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Effect of Air Pollution on the Deterioration of El-Manial Palace and Museum for Greater Conservation of Egyptian Cultural Heritage

Asmaa El-Mekawy[a]*, Abdel Hameed A. Awad[a], Alia Shakour[a], Inas A. Saleh[a], Yasser H. Ibrahim[a], Nasser M. Abdel-Latif[a] and Salwa K. Hassan[a]

[a] *Air Pollution Research Department, National Research Centre, Giza, Egypt*

Abstract

Ancient archaeological buildings are witness on human civilization and cultures. Saving and conserving of cultural heritage is an urgent priority in Egypt and worldwide. El-Manial palace and museum is one of the most important Egyptian ancient archaeological buildings. It has a great historical and cultural value due to the presence of personal valuable property and memorabilia of Prince Mohammed Ali Tewfik objects. It is also reflecting the settings and lifestyle of the late 19th and early 20th centuries of Egyptian Royal Prince and their apparent. Unfortunately the palace is situated in a very crowded and polluted spot, so this study has been carried out for measuring the effect of surrounding pollutants on the palace building and monuments collections on it. RH%, temperature, particulate matter (PM) and its ionic species and gaseous air pollutants (sulphur dioxide, nitrogen dioxide, ammonia, hydrogen sulfide and formaldehyde) were measured inside and outside the museum. The annual mean concentrations of SPM in outdoor and reception hall exceeded both National and International limits. A/C ratios for all locations were greater than one, indicating that SPM were in acidic state, which had hazardous effect on the palace and its heritage constituents. Also, HCHO and NH_3 gases concentrations were high if compared with previous studies. Moreover, SO_2 and NO_2 gases were higher than international standards which form a critical negative impact on the palace.

Keywords: El-Manial palace and museum, PM, RH%, temperature, gaseous air pollutants, ionic air pollution, cultural heritage.

1. Introduction

In the last decades, indoor air pollution causes a global problem [1, 2]. The main source of indoor air pollutants is the outdoor air pollution; however indoor air pollutants may be of greater concern [3]. Moreover, indoor pollution in museums is one of the main causes of the cultural heritage deterioration and significantly influences the weathering of monuments and the deterioration of museum objects [4, 5]. The assessment of air pollution in indoor cultural heritage buildings is a major concern for curators and conservators [6]. The conservation of typical collections is directly related to the indoor environmental conditions of the museums [7].

Airborne particulate matter (PM) is a complex mixture of organic and inorganic substances. It is made up of a number of components, including acids, organic chemicals, metals, and soil or dust particles

**Corresponding author: Asmaa M. El-Mekawy, E-mail: asmaamekawy75@gmail.com, Tel: +20 2 33371362*).
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[8]. Particulate matter is divided into two principal groups: coarse and fine particles, the smaller particles contain the secondarily formed aerosols. However, the larger particles usually contain earth crust materials and fugitive dust from roads and industries [9].

The deposition of particulate matter (PM) on monuments surfaces accelerates degradation, soiling, deterioration damages and disfiguration of objects (6, 10). The degree of damage happen depends on pollutant kind, its concentration, its chemical composition and particle size. Particulate matter can be indeed corrosive for its intrinsic nature, as for the presence of sodium chloride, or can act as carrier of more corrosive pollutants [11]. Damage can be intensified through the synergistic effects from air pollutants, temperature and/or humidity [12].

In the presence of humidity, NO2 and SO2 can be converted into nitric acid (HNO3) and sulphuric acid (H2SO4), respectively. Acidic air pollution leads to hydrolytic degradation causing significant damage of the artifacts [13]. Formaldehyde (HCHO) is a major intermediate reaction product in atmospheric photochemistry. A major source of formaldehyde is incomplete combustion of hydrocarbon fuels, especially from vehicle emissions [14].

Hydrogen sulfide (H2S) gas enters the environment from both natural and human processes [15]. The levels of hydrogen sulfide in air are typically low. Cairo is one of the most polluted cities in the world, in spite of the fact that it has a large number of archeological building, which represent a critical danger for these cultural heritages, so the aim of this study was to measure the most harmful pollutant indoor El-Manial Palace and museum and comparing the concentrations with local and international standards to evaluate the degree of danger this museum is subjected to for better conservation for this great cultural heritage.

