بسم الله الرحمن الرحيم

ظَهَرَ الْفَسَادُ فِي الْبَرِّ وَالْبَحْرِ بِمَا كَسَبَتْ أَيْدِي النَّاسِ لِيُذِيقَهُمْ بَعْضَ الَّذِي عَمِلُوا لَعَلَّهُمْ يَرْجِعُونَ

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Air Pollution In Archaeology

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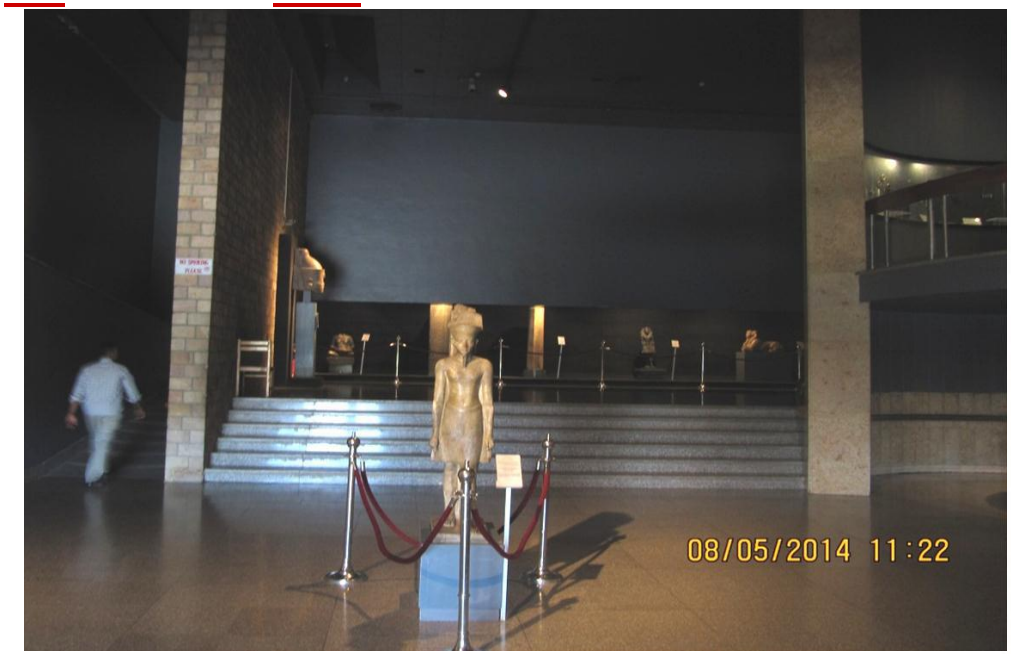
Air pollution is one of the most aggressive and severe factors affecting archaeological materials, especially in outdoor environments, creating many deterioration aspects especially with the presence of other factors, such as rainwater, air temperature, relative humidity, and wind currents.

Air Quality and Its Impact on Indoor and Outdoor Archaeological Sites: Luxor museum (Egypt) and Amman castle (Jordan) as case studies

INTRODUCTION

Air pollution, as a general term, means **that there are unexpectedly particles of pollutants with high concentration**. It occurs almost everywhere and has a long history. It results in weathering and deterioration of stone monuments, particularly near urban and industrial areas. Therefore, if people fail to stop or slow down the deterioration processes resulting from air pollution, no cultural heritage will be preserved in the future. The present study aimed to explain the threat of air pollution as a severe deterioration factor affecting most archaeological materials in both indoor and outdoor environments. In this regard, it evaluated two of the most important archaeological sites, i.e. *Luxor Museum* in Egypt and *Amman Castle* in Jordan to asses the severe effects of air pollution and its forms.

Air pollution as an indoor deterioration factor affecting Luxor Museum



Lies in the heart of Luxor between Karnak and Luxor temples, on the east bank of the Nile, facing the Theban Necropolis. It is prone to the damage of its materials by several types of gaseous and pollutants. Furthermore, the cultural property inside the museum can be threatened either by outdoor pollutants, such as car exhausts, or indoor pollutants generated from sources within the museum, such as fumes from cleaning products. All of these factors cause some aggressive pollutants, such as TSP, fuels, dust, oxides, organic materials, hydrocarbons, and some effective gases. These factors and related mechanisms have resulted in many deterioration forms.

