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A Quantitative Approach to Estimate the Damage Inflicted by Traffic Pollution on Historic Buildings in Al-Salt City, Jordan

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Abstract
Traffic in the city of Al-Salt is not only putting pedestrians at risk and threatening the health of citizens, it is also damaging the town's historic buildings. Most stone buildings in the heritage-rich city are suffering adverse effects from vehicle-related pollution. This effect is highly visible soiling and discoloration from deposited carbon particles in the form of fine soot on most buildings. The level and progress of the damage depends on the geology of the stone and the proximity of the structure from traffic congestion. The accumulation of soot leads to the buildup of black sulfate (gypsum) skins on the limestone facade which causes the sound stone behind it to disintegrate. It is vital to the well-being of this historic treasure that the volume of the city traffic must be reduced and traffic flow improved. The main objective of this study is to qualitatively and quantitatively assess the damage caused to buildings of historical and cultural value by traffic pollution. Age of vehicles running on city's streets and the rate of their emissions are quantified and analyzed. Several field investigations and laboratory tests were conducted to identify the chemical relations between pollutants and stone decay on these buildings.
Keywords: Traffic pollution, tailpipe emission, vehicular emission, historic buildings, limestone

1. Introduction
It is our duty to preserve what our ancestors left for us and pass it to future generations. This includes cultural heritage and historic buildings. The amount of damage inflicted by human activities on these structures in the past three decades is tremendous. Air pollution caused by human activities in general and traffic operations in specific are resulting in the rapid decay of the stone structures. Volatile chemical and mechanical compositions released by traffic are the main cause of the deterioration of the historic stone structures. Effects resulting from Sulfur, Carbon, Nitrogen, and their compounds are reported. Many researchers realized the values of the historic buildings worldwide. C. Saiz-Jimenez discussed the adverse effect of air pollution on historic monuments in several European cities [C. Saiz-Jimenez et. al, 2004]. Emilio and Fulvio made significant effort to evaluate the effects of the environment on weathering of historic buildings in the Mediterranean Basin [Emilio Galan and Fulvio Zezza, 2002]. Little research has been conducted to quantify the effect of traffic pollution on limestone historic structures.

2. Historical Review
Al-Salt City is a cultural and historical asset for all Jordanians. It is located half an hour northwest of the capital Amman on the old highway leading to Jerusalem. Situated in the Balqa' highland (over 1100 meters above sea level) the town is built in the crook of three hills. The city's historical merit is reflected in the particular style and architectural artistry which displays the strong association with the significant people who lived in the city. Additionally, it reflects the different social patterns of its time. Figure 1 shows the architectural merit of the city where the virtue of its design conforms to its past and present sense of beauty. This is manifested in the many architecturally elegant buildings representing four centuries.

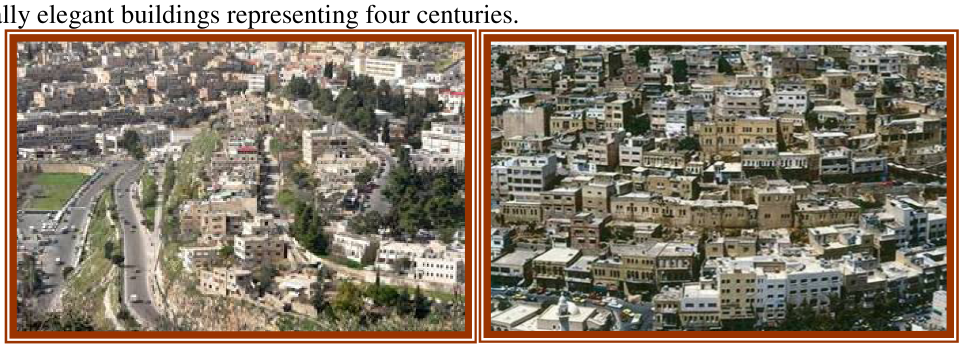

Figure 1. Views of Al-Salt City

Al-Salt is one of the most historic cities in Jordan. It was, for a long time, the most important settlement between the Jordan River in the west and the desert to the east. Its golden age was in the late 19th and early 20th century (see Figure 2). Its climate, water, and fertile soil have attracted settlers since the Iron Age. The city's diverse population and its trading tradition created an atmosphere of tolerance and coexistence, along with a rich culture. During the Byzantine period it was known as Saltos Hieraticon [www.salt.gov.jo]. That is where the city gains its name (Al-Salt).

