Sabil Muhammad Ali in Al-Aqqadin, Cairo: A Study in Applied Geomorpho-Archaeology

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Abstract:

The city of Cairo includes many sabils, and perhaps the most famous of them is Sabil Muhammad Ali in Al-Aqqadin, which was established in 1820 as a charity in memory of Muhammad Ali Pasha’s son, Prince Tusun. The purpose of its establishment was to facilitate obtaining pure drinking water throughout the year, particularly when the Nile water level is low, and this has been done by storing water in a cistern under the tasbil room. It is considered one of the largest remaining cisterns in Cairo. It has recently been subjected to many violations, which led to an evident deterioration in its architecture as well as its cultural, historical and aesthetic value. This is mainly due to the negligence and the variety of factors that damage the stones used in building the Sabil, such as climatic conditions, groundwater, and wrong restoration. Accordingly, this led to limestone being affected by weathering, particularly salt weathering, which led to the spread of many manifestations of damage in Sabil Muhammad Ali including seepage, efflorescence, fragmentation, potholes, gaps, and falling blocks, ornaments and decorations [Bul. Soc. Géog. d’Égypte, 2023, 96: 1-33].

Keywords: Geomorpho-Archaeology; Weathering; Sabil Muhammad Ali.

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1. Introduction:

Sabils are places that are prepared and equipped for watering passers-by for the cause of Allah and the sake of goodness (Al-Husseini, 2012). Sabal (give something out), in essence, means making something permissible for the cause of Allah (Amin and Ibrahim, 1990). The sabil builder hoped that Allah would reward him for his good in the hereafter and that it would raise his social status and perpetuates his memory.

The Sabil is a building that Muslims usually built inside and outside cities, aiming to facilitate obtaining pure drinking water throughout the year, particularly when the Nile water level is low. There has been a concern that sabils should overlook the main street, and this concern is to confirm the function of the sabil, which is to water passers-by in front of the establishment.

The architecture of the sabil relied on storing water in a reservoir throughout the year in the ground, in order for the water to be collected in it at the time of the Nile's increase, so that people could benefit from it by tasbilling (giving it out) for the rest of the year. This reservoir is known as a cistern, and for this reason the endowers took care of it and allocated part of the endowment proceeds for the facility to clean it and to buy fresh water to fill it at the time of the flood every year (Noisser, 1970). It is either large or small, according to the size of the establishment, the financial capacity of the builder, and the space allotted as well. It has taken a fixed shape, close to square or rectangular and covered with shallow domes carried on arches resting on pillars (Mubarak, 1969). The cistern is the first floor of the sabil formation and the element that is not visible to the eye. Above the cistern is a second floor, at ground level or slightly above it, overlooking the road, which is the tasbeel (water fountain) room? This floor plays the role of mediator between the cistern with its water and the public with their needs of this water (Noisser, 1970). Since the tasbil room along with its attachments is the visible part from the sabil on the surface of the ground, it was subject to many conditions, including the location, the allocated area, the various artistic influences, and the incoming external influences.

All this led to different shapes and patterns from time to time and from one sabil to another.

The study aims to know the historical and archaeological characteristics of Sabil Muhammad Ali in Al-Aqqadin in Cairo, and to analyze and explain the causes of damage and deterioration from a geoarchaeological perspective. This is mainly due to the fact that the sabil was recently subjected to many violations, leading to a clear deterioration in its architecture (Figure 1). This, in turn, has led to a direct deterioration in its cultural, historical and aesthetic value. Negligence has even reached the point of not caring about the guiding signs that provide information about the sabil’s origins and components (Figure 2).

In order to achieve the aim of the study, the subject was addressed as follows:

2. The Historical and Archaeological Characteristics of Sabil Muhammad Ali:

Sabils appeared in Cairo for the first time in the fourteenth century, and were attached to mosques and other religious buildings established by sultans and princes. Then the wealthy built sabils as separate buildings. Cairo includes many sabils that indicate the association of Islamic architecture with the daily life of the Egyptians. Perhaps the most famous of them is Sabil Muhammad Ali in Al- Aqqadin(1), which was established in 1820 as a charity in memory of hisson, Prince Tusun, who died of the plague in 1816, aging 22 years old atthe time (Fahmy and Dobrowolska, 2005). This monument is located inthe Al-Aqqadin area, at the head of Harat Al-Rum branching from Al- Muizz Lidin Allah Al-Fatimi Street, at the intersection of latitude 30° 2'38" North and longitude 31° 15' 30" East (Figure 3).

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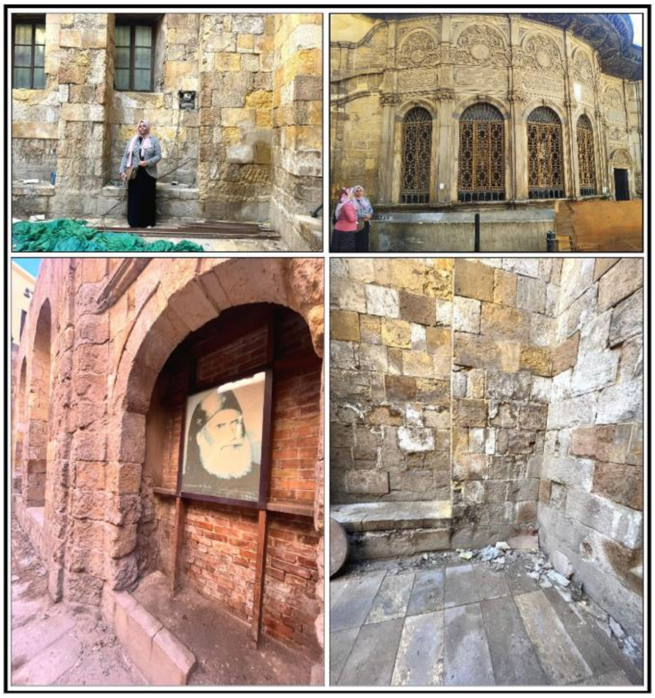
(1) There is another Sabil in the name of Sabil Muhammad Ali in Al-Nahhasin “Al- Muizz Lidin Allah Al-Fatimi” in front of Al-Nasser Muhammad Bin-Qalawun School, Al-Gamalia District, Cairo. It was built by Muhammad Ali Pasha, the governor of Egypt in the year (1244 AH / 1828-1829 AD), as a charity in memory of his son Ismail Pasha, who died in Sudan in 1822.