Deterioration forms affecting the internal parts of (LM) (1)

It has been affected by some types of pollutant emission and gases, including CO, CO_2, SO_2, and NO_x in particular. These pollutants play an important role in oxidation processes and cause many deterioration effects, mechanisms "chemical and/or physical", and related forms. The used passive indicator proves the existence of ammonia and acetic acid pollutants in the open display areas in the Old Museum on the 1st and the 2nd floors. These factors and their related mechanisms creat many deterioration forms, such as:

Metal corrosion bronze and cooper alloys

Deterioration forms affecting the internal parts of (LM) (2)

Salt crystallization & Flaking of stone artefacts

Metal corrosion bronze and cooper alloys

Deterioration forms affecting the internal parts of (LM) (3)

Embattlement and discoloration of the papyrus

Mechanical deterioration of wood related to thermal expansion & living organisms

Air pollution as an outdoor deterioration factor affecting Amman Castle

It is the most famous archaeological site in Amman with its complicated buildings extending over several eras beginning from the 2nd Iron Age to the Islamic period. It has a plain shape from the north-west to the south-east surrounded by many valleys from all directions except the northern one, which faces Al-Hussein Mountain. It includes many archa-eological sites characterized by many artistic features, such as the Open Historical Lake, Umayyad Houses, and Umayyad Liwân “the topic of our study”. It has been affected by different sources of pollution that could be divided into stationary sources and mobile sources.

Deterioration forms affecting the external parts of (AC) (1)

A complete survey of the Castle's exterior part carried out by field observation, digital photography, and close visual inspection reveals complicated processes of destruction affecting its external parts of the castle. All of these processes resulted essentially due to both *stationary* and *mobile* sources, which, led to create different sources of pollutants such as *TSP* SO_2 CO_2 No_x and *Pb* These processes have caused typical structural changes, as well as different types of deterioration aspects and weathering forms, such as:

Severe etching and loosing of calcite grains on the stone surface due to dissolution processes by acid rains

Deterioration forms affecting the external parts of (AC) (2)

Presence of colored hard crusts resulting from acid rain, heavy metals dominating the air composition, and fly ashes "ferrous oxides

Black aspects resulted from the components of air pollution including soot and organic black matters

Deterioration forms affecting the external parts of (AC) (3)

Eroded of stone surfaces due to botanical and microbiological effects, depending on accumulated pollutants

Discolouring of some zones on the stone surfaces due to soot, dirt, and impurities of polluted oxides

MATERIALS AND METHODS

The experiments used are divided into two parts:

The 1st part was applied to Luxor Museum using *several instruments:*

- **Digital hygro-thermometer** *to evaluate daily AT and RH values*.
- **Passive indicators** *to asses the pollutant levels*
- **PH meter** *to define the acidity of the objects' environments*.

The 2nd part was applied to Amman Castle as follow:

- **Wild Heerbrugg stereo microscope** connected to **Wild MPS 51 camera** and **Wild MPS 45 photo-automat unit** *to investigate different deteriorated features affecting the stone surfaces*.
- **6000 - Shimazu XRD** to *identify the microcrystalline phases (present) and deterioration compounds (affecting) the stone surfaces*.
- **Varian Vista Series ICP-OES Spectrometers**, **Glass electrode** and **Digital conductivity meter**" *to detect some trace elements in several rainwater samples collected from the study area*.