Figure 2. Historical Sites in Al-Salt

3. Background

The city has about 350,000 inhabitants (2005) near 6.7% of the total population in Jordan. Traffic congestion in the city is not only threatening the town's economic revival and putting pedestrians at risk it is also having an extremely damaging effect on the town's historic buildings. The combination of high volumes of traffic and long slow moving queues passing through the town centre, has now reached the point where the very fabric of the town's architecture is under serious attack. Without improved access to and from the city center, buildings in the town will continue to discolor and decay.

Most stone buildings in the town are suffering adverse effects from vehicle-related pollution. For many structures, the effects are highly visible with soiling and discoloration from deposited carbon particles in the form of fine soot (see Figures 3 and 4). Problem areas include the city center, the Sarraya area, and Sahat Al-Hamam area; where the facades of the buildings are universally dirty, being soiled by deposits contained in exhaust fumes, especially diesell particulates [Grosclaude and Soguel, 1994]. The level and progress of damage depends on the geology of the stone used [John Hart, 2004]. Most historic buildings in the city are constructed of limestone. The older the stones, the softer many of them tend to be and the more vulnerable to decay caused by airborne carbon particles from exhaust fumes.

4. Problem Identification

Traffic congestion is becoming the reality of urban Jordan. The city of Al-Salt is no exception. Slow traffic produces higher concentrations of pollutants and, therefore, accelerates the decaying action on the façade of limestone buildings. Fast traffic, however, splashes oil-laden water collected on pavement surface against the stone walls.

The stones from which the historic buildings in Al-Salt are constructed are particularly vulnerable to decay due soot, exhaust gases, and carbon particulates. The vulnerability is seen along the road-side of the city, where the lower rows of limestone have eroded far more extensively than those higher up the buildings. This is due to the higher concentration of vehicle emissions and other pollutants at low levels (see Figure 4). Additionally, field investigation showed that buildings which are located away from street traffic suffer less decay and little damage (see Figure 5).

There is little coordination between the regulatory body of Tailpipe emission standards and the enforcement agency in Jordan. The regulatory body is represented by the Ministry of Environment (MOE) and the enforcement agency is represented by the Police Department in the Public Security Directorate (PSD) which is a division in the Ministry of Interior (MOI). Tailpipe emission standards specify the maximum amount of pollutants allowed in exhaust gases discharged from internal combustion engines. The regulated tailpipe emissions include: Carbon Monoxide (CO), Carbon Dioxide (CO_2), Nitrogen Oxides (NO_x), Diesel Particulate Matters (PM), and Hydrocarbons (HC).

Figure 3. Discolorations and Decay of Limestone Structures due to Traffic Pollution

Figure 4. Discolorations, Decay, and Disintegration of Limestone Structure at Low Levels due to the High Concentration of Traffic Pollutants.

Figure 5. Low Rate of Discoloration, Decay, and Disintegration of Limestone Structures at Locations away from Traffic Congestion

5. Study Objectives

The main objective of this research undertaking is to bring public attention and awareness to a serious challenge threatening historic sites which are the symbols of our heritage in the Kingdom of Jordan in general and the city of Al-Salt in particular. Other objectives of the study include a qualitative and quantitative approach to assess and evaluation the damage inflicted by the city traffic on the historic buildings in Al-Salt. Corrective and preventive measures will be proposed to mitigate the adverse effects inflicted by the traffic and therefore, slow the decay process inflicted on our national treasures.