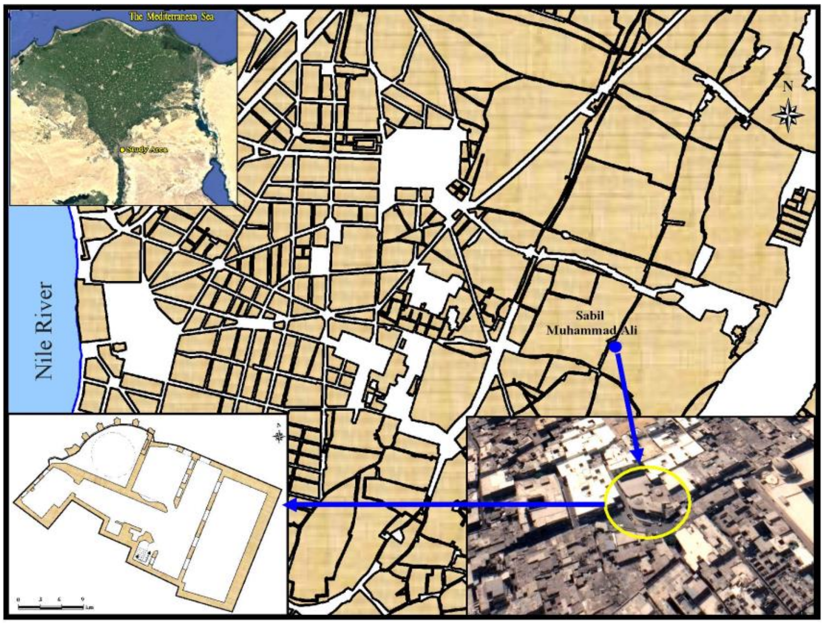


Source: Field study, 2022.

Figure 1: The Deterioration of the Architecture of Sabil Muhammad Ali

Source: Field study 2012 & 2022.

Figure 2: The Deterioration of the Cultural, Historical and Aesthetic Value of Sabil Muhammad Ali



Source: Public Survey Authority, Cairo map showing Islamic monuments, scale 1: 5000, 1948, and Google Earth, 2022 & Ministry of State for Antiquities Affairs, Registration Center for Islamic and Coptic Antiquities.

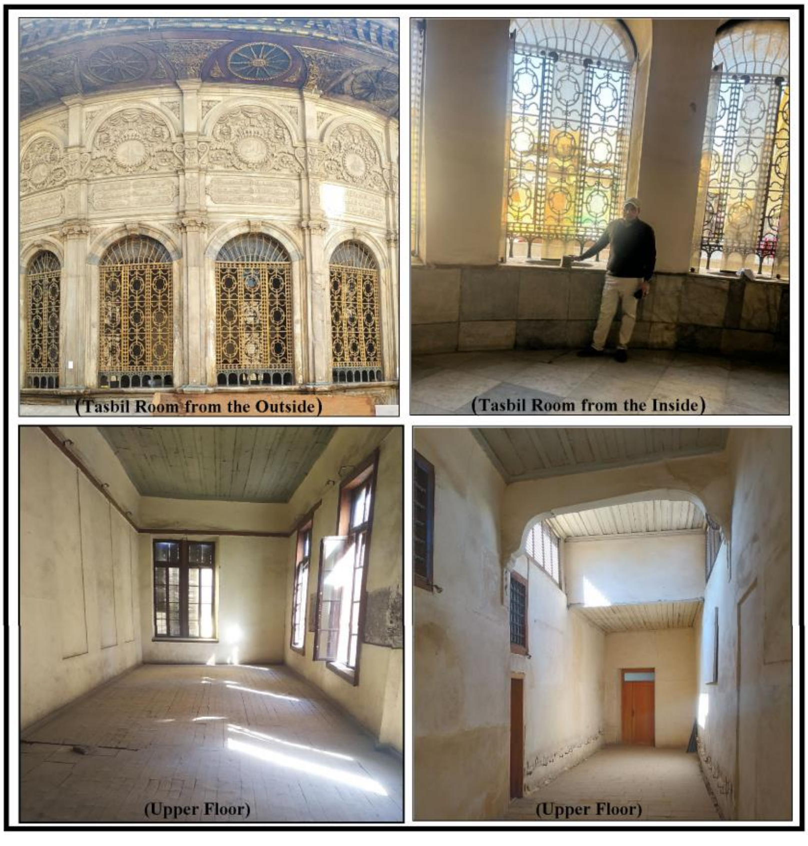
Figure 3: The Geographical Location of Sabil Muhammad Ali

The sabil is located in an active and crowded part, as Muhammad Ali Pasha, upon its founding, chose a prominent location in the active commercial area (Figure 4), and it was buzzing with life for about two hundred years. Accordingly, the sabil drew the thirsty, the poor, and the passers-by.

Source: http://mandomando334.blogspot.com/2013/12/blog-post_19.html.

Figure 4: Sabil Muhammad Ali at the Beginning of the Twentieth Century

The establishment is characterized by the Turkish style of construction, where we find the tasbil room with an arched façade with its copper windows surmounted by a dome decorated with wall oil paintings. The exquisite marble, metal and oil decorations of the sabil, particularly the ones in its facade and the dome of the tasbil room, reflect the Ottoman art style influenced by European arts in the seventeenth and eighteenth centuries. Muhammad Ali Pasha imported wood and white marble from Turkey. There are four rectangular windows for tasbil, tied with semi-circular arches (Tarbush, 1995). An upper floor was added to the sabil, but it is devoid of decoration, which confirms that it was built for a practical purpose (kuttab for memorizing the Holy Qur’an), and all rooms are supported by rectangular openings to support the interior with sufficient natural light that students need (Figure 5).



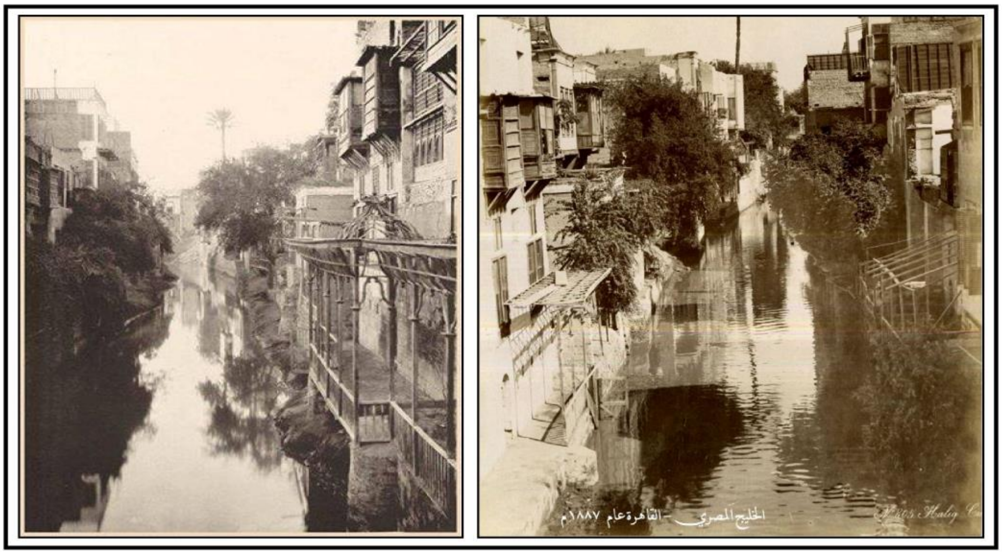
Source: Field study, 2022.