RESULTS

Data of (T) and (RH) at the 1st & 2nd floors in (LM) (1)

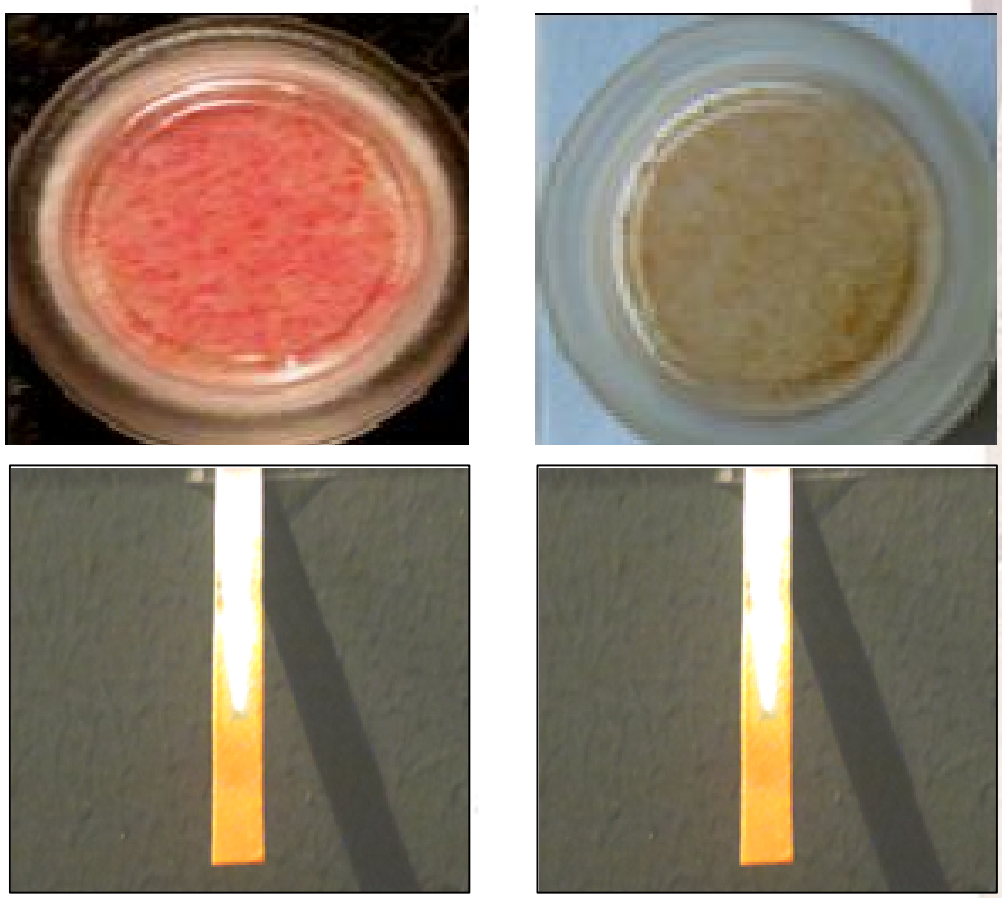
Measuring Area	Temperatures °C		Relative Humidity %	
	Highest	Lowest	Highest	Lowest
First hall (1st Floor)	24	**22**	**28**	27
Open display area (1st Floor)	25	**22**	**28**	28
Coins vitrine (2nd Floor)	25	23	26	25
The golden statues of king TUT.V.4	26	23	23	**22**
The wooden boats V.4	26	24	23	**22**
The metal candlestick	28	25	25	24
The wooden coffins V.4	30	27	25	24
Open display area (2nd Floor)	**31**	28	27	25

Data of (T) and (RH) at new extension part in (LM) (2)

Measuring Area	Temperatures °C		Relative Humidity %	
	Highest	Lowest	Highest	Lowest
The chariot	27	26	28	24
Royal arrows	23	24	32	24
Royal mummies	24	23	46	34
Weapons vitrine	24	23	33	28
Open display area 1st Floor	25	24	33	29
Open display area 2nd Floor	23	22	33	29
The wooden coffins	25	23	34	29

Data of (T) and (RH) at new extension part in (LM) (3)

