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THE INFLUENCE OF OZONE ON THE DETERIORATION OF JORDAN HERITAGE

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ABSTRACT

This paper looks at the changes in urban air quality and the effect on building materials, particularly concerning their deterioration arising from pollution due to vehicles. The paper aims to review basic information on the likely effect of ozone on calcareous building materials (limestone, marble, dolomite, and calcareous cemented sandstone). Controlling factors in the reaction and oxidation of sulphite to sulphate is the type and porosity of the stone. The level of humidity, is effected by the nature of the oxidants and to a lesser extent the presence of other extraneous reactants, e.g. metal oxides, chlorine and ammonia salts.

KEYWORDS: Management, Museology, Jordan, Ozone

1. INTRODUCTION

During the past decade, there has been a growing concern about the changes in urban air quality. Ozone is a very reactive gas. Tropospheric ozone causes negative health effects in humans and can deteriorate valuable materials (Miller 2001:8–9; Blades et al. 2000: 25; Weschler 1989: 542). It is 100 times or faster than the catalytic action of iron and manganese with O2 (Radojević 1984: 551). Much of this concern has focused on public health issues. A complementary issue is an effect on building materials particularly their deterioration and maintenance arising from pollution. Ozone is a very reactive gas. Tropospheric ozone causes negative health effects in humans and can deteriorate valuable materials. This paper aims to provide basic information on the likely effects of ozone on buildings with particular emphasis on contributions from vehicles (Nicolas 2007: 3129-3132).

Concentrations of ozone from 17 to 47 ppb, monthly averages, have been measured in rural areas in Norway (Girgždienė 2009: 433). Typical concentrations in museum rooms are 1-10 ppb (Brimblecombe 1990: 1-8). For museum rooms, the recommended concentration of ozone is set to 0 ppb (Alghazawi et al. 2015: 360 and Thomson 1986), for paper-based records, it is set to < 13 ppb. Indoor concentrations of ozone are reduced from those present outdoors by deposition to decomposition/reaction on indoor surfaces. The rate of this deposition is material specific. To reach the goal of low indoor ozone concentrations, indoor building materials should have a high deposition capacity. This would be particularly important in museums where ozone-vulnerable objects are on display. It is therefore of interest to measure the rate of indoor deposition of ozone, termed the ozone dry deposition velocity. This rate would determine both the possible damaging effect on materials and their ability to lower indoor concentrations of ozone (Blades 2000 and Lopez Marzo 2013: 3532-3538).

2. JORDAN MUSEUMS

2.1 The museum context in Jordan

The Jordanian museums contain important collections that require certain environments to ensure their preservation and minimize deterioration. In the absence of suitable and efficient indoor environmental controls, these objects would be in great danger. In the following chapters, those indoor environmental aspects will be addressed. However, all those indoor environments have a common connection with the outdoor climate environment, which varies strongly throughout the country, so this aspect should be dealt with first. The museum collections in Jordan are generally housed in non-specific buildings; furthermore, these collections are varied, resulting in a variety of types of museums, but with a large majority of archaeological ones. Therefore, special attention should also be paid to archaeological collections and their acquisition in this introductory chapter.

2.2 Jordan museums

Jordan is one of the most important historical regions for the finding of artefacts because of its rare geographical location in the middle of the main Continents of the world map as we know these days. Large groups and significant civilization lived or kept traces here, either they were immigrating to other areas or settled and lived in Jordan. The growth of interest in museums is indicative by the fact that museums are focused so that many of our global and local preoccupations can coalesce. The expansion and diversification of the museums in Jordan, particularly since the 1990s, has raised the awareness of the Jordanian local community about museums and the subject of museology in general, which lead the government, on one hand, to pay more attention to the current situation of the existing museums, and on the other hand to reconsider establishing new specialized ones. This was the result of the massive increase in the amount of critical commentary on museums (Al-Bashaireh 2022: 103305).

2.3 Buildings of Jordanian museums as containers of objects

Buildings in Jordan are usually constructed from concrete bricks, with the exterior façade made from stone bricks. This kind of building in general does not provide an adequate insulation environment for objects kept or displayed inside. Even providing these buildings with an air conditioning system to maintain proper temperatures according to the international standards of museum indoor environments is difficult to achieve. Furthermore, it is expensive to maintain. The museums in Jordan are built in the same way. Many were not built as ‘museums’; they are restored historical buildings and therefore it would be difficult for these buildings to transform into a museum, and they require great effort and expertise to make these buildings capable to provide a suitable environment for preserving objects from deterioration. By contrast, a new purpose-built national museum, the Jordan Museum, has recently been constructed in Amman but has not yet opened to the public. Also, the Museum of Jordanian Heritage at Yarmouk University was built to be a museum (Alzouby and Attia 2022: 147-155). It has a specific style of architecture that replicates Islamic building concepts from the Ottoman period and, in this way, is distinct from other local museums. Here it should be noted that this present study and research applies not only to museum buildings but could also be applied to other institutions with collections, such as libraries, archives, churches and historical buildings. Therefore, these buildings have also been included in the literature review.

2.4 Types of Museums in Jordan

Museums vary in terms of the function they perform. Referring to Table 1.1 in the book Museum Basics (Ambrose and Paine), it can be seen that museums can be classified in many different ways (Kamba 2022). Thus, if museums are classified by their collection, Jordan possesses museums specializing in archaeology, art history, natural science, geology and ethnography. But it should not be forgotten that there are other ways of classifying museums, depending on, for example, the audience they serve, or the area they serve, like the Museum of Jordanian Heritage (university museum) and the Umm Qeis Museum (site museum).

2.5 Types of archaeological collections

Most of the museums in Jordan are archaeological museums. That is because of the large number of archaeological sites in Jordan and the amount and scale of archaeological excavations. Large amounts of archaeological material have been accrued from these excavations. Each site yields archaeological objects and artefacts that are ultimately destined for either museum display or storage. It should be noted that under the current law, all archaeological objects are owned by the Jordanian State, represented by the Department of Antiquities. In general, objects exhibited in Jordanian archaeological museums vary in the form and historical periods they represent, ranging from the Stone Age up to the different Islamic Ages. Archaeological excavations carried out by the Department of Antiquities, both in collaboration with domestic institutions and foreign missions, are the main source of the existing collections. Other objects have been obtained by gift, donation, or through exchange with local museums. The objects in the archaeological museums include handmade pottery from all over the country and belonging to different eras; stone quarrying, rock engravings, mined materials, inscriptions and seals; human and animal bones belonging to different historical periods; numismatics, accessories, agricultural implements, artefacts relating to transport and commerce, including saddles and supply wagons, tools representing craftsmanship and industry; different kinds of glass artefacts; papers and wooden objects; works of art, portraits, national fashions, cosmetics, medicine and ethnographical common amulets and mining detritus.