Figure 5: Some Components of Sabil Muhammad Ali

The water in Sabil Muhammad Ali is preserved in a huge cistern under the tasbil room, and it is one of the largest remaining cisterns in Cairo, with a depth of 9 meters and a capacity of 455,000 liters, sufficient to fill a million and a half cups of water. It is roofed with stone domes, and its walls are lined with waterproof mortar (Figure 6). It was fed with water by pipes filled by wheels on the Egyptian Gulf, which was penetrating the city at the time (Al-Sayed, 2021). However, the Gulf was neglected after the opening of the Suez Canal in 1869, the establishment of the Cairo Water Company, and the extension of pure water pipes to many neighborhoods in Cairo. Khedive Abbas Helmy II ordered it to be filled in, out of consideration for public health in 1898, and its location was transformed into a street called "Egyptian Gulf Street." In 1956, its name was changed to Port Said Street (Figure 7).

Source: Field study, 2022.

Figure 6: The Cistern in Sabil Muhammad Ali and the Channel for Water Transport from outside the Sabil to the Cistern



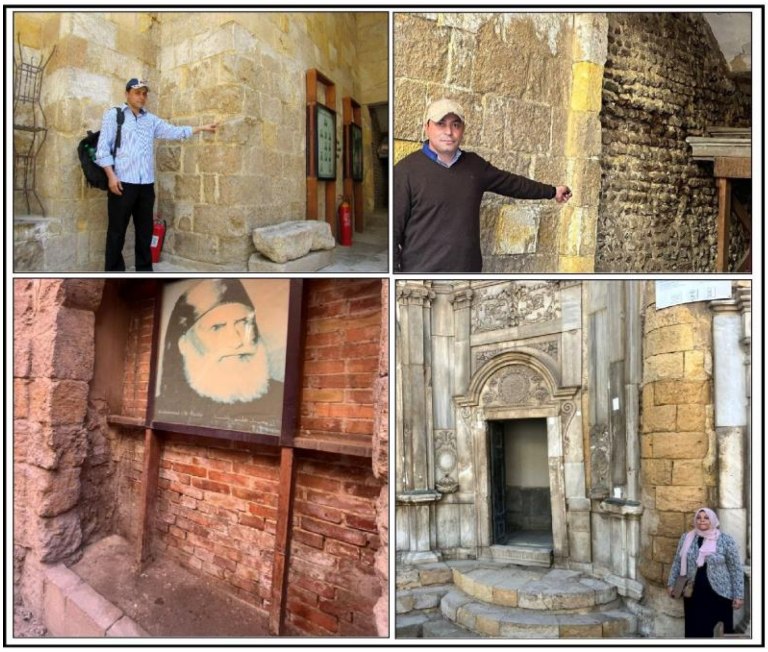
Source: https://www.facebook.com/Ahl.Misr.Zamaaan/photos/.

Figure 7: The Ancient Egyptian Gulf in Cairo

3. Characteristics of the Building Materials Used in Sabil Muhammad Ali:

The characteristics of building materials determine the mechanics of damage and deterioration to which archaeological buildings are exposed, in addition to controlling the type and method of conducting treatment processes. Accordingly, it is significant to study and identify these characteristics. The following is a presentation of the most important of them:

3.1. Mineral composition: Limestones were used in the construction of sabil Muhammad Ali as a basis for the building, in addition to red bricks and marble (Figure 8). The analysis of limestone samples by X-Ray indicates that the main component of limestone samples is calcium carbonate ($\mathrm{CaCo3}$), which is considered the basic stone material, with a percentage exceeding 80.0%, noting the presence of a small percentage of quartz mineral ($\mathrm{Sio2}$) ranging between 2.01% and 4.17 %. As for the chemical analysis of red bricks, it indicates that they contain quartz with the highest percentage of 31.2%. Hematite is also present in the sample in a significant proportion, and its presence with quartz along with orthoclase gives the red brick durability and strength (Darwish, 2007).

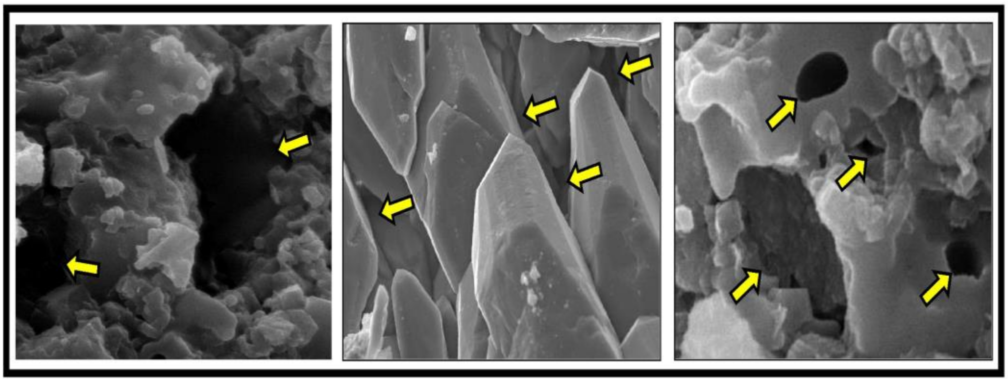


Source: Field study.

Figure 8: The Variety of Stones Used in the Construction of SabilMuhammad Ali

3.2. Degree of hardness: The limestones with which Sabil Muhammad Ali was built are characterized by their weak bearing, ranging between 69 and 73 kg/cm3. Therefore, they are more susceptible to damage and fragmentation if they are affected by salts (Appendix 1).

3.3. Porosity and the degree of water absorption: The pores of limestone appear clear with a diameter of up to 5 microns (Figure 9), with a high degree of porosity in general, ranging between 19.30% and 24.3%. If this indicates anything, it indicates that salt weathering has a significant role in increasing the degree of porosity, particularly the secondary one. That is, it led to the dissolution of some salts present within the materials, and the transition between the processes of crystallization and hydration led to the expansion of voids within the stone. Hence, it increased the degree of porosity and its high ability to absorb water, which ranged between 9.2% and 10.7% (Appendix 1).



Source: Analysis in the Metallurgical Research & Development Center (Scanning Electron Microscope).

Figure 9: The Spread of Secondary Porosity in Limestones in Sabil Muhammad Ali

4. Factors of Damage to the Stones Used in the Construction of Sabil Muhammad Ali:

4.1. Climatic conditions (1):

4.1.1. Temperature and evaporation: The average annual temperature in the study area was 20° C, with a rise in the summer reaching 28.7° C, bringing the highest rate of evaporation to 10.6 mm. In winter, the temperature was 14.7° C, which led to a decrease in evaporation rates to reach 5.0 mm. There is no doubt that this change affected the activity of salts in Sabil Muhammad Ali. That is, the high temperature led to the rapid evaporation of salt solutions inside the walls, as they moved inside the pores of the monument in the direction of the exits of those pores, so the liquids evaporated and the salts gradually crystallized on the surface and inside the walls. This, in turn, led to the occurrence of local stresses that caused damage and fragmentation of the surfaces.