2. Experimental:

2.1. Sampling site Description

El-Manial Palace was built by Prince Mohammed Ali Tewfik in year 1875. It was designed with an integrating European art style with remarkable traditional Islamic architecture. It housed his extensive art, furniture, clothing, silver, objects d'art collections, and medieval manuscripts dating back to the middle Ages.

The palace and estate has been preserved as an Antiquities Council directed historic house museum and estate, reflecting the settings and lifestyle of the late 19th and early 20th century Egyptian royal prince. The residence compound, composed of five separate and distinctively styled buildings, is surrounded by Persian garden (~34000m) within an extensive English landscape garden, along a small branch of the Nile.

The five detached palace buildings formed the ensemble of El-Manial Palace where Turco-Islamic architecture prevailed (whether in the salamlik--reception quarters, the haramlik--main residence; the throne room, the golden hall or the palace mosque).

The palace and museum is located in El-Manial district which is characterized by high traffic density, parking and located nearby the Cairo University and El-Qaser Eleyny hospital. Its coordinates are 30°01′39″N31°13′47″E.

In the present study indoor samples were collected from reception tower and residence palace only.

Figure (1): Map for El-Manial Palace and Museum

Figure (2): Prince's vintage butterfly collection

2.2. Air sampling and analysis:

The sampling was performed inside and outside of El-Manial palace and museum for a complete one year. The sampling was carried-out at two locations inside the museum. The description of the two sampling location are shown in Table (1). Field measurements and sampling were carried out at three sites, reception tower, residence palace and outdoor. Samples were taken at each sampling site during the working hours and routine daily activities in the period between 9 am and 4 pm, with 4 times every month. The samples were collected from fixed positions, at a height of ~ 1.5 m above the floor level at the center of the each building, and from 3-5 m outside the building to determine background level of air contamination. Sampling was carried out along one year from spring 2017 to winter 2018.

Microclimatic monitoring

Indoor/ outdoor temperature and relative humidity were measured using a portable weather instrument (SATO, PC- 5000 TRH-II sampler) at the time of sampling.

Determination of Suspended particulate matter

Suspended particulate matter (SPM) was collected through pre-weighted using Sartorius balance TE2145, Germany; and cellulose nitrate membrane filters (0.45 µm pore size and 47 mm diameter). The rate of sampling was 10 L/min. for 24 hour sampling occurred from 9.00 a.m. to 4.00 p.m. for three successive runs with three days a week. Filters were reweighted after sampling and difference in weight was SPM and expressed in µg/m^3.

Ion profile of suspended dust

The sampled dust filters were washed in 20 ml distilled water, shaken vigorously for 60 min and analyzed for water soluble ions, cations: Li^+, Na^+, NH_4^+, K^+, Mg^{2+}, and Ca_2^+ and anions: F^-, Cl^-, Br^-, NO_2^-, NO_3^-, PO_4^{3-} and SO_4^{2-} concentrations using ion chromatography (Dionex-ICS-1100, USA). The concentrations of soluble ions were expressed as (ng/m^3) of air.

Gaseous air pollutants

Sulphur dioxide (SO_2), nitrogen dioxide (NO_2), ammonia (NH_3), hydrogen sulfide (H_2S), and formaldehyde (HCOH) gases were measured according to previous studies [16 -20] using gas bubblers and vacuum pumps calibrated to draw air at flow rate of 1 L/min. The absorbance of the solution was measured by means of a UV–Visible spectrophotometer (Novaspec – LKB model 4049 – Biochrom, Cambridge, England), and concentration of gaseous air pollutant was expressed as µg/m^3.

2.3. Statistical analysis

Spearman's rank correlation test was used to determine relationships between suspended dust and gaseous air pollutants. A probability of less or equal to $P \leq 0.05$ was considered significant.

3. Results and discussion

3.1. RH% and Temperature measurements

Relative humidity (RH%) records were slightly higher in the residence and reception halls regarding to outdoor (Table 2). Relative humidity ranged within 44-54.5% in indoor air and 31.8-50.5% in outdoor air. Temperature records ranged between 13.6-28.7ºC in indoor air and 13.2-31ºC in outdoor air (Table 2). Microclimate conditions indoor and outdoor are closely similar, indicating the effect of outdoor weather conditions on indoors due to the absence of air conditions (artificial ventilation). The most acceptable temperature and RH% for the majority of archeological objects inside the museums is between 18 and 24^{O}C, and between 40 and 55%, respectively, in order to avoid changing in the proportions of organic material [21], according to that temperature is considered high during summer season which form a hazard on the museum.