3. GEOGRAPHICAL ASPECTS, GEOMORPHOLOGY AND CLIMATE OF JORDAN

Jordan lies in the extreme north-western part of the Arabian Peninsula. The location of Jordan in the Mediterranean region, combined with its climatic and historical characteristics, determines this country's high recreational potential. Jordan occupies an area of approximately 96,000 square kilometres. Despite this small area, it has a diverse terrain and landscape and therefore a varied climate. Jordan consists mainly of a plateau, which is between 600 and 1500 meters high and which is divided into ridges by east-west running valleys and gorges, going down into the Rift Valley, which runs from Turkey southward alongside the Sinai Peninsula. The eastern edge of Jordan is part of this rift, the Jordan Valley, which falls to 4 meters below mean sea level, the Dead Sea and Wadi Araba into the Gulf of Aqaba. Although Jordan is an earthquake-prone region, no severe shocks have been recorded for several decades. Jordan's plateau and mountains, together with the wide, deep valleys result in a strong diversity of climatic zones in this country. Thus, Jordan can be divided into three main physiographic regions, described below, each with distinct climate regimes based on equi-topographical features.

3.1 The Jordan Valley region (al-Ghor)

Along the western edge, the Jordan Valley region (al-Ghor) is part of the Great Rift Valley that extends from southern Turkey through Lebanon and Syria to the salty depression of the Dead Sea, where it continues southwards towards the Red Sea. The Jordan Valley is the most fertile region in Jordan and it is the 'food bowl' for the country. At its highest point, the valley lies 32 meters below the mean sea level and falls to about 405 meters below the mean sea level at the Dead Sea, the lowest place on the earth's surface. This region is several degrees warmer than the rest of the country because of its location on the lee side of the West Bank Mountains from which the prevailing dry and hot westerly wind descends into the region. The maximum temperature is rarely below 40 °C in summer or below 20 °C in winter.

3.2 Mountain Region

The mountain, or highland, region is located to the east of the Jordan Valley, extending as a narrow strip from north to south, alongside the Jordan Valley. Parts of this region are rugged and are intersected by valleys and riverbeds. The majority of the population inhabits this region, suitable for agriculture because of its Mediterranean bio-climate. It receives the highest rainfall in Jordan, especially in the northern parts such as Ras Munif and Irbid, which are included in this study. This region, especially in the north, is exposed to the frontal depressions that invade the East-Mediterranean region mainly in winter. The area is considered to be the principal track of the Cyprus low depression. In addition, the highland area is exposed directly to the sea track over the Mediterranean Sea, which intensifies the rainfall rates in this area. The southern heights, in comparison, have medium amounts of rainfall since the area is not exposed directly to the frontal depression. Besides, the area is located to the east of the Sinai desert, where the frontal depressions follow a long land track and lose humidity. The elevation of the mountain heights varies from 600 metres to more than 1500 metres above mean sea level. Because of the abundance of water and its strategic location, the highlands are the most densely populated area todareancompassing most of the major cities in Jordan. It is in these highlands that we find the major remains of ancient civilizations, from north to south, in the cities of Umm Qeis, Jarash, Amman, Madaba, Karak and Petra.

3.3 The eastern semi-arid region or Badia region

The term Badia is used throughout much of the Middle East and refers to arid, desert environments, where there is little or no permanent vegetation, infrequent precipitation and intermittent surface water. In Jordan, the Badia is subdivided into several areas. The eastern Badia extends from the margin of the Amman conurbation towards Iraq and between the international boundaries of Syria to the north and Saudi Arabia to the south. This region comprises about 75% of the total area of Jordan. The eastern Badia is characterized by low, gently undulating topography. Altitude reaches a maximum of 1200 meters in the north, on the foot-slopes of the Druze Mountains in Syria, with a gradual decline in absolute relief to around 400 meters in the south. The aridity of the region is due to its location to the east of two mountainous terrains, the western hills in Palestine and the eastern hills in Jordan, where the westerly prevailing wind descends dry and hot into this region. Mean annual temperature and precipitation figures for the eastern Badia highlight the seasonality of climate and the relief control of the Druze Mountains. Mean annual temperatures reach a maximum of 35 °C to 38 °C in August and a minimum of 2 °C to 9 °C. In winter, when cold air reaches eastern Badia from the continental interior, it is not unusual for temperatures to drop below freezing. The highest and lowest recorded temperatures in the ern Badia are 46 °C and −12 °C respectively. Mean annual rainfall ranges from less than 50 millmillimetres the south to over 250 millimetres in the north.

3.4 Summarizing climate variability in Jordan

Jordan is located about 80 kilometres east of the Mediterranean Sea, between 29°10 'N to 33°45 'N and 34°55 'E to 39°20 'E with an area of 89 329 square kilometres and a population of 5.5 million. The western part of the country is the world’s lowest valley, which lies in a north–south direction between two mountain ranges and has a length of about 400 kilometres. The width of the valley varies from 10 kilometres in the north to 30 kilometres in the south and it lies between 170 meters and 405 meters below mean sea level. The Jordan River passes through this valley from north to south down to the Dead Sea and comprises approximately one-third of the border between Jordan, Palestine and Israel. The Jordan River is the main source of irrigation in the Jordan Valley. Just to the east of the Jordan Valley, the north–south mountain range rises to about 1150 meters above mean sea level in the north and to about 1500 meters above mean sea level in the south, reaching its highest peak of 1854 meters in the southernmost region. To the east of this mountain range is a semi-desert plateau that covers approximately 80% of the country. With assistance from the Jordan Meteorological Department, I was 2009 provided with the Jordan weather track information gathered from 14 precipitation stations, with record lengths ranging between 33 and 78 years and from 14 temperature stations, with record lengths varying between 30 and 78 years. The average temperature in Amman the capital ranges from 8 °C in January to 25 °C in July. The temperature in the city of Aqaba also varies significantly throughout the year, from 16 °C in January to 33 °C in July.