6. Scope and Methodology

The study begins with an overview of traffic pollution issues in urban Jordan and their effects on historic buildings. Traffic data is collected from previous and contemporaneous studies and are presented and analyzed. A site survey conducted by the study team is also presented. Photos are collected to show and assess the conditions of different historic buildings at different locations in Al-Salt.

The traffic data collected and used in the analysis includes the tailpipe emissions rates, the age and type of vehicles in the traffic stream. Emission rates exceeding the standard limits are recorded and analyzed. Qualitative assessment and quantitative measures are made to show the effect of high concentrations of pollutants on the stone decay rate. Conclusions are then drawn and recommendations are finally suggested.

7. Traffic Pollution in Urban Jordan

There are more than 800,000 vehicles in Jordan according to several studies conducted in the year 2007 [Public Security Directorate, Jordan Traffic Institute, 2007]. This number of vehicles grew from 3426 vehicles in 1950 (see Figure 6). The roadway transportation sector in Jordan is by far the only transportation sector moving people and commercial goods at the local level. People are transported using private automobiles or public transportation. The private auto fleet consists of approximately half of the total number of vehicles and 50% of these vehicles are more than 10 years of age [Al-Shawabkeh and Suliman, 2005]. Vehicle age in the city of Salt is five years higher than average vehicle age in the capital Amman.

Gasoline fuel is used in about 60% of the total vehicles, light-to-medium diesel trucks are about 15% and heavy vehicles including transit buses total 25%. The local gasoline is produced by the only oil refinery in Jordan and is located in Al-Zarka area. Diesel fuel produced at the Jordan Refinery contains up to 1.5% sulfur [Al-Shawabkeh and Suliman, 2005]

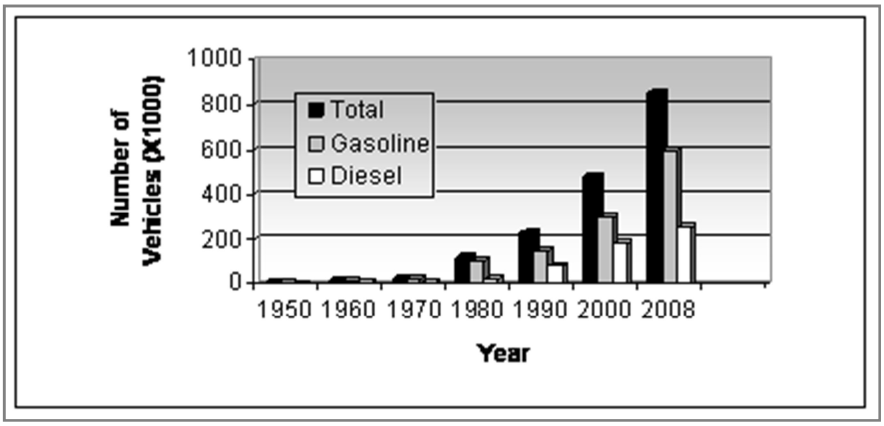

Figure 6. The Growth in Number of Vehicles in Jordan.

8. Emission Data Collection

The data presented in this research includes samples compiled by the research team and data provided by the Ministry of Environment (MOE) in a joint undertaking with the Public Security Directorate. The sample consists of 850 vehicles distributed into five age groups as shown in Table 1. The study includes the identification and the levels of pollutants emitted by all vehicles. Levels of CO, CO_2 and HC where detected and measured. The results were compared with the local emission standards and reported accordingly. Other pollutants such as SO_2, particulate matter (PM) and/or suspended particles (SP) were identified.