3.2. Suspended particulate matter (SPM)

SPM is complicated in composition, causing corrosion and soiling of exhibition materials. Vehicles are main sources of dust and smoke and their concentrations are influenced by daily activities, sampling site, nature of soil, plant cover and geographical characters in addition to ventilation type, occupancy load and household activities [22].

Fig 3 shows seasonal and annual average concentrations of SPM. The maximum seasonal concentrations of SPM were recorded in outdoor and reception hall air during autumn season (380.8 and 345.4 µg/m^3, respectively),

while the lowest concentration was in residence hall during spring season (35µg/m^3).

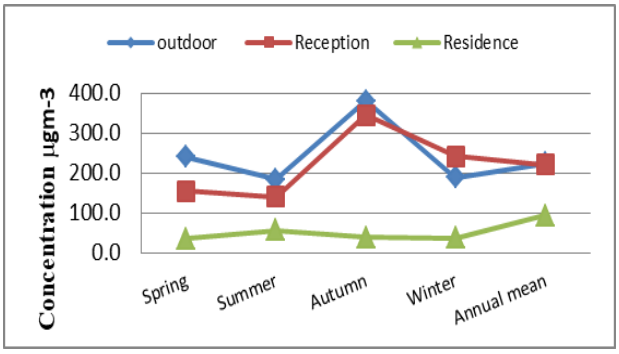

Figure 3: Seasonal variation and annual average concentrations of SPM at different locations of the museum

I/O ratios of SPM concentrations for reception hall exceeded 1 during winter season, which indicates that indoor pollutants play a major role in reception hall air pollution. I/O ratios of SPM concentrations for residence hall did not exceed 1 during other seasons, indicating that outdoor environment was the main source of SPM.

The maximum annual mean concentration recorded in outdoor followed by reception hall (223.4µg/m^3 and 220.4µg/m^3, respectively), while the minimum annual concentration recorded in residence hall 92.8µg/m^3. In the present study SPM concentrations exceeded the limit values set by the EPA, museum US National Bureau of Standards and The Kuwait EPA (75µg/m^3) [23-25], the Egyptian ambient air quality standard (125µg/m^3[26]), WHO range (60–90 µg/m^3) [27], the Malaysian National Standard and the Australian NHMRC (90µg/m^3) [24, 28], and much higher than concentration found by El-Mekawy et al. in indoor air of Sohag university museum (52.3 µg/m^3 [29]. High SPM concentrations in the museum can cause a significant change in the colour and in the physical properties of the coating layer of the oil painting present in the museum which can cause small holes on the surface of the oil paintings [30].

The high concentration of SPM inside the reception hall is attributed to its location nearby the crowded road and traffic area, so it is affected by emissions from outdoor. Outdoor environment is characterized by heavy traffic, other anthropogenic activities, and the museum is located nearby the Cairo University.

Significant correlation was found between SPM concentrations outside and inside the reception hall ($p \leq 0.01$) and non-significant correlation was found between SPM concentrations outside and inside residence hall ($P \geq 0.05$), respectively.

3.3. SPM Soluble ions profile

3.3.1. Anions

Figure (4) illustrates anion concentration in each site under investigation. As clear from this figure, the maximum concentration for all anions (except PO_4^{3-}) in outdoor air was during autumn season. NO_3^- anion was the most abundant anion in outdoor air ranged from 82.2ng/m^3 in autumn to 14.2ng/m^3 in spring. On the other hand, Br was the least abundant anion in outdoor air, ranged from 0.041 ng/m^3, in autumn, to 0.022 ng/m^3 in summer. Furthermore, spring season was the most rich season in anions in both reception and residence halls. NO_3^-anion was the most abundant anion in reception hall ranged from 110.5 ng/m^3 during spring to 23.8ng/m^3 during summer with mean concentration of 60.27ng/m^3, while SO_4^{2-} was the most common anion in residence hall ranged from 66.2ng/m^3 during spring to 9.08ng/m^3 during autumn with mean concentration of 33.4ng/m^3. Br^- anion formed the least SPM constituent in both reception and residence halls ranged from 0.047 ng/m^{3}during autumn to 0.039 ng/m^3 during summer (with mean concentration of 0.044 ng/m^3) in reception hall and from 0.031 ng/m^3 during spring to 0.002 ng/m^3 during summer (with mean concentration of 0.017 ng/m^3) in residence hall.