4. OZONE AND ITS EFFECTS ON BUILDINGS

Ozone is produced in the stratosphere at a height of 20-30 km by the action of UV radiation on oxygen. The UV concerned here is of a much shorter wavelength than even penetrate to the surface of the earth (Thomson 1986). A complementary issue is an effect on building materials, particularly their deterioration and maintenance arising from pollution. Presently those concerns relate specifically to the rise of pollution from vehicles (Bikis et al., 2022). It is worth noting that No emissions from vehicles have doubled during the period 1950-1985 whilst over the same period recession rates for calcareous stone have dropped by a factor of 10 (Massey, 1998). This is why there is no UV of wavelength shorter than 300 nm at ground level, l is that the ozone in the stratosphere effectively absorbs it. The destruction of this ozone shield would have serious consequences for life on earth, and there is a current argument about whether, on the one hand, supersonic aircraft, and on the other, fluorocarbon aerosol propellants, many can do just this (Thomson 1986). Airborne pollutants affect buildings in two ways decay and soiling. Soiling is the discolouration of a building whilst decay results in the destruction of the building fabric. It has been found that indoor concentrations of ozone are generally lower than outdoor concentrations (Weschler 2000).

Typical concentrations in museum rooms are 1-10ppb for museum rooms; the recommended concentration of ozone is set to 0ppb (Thomson 1986). Most of their indoor ozone seemed to originate outdoors as indoor (I) and outdoor (O) concentrations correlated closely over time (Weschler et al., 1989). Indoor O_3 levels also correlate positively with outdoor temperatures. In addition, the I/O ratio is affected by homogenous and heterogeneous chemical reactions. That is, ozone is removed by reactions in the gas phase and by deposition and reaction on the room surfaces. Consequently, a high rate of reaction of O_3 on indoor materials will reduce the I/O ratio (Avol et al., 1998: 463).

Airborne pollutants affect buildings in two ways decay and soiling are the discolourations of a building whilst decay destroys the building fabric. In order to understand these processes, we need to look at the chemical interaction and the physical changes occurring at the building surface. Sulphur dioxide and nitrogen oxides are gaseous components which react directly with the stone surface by forming acids in the presence of water and oxidizing agents. These acids react with the stone to form salts which either crystallize out within the stonework resulting in physical damage or they are washed away resulting in a loss of material. This is the primary damage mechanism which, since it is a chemical reaction, continues at all sulphur dioxide concentrations. Nitrate salts are more soluble and expand less than salts of sulphate, leading to little, if any damage by this mechanism. Thus, a reduction in erosion rates would be anticipated with the reduction in sulphur dioxide.

5. DETERIORATION OF HERITAGE MATERIALS DUE TO OZONE

The ozone surface reaction could be a pure decomposition of ozone or an oxidation of the surface material. Inorganic materials with unsaturated carbon bonds, a surface oxidation reaction could increase the reaction rate (Varotsos et al., 2009). Aldehydes and some other VOCs have been detected as reaction products of ozone deposition on polymeric organic materials (Moriske et al., 1998). Ozone has a specific and complete action on unsaturated organic compounds, that is to say, it will break every double bond on a carbon chain with which it comes into contact. This destroys the material. In this way, transverse cracks appear on rubber bands which then snap when stretched. However, attack by ozone does not end with rubber bands. It is a powerful oxidant, that is to say, a destroyer, of almost all organic material. The effect of ozone on certain materials such as cellulose may be due to its partial conversion to hydrogen peroxide by reaction with water. Ozone also increases the rate of oxidation of silver and iron and the sulfidation of silver and copper. Hopefully one may suppose that the visitors may in this case help conservation since every inhalation is likely to destroy all the ozone in the breath (Thomson 1986). It seems that ozone undergoes unimolecular decomposition on the surface. The surface would form moderate to high humidity, and be covered with an increasing number of monolayers of water molecules (Girgždienė et al., 2009). Saber Sky et al., (1973) work showed that O3 most probably is diffusing to the surface where it would solvate to some extent before further decompositions. The decomposition reaction is differently initiated in alkaline and acidic solutions (Sehested et al., 1991).

Lowered measured deposition velocities of O_3 in conservation runs on the concrete sample may be related to changed surface properties probably affecting the bonding strength and surface coverage of adsorbed water (Grontoft, 2002). Sulphur dioxide and nitrogen oxides are gaseous components which react directly with the stone surface by forming acids in the presence of water and oxidizing agents. These acids react with the stone to form a salt which either crystallizes out within the stonework resulting in physical damage or they are washed away resulting in a loss of material. Atmospheric concentrations of No are strongly linked to the amount of O_3, another major oxidant within the system, during daylight hours since the reaction between the two is mediated by the amount of sunlight. The balance between the two is also affected by the presence of free radicals. The principle reaction at night time is the formation of NO_3 and N_2O_5, accompanied by a reduction in O_3. N_2O_5 is a moderately strong oxidizing agent anis d readily removed by water vapour to form the acid HNO_3 (Photochemical Oxidants Review Group, PORG). Thus, a reduction in erosion rates would be anticipated with the reduction in sculpture dioxide (Butlin et al., 1992).

Johnson et al., (1996) looked at the co-deposition of HCL, SO_2, NO, and O_3 gas in conjunction with coal and diesel-coated sample using mass change and water-soluble reaction products as the measure of deterioration. They conclude that HCl acts addictively with all combinations of the gases and again observe a marked increase in the amount of deterioration when SO_2, NO, and O_3 are combined (Johnson et al. 1996). Elfving et al., (1994) used IR at gas concentration of 1ppm to establish the effect of both NO_2 and O_3 in the process of sulphation. For SO_2 alone there is an immediate formation of sulphite at the surface of the calcite under humid conditions. NO sulphite is formed in dry conditions. The surface sulphite gradually deteriorates under humid conditions. On precondition sulphite surfaces formed on calcite NO_2 are less efficient than O_3 in oxidizing the sulphite NO2Requires moisture to be present whilst the O_3 operates in both moist and dry conditions albeit at slower rates for the latter condition (Elfving et al. 1994a, b).

