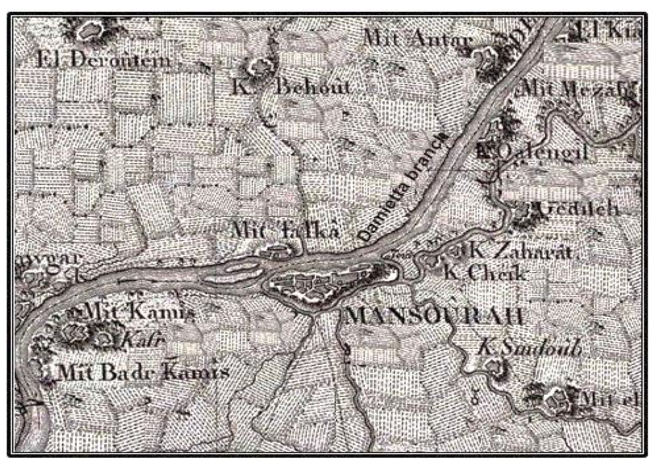
3.3. Groundwater:

The city of Mansoura suffers from the problem of population overcrowding in addition to urban expansion, which has led to an increase in the loads of services and facilities and the emergence of the problem of sewage leakage on the foundations and walls of buildings. This in turn led to the increase of its leakage into the groundwater reservoir and the occurrence of clear changes in ground water levels, as groundwater depths vary from one area to another in Mansoura City, which ranged between 2 and less than 0.5 meters below the ground level (Fig. 11). This is because the study area in the past was interspersed with some ponds and canals that although were filled in but whose impact is still evident on the neighbouring areas until now. This is in addition to the presence of the Nile River, the Damietta Branch, which passes through the city (Fig. 12). The data indicates that the groundwater level is below the ground level by less than two metres, which is an exceptionally high level and is rarely exceeded in reality (Deif & Salim, 1999, p. 95), while the concentration of salts ranges between 140, 1440 ppm (Fig. 13), which indicates an increase in the percentage of salinity in the east, centre and south of the city, while the percentage decreases as we head west. All of this has led to some heritage buildings in Mansoura being exposed to the problem of the rise of groundwater rich in dissolved salts to the top to reach the foundations of buildings through pores and cracks by capillary action and the occurrence of Serious damage, such as damage and corrosion of stones and walls of heritage buildings.



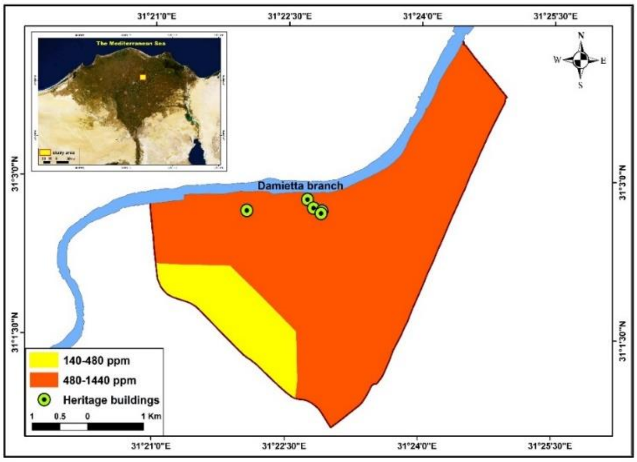
Source: Topographic maps, scale1: 25,000, 1989, Daif, & Salim, 1999, p. 95, Using ArcGIS 10.6.1.

Figure 11. Ground water levels in Mansoura city



Source: French campaign maps, Mansoura San painting, scale1:100,000,1826.

Figure 12. The Spread of Ponds and Canals in Middle Mansoura City in Ancient Times



Source: Topographic maps, scale1: 25,000, 1989, AlTohamy, 2014, p. 139, Gouda, 2004, p. 248, using ArcGIS 10.6.

Figure 13. Ground Water Salinity in Mansoura city

4. Characteristics of building materials used in archaeological and heritage buildings in Mansoura:

Ten samples were collected from the five heritage buildings under investigation in a non-destructive manner through field work (Fig. 14) and tested in the laboratory to identify the natural characteristics of the rocks, as the properties of building materials determine the type of damage and deterioration to which exposed archaeological buildings were exposed, in addition to controlling the type and method of restoration.

Accordingly, it was important to study and define these characteristics as follows:

4.1. Petrophysical characteristics:

Studying the petrophysical properties of building materials at archaeological sites is useful as it reflects the structural condition and determines the nature of the rock and the extent of its response to weathering processes (Abdel Maqsoud, 2022, p. 395). Therefore, the impact of weathering processes at the study area had been examined numerically at the heritage buildings through petrophysical investigations using immersion method and applying the ultrasonic waves measuring for the Cp and Qc of the weathered samples as well as the control samples. This is to correlate the damage in rock texture reflected by reduction of Cp and increase of Qc with the petrophysical results by the immersion method.

These properties are represented by the degree of hardness, porosity, and degree of water absorption, as shown in Table. 2.

Table 2. Petrophysical properties results of the samples collected at the Heritage sites, Mansoura City

Site Name	Sample Code	Lab. Temp. (°C)	Petrophysical Properties		
			Porosity %	Water Absorption %	Bulk density (gm/cm^3)
Dar Ibn Luqman	DBL (1)	25.2	15.2	13.2	2.25
Dar Ibn Luqman	DBL (2)	25.1	14.6	12.6	2.26
Al-Najjar Mosque	NM	25.2	22.6	20.2	1.34
Al-Salih Ayyub Mosque	SAM (1)	25.1	21.3	18.7	1.76
Al-Salih Ayyub Mosque	SAM (2)	25.3	15.3	14.6	1.87
Al-Shinawi Palace	QSH (1)	25.1	15.5	13.3	2.22
Al-Shinawi Palace	QSH (2)	25.2	16.6	14.9	1.46
Al-Shinawi Palace	QSH (3)	25.2	15.3	13.1	2.23
Al-Shinawi Palace	QSH (4)	25.1	22.4	20.1	1.35
Idris Mosque	IM (1)	25.2	22.4	20.1	1.32

Source: Laboratory test results of rock samples in the Geology Department laboratory, Faculty of Science, Menoufia University.

Source: Field Study (2024).

Figure 14. Sampling locations of heritage buildings of Mansoura City

4.1.1. Porosity and the degree of water absorption and bulk density:

The degree of porosity varies clearly within the different stones used in building and constructing heritage and archaeological buildings and is used to identify the hardness of the rock and the extent of its vulnerability to weathering (Kamh, 2017, p. 1).

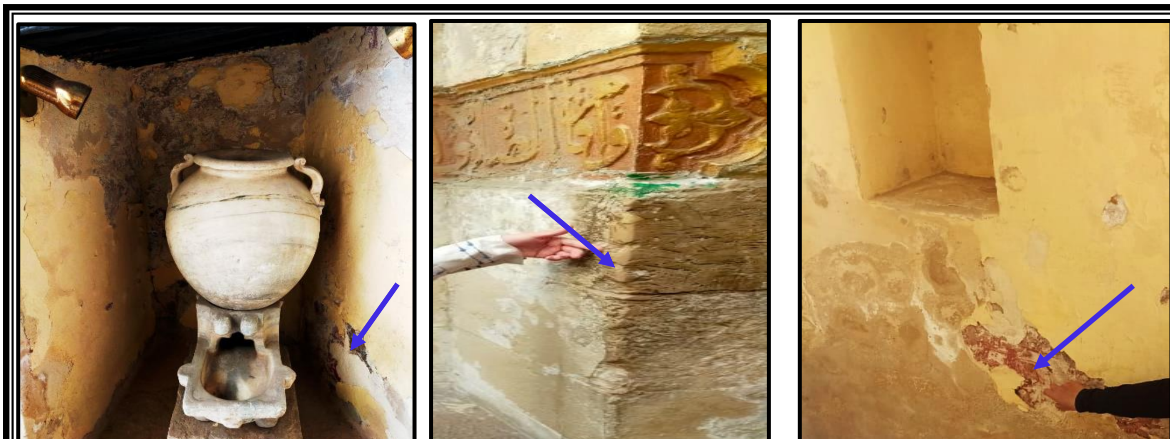
The building material's porosity, water absorption and bulk density had been examined as controlling parameters for rock susceptibility to weathering, particularly salts. The damage category of the site under investigation had been highlighted in the light of reduction of bulk density and the increase of porosity and water absorption (Steiger & Asmussen, 2008; Swe & Oguchi, 2010). The results of this test had been listed in (Table. 2) These results will be correlated with the field classification of damage category of each site and the other laboratory results, as it is clear that there is a high degree of porosity within the ancient limestone, ranging between 14.6 and 22.6%. This is due to the role of salt weathering in increasing the degree of porosity, as a result of the crystallization of salts within the voids and pores, which occurs first in the large pores, and when they are filled with salts, the salts then move to the narrow pores to fill them as well (Kamh, 2011, p. 129), which results in the expansion of those voids. In the stones and then their collapse, while the risk is less in stones that contain a low degree of fine pores. The susceptibility of rock to damage is known from its degree of water absorption, which ranges between 12.6 and 20.2%. The higher the degree of absorption of water or humidity, the greater the rates of seepage and leaching, and thus the activity of the weathering process. It was noted from the above that the greater the degree of porosity in the rock, the higher the degree of absorption of water by the rock. while the degree of bulk density "the density of rock grains with salts" ranged between 1.32 and 2.26 kg/cm^3.