Table 1. Tested Sample of Vehicles According to Age Groups

Age Group	Regular Leaded Gasoline	Super Leaded Gasoline	Diesel	Sub Total
0 – 5	58	15	53	**126**
6 – 10	94	23	153	**270**
11-15	140	10	72	**222**
> 15	147	4	81	**232**
Total	**439**	**52**	**359**	**850**

The study consists of testing exhaust emissions one day a week for a six month period. The test period started in May and ended in October 2007. Eight different locations were selected within and on the outskirts of the city. A random test sample of 850 vehicles was taken to represent the traffic mix. These vehicles were divided into four age groups. Two test devices were used in this process. One to measure the emission levels of CO, CO_2, and HC. The other device was used to measure opacity of the diesel vehicles. The Traffic Department and Highway Patrol helped in stopping and organizing the tested vehicles. Table 2 shows the number of vehicles exceeding the allowable emission pollutants level with respect to age groups and type of fuel used.

Table 2. The Proportions of Vehicles Exceeding the Allowable Emission Levels According to their Age Group and Fuel Type

Age Group (Years)	Regular Leaded Gasoline %	Super Leaded Gasoline %	Diesel %	Mean %
0 – 5	**71**	**60**	**50**	**60.3**
6 – 10	**55**	**39**	**59**	**51**
11 – 15	**72**	**60**	**62**	**64.7**
> 15	**66**	**75**	**68**	**69.7**
Mean %	**66**	**58.5**	**59.8**	**61.4**

9. Analysis of Results

The Table shows that more than 60% of tested vehicles are in violation for emission standards. 66% of the tested leaded gasoline vehicles exceeded the allowable Jordanian standards of one or more pollutants. This is due to the fact that many vehicles running on leaded gas are designed for unleaded only. About 60% of the tested diesel vehicles were in violation of the emission standard in the Kingdom. These local standards tolerate higher limits and are less restrictive than US and European Standards. The analysis of results showed different degrees of violation depending on the vehicle age group and fuel type. A higher rate of violation (69.7%) was found for the subgroup of vehicles representing the age of more than 15 years. The vehicles age group of six to ten years showed the highest rate of success in meeting emission requirements.

Figure Seven shows the proportions of vehicles according to fuel type and age group from the total vehicles violating emission requirements in the same group of fuel type. The rate of violations among vehicles using regular gasoline increases with age. Data from vehicles with super gasoline is inconsistent due to their sample size in addition to the fact that most owners of cars requiring super gas with high octane choose to use regular leaded gas instead, for the lower price. On the other hand, Diesel type vehicles group shows substantial increase in violations in the first ten years, then the rate of violation drops to half in the next five years (group 11 to 15), the rate then steadily increases thereafter. A field sample in this regard reported that most diesel vehicles undergo an overhaul operation during the age of 11 to 15 years (see Figure 7).

The mountainous topography of the city worsens the tailpipe emissions. Traffic in Al-Salt is concentrated in the city center where most of the historic buildings are located.

Small scale surveys conducted by the study team in the city showed vehicle maintenance is given less attention in Al-Salt than in Amman. Additionally, the enforcement is less restricted in the city in comparison with Amman. This is one of the reasons why some car owners from urban Amman choose to get their annual vehicle inspections in Al-Salt city.

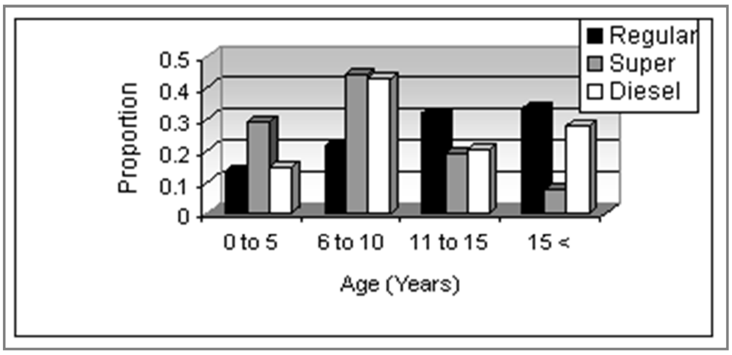

Figure 7. The Proportion of Vehicles According to Fuel Type and Age Group from the Total Vehicles Violating Emission Requirements in the Same Category of Fuel Type