4.1.2. Rain: The annual average is 2.3 mm, and the largest amount of rain falls in the winter up to 2.8 mm. Although it is low and irregular, it is concentrated in the winter, which is the season when the temperature drops which, in turn, increases its effectiveness, as the stones retain water for a longer period. Accordingly, this increases the activity of the dissolution process, in addition to the rain containing many salt ions that damage the stones, resulting in calcium sulphate salt ($CaSo4$) that is one

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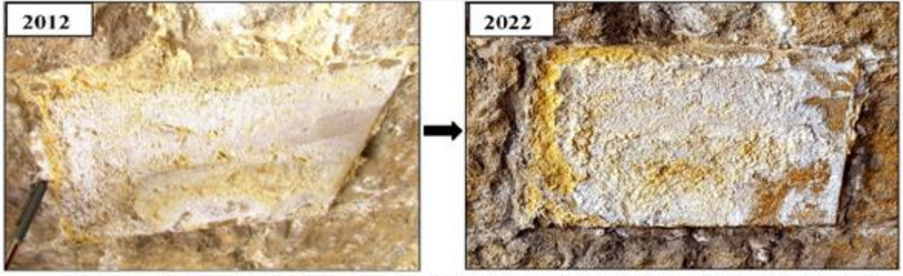
(1) Climate data source, Meteorological Authority from 2000 to 2020.

of the most famous salts that crystallize on the roof of buildings, in the presence of rainwater and sulfur dioxide (So2). As a result of the presence of carbon dioxide (Co2) as a natural component in the atmosphere, carbonic acid is dissolved in rainwater and turns into a carbonic acid solution. It thus converts calcium carbonate (CaCo3), whether it is present in lime mortar, or as impurities in gypsum mortar or various building materials, into calcium bicarbonate (Ca (HCo3)) that is soluble in water, and is displaced by water, leading to further disintegration and weakening of building materials (Shouli, 1991).

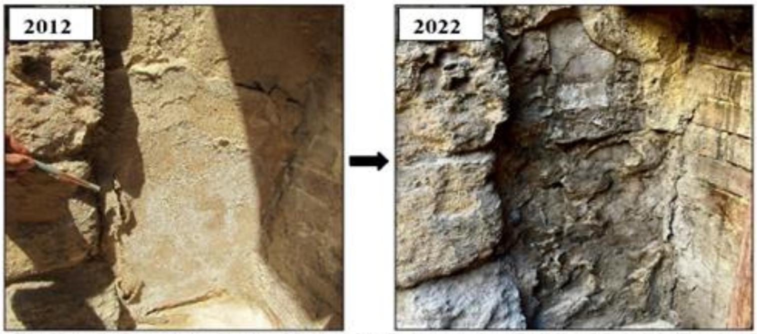
4.1.3. Relative humidity: Relative humidity increases in the fall and winter seasons, reaching 60.4% and 59.1%, respectively, followed by the spring and summer seasons, reaching 56.0% each. It is one of the most dangerous factors of physicochemical damage; that is why it is considered a common denominator in most chemical weathering processes, resulting in severe damage within building materials and even hastens the end of those materials, thus leading to cracking and collapse of the archaeological building (Saber, 2012).

4.2. Groundwater: The depth of the groundwater in the area of Sabil Muhammad Ali was 1.3 m below the surface of the earth, and the total salt concentration was 2900 ppm, with the predominance of the concentration of sodium and chlorides, which exceeded 15 Meq/L (Saber, 2013). This rise in the groundwater level and the increase in the percentage of salts is due to the fact that the city of Cairo was once interspersed with ponds, swamps and canals that were filled in, the most important of which was the Egyptian Gulf. Although it has been filled in, its effect is still evident on the neighboring areas. For one thing, its level is lower than the surrounding areas, which made it a drain for leaking water from the water and drainage networks. For another, it increased the percentage of salts in the groundwater, which seriously damaged the antiquities, including Sabil Muhammad Ali, where the groundwater containing dissolved salts seeps from the soil to the foundations of the building through pores, cracks, and micro- cracks in building materials by capillary action, absorption force, diffusion force, and osmotic force (Abdullah, 2000).

4.3. Wrong restoration: The deterioration was linked to incorrect restoration practices that caused the replacement of the original stones with incoherent ones of different colors and fabrics (Figure 10/a), in addition to poor maintenance practices, which led to increased levels of moisture and salinity. Subsequently, this led to rapid erosion of the facades that resulted in cracks, causing a general deterioration in the building structure (Ismaeel and Elsayed, 2018). In addition, it was indicated that a dangerous cement mortar was used, the most famous of which is Portland cement (Figure 10/b), which contains calcium silicate, aluminum silicate, calcium sulphate and some alkaline salts that penetrate into building materials, causing serious damage to them, such as crystallization of salts as well as the emergence of micro and wide cracks. These cracks are the result of the difference in the coefficient of expansion and contraction between the old building materials and the cement used in this restoration (Lamei, 1995).



A-The Replacement of the Original Stones with Incoherent Ones of Different Colors and Fabrics in Sabil Muhammad Ali



B- The Use of a Dangerous Cement Mortar that Penetrates into Building Materials Causing Serious Damage to Them

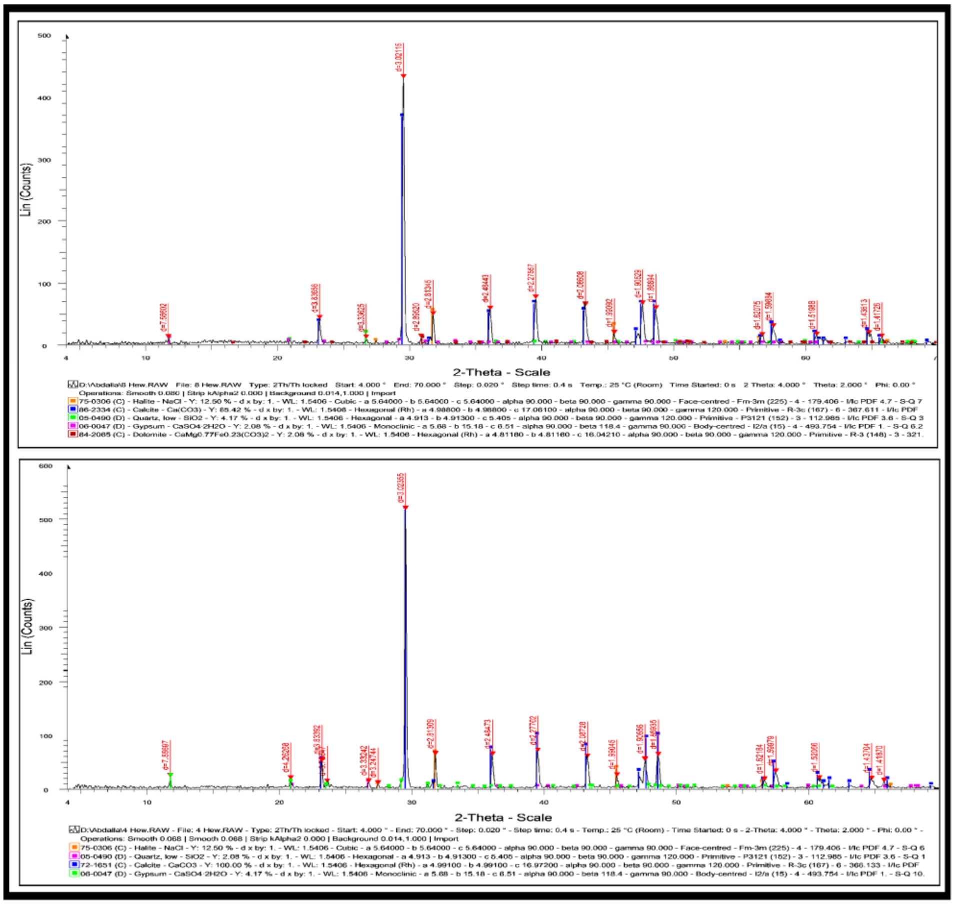
Source: Field study, 2012 & 2022.