4.1.2. Degree of hardness:

What is meant is the ability of the stone to resist the loads placed on it before it shatters or before it turns into loose granules, and it is estimated in kilograms/cm^3 (Abdul Hamid, 2009, p. 48), as it was shown that the limestone with which the city's archaeological and heritage buildings were built is characterized by weakness and lack of resistance to the resulting pressure. From the loads imposed on it as a result of its impact on salt weathering processes, which made it more susceptible to damage and disintegration.

4.2. Mineral Composition of Rocks:

Most rocks contain some basic components of salts or chemical elements that may be salts after being released from the crystalline network of minerals that make up the rock through chemical weathering (Saber, 2012, p.30). The field study showed the use of limestone as a basis for construction. In addition to the red bricks (Fig. 15), and to identify the mineral composition of the rocks, the following analyses were performed:



Dar Ibn Luqman | Idris Mosque | Dar Ibn Luqman

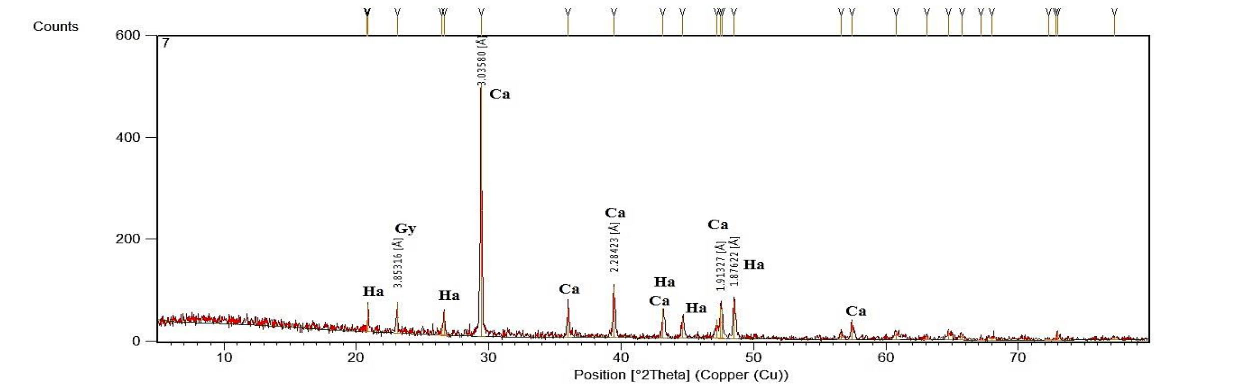
Source: Field Study (2022).

Figure 15: The use of limestone and red brick in heritage buildings of Mansoura City

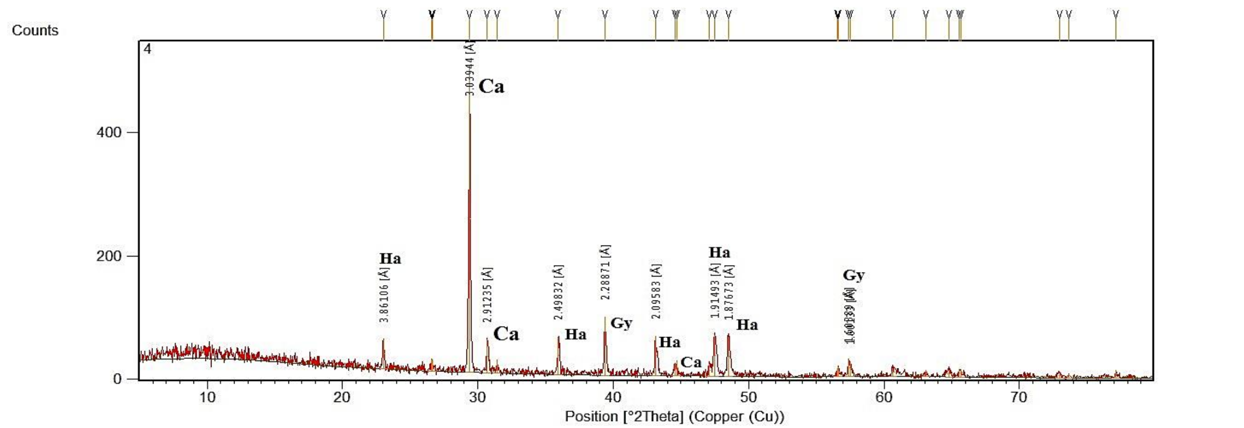
4-2-1 X-Ray

It is one of the methods that directly give the name and quantity of compounds or minerals within the sample, as well as identifying the manifestations of damage, and through which the degree of impact resistance to various weathering processes can be identified. (Saber & Al-Bana, 2023, p.14).

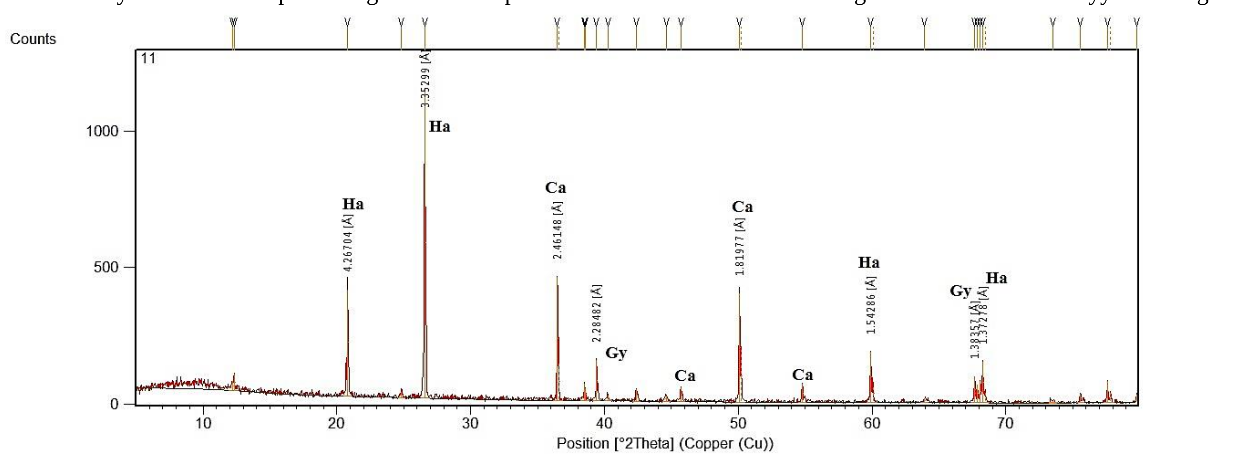
Mineralogic investigation had been conducted for rock powder prepared from the collected rock samples then exposed to X-ray diffraction that works at a wide range of 2Ɵ to detect all mineral composition. It was shown from (Fig.16) that the basic minerals included in the rock samples consist of:



1- X-ray diffractometer presenting mineral composition and salt content in a building material of Al-Shinawi Palace heritage.



2- X-ray diffractometer presenting mineral composition and salt content in a building material of Al-Salih Ayyub heritage



3- X-ray diffractometer presenting mineral composition and salt content in a building material of Al-Najjar Mosque

Source: Laboratory test results of rock samples in the Geology Department laboratory, Faculty of Science, Menoufia University

Figure 16. X-ray Analysis of Stone Samples of Heritage buildings in Mansoura city

- Calcite in a large proportion, which indicates a high percentage of calcium carbonate salts ($CaCo_3$) in the samples.
- Halite resulting from the high percentage of sodium chloride salts in all samples, especially the Najjar Mosque sample.