Measuring AT & (RH) by digital hygro-thermometer

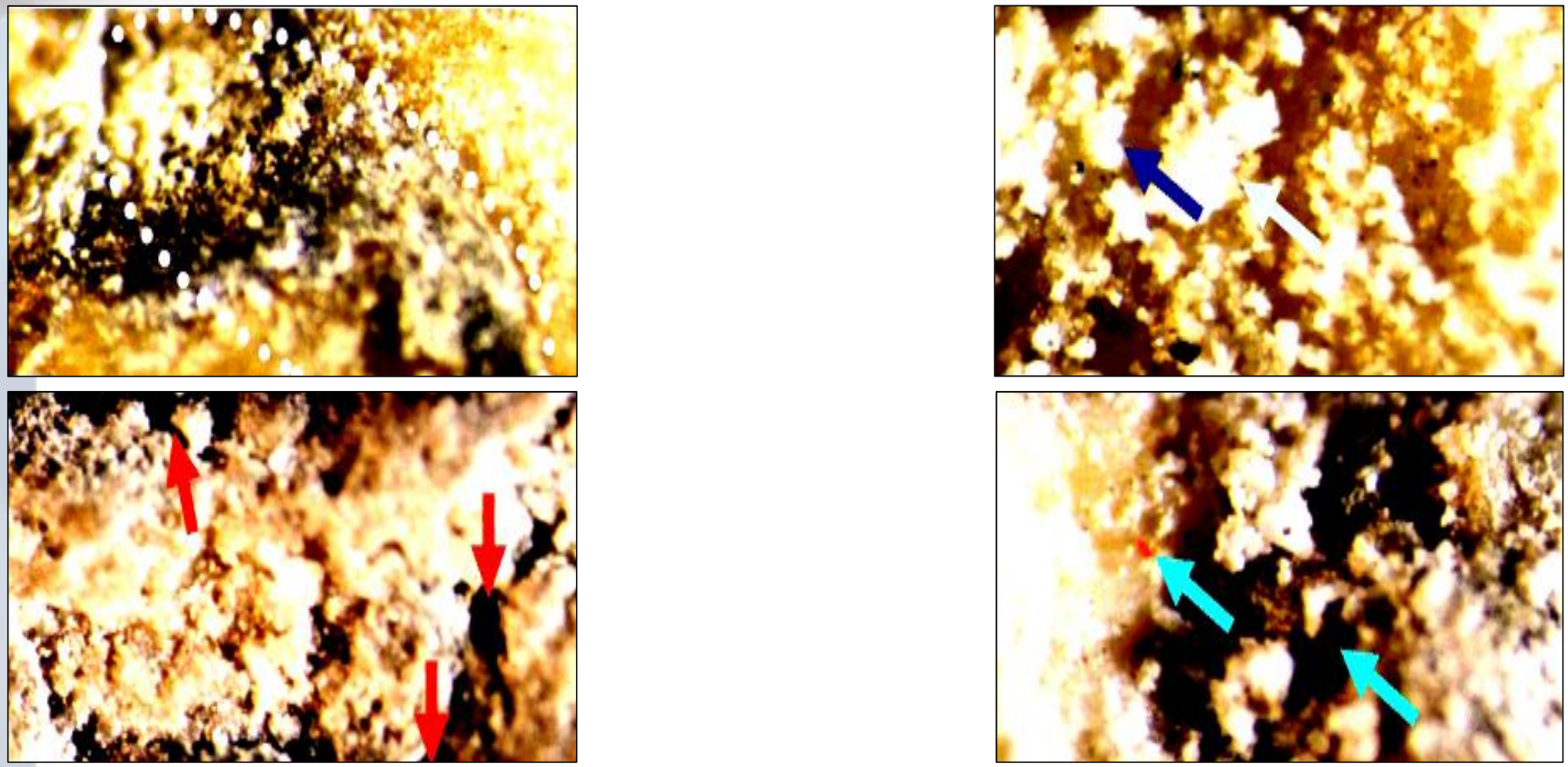


Measuring of: a) Ammonia, b) Acetic acid c) Acidity, d) Alkalinity by passive indicators

Chemical analysis data by AAS (AC) (1)