Figure 10: Wrong Restoration Practices in Sabil Muhammad Ali

5. Methods for Identifying Damage to Stones Used in the Construction of Sabil Muhammad Ali:

5.1. X-ray (1):

It is one of the methods that directly gives 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 (Mustafa, 2009) (Figure 11).



Source: The analysis was carried out in the National Research Center.

Figure 11: X-ray Analysis of Stone Samples with which Sabil Muhammad Ali Was Built

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(1) Two limestone samples were analysed.

Figure 12 indicates the following:

5.1.1. The presence of halite in a large percentage, which indicates that the samples have a high percentage of salts.

5.1.2. The presence of gypsum in limestone samples, which is a manifestation of damage resulting from the conversion of calcium carbonate to calcium sulphate as a result of its interaction with sulfur dioxide gas in the presence of water.

$CaCo_3+So_2+H_2o \quad CaSo_4+H_2o+Co_2$ (Darwish, 2007)

5.1.3. The presence of halite in a large percentage, which indicates that the samples have a high percentage of salts.

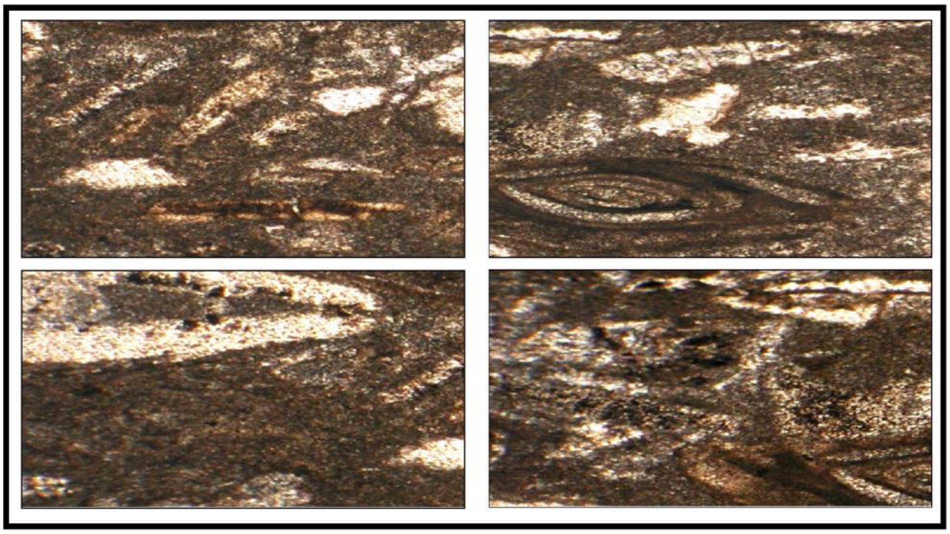
5.1.4. The presence of anhydrite, resulting from the transformation of hydrated gypsum by heat and water loss, and its transformation into anhydrous gypsum.

5.1.5. The presence of sodium nitrate salt with a high percentage in the red bricks as a result of the presence of groundwater, mostly sewage water, at the bottom of the building, and it rose to the walls through the capillary action (Darwish, 2007).

5.2. Thin-section:

It is used to identify the mineral composition of the sample and its fabric, and to examine any initial damage processes. It is also used to detect the mechanical damage that can occur within the mineral grains of the sample as a result of increased pressure affecting them and to identify the presence of salts.

It is evident from the analysis of samples of stones with which the building of Sabil Muhammad Ali was built using thin-section (Figure 12) that they are limestone rich in parallel nummulites, and has dark minerals such as clay, and some sparite crystals accumulate in the micrite spaces. Its fabric is wackestone, and it is less resistant to salt crystallization; it is characterized as being less flexible, and thus in the case of crystal growth of salts, it puts pressure on this fabric, which causes fracture or fragmentation. In addition, there is a spread of nummulites and foraminifera fossils in these samples. All these factors reduce the rock ability to resist the pressure resulting from the growth of salt crystals.



Source: Captured under polarized light, 100x magnification.

Figure 12: Analysis of Samples of Stones with which Sabil Muhammad Ali Was Built Using Thin-Section

5.3. Ultrasonic Pulses:

It is one of the most important methods for examining archaeological surfaces and detecting any internal defects such as cracks as well as surface and deep gaps. The speed of ultrasonic pulses ranged between 1.6 and 2.1 km/sec in three samples of the stones of Sabil Muhammad Ali, while the degree of internal friction ranged between 6.9 and 8.1 (Appendix 1).

It is worth noting that there is a very strong inverse relation between the speed of ultrasonic pulses and the degree of friction. That is to say, the greater the gaps and voids, the greater the degree of friction, and the lower the speed of ultrasonic pulses. Accordingly, the study samples, which represented the limestones with which Sabil Muhammad Ali was built, were affected by weathering, the salt one in particular. This, in turn, caused damage and deterioration.

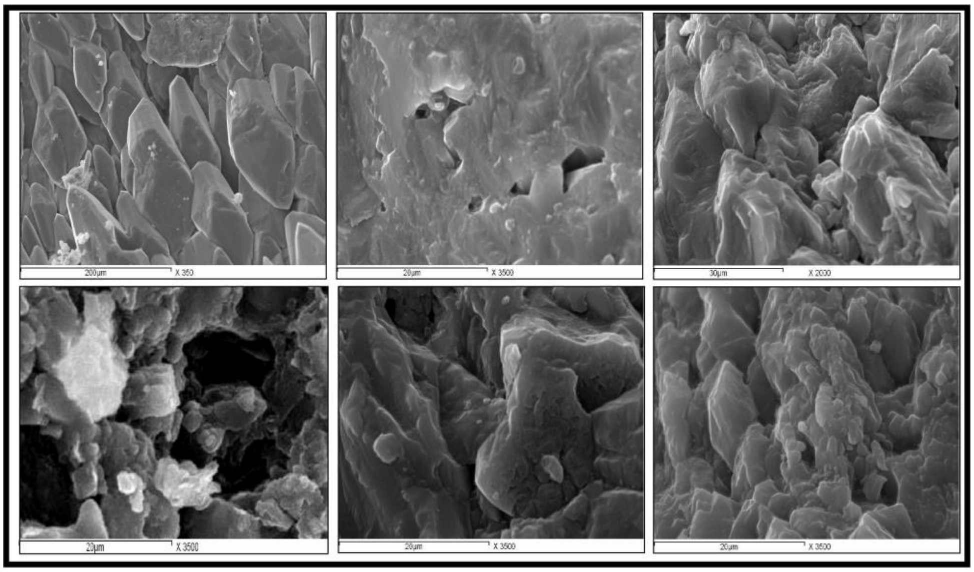
5.4. Scanning Electron Microscope (SEM):

This device is widely used in the diagnosis of damage outcomes and manifestations within building materials, and is also used in the study of microbiological damage processes that occur to carbonate stones.