10. Building Decay Related to Traffic Pollution

Most buildings near the traffic path have thick sulfation crusts in many places. Where it does not, it is because these crusts have blistered and detached, taking significant volumes of stone with them (see Figure 3). These sulfation crusts will re-establish over time and continue the process of decay [Grosclaude and Soguel, 1994]. Some of these buildings have suffered significant decay and loss of detail as a result (see Figure 8).

It is clear that the current level of vehicle traffic within the city is doing quantifiable damage to the historic fabric of this urban environment. Without change the damage will accelerate.

Figure 8. Lose of Details and Stone Disintegration is Evident

11. Field Testing

Field tests were conducted by the research team on selected historic buildings near the city center where traffic congestion is usual and in the outskirts of the city away from traffic congestion. Investigations included measurements for crust and decay patches (frequency, size and depth), and stone sampling for laboratory testing. Figure 9 shows the depth of crusting and decay of stones.

Figure 9. Depth of Crust on the Façade of a Historic Building is the City Center (the crust was removed before taking the measurement)

12. Frequency and Severity of Decay

The frequency and severity of crust patches and decay decrease as we move away from traffic congestion. The depth of decay and crusting near the city center is about twice those recorded for samples away from traffic (see Figures 10, 11). The vertical position of samples above street level made a big difference in depth measurements around the city center where it is more than double at the bottom than the top of the sampled structures (see Figure 10).

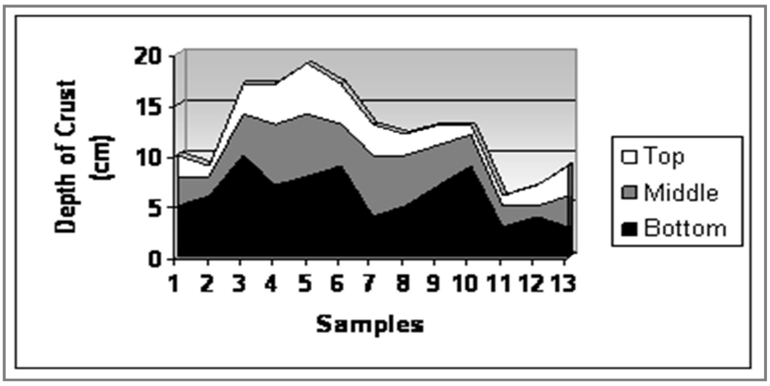

Figure 10. Depth of Decay and Crusting on the Façade of Limestone Structures near the City Center

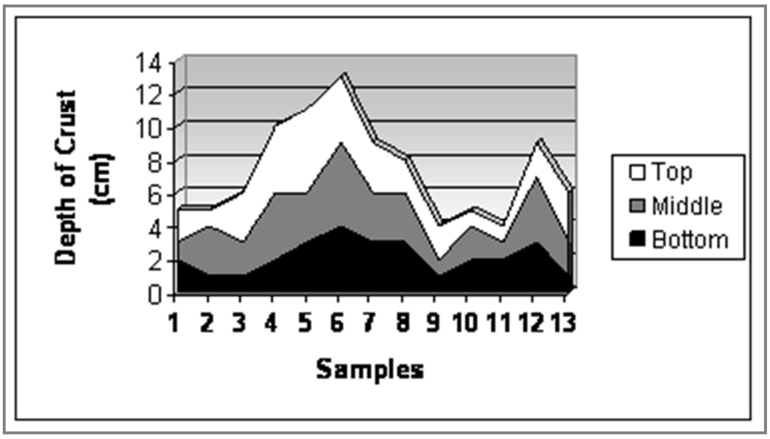

Figure 11. Depth of Decay and Crusting on the Façade of Limestone Structures away from City Center

13. Laboratory Testing

Samples were transported to the Faculty of Engineering Technology (FET) at Balqa Applied University (BAU) for further testing. The testing included coring, Porosity and permeability of the stone material. Cores were used to study the inner layers of the stones and determine the thickness of the crust on the face of stones (see Figure 12). Results show that softer stones have higher porosity. Samples originated near the city center showed higher permeability close to the façade of the stone (see Figure 13). The Figure shows that the permeability is high at stone surface and decreases as we move toward the core where the sound stone is away from weather elements and pollutants.