Exposing calcite to SO_2 and O_3 simultaneously demon started that sulphate is the preferred reaction product. Simultaneous exposure to SO_2 and NO_2 demonstrated that a catalytic reaction takes place which increases the rate of sulphate production after 30-h exposure. The author's conclusions from this experimentation are:

Ozone reacts rapidly with surface sulphite to form sulphate both in dry and humid conditions. Simultaneous exposure of calcite to O_3 and SO_2 at dry conditions does not result in any sulphite or sulphate formation at the surface. Simultaneous exposure of calcite to O_3 and SO_2 at humid conditions results in rapid sulphate formation (Elfving et al., 1994). This suggests that the reaction occurs at the surface of the calcite and not in the gaseous phases and the increased production of sulphate is by an activated complex involving the surface water film, NO_2, SO_4, and O_2 (Ntelane et al., 2022).

It has been found that indoor concentrations of ozone are generally lower than outdoor concentrations (Weschler 2000). The indoor/ outdoor ratio, I/O ratio, of ozone has been measured by several researchers (see Weschler 2000) in the range from 0.1 to 0.8. Most of the indoor ozone seemed to originate outdoors as indoor and outdoor concentrations correlated closely over time.

6. OZONE REACTION MECHANISM

The ozone surface reaction could be a pure decomposition of ozone or an oxidation of the surface material. On organic materials with unsaturated carbon bonds, a surface oxidation reaction could increase the reaction rate. Aldehydes and some other VOCs have been detected as reaction products of ozone deposition on polymeric organic materials (Weschler 1989: 1562-1568). The reaction of ozone with other gaseous, adsorbed or dissolved species could complicate the matter, but will not be considered here. The most important path for ozone removal on inorganic surfaces is probably the heterogeneous deposition and decomposition of ozone itself. It seems that ozone undergoes unimolecular decomposition on surfaces. The surfaces would, from moderate to high humidity, be covered with an increasing amount of mono-layers of water molecules (2-10), mediating the reaction (Girgždienė et al., 2000: 24-26). Evaluation of calculated maximum transport rates and reaction probabilities, together with measured decomposition rates of O_3 was done by Sabersky et al., (1973). Their work showed that O_3 most probably is diffusing to the surface where it would solvate to some extent before further decomposition. The decomposition reaction is differently initiated in alkaline and acidic solutions (Sehested et al., 1991: 1589-1596)(ad:adamantane; aq:aqueous; I:liquid):

$O_3(g) \rightarrow O_3$ (*ad*) or O_3 (*aq*) (1) Depending on humidity

Alkaline solution:

$$O_{3\left(\frac{ad}{aq}\right)} + OH^{-}_{(aq)} \rightarrow HO^{2-}_{(aq)} + O_2 \quad (2)$$

Acidic solution :

$$O_{3\left(\frac{ad}{aq}\right)} \leftrightarrow O_{\left(\frac{ad}{aq}\right)} + O_2 \quad (3)$$

$$O_{\left(\frac{ad}{aq}\right)} + H_2\,O_{(l)} \rightarrow 2OH_{(aq)} \quad (4)$$

Radical reactions involving OH and HO_2 (see Sehested et al., 1991) giving: $O_2(g)+H_2O(_I)$.

Above pH = 8-9, reaction (2) has been proposed to initiate the O_3 decomposition reaction (review by Sehested et al., 1991). Below pH=4, Sehested selected et al., (1991) proposed reactions (3) and (4) to be initiated. At intermediate pH, it seems more uncertain which, if any of these reactions is initiating. The low concentration of OH ions compared to H_2O molecules below pH=8 may suppress the alkaline reaction in favour of the reaction of O_3 with H_2O even if the rate constant for the reaction with the OH ions is higher.

7. THE URBAN ENVIRONMENT

The urban environment is a very complex system with varying concentrations of pollution and fluctuating temporal variations. Observation of single reactions, conjectured reactions and sample measurements have to be considered against this complex backdrop. It is almost impossible to focus in on one facet of the problem without other areas encroaching on the discussion. This is entirely true of the NO_X and SO_2 systems. The oxidation of the SO_2 aqueous phase is the key step in the formation of gypsum on the surface of the stone. This is affected by several different catalysts which may be present in the system. NO_X is only one of a possible number of oxidants and oxidation catalysts. Given that in the urban environment, the major source of the NO_X is vehicles and with this there is an associated increase in the amount of particulate matter (carbonaceous, VOC, iron and manganese), which can act as catalysts, it is very difficult to determine the precise effect of NOx on its own. Atmospheric concentrations? of NOx are strongly linked to the amount of O_3, another major oxidant within the system (Photochemical Oxidants Review Group PORG, 1997), during daylight hours since the reaction between the two is mediated by the amount of sunlight. The balance between the two is also affected by the presence of free radicals. The principlal reaction at night-time is the formation of NO_3 and N_2O_2, accompanied by a reduction in O_3. $N2O_5$ is a moderately strong oxidizing agent and is readily removed by water vapour to form the acid HNO_3. A further complicating factor is the dry deposition of the various non-gaseous species and their reaction products onto the surface of the stone with the possibility that the dry deposition includes catalysts and reagents that greatly affect the adsorption and desorption of the gases (Amoroso and Fasina, 1983). A fall in the SO_2 levels means that more subtle effects may begin to come into play, e.g. NO_X. Rising NO_X emissions are a cause for concern yet there is some evidence that the urban NO_X burden can decrease with the introduction of catalytic converters (Sjödin et al., 1996). However, experience from monitoring in the UK has shown that the effect of introducing catalytic converters has yet to make an impact on the kerbside measurements of NO_2 (ENDS Report 280, 1998).