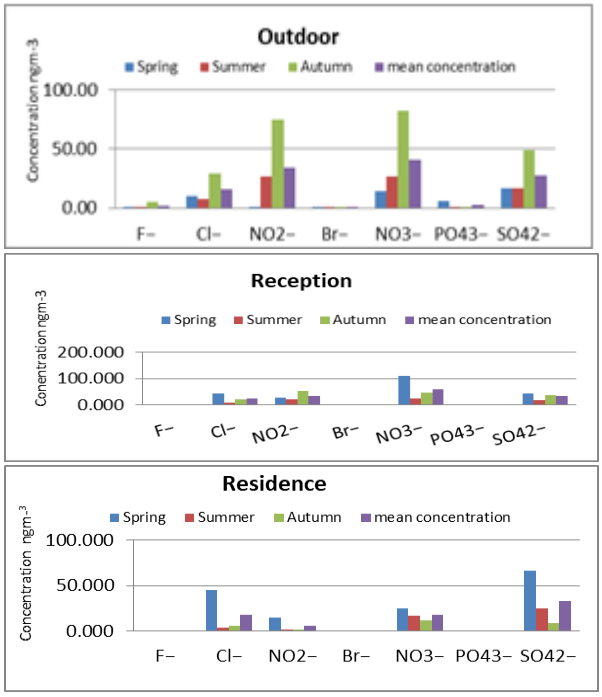

Figure 4: Anion concentration at each site under investigation

Figure (5) shows mean anion concentration in the investigated locations. Reception hall had the greatest anion constituent comparing to other sites followed by outdoor, while residence hall recorded the least anion concentration. I/O ratios for reception anions were greater than 1 for most anions (Figure 6) which indicates that this site is affected by both indoor and outdoor air pollutants; meanwhile I/O ratios for residence hall were less than 1 for all anions except for Cl^- and SO_4^{2-} anions.