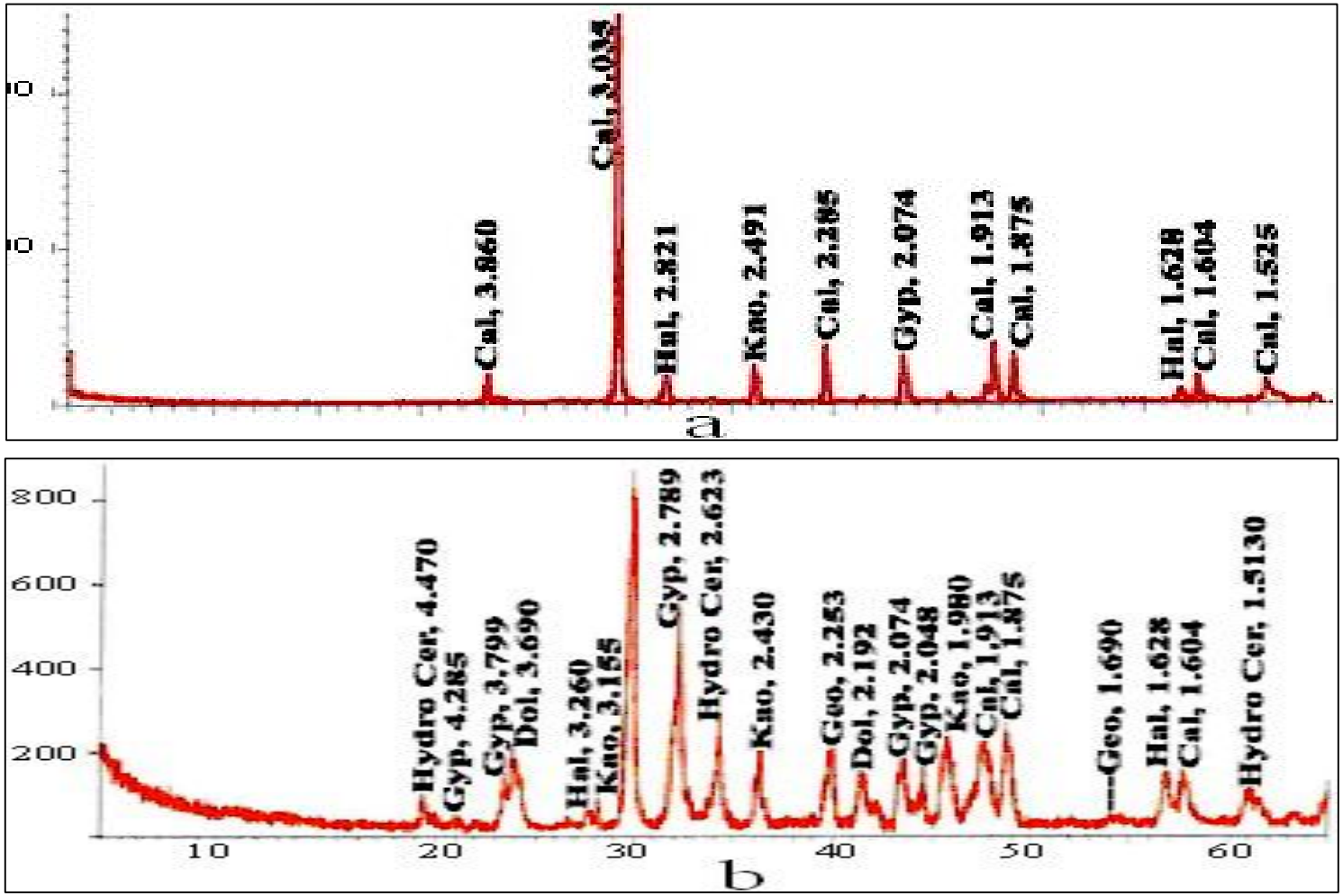
Analytical results							
Cations				Anions			
Elements	*mg/l*		*%*	*Elements*	*mg/l*		*%*
Na^{+}	277.0		3 24.44	HCO^{-}	70.0		19.64
Mg^{++}	196.03		17.32	Cl^{-}	234.0		65.65
Al^{+}	0.13	1133.3 mg/l	Undetectable	SO^{--}	28.23	356.43 mg/l	7.92
K^{+}	98.0		3 8.65	NO^{-}	24.20		6.79
Ca^{++}	562.0		49.59				Other Values
Mn^{++}	0.003		Undetectable				PH 5.38l
Fe^{++}	0.09		Undetectable				EC 483 µs
Pb^{++}	0.04		Undetectable				TDS 163.0 mg/l