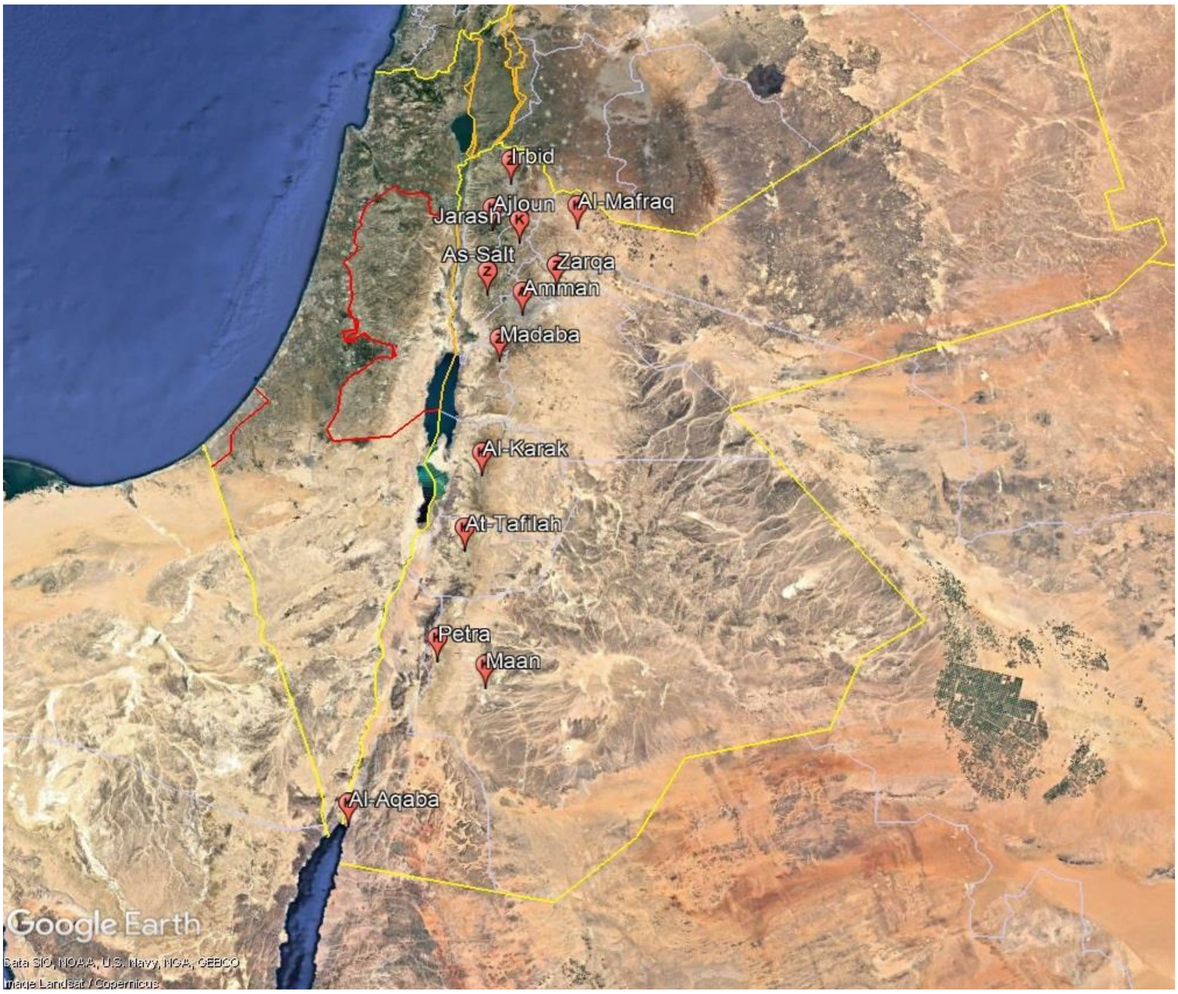

Figure 1. Jordan map with significant places (© google earth)

8. JORDANIAN STANDARD FOR AMBIENT AIR QUALITY MONITORING

The Jordanian government (Ministry of Environment) regularly reports on air quality as obligated by Environmental Protection Law No. 6 of 2017 and the Air Protection Bylaw No. 28 of 2005, which include the obligation to monitor air pollution in the interest of public health. In the next part, a report we will be presented about Air Quality Monitoring in Jordan (see Figure 2).[1]

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[1] http://moenv.gov.jo/ebv4.0/root_storage/en/eb_list_page/2019_year_naqs_report_english.pdf

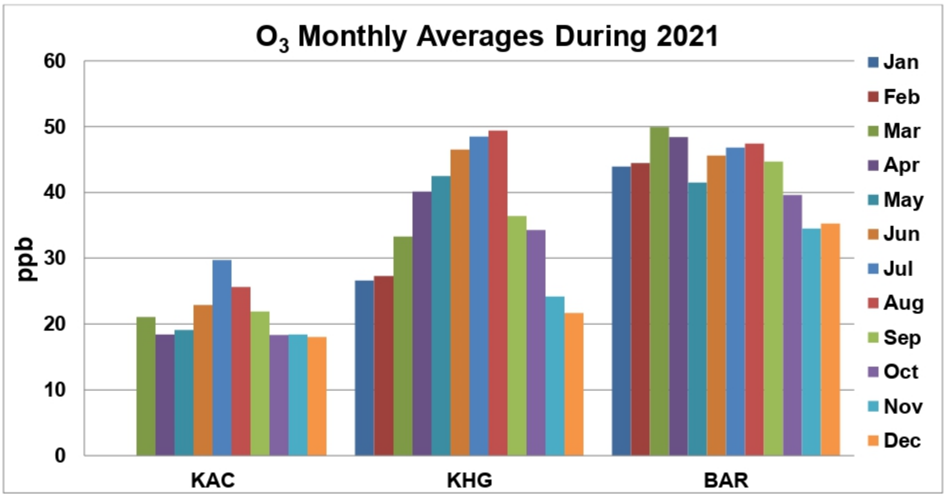

Figure 2. O_3 Monthly Averages during 2021

Table 1. Jordanian Standard for Ambient Air Quality No. 1140/2006

Pollutant	Sample Duration	Maximum Allowable Limit	Number of Allowable Exceeded Events
Sulphur dioxide (SO_2)	One Hour	0.3 part per million (ppm)	3 times in any 12 months period per year
	24 Hours	0.14 part per million (ppm)	Once per Year
	Yearly	0.04 part per million (ppm)	-
Carbon monoxide (CO)	One Hour	26 parts per million (ppm)	3 times in any 12 months period per year
	8 Hours	9 parts per million (ppm)	3 times in any 12 months period per year
Nitrogen dioxide (NO_2)	One Hour	0.21 part per million (ppm)	3 times in any 12 months period per year
	24 Hours	0.08 part per million (ppm)	3 times in any 12 months period per year
	Yearly	0.05 part per million (ppm)	-
Ozone (O_3)	One Hour	0.12 part per million (ppm)	-
	8 Hours	0.08 part per million (ppm)	-
Particulate Matter (PM10)	24 Hours	120 Microgram (µg/m3)	3 times in any 12 months period per year
	Yearly	70 Microgram (µg/m3)	-

Table 1 shows the allowed limits of gases and particulate matter emissions to the ambient air as specified in the Jordanian Standard No. 1140/2006 for the quality of the ambient air. Additionally, the results of the monitoring were compared with the allowed limits and the numbers of exceeded events are shown below.