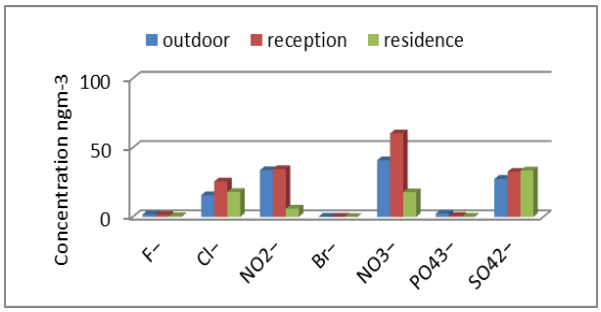

Figure (5): mean anion concentration at investigated sites

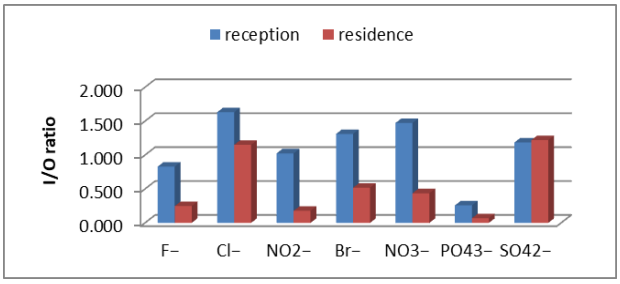

Figure (6): I/O ratios of anions in reception and residence halls

3.3.2. Cations

Cations concentrations in investigated sites are illustrated in Figure (7), which shows that Li^+ cation was under detection limit in all sites. Maximum cations concentrations in outdoor were detected during autumn season, while in reception and residence halls were detected during spring season (except Mg^{2+} and Ca^{2+} in reception were during autumn). The most abundant cations in outdoor were Na (ranged from 34.8 ng/m^3 during autumn to 8.33ng/m^3 during spring with mean concentration 17.6 ng/m^3) and Ca^{2+} (ranged from 36.3 ng/m^3 during autumn to 9.4 ng/m^3 during spring with mean concentration 19.2ng/m^3). On the other hand, the most abundant cations in both reception and residence halls were NH_4^+ (ranged from 81.7 ng/m^3 during spring to 4.8 ng/m^3 during summer with mean concentration 33.1 µg/m^{3}in reception hall and from 23.1 ng/m^3 during spring to 2.7 ng/m^3 during autumn with mean concentration 10.3 ng/m^3 in residence hall) and Ca_2^+ (ranged from 60.9 ng/m^3 during autumn to 12.2 ng/m^3 during summer with mean concentration 31.1 ng/m^{3}in reception hall and from 56.04 ng/m^3 during spring to 4.27 ng/m^3 during autumn with mean concentration 23.1 ng/m^3 in residence hall). The least abundant cation in all investigated sites was Mg^{2+} (mean concentration 3.3, 3.3 and 5.06 ng/m^{3}in outdoor, reception and residence halls, respectively.

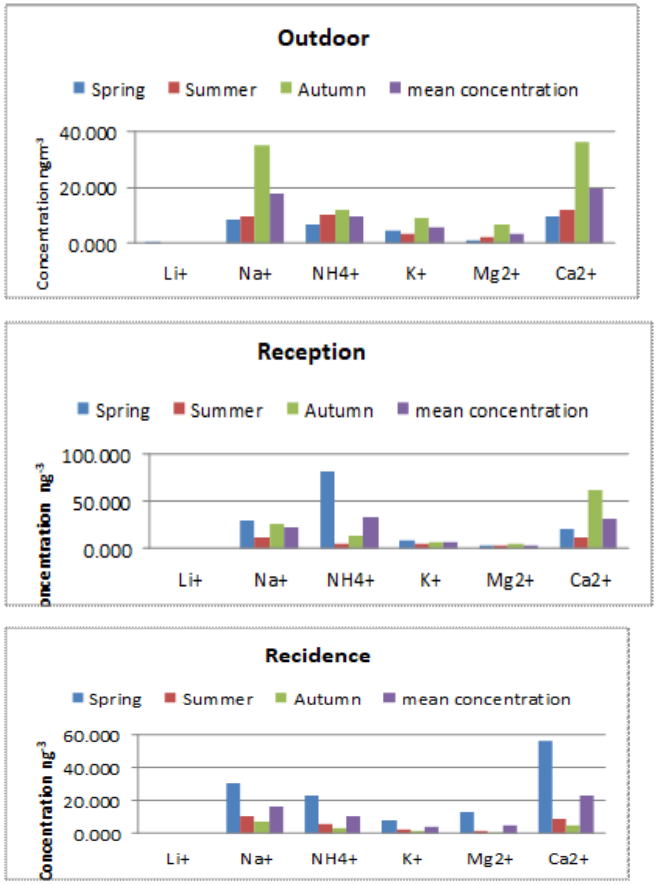

Figure 7: Cations concentration in locations under investigation

Reception hall had the greatest cation concentration comparing to other sites fallowed by residence then outdoor (as seen from figure 8). I/O ratios for cations in both reception and residence halls were greater than or near 1 for most cations (as shown in Figure 9) which indicates that these locations are affected by both indoor and outdoor air pollutants in contamination with cations.

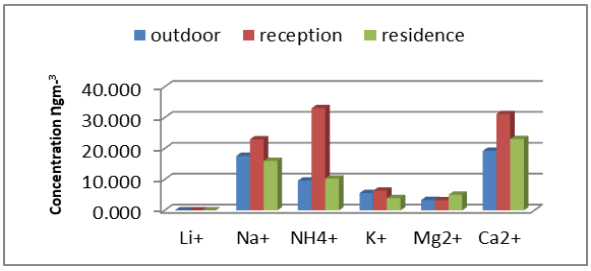

Figure (8): mean cations concentration in investigated sites

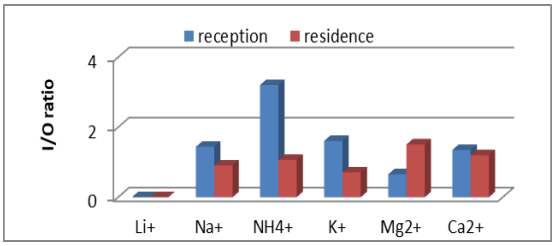

Figure (9): I/O ratios of cations in reception and residence halls

Acidity of SPM

The acidity of SPM is an important factor that affecting the reactions of SPM with surrounding objects [31,32]. To evaluate the acid-base balance of SPM the ratios of anion (A) and cation (C) microequivalents are calculated. A/C ratio greater than 1 indicates that particle is in acidic. Particles in ionic equilibrium state when the A/C ratio be close to 1 [33,34].