Figure 12. Coring of Stone Samples Shows Crust Thickness and Porosity of the Materials.

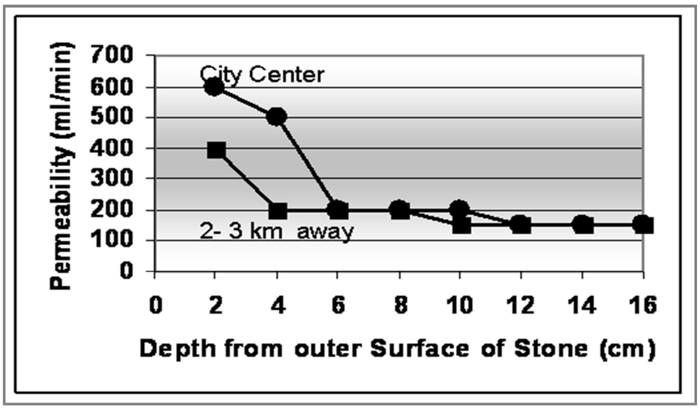

Figure 13. Average Permeability for Stone Samples

14. DISCUSSION

Numerous factors are leading to the alarmingly rapid deterioration and decay of historic buildings in Al-Salt city in specific and in the Kingdom of Jordan in general. Researchers have different views on the degree in which each factor or group of factors contribute to the deterioration process. Many of these researchers agree, however, on the detrimental effect that air pollution has on the acceleration of the deterioration process [J. Simao et al, 2007]. In Al-Salt city, traffic tailpipe emission is the main cause of air pollution in the city. Previous sections showed substantial evidence in supporting claims calling for the accelerated damage caused by vehicle operation on the city's historic buildings. This damage is the result of mechanical and chemical reactions between the stone materials and the pollutants. Limestones used in these buildings are quite homogeneous in their chemical characteristics, their composition is dominated by $CaCO_3$, but they are highly variable in terms of physical characteristics. The physical characteristics include hardness, fossil content, porosity, and permeability. The variable durability of limestone is largely determined by these physical characteristics. Chemical reactions between the stone material and the weathering conditions including pollutants may change the physical characteristics of the stone, and therefore, reducing their durability and structural integrity. Figure 14 is a suggested conceptual model for the acceleration process of deterioration and decay of limestone used in historic buildings in Al-Salt City.