Figure 13 indicates the presence of fully crystallized calcite crystals. However, it appears that there is a relative absence of sealing substance in some samples, which helped accelerate weathering. Subsequently, this led to the dissolving of the crystals. It is also evidenced that there is a spread of dissolution gaps within calcite crystals, which is a good place for the accumulation of salts and moisture, which facilitates and increases the process of salt weathering on that stone. In addition, there were a presence of a flake across the levels of cleavage, a spread of fragmentation in the calcite crystals, and a presence of salts accumulated in a smooth form on the calcite crystals of the rock.

5.5. Hydrochemical Characteristics:

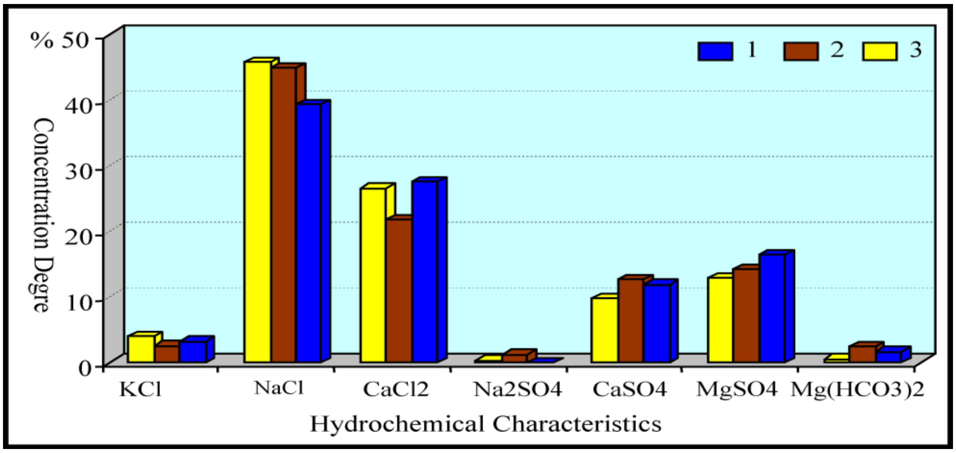
Hydrochemical analyses in Appendix 1 shows a high degree of concentration of salts in limestones in Sabil Muhammad Ali, ranging between 29925 and 36560 ppm. Chloride salts are among the most common crystalline salts in the solid salty layer above the surfaces of the sabil walls. This type of salt is characterized by its ability to absorb a large amount of moisture water owing to its high porosity, with the ease of losing it again when dehydrated (Al-Homsani, 2007). Furthermore, chlorides appear in the walls in the form of a dividing line when the moisture level of the wall ends (Tawfik, 2005).



Source: Analysis in the Metallurgical Research & Development Center.

Figure 13: Analysis of Samples of Limestone with which Sabil Muhammad Ali Was Built Using-scanning Electron Microscope

As indicated by the hydrochemical analysis of stone samples (Appendix 1 and Figure 14), there is a presence of chloride salts such as the following: potassium chloride, calcium chloride and sodium chloride salt. The sodium chloride concentration degree ranged between 39.3% and 47.9%, followed by calcium chloride between 25.5% and 31.8%, then chloride potassium by not more than 4.6%.



Source: Based on Appendix 1.

Figure 14: Hydrochemical Characteristics of Stone Samples in Sabil Muhammad Ali

Sulphate salts play a serious role in the damage and destruction of the various mineral components of stones and mortars, and their transformation into brittle materials (Feilden, 1982). As a matter of fact, the danger of sulphate salts is represented in its high ability to dissolve in water, as they are one of the hygroscopic salts of high ability to absorb water so that it can crystallize with different amounts of water depending on the temperature and humidity in the surrounding environment. These salts are deposited in the form of their supersaturated solutions inside the pores of the walls, causing internal pressure as a result of its continuous growth. This leads to cracking of the walls of pores, and thus the disintegration of the wall fabric (Al- Homsani, 2007).

The results of the analyses prove that the most important sulphate salts found in those samples are as follows: magnesium sulphate, with a percentage ranging between 18.2% and 26.0%, and calcium sulphate between 10.7% and 11.8%.

In fact, the presence of magnesium sulphate is due to the interaction of sulfur ion in the atmosphere with magnesium in the dolomite present as a secondary component of limestone in the humid atmosphere and the occurrence of damage that resembles sugar grains. Magnesium sulfate crystallizes directly under the stone surface, which leads to its disintegration and destruction of the decorations and inscriptions on those surfaces (Tawfik, 2005). Moreover, this salt can cause severe damage to building materials, particularly mortars.

From the above-mentioned, it is evident that chloride salts are present in high concentrations, and thus it is considered an indication that their source is groundwater since the water absorbed by the wall moves to the dry surfaces of walls, carrying this salt. Due to the high temperatures in the study area, the water dissolved in the salts evaporates, leaving the salts to crystallize on the surfaces of walls or below these surfaces. The crystallization of these salts has led to the existence of serious damage manifestations, which appear in the form of flakes, potholes and gaps inside the building materials, and then make them rough surfaces, or even lead to the complete destruction of the surface. In fact, the presence of both sulphate and chloride salts together has a devastating effect on the surface of the stone or within cracks, causing the stone to detach in the form of flakes, which destroys the stone surface.

6. The Manifestations of Damage in Sabil Muhammad Ali:

The effects of damage appear on the archaeological buildings, starting with water seepage and then efflorescence. The continuous transition between the two stages leads to a breakdown of the bonding and cohesion between the components of the stone, in addition to the emergence of many manifestations of cracking, flaking, disintegration of the wall tissue, erosion of the sealing material, and the destruction of the decorations in the monument. Its continuous formation leads to the complete elimination of archaeological stones, which can be studied in detail as follows:

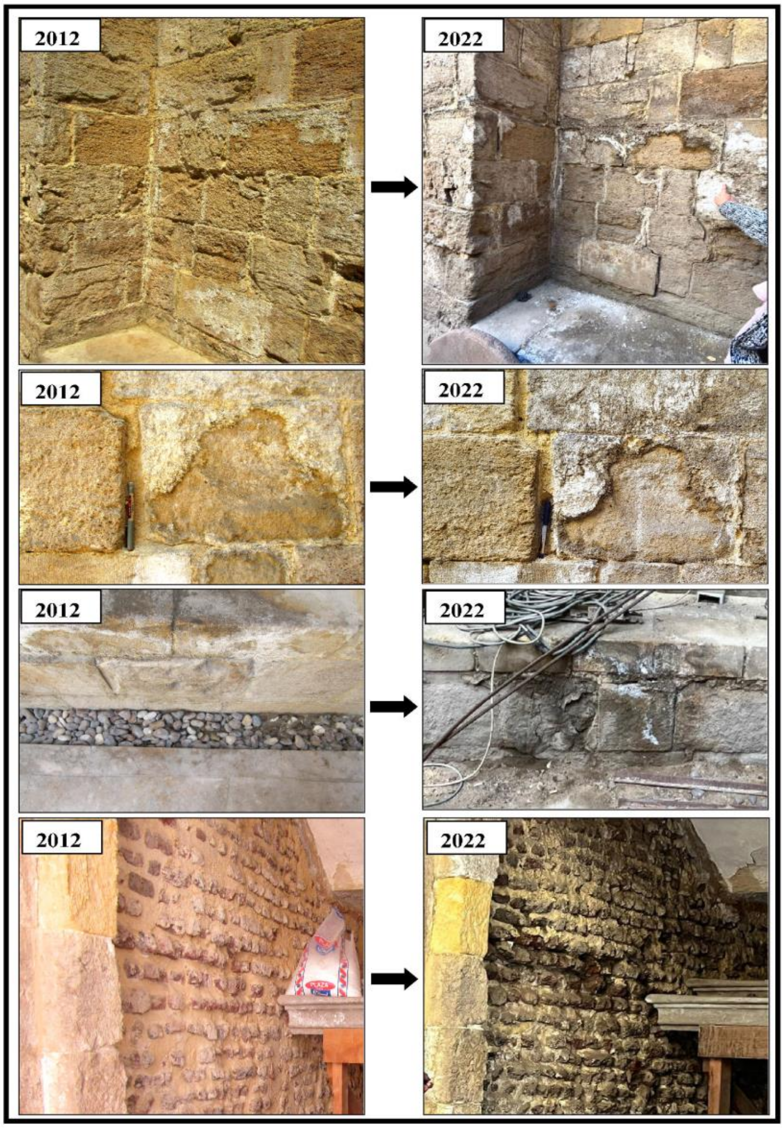
6.1. Moisture Levels (Seepage and Efflorescence Domains):

6.1.1. Domain A (Seepage Domain): It shows a lesser manifestation of the damage, and it is located directly above the ground surface. It is the domian of seepage or infiltration, due to the high levels of groundwater, which led to its rise to the top through the capillary action. The height of seepage ranged between 0.40 and 1.10 m.

6.1.2. Domain B (Efflorescence Domain): It is the most damaged domain, and it includes those salt efflorescence and flakes, which consist of sulphate salts and chlorides, particularly magnesium and sodium. The danger of salts lies in the pressure resulting from hydration pressure or crystallization pressure, which results in hydrothermal stresses (Al-Homsani, 2007).

The height of the efflorescence domain was measured from the lowest level starting from the efflorescence line to the highest level it reached, which is the area that includes the stage of crystallization of salts. They vary and spread widely in Sabil Muhammad Ali, ranging between 1.0 and 3.90 m. In essence, they are salt layers on the surfaces of the sabil stones, and the thickness of these layers ranges from less than 0.1 mm to several millimeters, and in some cases the thickness reached one centimeter (Figure 16). It was also found that the colors of these salt layers vary between white and black. Most of the salt layers monitored by the 2012 field study turned from white to black in 2022 (Figure 15). This is due to the fact that these layers consist of various iron oxides, as well as sulphate, particularly calcium sulphate and silica minerals. The main resources of the aforementioned components include solid air pollutants from the environment surrounding the monument, such as dust and fumes, as well as some minerals resulting from the internal environment of stones and mortars (Saber, 2012).

It is worth noting that these solid salt layers contain many cracks and fissures that facilitate the penetration of moisture into the stones, which leads to more damage such as flaking and cracking of the surfacelayers of the stones.



Source: Field study, 2012 & 2022.

Figure 15: The Spread of Salt Layers on the Surfaces of the Stones of Sabil Muhammad Ali, with Most of Them Turning from White in 2012 to Black in 2022

6.2. Flaking and Fragmentation:

The phenomenon of flaking and fragmentation spreads in Sabil Muhammad Ali (Figure 16), where a contour flaking occurred, with a thickness ranging between 0.5 and 4 mm. This is due to the spread of sulphate salts, particularly sodium sulphate salts in the limestones, where the volume of sodium sulphate salts increases by 300% and pressures occur on the walls of the pores of the stone blocks, leading to destructive hydration stresses to the environment of the stone and the occurrence of its flaking and fragmentation (Abdulhadi et al., 1996). This also occurs when the magnesium sulphate salt crystallizes behind the surface of the stone, causing it to flake and detach, as the magnesium sulphate salt causes damage and corrosion of the building materials used in the construction of Sabil Muhammad Ali, about 35% more than what is caused by the different phases of the sodium sulphate salt during the crystallization cycles of this salt. The magnesium sulfate salt is considered one of the fastest salts in the process of hydration, as the process of hydration of this salt takes place within 6 hours when exposed to moisture, while the process of hydration of sodium sulphate salt may take several days to complete (Hamida, 2003).The limestones with which Sabil Muhammad Ali was built were severely affected by the salt weathering process (crystallization of salts), which appears in the form of granular fragmentation, cracks, potholes and flakes in the limestone fabric. This caused severe fragmentation and erosion in the limestone fabric, which led to erosion or contour retraction in many stones (Figure 16). In the case of continuous damage and lack of maintenance and restoration of this deterioration, the sabil will be exposed to more erosion and danger.

Source: Field study, 2022.

Figure 16: The Spread of the Phenomenon of Flaking andFragmentation in the Stones of Sabil Muhammad Ali

6.3. Potholes and Gaps:

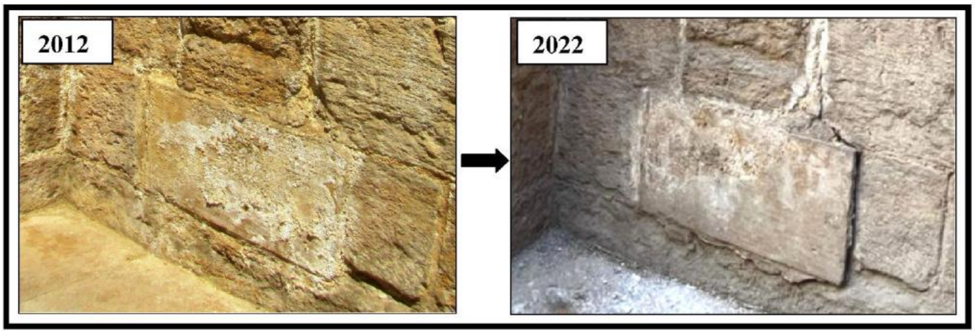
This phenomenon is widely spread in Sabil Muhammad Ali (Figure 17), where irregular erosion of stone surfaces was observed with the formation of voids or cavities of different sizes, along with the formation of gaps connected to each other, in a form resembling honeycomb and Tafoni pits. This phenomenon spreads in internal and external surfaces, and at the entrance to the reservoir (cistern), with average diameters ranging between 0.5 and 7.0 cm, and a depth of more than 5 cm in some stones. This, in turn, confirms that the sabil has reached a high level of deterioration. One of the main reasons for the spread of this phenomenon is the presence of sodium sulphate salts; they grow in one direction to take the prismatic shape, which increases their destructive force to the building stones due to the increase in size and its solubility. Moreover, the presence of these gaps is due to the susceptibility of calcium sulphate, whether present on the stone surface or inside it, to dissolve and be displaced by rainwater, noting that the successive sedimentation and dissolution cycles of salts lead to deepening these gaps more and more.