A/C ratios for all under investigation locations exceeded one (Table 3), indicating that SPM were in acidic state, which could cause deterioration and corrosion of works of art inside museum.

3.4. Gaseous pollutants

Figure (10) shows the seasonal mean concentrations of the gaseous pollutants in sites under investigation in El-Manial museum. The most common gas in the reception hall and residence hall was HCHO gas followed by NH_3 gas; while the least gas concentration was for H_2S gas. On the most abundant gas in outdoor air was NH_3 gas followed by HCHO gas. The maximum HCHO concentrations (236.8 and 205.4 µg/m^3) were recorded during spring in outdoor air and reception hall air, respectively. On the other hand the minimum HCHO concentration (38.7 µg/m^3) was found in outdoor air during summer season.

The maximum concentrations of NH_3 were recorded during winter season in all sites under investigation, while the minimum concentrations were recorded during spring season. H_2S was the least abundant gas in air of investigated sites. The maximum H_2S seasonal concentration 21.6 µg/m^3 was recorded during spring in reception hall air, while the minimum seasonal concentration was 0.019 µg/m^3 in residence hall air during spring season. The maximum seasonal concentrations of both NO_2 and SO_2 gases were during winter season, while least concentrations were during summer season.

The highest annual mean concentration of gases in air of studied sites was NH_3 gas followed by HCHO and NO_2 gases (Figure 11). On the other hand, the less abundant gas was H_2S gas. The highest gas concentration was recorded for HCHO gas in reception (126.1 µg/m^3) followed by NH_3 gas in reception too (116.06 µg/m^3). High HCHO gas concentration may be attributed to the location of this hall, which is located on the road, so it is affected by both outdoor and indoor pollution. This hall is characterized by the presence of several old stuffed and surrounding vegetation, renovation, and inadequate ventilation [35]. Formaldehyde is identified as a danger to museum collections [36]. Pavlogeorgatos [36] observed elevated concentrations of formaldehyde in Zoological Museum.

HCHO gas was high in outdoor air too. High concentration of HCHO in outdoor air may be attributed to the location of the museum near highly traffic road and the presence of AlQasr AlAyni hospital which is characterized by the presence of its incinerator, as boilers and incinerators consider a main source of HCHO in air [14, 37]. Annual mean concentrations of HCHO in reception and outdoor air are higher than limit values set in Canada 50 µg/m^3 8 hour average and 60 µg/m^{3}as a ceiling limit value for lo ng–term exposure [38, 39], and in Sweden and Poland 100 µg/m^3 [40, 41].

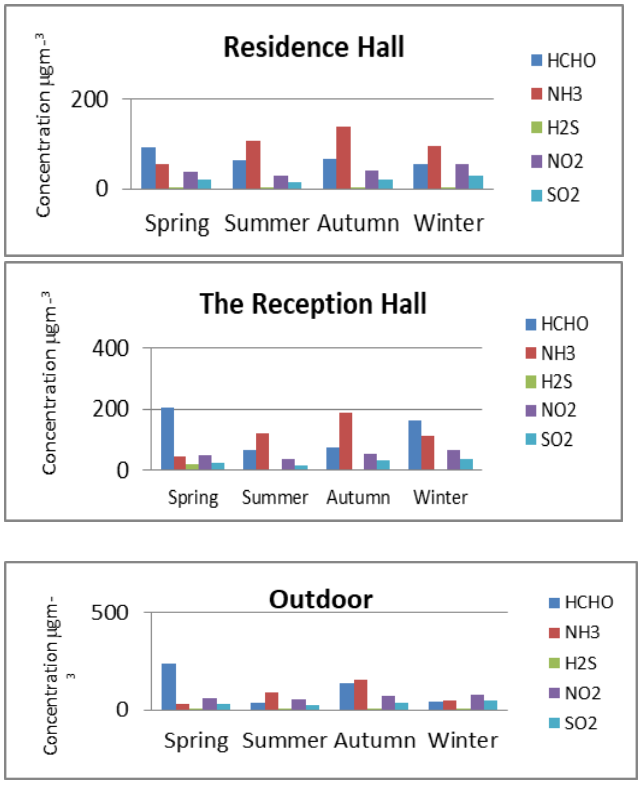

Figure (10): seasonal mean concentrations of gases in the different investigated sites