Table 2. Pollutants monitored in each station (PM20: particulate matter)

Type of station	Station Name	Short name	CO	NO_2	SO_2	O_3	PM10	MET
Amman								
Background	King Hussein Gardens	KHG		1	1	1	1	1
Urban	Greater Amman Municipality	GAM	1	1	1	1	1	
Traffic	Northern Bus Station Tabarbour	TAB	1	1			1	
Urban	Marka / Mahata	MAH		1	1		1	
Traffic	University street /Sweileh	UNI		1			1	
Industrial	King Abdullah II Industrial City / Sahab	KAC		1	1		1	
Industrial	Yarmuk	YAR		1	1		1	
Zarqa'a								
Traffic	Wadi Hajjar Health Center	HAJ	1	1	1		1	1
Industrial	Massane’	MAS		1	1		1	
Urban	Hashemite Hall	ABK/HH		1	1		1	
Irbid								
Traffic	Al Hassan Sport City	HSC	1	1			1	
Urban	Al Barha Street	BAR		1	1	1	1	1

Table 3. The type of devices used to measure concentrations of gases and particulate matter at monitoring stations and the approved examination certificates that belong to them

Pollutant	Model	Examination certificate	Principle of Operation
Particulate Matter (PM10)	Thermo 5014i	U.S. EPA Approved PM-10 (EQPM1102-150	Beta attenuation
Nitrogen dioxide (NO_2)	Thermo 42i	U.S. EPA Reference Method: RFNA-1289- 074; MCerts Certified: MC070093/00; EN14211: 936/21203248/C Report; NF Certificate: 05/01	Chemiluminescence
Sulphur dioxide (SO_2)	Thermo 43i	US EPA Equivalent Method: EQSA-0486-060, MCERTS Certified Sira MC070094/00, EN14212: TÜV 936/21203248/D Report	UV-Fluorescence
Carbon monoxide (CO)	Thermo 48i.	US EPA Reference Method: RFCA-0981-054, MCERTS Certified Sira MC070095/00, EN14626: TÜV 936/21203248/A Report	Infrared
Ozone (O_3)	Thermo 49i	US EPA Equivalent Method: EQOA-0880-047, MCerts Certified MC070096/00, EN14626: 936/21203248/13 The report, NF Certificate: 05/01	Ultra-Violet Photometry

Table 4. Yearly Averages of pollutants in all stations

No	Station	Short Name	PM10	NO^2	SO^2	CO	O^3
			µg/m³	ppb	ppb	ppb	ppb
		Average as in Jordanian Limits 1140/2006					
			70 µg/m³	50 ppb	40 ppb	Not Found	Not Found
Amman							
1	King Hussein Gardens	KHG	36.1	9.2	4.4	-	39.7
2	Greater Amman Municipality	GAM	63.1	26.1	12	2682	
3	Northern Bus Station Tabarbour	TAB	63.4	42.2	-	1641	-
4	Marka / Mahata	MAH	70.6	41.7	13.2	-	-
5	University street Sweileh	UNI	52.7	29.8	-	-	-
6	King Abdullah II Industrial City / Sahab	KAC	63.7	19.3	9.8	-	-
7	Yarmuk	YAR	64.3	21	4.7	-	-
Zarqa							
8	Health Center Wadi Hajjar	HAJ	65.5	33.7	18.9	1791	-
9	Main slaughterhouse Masane' Zone	MAS	55.4	20.1	8.9	-	-
10	Hashemite Hall	ABK/HH	58.6	15.5	10.4	-	-
Irbid							
11	AL Hassan Sport City	HSC	47.7	19.5	-	1939	-
12	Al Barha street	BAR	37.6	20.5	7.3	-	47.2

Table 2 shows a visual presentation of the monitored pollutants in each station andTable 3 shows the devices' model and their respective examination certificate.

Table 4 shows the annual averages of air pollutants that were monitored in all stations during the period from 1/1/2019 to 31/12/2019, Red colour indicates that this value exceeded the Jordanian Limits 1140/2006.

Table 5 shows the number of exceedances each according to what is required in technical specification number JS1140 for the year 2006 regarding the ambient air quality.

Table 6 shows the permissible limits for emissions of gases and particulate matter to the ambient air as outlined in Jordanian Standard No. 1140/2006 for the quality of the ambient air.

Table 5. Number of exceedances in all stations

			PM10	NO_2	NO_2	SO_2	SO_2	CO	CO	O_3	O_3
Station			24hr	24hr	1hr	24hr	1hr	8hr	1hr	8hr	1hr
			AVG	AVG	MAX/	AVG	MAX/	AVG	MAX/	AVG	MAX/
					24hr		24hr	MAX/ 24hr	24hr	MAX/ 24hr	24hr

Limits			120 $\mu g/m^3$	80 ppb	210 ppb	140 ppb	300 ppb	9000 ppb	26 ppm	80 ppb	120 ppb
Number of allowed exceedances			3	3	3	3	3	3	3	-	-
Amman											
1	King Hussein Gardens	KHG	10	-	-	-	-	-	-	-	1
2	Greater Amman Municipality	GAM	26	-	-	-	-	-	-	-	-
3	Northern Bus Station Tabarbour	TAB	25	7	-	-	-	-	-	-	-
4	Marka – Mahata	MAH	47	19	33	-	-	-	-	-	-
5	University street Sweile	UNI	12	-	-	-	-	-	-	-	-
6	King Abdullah II Industrial City/Sahab	KAC	31	-	1	-	-	-	-	-	-
7	Yarmuk	YAR	27	-	-	-	-	-	-	-	-
Zarqa											
8	Health Center Wadi Hajjar	HAJ	35	-	-	-	-	-	-	-	-
9	Main slaughterhouse Masane' Zone	MAS	12	-	-	-	-	-	-	-	-
10	Hashemite Hall	ABK/HH	17	-	-	-	-	-	-	-	-
Irbid											
11	AL Hassan Sport City	HSC	9	-	-	-	-	9	-	-	-
12	Al Barha street	BAR	4	-	-	-	-	-	-	-	-