Deterioration features affected stone surfaces by SM (AC) (2)



*SM shows **a.** black hard crusts, **b.** some features of salt efflorescence and sub-efflorescence, **c.** dissolution and erosion of stone surfaces, **d.** colored spots and strange grains*

Deterioration features affected stone surfaces by XRD (AC) (3)



XRD patterns collected from Amman Castle show
a. *sheltered (non-deteriorated parts)*
b. *affected (deteriorated parts)*

DISCUSSION

The different concluded results revealed that air pollution could significantly affect the deterioration of archaeological materials in both the indoor and outdoor environments. Both outdoor and indoor air pollutants cause several chemical and physical damages to the monumental buildings by the deposition of particulate material or absorption of gases. In our cases, visual examination showed that the deterioration aspects' rates affecting the building materials are essentially due to air pollution as a complex multi-parameter function

In Luxor Museum, most of the passive indicators give higher results than the average level and suggesting that they require urgent treatment to minimize their level. The average level of ammonia in the open display areas results from the upper unpainted cement concert parts above the artifacts in the old and the new parts of the museum. The other pollutant sources result from car exhaust, Luxor general hospital, internal generators, and natural ventilation. With the high RH value, the alkaline PH value forms alkaline solutions inside the Museum. It causes deterioration of the inorganic and the organic archeological materials, such as the acceleration and degradation of lignin and hemicellulose of wood artefacts. All of these deterioration mechanisms are mostly enhanced by the alternative effects between **A** and **RH** up and down, which led to different related deterioration features.

In Amman Castle, the stone surface shows various degrees of damages resulting from severe effects of air pollution due to many deterioration mechanisms. These damage aspects are divided into 3 essential aspects, as follows:

1) ***Light polluted surfaces*** are mostly due to ***physical mechanisms*** that result essentially from different dry deposits. These materials are composed of "SO, SO_2, CO_2, and NH", dark impurities, dust, soot, and hydrocarbon. They cause many physical aspects and are characterized by light to little dark colors and a low thickness "0.15-0.48 **mm"**.
2) ***Moderate polluted surfaces*** mostly caused by ***corrosive chemical mechanisms*** result from air pollution with other synergetic effects as rainwater or different sources of moisture. For example, we can notice that the sulfate found in some stone surfaces is formed by chemical reactions between SO_x and $CaCO_3$, which, leads to the formation of some aggressive salty hard crusts as Gypsum "$CaSO_4$. $2H_2O$", which is considered the most ubiquitous salt found as a result of dissolution processes of Calcite "$CaCO_3$".
3) ***Heavy polluted surfaces*** are caused by **severe physical and chemical mechanisms**, which resulted from synergetic effects of deterioration dominated in the area and cause many deterioration aspects with severe characterizations, such as high dark color index and high thickness "1.22-1.29 mm". These layers are mostly composed of gypsum and anhydrite crusts that are considered common features of carbonated rocks in the polluted area, especially after water evaporation. They cause some crystals of halite, which is considered one of the most aggressive salts that affect limestone surfaces particularly with continuous alternative cycles of wetting and drying.

CONCLUSION

Some scientific methods and interventions should be developed to reduce all factors of air pollution and remove the harmful concentrations from historic and archaeological sites through traffic management and taking account of the effects of air pollution phenomena during town planning studies. From this point of view, a successful working schedule should be taken into consideration. It should include many scientific tools to prevent the harmful effects of air pollution such as:

a) Following the scientific diagnosis using several methods and analytical techniques

b) Using consequences methods of cleaning according to deterioration status

c) Applying some types of consolidants and water repellents through suitable scientific techniques to reinforce and restore the affected stone surfaces and maintenance procedures

d) Minimizing all interventions, such as protection against all sources of moisture especially the effects of acid rains, dirties, particles, and surface accumulations through a complete project that includes three scientific levels of interventions, i.e. "Immediate or Urgent, Necessary Permanent"

Many Thanks For Your Attention

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