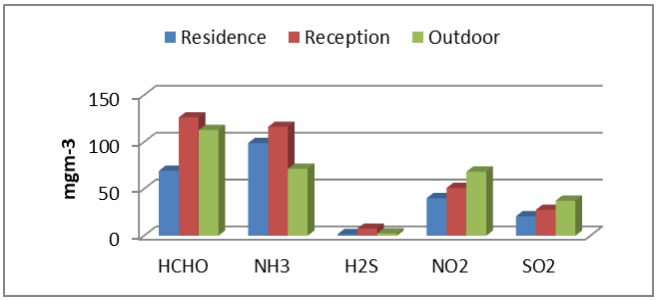

Figure (11): annual mean concentration of investigated gases

SO_2 concentrations were lower than NO_2 concentrations in most of sites under investigation, due to decline in fuel oil use and reduction in the sulphur content of gas oil and diesel fuel. In locations such as busy roads nitrogen dioxide concentrations are relatively high. In museum environment it is very difficult to decide at what level a pollutant becomes a threat. This is because of the prolonged exposure period, which may be detected in decades and over a time span, even quite low concentrations may be dangerous. Thomson [42] suggested that sulphur and nitrogen dioxides concentrations should not exceed 10µg/m^3. The US National Bureau of Standards has made even more stringent recommendations of less than 1µg/m^{3}sulphur dioxide and less than 5µg/m^3 nitrogen dioxide for archival storage conditions [43], the EU and WHO set value 40 µg/m^3 for NO_2 gas in air and 20 µg/m^3 for SO_2 gas [44, 45]. SO_2 and NO_2 annual mean concentrations exceeded 35 µg/m^3 and 53 µg/m^3 at outdoor and reception hall, respectively. NOx primarily emitted by motor vehicle and stationary combustion sources, and NH_3 primarily emitted by agricultural operations. In the present study NO_2 and SO_2 concentrations exceeded the previously mentioned limit values. Sulfur dioxide (SO_2) and nitrous oxide (NO_2) have great effects on cultural heritages (buildings, marble, limestone, tuff and sandstone) due to the formation of acid rains which dissolves the surface increasing weathering of materials and can even destruct the object itself [46]. Ingo [11] attributed corrosion phenomena on alloy surface, in an Egyptian museum, to sulphur and chlorine that react in different ways, depending on the exhibition conditions.

The concentration of NO_2 is usually high in an urban atmosphere, due to its emission by automobiles [6].

I/O ratio of gaseous pollutants

The annual indoor /outdoor ratios of gaseous pollutants are shown in figure (12). I/O ratios of NH_3 and H_2S were ≥ 1 at indoor locations, and HCOH only in reception hall, confirming the presence of internal sources of these gaseous pollutants. I/O ratios confirmed that outdoor sources are the main sources of SO_2 and NO_2 indoor. I/O ratio of HCOH exceeded 1 at the reception hall, less than 1 at the residence, indicating that HCOH has indoor and outdoor sources. Variations of I/O ratios indicate outdoor free air movement at different locations.

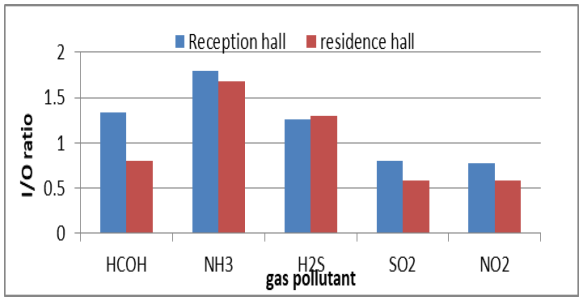

Figure (12): Annual I/O ratios of gaseous pollutants

There were strong correlation between outdoor and residence HCHO (as seen from table 4), also there were strong correlation between outdoor NH_3 and NH_3 in both residence and reception halls, and between outdoor (SO_2 and NO_2) and SO_2 and NO_2 in both residence and reception halls.