Source: Field study, 2022.

Figure 17: The Spread of Potholes and Gaps in the Stones of SabilMuhammad Ali

6.4. The Detachment of Blocks and Falling of Decorations:

The problem of the detachment and falling of blocks and decorations is considered one of the most important, dangerous and destructive problems for Sabil Muhammad Ali. Due to the severe neglect that the sabil was subjected to, particularly in the last ten years, as well as the lack of any restoration or maintenance, it significantly deteriorated in its rocky and aesthetic structure. The field study monitored the detachment of many of the blocks that were intact in 2012 (Figure 18), where the phenomenon of detachment spread in all the walls of the sabil built with limestone, particularly the northern and eastern walls, which are two of the most neglected places in the sabil. In addition, it was shown that parts of the decorations and ornaments that adorn the façade of the sabil from the outside have fallen, which consist of limestone and surround the tasbil room and the northern entrance (Figure 19), which resulted during the crystal growth of salts in its walls because of the increase in the proportion of sulphate salts, particularly the calcium sulphate ones. In spite of its scarce solubility in water, it crystallizes in the dry and elevated parts. Besides, the formation of detached layers and agglomerations of calcium sulphate salt on the surfaces or under the surface of building materials may result in damage to these surfaces and their transformation into powder (Hamida, 2003). The field study also monitored the detachment of some marble decorations on the front side of the sabil (Figure 19). As previously mentioned, this indicates that the sabil has reached a very high degree of deterioration, and if neglect continues in this way, it will lead to the destruction of the monument in a way that its historical and archaeological origin would not be ever restored.



Source: Field study, 2012 & 2022.

Figure 18: The Detachment of Stone Blocks in Sabil Muhammad Aliduring the Period from 2012 to 2022

Source: Field study, 2022.

Figure 19: The Detachment and Falling of Stone Blocks, Decorationsand Ornaments in Sabil Muhammad Ali

7. Conclusion (Results and Recommendations):

7.1. Results:

The geomorpho-archaeological study of Sabil Muhammad Ali revealed several facts, which can be summarizing as follows:

7.1.1. The water in Sabil Muhammad Ali is preserved in a huge cistern under the tasbil room. It is one of the largest remaining cisterns in Cairo, with a depth of nine meters and a capacity of 455,000 liters, and its walls are lined with waterproof mortar. Besides, it was fed with water by pipes filled by wheels on the Egyptian Gulf, which was penetrating the city at the time.

7.1.2. The factors of damage to the stones used in the construction of Sabil Muhammad Ali varied, such as climatic conditions, groundwater, and wrong restoration, which led to damage, fragmentation, and disintegration of surfaces, the appearance of fine and wide cracks, and the general weakness of building materials due to the crystallization of salts in them.

7.1.3. Methods for identifying damage to stones used in the construction of Sabil Muhammad Ali, such as x-ray, thin- section, ultrasonic pulses, Scanning Electron Microscope, and hydrochemical characteristics, confirmed that limestones were affected by weathering, particularly salt weathering. This caused damage, deterioration, flaking through cleavage levels, and the spread of fragmentation and cracks, causing the stone to separate in the form of flakes, which destroys the stone surface.

7.1.4. The manifestations of damage to Sabil Muhammad Ali varied, namely:

7.1.4.1. Moisture levels (seepage and efflorescence domains): The height of seepage ranged between 0.40 and 1.10 m, and the domain of efflorescence between 1.0 and 3.90 m. In essence, they are salt layers on the surfaces of the sabil stones, and the thickness of these layers ranges from less than 0.1 mm to several millimeters, and in some cases the thickness reached one centimeter. It was also found that the colors of these salt layers vary between white and black. Most of the salt layers in 2012 turned from white to black in 2022. It is worth noting that these solid salt layers contain many cracks and fissures that facilitate the penetration of moisture into the stones, which leads to more damage such as flaking and cracking of the surface layers of the stones.

7.1.4.2. The phenomenon of flaking and fragmentation spreads in Sabil Muhammad Ali, where a contour flaking occurred, with a thickness ranging between 0.5 and 4 mm. The limestones with which Sabil Muhammad Ali was built were severely affected by the salt weathering process (crystallization of salts), which appears in the form of granular fragmentation, cracks, potholes and flakes in the limestone fabric. This caused severe fragmentation and erosion in the limestone fabric, which led to erosion or contour retraction in many stones.

7.1.4.3. The phenomenon of potholes and gaps is widely spread in Sabil Muhammad Ali, where irregular erosion of stone surfaces was observed with the formation of voids or cavities of different sizes, along with the formation of gaps connected to each other, in a form resembling honeycomb and Tafoni pits. This phenomenon spreads in internal and external surfaces, and at the entrance to the reservoir (cistern).

7.1.4.4. The detachment and falling of blocks and decorations is considered one of the most important, dangerous and destructive problems for Sabil Muhammad Ali. The phenomenon of detachment spread in all the walls of the sabil built with limestone, particularly the northern and eastern walls, which are two of the most neglected places in the sabil. In addition, it was shown that parts of the decorations and ornaments that adorn the façade of the sabil from the outside have fallen.

7.2. Recommendations:

7.2.1. Using safe water withdrawal techniques below the foundations of Sabil Muhammad Ali, the improvement and development of drainage networks, and the reduction of the groundwater level. However, all necessary research and studies must be done before conducting groundwater dewatering operations, as this is extremely dangerous.

7.2.2. Using the method of cutting the walls with a cutting saw, and then placing strips of plastic with great durability in the places of cutting to prevent the rise of groundwater by capillary action inside the walls (Abdulhamid, 2006).

7.2.3. Protecting buildings from the impact of rainwater and making the necessary connections to connect this water to drainage directly so as to prevent it from collecting near or on the sabil surface.

7.2.4. Changing worn-out stone blocks with new ones of the same type as the old stone.

7.2.5. Carrying out periodic maintenance and restoration, speeding up its implementation, and dealing with the manifestations of damage in its early stages, so that the sabil is not exposed to erosion and the loss of its historical and archaeological value.

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Appendix 1

Some Physical and Chemical Characteristics of Limestones with which Sabil Muhammad Ali Was Built

Sample No. / **Limestone Characteristics**	**1**	**2**	**3**
Porosity (%)	19.3	23.2	24.3
Degree of Water Absorption (%)	9.2	10.0	10.7
Degree of Rock (kg/cm^3) Bearing	69	72	73
Ultrasonic Pulses (km/sec)	1.6	1.9	2.1
Internal Rock Friction	8.1	7.8	6.9
"T.D.S. " ppm	29925	28481	36560
KCl (%)	3.2	2.6	4
NaCl (%)	39.3	44.9	45.8
CaCl2 (%)	27.5	21.8	26.5
Na_2SO_4 (%)	0	1.3	0.4
$CaSO_4$ (%)	11.9	12.7	9.8
$MgSO_4$ (%)	16.4	14.2	12.9
$Mg(HCO_3)_2$ (%)	1.7	2.5	0.6