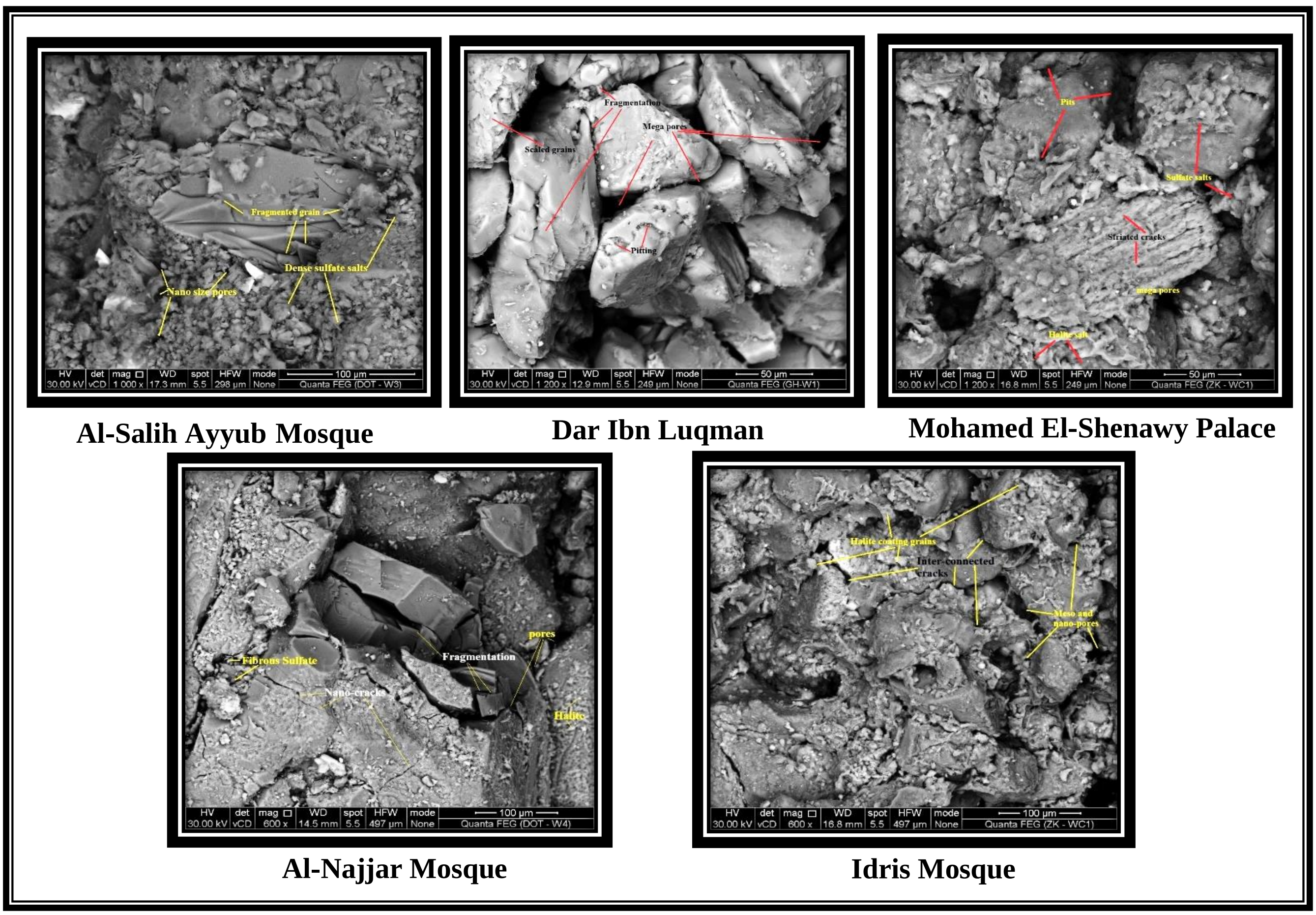
- Hydrated gypsum ($CaSo_4.H_2o$) in limestone samples, which is one of the manifestations of damage resulting from the transformation of calcium carbonate into calcium sulfate because of the interaction with sulfur dioxide gas in the presence of water.

4.2.2. Scanning electron microscope (SEM):

It is used to diagnose various signs of damage resulting from weathering within building materials. It is also used to identify the salts that make up the rock.

It had been conducted for the collected rock samples using scanning electron microscope (SEM) to detect weathering on micro-scale as well as pore shape and any crystalline salt if found. The analysis of Figure 17 indicates the following:

- There are cracks, pitting, and enlargement on the microscale, as well as pores among rock grains. Some salts such as halite and sulfates can be observed in the building of Al-Shinawi Palace.
- There is fragmentation and cracking on the microscale, as well as micropores among rock grains. Some salts such as halite and sulfates can be observed in the Great Mosque of Al-Salih Ayyub.
- There is fragmentation, interconnected cracks and pores on the micro- and meso-scale among rock grains in the Idris Mosque.
- There is fragmentation, macrocracks and interconnected pores on the micro- and meso-scale among rock grains. Some salts can be observed in the Al-Najjar Mosque.
- There is detachment of rock grains, macropores and scaling of the surface of grains in Dar Ibn Luqman.



Source: Analysis was done at the National Research Center in Cairo, (scanning electron microscope).

Figure 17: Separation of grains and the spread of pores, cracks and peeling in the rocks of heritage buildings

4.3. Hydrochemical properties:

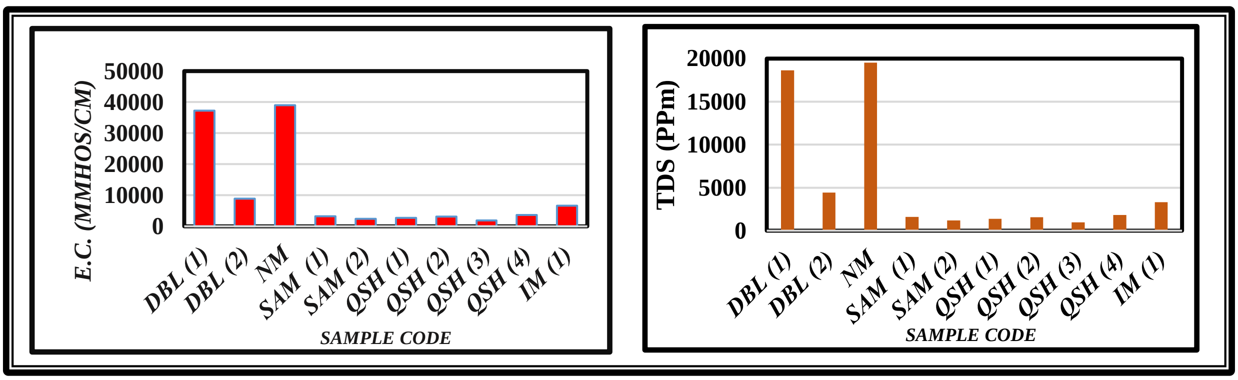
They were identified by hydrochemical analysis of stone by measuring the percentage of total dissolved salts, cations and anions, in addition to chlorides and sulfates, as shown in Table 3 and Figure 18, and the results were as follows:

- The hydrochemical analysis for the collected samples at the sites under investigation indicated noticeable difference in total dissolved salts where El-Salih Ayyub mosque and Qasr El-Shinnawi have the lowest total dissolved salts compared with Dar ibn Loqman and El-Najjar mosque
- Rock salinity is a measure of the percentage of minerals and salts that can be dissolved in water, The prevailing salts in building materials of these sites are chlorides and sulfates. These salts are expected to destroy building material texture by salt crystallization (for chloride salts), particularly that the area under investigation is arid dry area (based on climatic condition Table.1).
- the degree of total dissolved salts varies between 18,650 parts per million in sample (1) in Dar Ibn Luqman to 987 parts per million in sample (3) in Al-Shinawi Palace, which indicates that the building rock samples Heritage sites have a high percentage of salts as a result of their exposure to weathering factors.
- The percentage of the sodium cation Na^+ ranged between 3079 parts per million in sample (1) in Dar Ibn Luqman and 252 parts per million in sample (2) in Al-Shinawi Palace, followed by the calcium cation Ca+2 with a percentage that ranged between 4231 parts in million in Al-Najjar Mosque sample and 136 parts in million in the sample (3) at Al-Shinawi Palace.
- The percentage of chloride anion salts, Cl-, ranged from 5732 parts per million in Al-Najjar Mosque sample to 205 parts per million in sample (3) in Al-Shinawi Palace, while the percentage of sulfur anion So_4^{-2} ranged between 9411 parts per million in sample (1) in Dar Ibn Luqman and 311 parts per million. One Million Samples (3) at Al-Shinawi Palace.
- All samples contain chloride and sulfate salts, especially sodium chloride (halite), which ranges from 41.3% in Al-Najjar Mosque to 29.8% in sample (4) in Al-Shinawi Palace, followed by sodium sulfate with a percentage that ranged from 19.2% in Idris Mosque to 9.7% in Al-Najjar Mosque, then calcium sulfate. (Anhydrite), which ranged between 36.1% in sample (4) At Al-Shinawi Palace to 29.4% in sample (2) at Dar Ibn Luqman, The danger here lies in that they are considered one of the most dangerous types of salts affecting that type of rock because they are hygroscopic salts that have the ability to absorb moisture from the surrounding air and form a brine solution that moves through the pores of the stones by capillary action (Hasan, 2018, p. 53), and thus the salts are transformed from the anhydrous form to the water image: Salts participate in chemical reactions in the presence of water and interact with minerals and rocks, transforming the surface of the rock into new materials that destroy the rest of the rock parts (Kamh, 2011, p. 97).
- The most important bicarbonate salts were sodium bicarbonate, which ranged from 4.3% in sample (3) in Al-Shinawi Palace to 1.7% in Al-Najjar Mosque, and magnesium bicarbonate, whose percentage ranged from 5.4% in sample (4) in Al-Shinawi Palace to 0.2% in sample (1) Al-Shinawi Palace.

Table 3: Hydrochemical analysis for the extracted solutions prepared from the samples collected at the archaeological sites, Mansoura City

Site name	Sample code	Lab. Temp. (oC)	TDS (PPm)	EC (mmhos/cm)	Cations (ppm)				Anions (ppm)				Hypothetical Dissolved Salts (%)						
					Ca	Mg	Na	K	Cl	SO4	CO3	HCO3	KCl %	NaCl %	MgCl%	Na2SO4 %	CaSO4%	Na2CO3 %	MgCO3 %
Dar Ibn Luqman	DBL (1)	25.2	18650	37300	2383	215	3079	116	3351	9411	95	0	9.1	38.2	5.3	11.5	32.8	2.2	0.9
Dar Ibn Luqman	DBL (2)	25.1	4440	8896	952	231	649	82	921	1301	304	0	7.1	38.5	2.6	17.4	29.4	3.3	1.7
Al-Najjar Mosque	NM	25.2	19515	39036	4231	622	1126	210	5732	7285	309	0	8.2	41.3	3.2	9.7	31.8	1.7	4.1
Al-Salih Ayyub Mosque	SAM (1)	25.1	1603	3266	352	46	476	21	265	440	3	0	9.8	37.3	7.2	11.8	30.1	2.1	1.7
Al-Salih Ayyub Mosque	SAM (2)	25.3	1208	2426	276	41	265	16	233	356	21	0	6.7	35.5	5.5	14.6	33.1	2.7	1.9
Al-Shinawi Palace	QSH (1)	25.1	1367	2734	254	45	278	22	253	462	53	0	4.2	39.1	4.8	18.7	30.2	2.8	0.2
Al-Shinawi Palace	QSH (2)	25.2	1552	3106	334	52	252	17	381	502	14	0	6.2	35.1	4.1	17.3	31.3	3.1	2.9
Al-Shinawi Palace	QSH (3)	25.2	987	1875	136	21	274	9	205	311	31	0	4.8	32.5	3.7	18.4	32.4	4.3	3.9
Al-Shinawi Palace	QSH (4)	25.1	1842	3686	325	73	385	22	395	622	20	0	3.9	29.8	4.4	16.8	36.1	3.6	5.4
Idris Mosque	IM (1)	25.2	3305	6620	657	84	616	38	774	1125	11	0	6.2	32.6	5.1	19.2	34.2	2.1	0.6

Source: Based on the results of laboratory analysis in the laboratories of the Geology Department, Faculty of Science, Menoukia University, 2024.



Source: Based on Table 3.

Figure 18: Electrical conductivity of salts and total dissolved salts in rock samples

It is clear from the above that the high percentage of salts among the stone samples damages the fabric of the heritage and archaeological buildings in the region because the crystallization of salts within the tissues and pores of the rocks puts enormous pressure on the walls of the monument, causing them to be damaged, deteriorate, and parts of them separate. The spread of salt crusts on the rock surfaces also leads to Change in rock color.

5. Manifestations of damage to heritage buildings in Mansoura city:

Regarding the field survey at the study area, all the weathering features had been considered to semi-quantify the damage category based on this non-destructive technique of Fitzner and Heinrichs (2002). The weathering features and their dimensions had been listed in Table.4. Then, they are grouped into the four groups to find out the damage category of each heritage considering all weathering forms. The grouping of weathering features and recording the intensity of each parameter of each feature enabled defining the damage category regarding each feature. Accordingly, using the DCAW of Fitzner[3] and Heinrichs (2002) enabled defining the overall damage category of each heritage building

[3] One of the founders of the salt weathering research group in Germany.

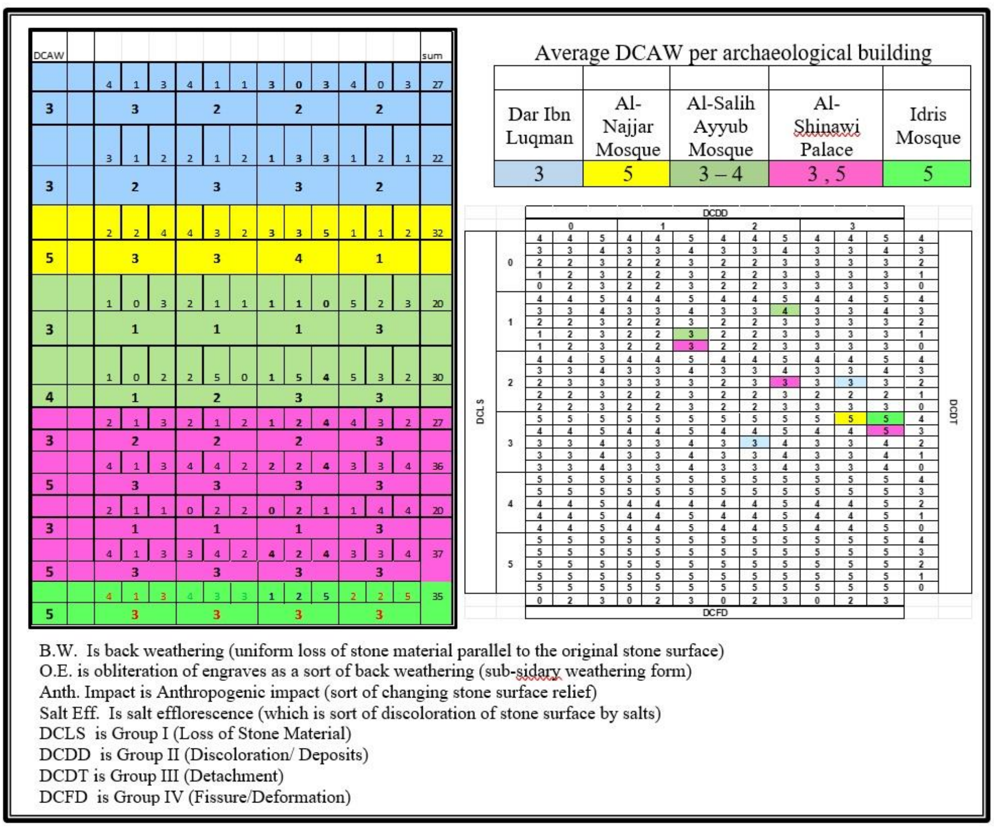
considering all the weathering features together at each building (Fig. 19). it was as follows:

Table 4: Presents weathering forms and the resultant damage category at the five heritage sites under investigation