There was a strong correlation between $NH_3$and H_2S and between SO_2 and NO_2 gases in outdoor air (table 5 (A)), and strong correlation between H_2S and both HCHO and NH_3 and betweenSO_2 and NO_2 in both residence and reception halls (table 6 (B and C)).

4. Conclusions

For better preservation of cultural heritage, special attention should be paid to the air pollutants and its constituents. The study showed that temperature records were slightly high. PM concentrations were higher than the national and international limit values. A/C ratios were greater than one, indicating that PM were in acidic state which have great effect on art exhibits inside museums.

Reception hall had the greatest anion and cations constituents comparing to other sites. NH_4^+ was the most abundant cation. HCHO was the most abundant gas in the air inside the museum. NO_2 and SO_2 concentrations exceeded the US National Bureau of Standards limit values. I/O ratios of SO_2 and NO_2 gases confirmed that outdoor sources are the main source for them in indoor air. Natural ventilation is very dangerous to the museum's objects and exhibits.

5. Conflict of interest

The authors have no actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, their work.

6. Funding

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5. Acknowledgment

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Table (1): description of sampling sites

Location	Description	Ventilation typ
Reception tower	It consists of two floors, each floor comprising of two halls. Its purpose was to receive official guests and contains rare antiques including carpets and Arabian furniture and tables. It is located near the crowded street.	natural
Residence palace	It was dedicated to residence of the prince, it consists of two floors; the ground floor consists of the reception and dining rooms, prince's office and library, whereas the upper floor was for bed rooms. It is located far from street and surrounded by big garden. It is located away from road.	natural

Table (2): Relative Humidity (RH %) and Temperature℃ outside and inside the museum halls

	Relative Humidity (RH %)			Temperature℃		
	Outdoor	**Reception**	**Residence**	**Outdoor**	**Reception**	**Residence**
Spring	31.8	44	49.6	26	19.2	18.4
Summer	35	45	54.5	31	28.7	27.2
Autumn	50.5	51.2	53	19.2	19	19.3
Winter	49.6	48.8	51	13.2	14.1	13.6
Annual average	41.7	47.2	52	22.3	20.2	19.6
S.D.	9.6	3.3	2.1	7.7	6.1	5.6
Max	50.5	51.2	54.5	31	28.7	27.2
Min	31.8	44	49.6	13.2	14.1	13.6

Table (3): Anions (A) and cations (C)microequivalents and there ratios

	∑anions ng/m^3	∑cations ng/m^3	A/C
Outdoor	122.03	55.53	2.1
Reception	155.06	97.03	1.5
Residence	75.97	58.47	1.2

Table (4): Correlation between gases in outdoor air and both Residence and Reception halls.

		Outdoor				
		HCHO	**NH_3**	**H_2S**	**NO_2**	**SO_2**
Residence	**HCHO**	**0.92**	-0.37	-0.51	-0.35	-0.46
	NH_3	-0.51	**0.93**	**0.90**	0.14	0.17
	H_2S	-0.62	0.85	0.85	0.25	0.29
	NO_2	-0.21	-0.26	-0.32	**0.94**	**0.96**
	SO_2	-0.12	-0.22	-0.28	**0.95**	**0.97**
Reception	**HCHO**	0.56	-0.86	-0.92	0.33	0.29
	NH_3	-0.43	**0.93**	**0.87**	0.23	0.25
	H_2S	0.90	-0.60	-0.72	-0.14	-0.24
	NO_2	-0.09	-0.19	-0.26	**0.96**	**0.97**
	SO_2	0.04	0.11	-0.05	**0.96**	**0.94**

Table (5): Correlation between gases in each site ((A) outdoor air, (B) Reception hall and (C) Residence hall)

	HCHO	NH_3	H_2S	NO_2
NH_3	-0.23			
H_2S	-0.45	**0.87**		
NO_2	-0.03	-0.03	-0.09	
SO_2	-0.16	-0.04	-0.07	**0.98**

(A)

	HCHO	NH_3	H_2S	NO_2
NH_3	-0.81			
H_2S	**0.76**	**-0.78**		
NO_2	0.44	0.09	-0.12	
SO_2	0.26	0.34	-0.14	**0.92**

(B)

	HCHO	NH_3	H_2S	NO_2
NH_3	-0.66			
H_2S	**-0.79**	**0.98**		
NO_2	-0.36	-0.05	0.08	
SO_2	-0.39	-0.007	0.13	**0.99**

(C)

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