Table 6. Permissible limits for emissions of gases and particulate matter to the ambient air as outlined in Jordanian Standard No. 1140/2006

Pollutant	Sample Duration	Maximum Allowable Limit	Number of Allowable Exceeded Events
Sulfur dioxide(SO_2)	One Hour	0.3 part per million (ppm)	3 times in any 12 months period per year
	24 Hours	0.14 part per million (ppm)	Once per Year
	Yearly	0.04 part per million (ppm)	-
Carbon monoxide (CO)	One Hour	26 parts per million (ppm)	3 times in any 12 months period per year
	8 Hours	9 parts per million (ppm)	3 times in any 12 months period per year
Nitrogen dioxide (NO_2)	One Hour	0.21 part per million (ppm)	3 times in any 12 months period per year
	24 Hours	0.08 part per million (ppm)	3 times in any 12 months period per year
	Yearly	0.05 part per million (ppm)	-
Ozone (O_3)	One Hour	0.12 part per million (ppm)	-
	8 Hours	0.08 part per million (ppm)	-
Particulate Matter (PM10)	24 Hours	120 Microgram (µg/m3)	3 times in any 12 months period per year
	Yearly	70 Microgram (µg/m3)	-

Table 7. The pollutants that are monitored in each station

Type of station	Station Name	Short name	CO	NO_2	SO_2	O_3	PM2.5	MET
Amman								
Background	King Hussein Gardens	KHG		✓	✓	✓	✓	✓
Urban	Greater Amman Municipality	GAM	✓	✓	✓		✓	
Traffic	Northern Bus Station Tabarbour	TAB	✓	✓			✓	
Urban	Marka / Mahata	MAH		✓	✓		✓	
Traffic	University street / Sweileh	UNI		✓			✓	
Industrial	King Abdullah II Industrial City/Sahab	KAC		✓	✓	✓	✓	
Industrial	Yarmuk	YAR		✓	✓		✓	
Zarqa								
Traffic	Wadi Hajjar Health Center	HAJ	✓	✓	✓		✓	✓
Industrial	Massane'	MAS		✓	✓		✓	
Traffic	Hashemite Hall	ABK/HH		✓	✓		✓	
Irbid								
Traffic	Al Hassan Sport City	HSC	✓	✓			✓	
Urban	Al Barha Street	BAR		✓	✓	✓	✓	✓

9. CONCLUSION

Controlling factors in the reaction and oxidation of sulphite to sulphate is the type and porosity of the stone, the level of humidity, the nature of the oxidants and to a lesser extent the presence of other extraneous reactants, e.g. metal oxides, chlorine and ammonia salts. Marble is much less reactive than porous limestone and the degree of activity has different relative humidity thresholds. The reaction of the stone with the gaseous compounds compound? occurs during the process of absorption onto the surface. This produces sulphite which is subsequently oxidised to sulphate. This process of oxidation is accelerated by the presence of NO_X and seems to depend on the NO_2 component. It is perhaps a moot point as to whether the stone is considered 'damaged' at the point of sulphite formation or after the subsequent conversion to gypsum. The rate of dissolution is certainly enhanced by the conversion since gypsum is some 150 times more soluble. Certainly, the NO_X accelerates the conversion process after the sulphite has formed by the interaction at the gas-water interface but it is clear that NO_X is only one of many possible oxidants in the urban and rural environment. Correlation studies of the damage to stone materials are unlikely to pick up the effects of NOX due to the nature of their duration and the rather transient nature of the appearance and removal of nitrates on the stone.

REFERENCES

Abu-Allaban, M., & El-Khalili, M. M. (2014) Antiquity impact of air pollution at Gadara, Jordan. *Mediterranean Archaeology & Archaeometry*, *14*(1), pp. 191-199

Adebanjo, S. A., & Shakiru, T. H. (2022) Dynamic relationship between air pollution and economic growth in Jordan: an empirical analysis. *Journal of Environmental Science and Economics*, *1*(2), pp. 30-43.

Al-Bashaireh, K. (2022) Quarry origin determination of marble statues from Umm Qeis Antiquities Museum, Gadara, Jordan by multi-analytical techniques. *Journal of Archaeological Science: Reports*, 41, 103305.

Alghazawi, R. (2015). Influence of Air Pollution on the Deterioration of Monuments and Museum Collections. *Journal of Environmental Science and Engineering A*, *4*, pp. 329-335.

Alghazawi, R., Alrousan, R., & Bader, M. (2015) The Effect of the Hot Springs at the Umm Qeis Archaeological Site and Museum. Journal of Environmental Science and Engineering B 4: PP.359-367.

Aljanabi, M., Shkoukani, M., & Hijjawi, M. (2020). Ground-level ozone prediction using machine learning techniques: A case study in Amman, Jordan. *International Journal of Automation and Computing*, 17, pp. 667-677.

Alsawair, J. K. (2011). *Ozone levels in the North and South of Jordan: effects of transboundary air pollution* (Doctoral dissertation). University of Nevada, Reno ProQuest Dissertations Publishing.

Alzouby, A. M., & Attia, A. S. (2022) Reviving the Traditional House Architecture in Irbid City, Jordan. *Planning*, 17(1), pp. 147-155.

Amoroso, G. and Fasina, V. (1983) *Stone decay and conservation*. Amsterdam: Elsevier.

Avol, E.; Nvidi, W. and Fcolome, S. (1998)Modelling ozone levels in and around Southern Californian Homes. *Environmental Science and Technology*, 32, pp. 463-468.