Site name	Sample code	TDS (PPm)	Group I (DCLS)			Group II (DCDD)			Group III (DCDT)			Group IV (DCFD)		
			B.W.	Relief		Discoloration		Soiling	Granular disintegration			Single fissure	Multiple fissures	
			O.E.	Honeycomb	Anth. Impact	Salt Eff.	Oxidation	dirts/paints	into powder	into sand size	into grus size		Not connected	intersected
Dar Ibn Luqman	DBL (1)	18650												
Dar Ibn Luqman	DBL (2)	4440												
Al-Najjar Mosque	NM	19515												
Al-Salih Ayyub	SAM (1)	1603												
Al-Salih Ayyub	SAM (2)	1208												
Al-Shinawi Palace	QSH (1)	1367												
Al-Shinawi Palace	QSH (2)	1552												
Al-Shinawi Palace	QSH (3)	987												
Al-Shinawi Palace	QSH (4)	1842												
Idris Mosque	IM (1)	3305												

D.C. 1
D.C. 2
D.C. 3
D.C. 4
D.C. 5

Source: Laboratory test results of rock samples in the Geology Department laboratory, Faculty of Science, Menoufia University



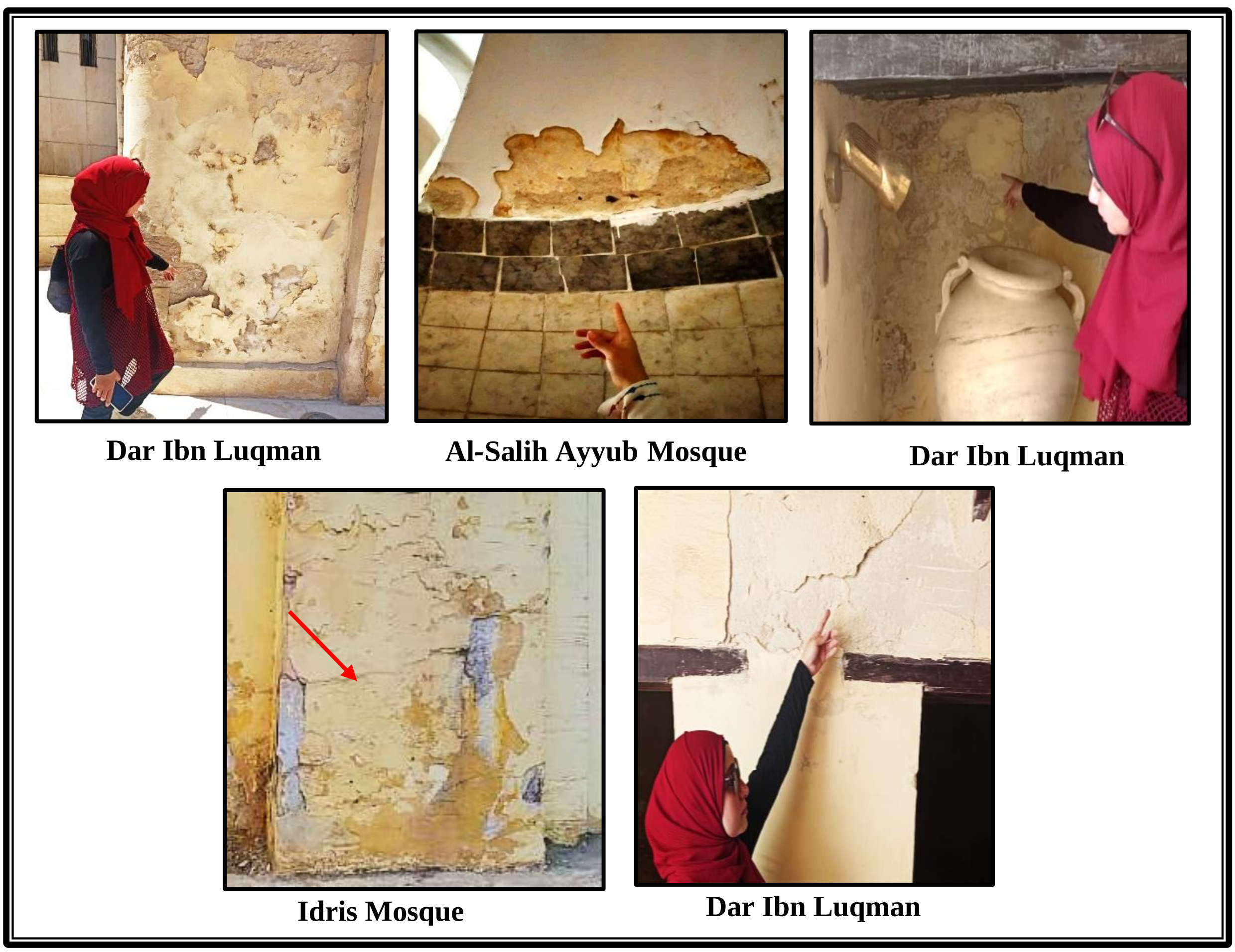
Source: Adapted from Table 3.

Figure 19: A graphical model that determines the degree of damage to the rock surface according to the classification (Fitzner et al., 2002)

5-1 Loss of Stone Material (DCLS):

Weathering is represented by the retreat of the surface of the rock. It is measured by the number of millimetres or centimetres that it recedes, and it is in the form of peeling or a change in the external appearance of the rock. Peeling of the rock is one of the geomorphological phenomena resulting from the salt weathering process that appears on the heritage and archaeological buildings in the city of Mansoura, and its shape is controlled by a group factor such as the degree of porosity in the rock, temperature, humidity, and evaporation, If the rate of saturation of the surface with the solution is sufficient to keep pace with the rate of evaporation, the salt will precipitate on the outer surface, and this process is described as efflorescence. If the rate of migration of the solution through the pores of the structure does not bring new liquid to the surface at a speed commensurate with the speed of evaporation, then a dry area expands. Gradually just below the surface, the dissolved salts are then deposited inside the stone at the border between the wet and dry area, resulting in crusts (Al-Homosani, 2007, p. 136).

It has been shown that the phenomenon of peeling is widespread in some archaeological buildings, such as Dar Ibn Luqman and the Great Mosque of Al-Salih Ayyub, with thicknesses ranging between 1 and 8 mm due to their exposure to humidity and salt weathering, and then the accumulation and crystallization of salts inside the pores of stone, especially limestone, such as sodium and magnesium sulfate salts, thus exposing them to corrosion and peeling (Fig. 20).



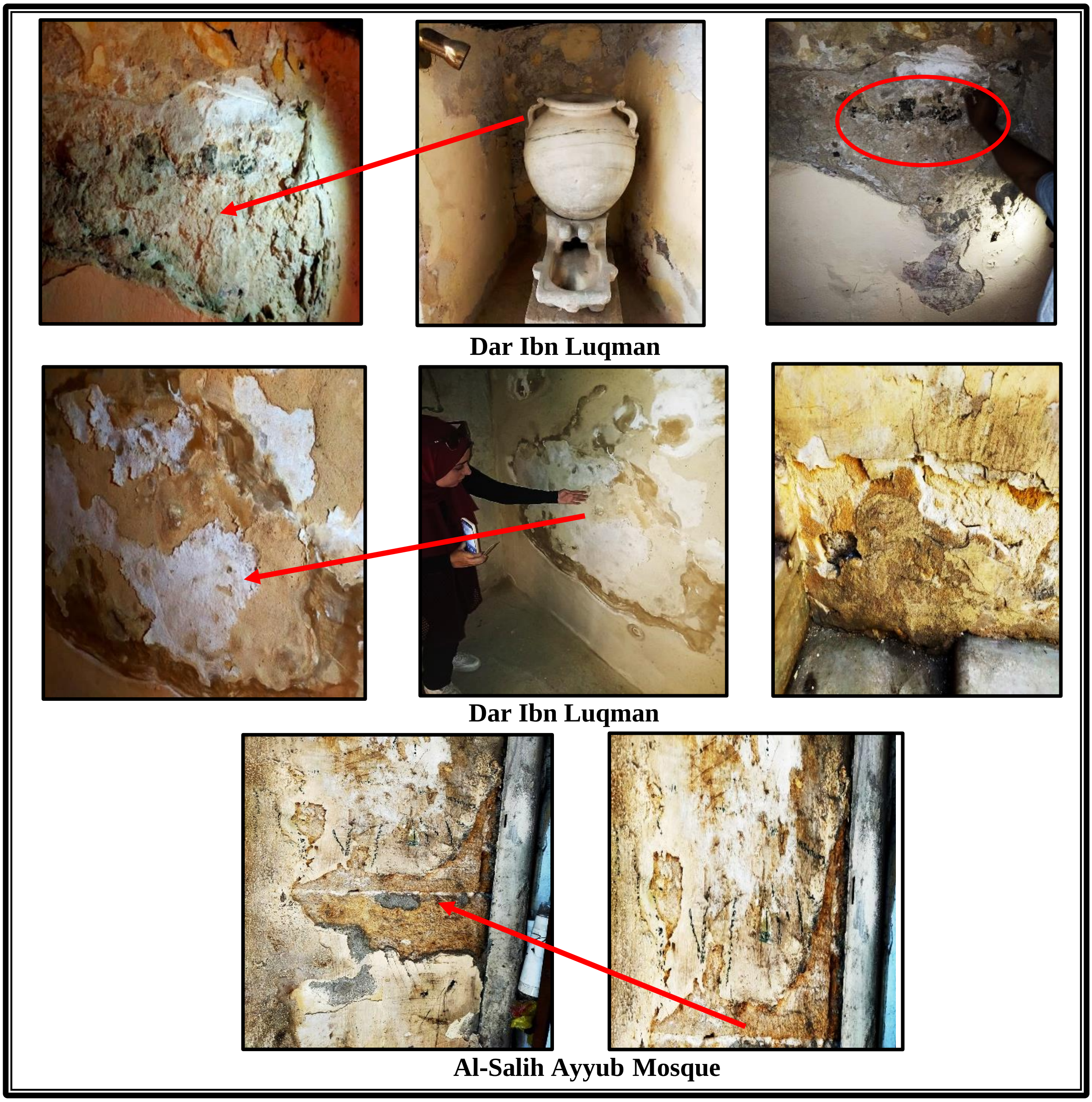
Source: Field Study (2024).

Figure 20: The Spread of the Phenomenon of Flaking in the Stone of heritage buildings

5-2 Discoloration (DCDD):

It means the appearance of salts on the surface of the rock in the Nasha zone, and the salts are concentrated especially at the upper end of the Nasha zone, where the salts collect directly under the surface of the rock and at a depth of several millimetres from this surface and form a salt surface that leads to the separation of a superficial sheet of this rock, and this process results in the phenomenon of foliation (Kamh, 2011, p. 139) The phenomenon of salt fluorescence is widespread, which changes the colour of the rock, as salts appear in the form of a shiny surface crust on the rock varying thickness.

It was shown through field work that the rate of change in surface colour reached 20% of the area of some walls in Al-Salih Ayyub Mosque and 40% in some walls of Dar Ibn Luqman. The spread of this phenomenon is due to the high percentage of sodium and calcium salts, sodium chloride, sodium sulphate, and calcium sulphate in these buildings (Fig. 21).

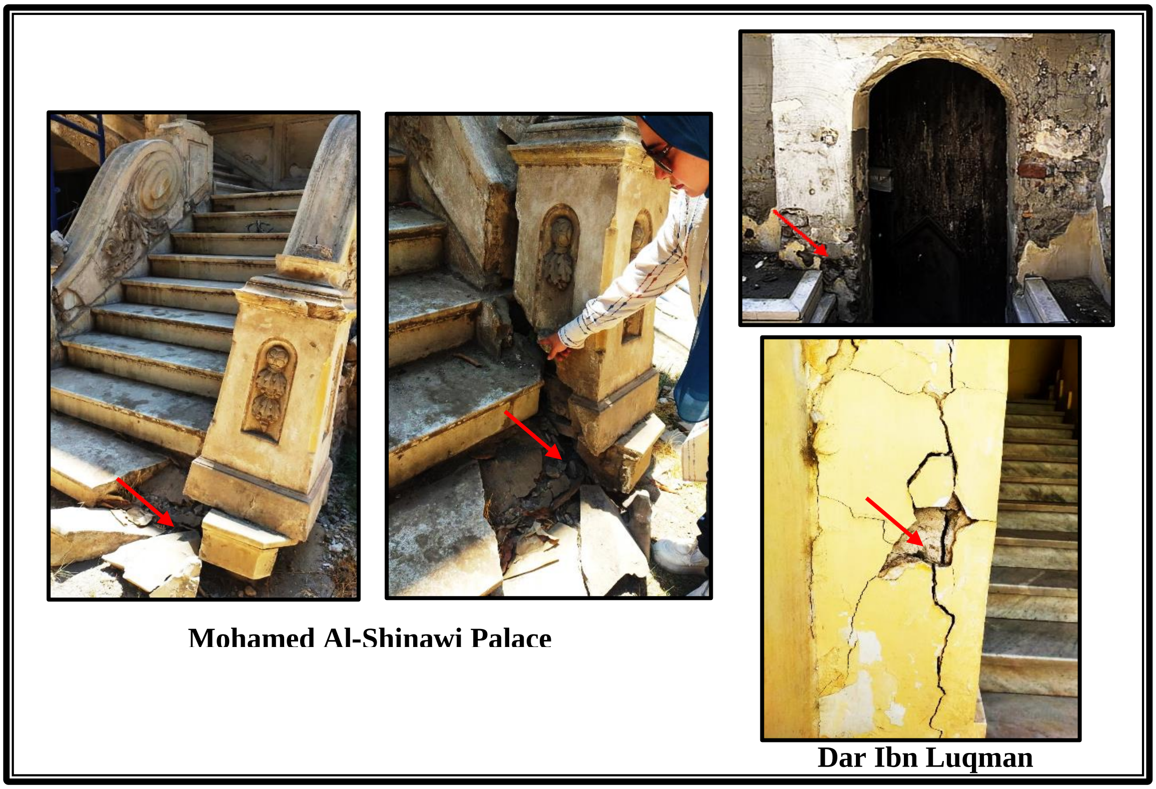


Source: Field Study (2024).

Figure 21. Examples of the color change of rocks in heritage buildings in Mansoura City

5-3 Detachment (DCDT):

It is considered one of the most serious problems facing heritage buildings in the study area, which is the falling and disintegration of stone blocks at the foot of the walls or the rocky body under study as a result of their exposure to weather factors represented by changes in temperature and humidity. Building materials expand as the temperature increases and contract as it decreases. Rain, along with fluctuations in seepage water, leads to the disintegration of building materials, the fallout of wall mortar, the change of colours, and the dissolution of salts. Then it crystallizes again inside the pores of the rock when it is exposed to dryness again, in addition to the lack of attention to it by officials and leaving it for long periods without restoration or maintenance. All these factors are considered a source of pressure generated inside the monument, which ultimately leads to its deterioration and fall, which was demonstrated by field study in Mohamed Al-Shinawi Palace and Dar Ibn Luqman (Fig. 22).



Source: Field Study (2024).

Figure 22. Disintegration and falling of stone blocks of some archaeological buildings of Mansoura City

5-4 Deformation and the cracks (DCFD):

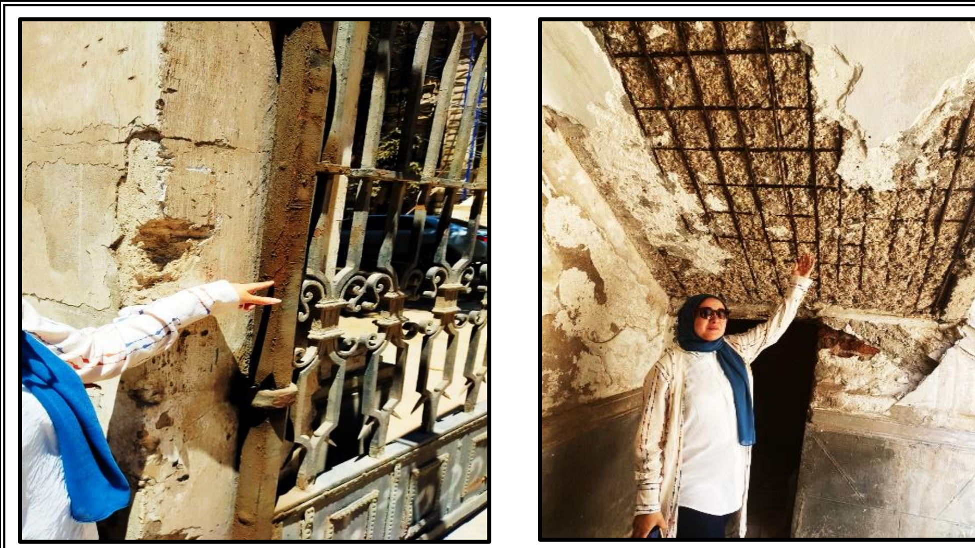
Cracks are considered one of the most common defects facing heritage buildings, which appear on the architectural facades or on the walls of the archaeological building in the form of minute or large cracks and lead to deformations and defects in the buildings As in Al-Salih Ayyub Mosque and Al-Shinawi Palace (Fig. 23). They are the result of a group of factors, which are represented by climatic and environmental factors in addition to the type of building material and the life span of the building. Cracks are mostly formed due to crystalline growth of salts or thermal expansion and contraction. Through the field study, it was found that the cracks that struck the walls and ceilings of the Al-Salih Ayyub Mosque in the study area appeared due to the ground shaking resulting from the explosion of the Security Directorate building next to it. Therefore, attention must be paid to knowing the causes of these cracks by conducting an inspection of the building and knowing the conditions of the sewage network in the location of the facility. To study the conditions of the soil beneath the building, measure the crack, and determine its width, while placing a mark at both ends of the crack with the necessity of making a gypsum "bug" approximately 2 mm thick to ensure faster and more accurate results, along with monitoring these cracks daily to notice the crack activity. If the crack activity is proven with knowledge of its direction, this means that there is a defect in the building (Supreme Council of Antiquities, unpublished reports, 2024), in order to begin its restoration and process it properly.