Bikis, A. and Pandey, D. (2022) Air Quality at Public Transportation Stations/Stops: Contribution of Light Rail Transit to Reduce Air Pollution. *Aerosol Science and Engineering*, 6(1), pp. 1-16.

Blades, N., Oreszczyn, T., Cassar, M., & Bordass, W. (2000) *Guidelines on Pollution Control in Museum Buildings*. Published by the Museums Association and distributed with Museum Practice, London.

Brimblecombe, P. (1990). The composition of museum atmospheres. *Atmospheric Environment. Part B. Urban Atmosphere,* 24(1), pp. 1-8.

Butlin, R. N., Coote, A. T., Devenish, M., Hughes, I. S. C., Hutchens, C. M., Irwin, J. G., & Yates, T. J. S. (1992). Preliminary results from the analysis of stone tablets from the National Materials Exposure Programme, *Atmospheric Environment. Part B. Urban Atmosphere,* Vol 26, Issue 2, pp. 189-198.

Druzik, J. R., Adams, M. S., Tiller, C., & Cass, G. R. (1990). The measurement and model predictions of indoor ozone concentrations in museums. *Atmospheric Environment. Part A. General Topics*, *24*(7), pp. 1813-1823.

Elfving, P., Panas, I., & Lindqvist, O. (1994a). Model study of the first steps in the deterioration of calcareous stone I. Initial surface sulphite formation on calcite. *Applied surface science*, 74(1), pp. 91-98.

Elfving, P., Panas, I., & Lindqvist, O. (1994b). Model study of the first steps in the deterioration of calcareous stone II. Sulphate formation on calcite. *Applied surface science*, 78 (1), pp. 83-92.

Girgždienė, R., Serafinavičiūtė, B., Stakėnas, V., & Byčenkienė, S. (2009). Ambient ozone concentration and its impact on forest vegetation in Lithuania. *AMBIO: A Journal of the Human Environment*, 38(8), pp. 432-436.

Johnson, J. B., Montgomery, M., Thompson, G. E., Wood, G. C., Sage, P. W., & Cooke, M. J. (1996). The influence of combustion-derived pollutants on limestone deterioration: 2. The wet deposition of pollutant species. *Corrosion Science*, 38(2), pp. 267-278.

Kamba, N. (2022). Significance of Conservation of Cultural Heritages in Museums. In: *Conservation Practices in Museums*, Springer, Tokyo, pp. 1-20.

Lopez Marzo, A. M., Pons, J., Blake, D. A., & Merkoçi, A. (2013). All-integrated and highly sensitive paper based device with sample treatment platform for Cd^{2+} immunodetection in drinking/tap waters. *Analytical chemistry*, 85 (7), pp. 3532-3538.

Miller, G. (2001). Tainted air. Is ozone responsible for the asthma epidemic in children? *New Scientist.* pp. 8–9.

Moriske, H. J., Ebert, G., Konieczny, L., Menk, G., & Schöndube, M. (1998) Concentrations and decay rates of ozone in indoor air in dependence on building and surface materials. Toxicology letters, 96, 319-323.

Nicolas, M., Ramalho, O., & Maupetit, F. (2007) Reactions between ozone and building products: Impact on primary and secondary emissions. Atmospheric Environment, 41(15): PP. 3129-3138.

Ntelane, T. S., Feleni, U., Mthombeni, N. H., & Kuvarega, A. T. (2022). Sulfate radical-based advanced oxidation process (SR-AOP) on titania supported mesoporous dendritic silica (TiO2/MDS) for the degradation of carbamazepine and other water pollutants. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 130276.

Radojević, M. (1984). On the discrepancy between reported studies of the uncatalyzed aqueous oxidation of SO_2 by O_2. *Environmental Technology*, 5(12), pp. 549-566.

Reiss, R., Ryan, P. B., Koutrakis, P., & Tibbetts, S. J. (1995) Ozone reactive chemistry on interior latex paint. *Environmental science & technology*, 29(8), pp. 1906-1912.

Sabersky, R. H., Sinema, D. A., & Shair, F. H. (1973) Concentrations, decay rates, and removal of ozone and their relation to establishing clean indoor air, *Environmental Science and Technology* 7: pp. 347-353.

Salmon, L. G., Cass, G. R., Bruckman, K., & Haber, J. (2000). Ozone exposure inside museums in the historic central district of Krakow, Poland. *Atmospheric Environment*, *34*(22), pp. 3823-3832.

Screpanti A, De Marco A. (2009) Corrosion on cultural heritage buildings in Italy: a role for ozone? *Environ. Pollut.*, 157(5), pp. 1513-20. doi: 10.1016/j.envpol.2008.09.046. Epub 2008 Nov 20. PMID: 19026474.

Sehested, K., Corfitzen, H., Holcman, J., Fischer, C. H., & Hart, E. J. (1991) The primary reaction in the decomposition of ozone in acidic aqueous solutions. *Environmental science & technology*, 25(9). pp. 1589-1596.

Shatnawi, N., & Abu-Qdais, H. (2021). Assessing and predicting air quality in northern Jordan during the lockdown due to the COVID-19 virus pandemic using artificial neural network. *Air Quality, Atmosphere & Health*, *14*, pp. 643-652.

Thomson, G. (1986). *The museum environment*, 2nd edition. Butterwoths, London.

Varotsos, C., Tzanis, C., & Cracknell, A. (2009). The enhanced deterioration of the cultural heritage monuments due to air pollution. *Environmental Science and Pollution Research*, 16(5), pp. 590-592.

Wechsler, B. A., & Von Dreele, R. B. (1989) Structure refinements of Mg_2TiO_4, $MgTiO_3$ and $MgTi_2O_5$ by time-of-flight neutron powder diffraction. *Acta Crystallographica Section B: Structural Science*, 45(6), pp. 542-549.

Wei, G., Yu, X., Fang, L., Wang, Q., Tanaka, T., Amano, K., & Yang, X. (2022). A review and comparison of the indoor air quality requirements in selected building standards and certifications. *Building and Environment,* 109709.

Weschler, C. (2000). Ozone in indoor environments: concentration and chemistry. Indoor air 10: Pp. 269-288.

Weschler, C. J., Shields, H. C., & Naik, D. V. (1989). Indoor ozone exposures. *Japca*, 39(12), pp. 1562-1568.