Source: Field Study (2024).

Figure 23. Cracks in some heritage buildings of Mansoura City

5.5. Iron rust:

Iron rust is one of the dangers facing the city's archaeological and heritage buildings, which exposes them to damage. It is a reddish-brown colour that appears on the surface of the iron. The colour varies according to the chemical composition of the metals on which the rust forms. This phenomenon is clearly widespread in the El-Shennawy Palace building (Fig. 24). As a result of the combination of dissolved iron ions with water to form iron (III) hydroxide, which occurs more quickly when iron is oxidized with oxygen atoms or water, especially salt water. This is because water combines with carbon dioxide present in the air and produces weak carbonic acid and the iron begins to decompose. Therefore, the problem of iron rust must be overcome by adding some other rust-resistant metals, such as nickel and chromium, to form rust-resistant stainless steel.



Source: Field Study (2024).

Figure 24. Rusting iron in the Al-Shinawi Palace building in Mansoura City

6- Field and Laboratory Results:

The geomorpho-archaeological study of heritage buildings in Mansoura City revealed several facts that can be summarized as follows:

- The results of field investigations represented by photo-documentation of weathering features were presented and listed in the four weathering groups (based on Fitzner and Heinrichs classification, 2002). This enables defining in a semi-quantitative form the damage category of each of the heritage building under investigation. This will be followed by laboratory results of rock's mineralogy, texture, physical properties, rock's salt content and weathering susceptibility index. This is to find out the severity limit of weathering processes and their mechanism prevailing at the study area on such valuable heritage buildings.
- Heritage buildings in Mansoura are ancient facilities that have a great historical and archaeological status.
- The geomorphological study revealed the exposure of heritage buildings to the factors of damage to the stones used in construction because of the change in climate conditions and the rise in ground water levels, in addition to incorrect restoration operations and negative human encroachments, which ultimately led to the weakness and fragmentation of building materials and the disintegration of the surfaces and thus their damage.
- Climatic characteristics play an important role in influencing the damage processes that affect the stones used in the construction of heritage buildings as a result of these buildings being exposed to the activity of the weathering process, especially salt weathering. Salt weathering is linked to high temperatures in summer, in addition to the amount of water rich in salts, whether it is sewage water or underground water with high humidity, so it is recommended to maintain it continuously.
- The field investigations conducted at the study area in the current research are known as non-destructive technique that must be followed particularly for the heritage buildings and the archaeological sites. However, for investigating the main culprit behind damage of such buildings, suitable laboratory investigations must be conducted using the techniques requiring the minimal rock samples from such sites to achieve the aims of the study.
- The problem of restoration work is represented in two axes: the first axis, which is administrative problems, and the second axis, which is technical problems.
- The high percentage of salt among stone samples leads to damage to the fabric of heritage and archaeological buildings in the region because the crystallization of salts within the tissues and pores of the rocks puts enormous pressure on the walls of the monument, causing them to be damaged, deteriorated, and parts of them separate. The spread of salt crusts on the surfaces of the rock also leads to a change in the color of the rock.
- The recorded weathering features at the five heritage buildings required petrophysical and hydrochemical analysis to find out the role and mechanism of salt weathering at such semi-arid to arid, highly populated area. Textural deterioration on micro-scale is also of value for such study to clarify the progress of such microscopic scale weathering to the macro-scale weathering noted at each heritage building. Therefore, an X-rays was used to identify their mineral composition, and scanning electron microscopic investigation had been conducted for visual recording of weathering on micro-scale.
- The SEM investigation indicated a variety of fragmentation of building material components, detection of chloride and sulfate salts, and scaling and pitting on nano-scale.
- The X-ray diffraction indicated a noticeable mineral composition represented by calcite as a main mineral composing the building material of the heritage under investigation in addition to Halite, Gypsum and other salt types as minerals included in these examined samples.
- The absence of continuous maintenance of the buildings, the misuse and inappropriate

exploitation of the building, the absence of archaeological and historical awareness among citizens and their lack of understanding of the historical value of heritage buildings.

- The difficulty of registering some heritage buildings by the Antiquities Authority due to their poor condition, because one of the criteria for registering an archaeological building is that it be architecturally and historically sound.

7. Suggestions and Recommendations:

There are many recommendations that must be followed to achieve sustainability in heritage buildings in Mansoura City to reduce the damage caused to them, by doing the following:

- Finding a mechanism for how to carry out architectural maintenance and restoration work in a correct engineering manner and on a regular basis by taking safety measures for the building by making strong reinforcements so that restoration is carried out without risks and under the supervision of the Antiquities' Inspectors.
- Not using modern materials that are not compatible with the materials of the monument and using materials that are consistent with the original materials used in its construction. In addition, completing the parts that were lost in the heritage buildings according to the building's specifications to restore it to its original condition by experts familiar with the foundations and fundamentals of restoration in order to avoid any errors and achieve the feasibility of the restoration operation.
- Taking into account the rules and controls of restoration operations by using materials that do not negatively affect the original materials used in its construction, using internationally recognized archaeological mortar, and working on injecting the walls and floors of buildings with insulating materials (silicon resins) that are impermeable to subsurface water to reduce the percentage of bricks in them (Supreme Council Antiquities, Unpublished Reports, 2024), and attention to scientific research by specialists and continuous field follow-up of the antiquities, in order to maintain the sustainability of the antiquities for long periods.
- Use of internationally recognized antique mortar and work on injecting the walls and floors of buildings with insulating materials (silicon resins) that are impermeable to subsurface water to reduce their moisture content.
- Providing administrative committees by the Ministry of Antiquities to supervise heritage and archaeological buildings and monitor them on an ongoing basis, and train specialists in the field of restoration and antiquities on the techniques of restoration work.
- Overcoming the problem of iron rust by adding some other rust-resistant metals, such as nickel and chromium to form rust-resistant stainless steel. Paying attention to scientific research to be carried out by specialists and carefully studying the history of the archaeological building, including the history of restoration and maintenance operations, and conducting the necessary analyses of the materials composing the archaeological building, especially in the case of treating damaged parts, in order to maintain the sustainability of the monument for long periods.
- Removing inappropriate human encroachments by vendors on the walls of the archaeological or heritage building with the necessity of launching large-scale removal campaigns of encroachments on the archaeological and heritage buildings.
- Providing heritage buildings with modern devices and means, such as alarms, fire extinguishers, and air conditioners, in addition to developing and improving sewage, water, and electricity networks.
- Establishing a unit to manage heritage and archaeological sites and buildings in Dakahlia Governorate and Mansoura City in order to achieve sustainability for those sites and buildings.
- Establishing a register to preserve the heritage of Mansoura City and Dakahlia Governorate registering all heritage sites and buildings.

- Raising heritage and cultural awareness among residents through the community role of the governorate, the Antiquities Authority, and the College of Tourism and Hotels.

8. Sources and References:

8.1. Sources:

General Authority for Military Survey: Topographic maps, at a scale of 1:25000, 1989, Cairo.

General Authority of Meteorology, Climate Department, climate data, period from 1980 to 2022, Cairo.

Ministry of Construction, New Communities, Housing and Utilities, Housing, Building and Urban Planning Research Center, Egyptian Code for the Design and Implementation of Drinking Water and Sanitation Network Lines, Sixth Edition, 1998 AD.

Supreme Council of Antiquities, unpublished reports, years 2013, 2024.

8.2. Arabic References:

Abdel Hamid, M. M. (2009): A study of the causes of cracking and collapse of Islamic archaeological buildings and proposed solutions for selected antiquities, unpublished master’s thesis, Department of Antiquities Restoration, Faculty of Archeology, Cairo University.

Abdel Maqsoud, A. A. (2022): Analysis and modeling of geomorphological controls of weathering processes and their impact on archaeological sites in the Youssef Al-Siddiq Center, Fayoum Governorate, a study in applied geomorphology using geomatics techniques, Journal of the College of Arts in Qena, South Valley University, Issue 45, Part One.

Abu Ajila, H. M. (2021): The remaining minarets of vanished monuments in the city of Cairo, Journal of the Association of Arab Universities for Tourism and Hospitality, Volume 21, Issue 4, pp. 194-211.

Ahmed, M. G., Al-Darbi, A.& Kamh, J.M. (2021): Factors and manifestations of damage affecting stone statues, International Journal, Interdisciplinary Studies in Architecture and Cultural Heritage, Volume 4, Issue 2, pp. 41-64.

Al-Homosani, Kh. M. (2007): Study of the Problem of Salts and their Treatment in Images and wall Inscriptions in the Saqqara Region, Applied to One of the Selected Tombs from the Old Kingdom Era, Master’s thesis, Department of Antiquities Restoration, Faculty of Archeology, Cairo University.

Al-Nasiri, I. F. (2020): The City of Mansoura, Defeating the Invaders and the Metropolis of the Last Ayyubid sultans, Dar Ibn al-Nafis, Amman, Jordan.

Al-Nuwairi, (1992): The End of Arabism in the Arts of Literature, edited by Muhammad Diaa al-Din al-Rayes, General Book Authority, Cairo.

Al-Rafi’i, A. (1929): History of the National Movement, Part One, First Edition, Al-Nahda Press.

Al-Salawi, S. A. (2020): The Biography of the Ayyubid Sultan Najm al-Din in Historical Sources and Popular Literature, Cannes Historical Periodical, thirteenth year, forty-ninth issue, pp. 38-54.

Deif, A. A. & Salim, S. I. (1999): The problem of rising ground water levels within cities and how to treat it, the Second International Conference on Ground Water Control in Urban Areas, Faculty of Engineering, Mansoura University.

El-Tohamy, M.A. (2014): Marshes in the Northern Nile Delta - a Geomorphological Study: using Geographic Information Systems, Master’s thesis, Faculty of Arts - Mansoura University.

Fikri, A. (2008): Cairo Mosques and Schools, Part Two, Second Edition, Dar Al-Maaref, Cairo.

Hassan, H. T. (2018): The Dangers of Weathering on the Hawara and Lahoun Pyramids in the Fayoum Depression, a Study in Applied Geomorphology, Egyptian Geographical Society, Geographic Research Series, Issue 110.

Kamh, G. M. (2011): Salt Weathering on Buildings and Monuments in Some Countries of the World, Menoufia University Press.

Mahsoub, M. S. (2004): “Drylands, their natural characteristics and environmental problems,” Cairo.

Saber, A. I. (2012): Dangers of Salt Weathering on Archaeological Buildings in Cairo, Egyptian Geographical Society, Geographic Research Series, Issue 47.

Shehata, A. A. (2002): Historical palaces in the Governorates of Dakahlia and Kafr El-Sheikh from the Mid-Nineteenth Century to the Mid-Twentieth Century, an Architectural Archaeological Study, unpublished doctoral dissertation, Faculty of Arts, Tanta University.

8.3. Foreign References:

Benavente, D., Cueto, N., Martinez, J., Cura, M. A.& Canaveras, J,C., (2007): The influence of petrophysical properties on the salt weathering of porous building rocks. Environmental Geology, V. 52, pp. 215 – 224.

Fitzner, B. & Heinrichs, K., (2002): Damage diagnosis on stone monuments- weathering forms, damage categories and damage indices. Understanding and Managing stone decay, Prikryl and Viles "eds.", The Karolinum Press, pp.11 – 56.

Fitzner, B., Heinrichs, K. & laouchardiere, D. (2002): Damage index for stone monuments. Protection and conservation of the Cultural Heritage of the Mediterranean Cities, Galan and Zezza”eds”, pp.315-326.

Flatt, R. J. (2002): Salt damage in porous materials: how high super-saturations are generated. Journal of Crystal Growth, 242, pp. 435 – 454.

Hall, C. & Hoff, W. (2007): Rising damp: capillary rise dynamics in walls. Proc. R. Soc. A., 463, pp.1871 – 1884.

Hall, C., Hamilton, A., Hoff, D. W., Viles, A. H.& Eklund, J. A., (2010): Moisture dynamics in walls: response to micro-environment and climate change. Proceedings of the Royal Society, A. 2011, 467, p p. 194 – 211.

Kamh, G. M. & Azzam, R., (2008): Field and laboratory investigations to examine the damage category of monumental sandstone in arid regions: Seti I Temple, Upper Egypt, a case study. Int. Journal for Restoration of Buildings and Monuments, 14 (3), pp.179 – 196.

Kamh, G. M. E. (2009): Rate and mechanism of alveolar weathering of coment based masonry bricks and mortar in arid climate, Restoration of Builidings and Monuments “ An International Journal”,V.15(3),pp.195-204

Kamh, G. M. E., (2009): Quantification and modeling of damage category of weathering forms of monumental rocks based on field measurements. Restoration of Buildings and Monuments “An Int. Journal”, 15 (1), pp. 21 – 38.

Kamh, G. M. E., (2017): Investigating Single and Mixed Resins for Treating Moderately Weathered Limestone of Archaeological Sites, New Applied Techniques, Earth Sciences Vol, x, No. x, pp.x-x. Doi: 10, 116481.

McBride, E. F., Rudrich, M. & Picard, M, D., (2004): Origin of honeycomb and related weathering forms in Oligocene Macigno Sandstone, Tuscan Coast near Livorno, Italy. Earth Surface Processes and Landforms. V. 29, pp. 665- 675.

McGreevy, J. P., (1996): Pore properties of limestones as controls on salt weathering susceptibility: a case study. In: Smith, B. J. and P. A. Warke (eds), Processes of Urban Stone Decay, Donhead, London, pp. 150 – 167.

Rodriguez, N. C. & Doehne, E., (1999): Salt weathering: influence of evaporation rate, super saturation and crystallization pattern. Earth Surface Processes and Landforms, 24, pp.191 – 209.

Rudrich, J., Bartelsen, T., Dohrmann, R. & Siegesmund, S. (2011): Moisture expansion as a deterioration factor for sandstone used in buildings. Environmental Earth Sciences, 63, pp.1573 – 1586

Saber, A., & Elbana, A. (2023): Sabil Muhammad Ali in Al-Aqqadin, Cairo: A Study in applied geomorpho-Archaeology. *Bulletin de la Société de Géographie d'Egypte, 96*(1), 1-29. https://doi.org/10.21608/bsge.2023.296303

Smith, B. J. & McGreevy, J. P. (1983): A simulation study of salt weathering in hot deserts. Geografiska Annaler, 65 A, pp. 127-133. https://doi.org/10.2307/520726

Smith, B. J., Magee, R. W. & Whalley, W. B. (1994): Breakdown pattern of Quartz sandstone in a polluted urban environment, Belfast, Northern Ireland, Rock Weathering and Landform Evolution, Robinson D. A. and R. B. G. Williams (eds.), pp.131 – 150.

Smith. B. J. (2009): Weathering Processes and Forms-Chapter 4. School of Geography, Archaeology and Paleoecology, Queen's University of Belfast. UK.

Sperling, C. H. B. & Cooke, R. U. (1985): Laboratory simulation of rock weathering by salt crystallization and hydration processes in hot arid environments, Earth Surface Processes and Landforms,10, pp.541 – 555. https://doi.org/10.1002/esp.3290100603

Steiger, M.& Asmussen, S. (2008): Crystallization of sodium sulfate phases in porous materials: the phase diagram Na_2SO_4-H_2O and the generation of stress. Geochimica Acta, 72, pp. 4291 – 4306.

Swe, Y.& Oguchi, C. T. (2010): Role of pore size distribution in salt uptake, damage, and predicting salt susceptibility of eight types of Japanese building stones. Engineering Geology, 115, pp. 226 – 236. https://doi.org/10.1016/j.enggeo.2009.05.007