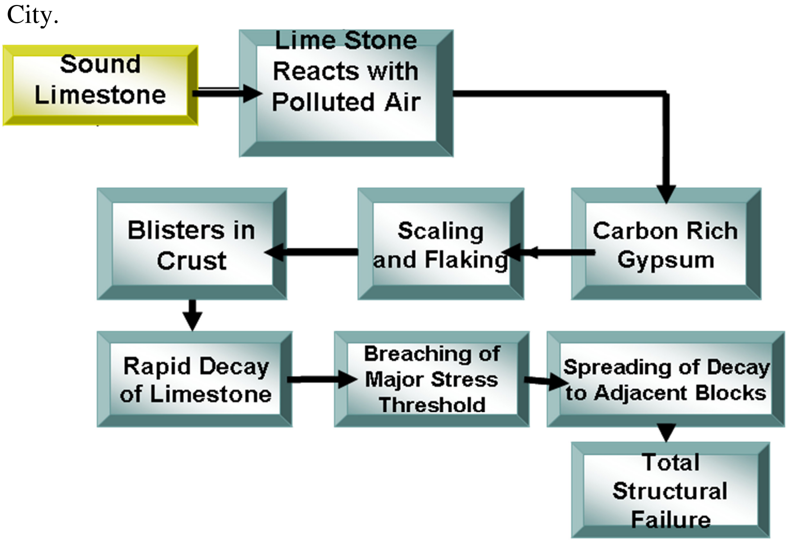

Figure 14. Conceptual Model of the Rapid Deterioration and Decay of Limestone Structures in Al-Salt City (Modified after Smith et al. 1994).

Chemical reactions which may occur between tailpipe pollutants and limestone materials are summarized in the following subsections.

14.1 Sulfur Compounds

The stone materials $CaCO_3$, pollutants; SO_2 and relative humidity are detrimental in speeding these chemical reactions. SO_2 and H_2S and humidity result in the decay of limestone in polluted environments. The dissolved $CaCO_3$ settles over the stone as $CaSO_4$ and with SO_4 this becomes $CaSO_4$.

The volume of $CaSO_4$ is almost twice the volume of $CaCO_3$. This expansion of volume causes the breakdown and the decay of the stone.

14.2 Carbon Compounds

Carbon compounds released by tailpipe exhausts including CO, CO_2, react with Oxygen and water resulting in the decay and deterioration of limestone.

Water dissolves the carbonates by bonding with CO_2 in the polluted air to dissolvable materials.

14.3 Nitrogen Compounds

Nitrates: Nitrogen Oxides which are the product of fossil fuels used by the traffic dissolved in water forming acid rain which leads to the decay of building stones.

15. Conclusion

Traffic congestion is becoming a reality of urban Jordan. The city of Al-Salt is no exception, the number of vehicles is rapidly increasing and traffic congestion is causing damage to our national heritage. The stones used in the construction of historic buildings in Al-Salt are particularly vulnerable to decay by exhaust gases and carbon particulates. Slow moving traffic is producing more pollutants. These pollutants are softening the stone structures and accelerating the decay action on the walls of historic building in the city. Passing vehicles inflict more damage by splashing adjacent stone walls buildings with oil-laden water during the wet seasons.

The collected data showed that the traffic mix in Al-Salt consists of relatively older vehicles. This substantiates study findings regarding the high rates of tailpipe emission violations in the city. This intensifies the damage inflicted on the historic structures. Lack of the necessary routine maintenance on vehicles in the city makes the problem worse.

The study shows that more than 60% of tested vehicles are in violation for emission standards. 66% of the tested leaded gasoline vehicles exceeded the allowable Jordanian standards of one or more pollutants. About 60% of the tested diesel vehicles were in violation of the emission standard in the Kingdom. Analysis of results showed different degrees of violation depending on the vehicle age and fuel type. A higher rate of violation (69.7%) was found for the subgroup of vehicles representing the age of more than 15 years. The vehicles age group of six to ten years showed the highest rate of success in meeting emission requirements.

Chemical reactions between the stone material and the weathering conditions including traffic pollutants may change the physical characteristics of the stone, and therefore, reducing their durability and structural integrity. Most buildings near the traffic path have thick sulfation crusts in many places. These crusts have blistered, detached and fallen in some places taking significant volumes of stone with them and exposing the sound stone for a repeat of the same cycle. Some of these buildings have suffered significant decay and loss of detail as a result.

Field and laboratory investigations show that buildings close to heavy traffic activities undergo decay and deterioration rates higher than other sites away from traffic activities. This indicates that the current volume of traffic within the city is causing quantifiable damage to the historic fabric of this urban environment. Without change the damage will accelerate.

Recommendations

To preserve the historic buildings in the city, we must reduce tailpipe emissions.

If not, we will all be collectively responsible for an unnecessary and unacceptable level of damage to our incredible heritage.

The reduction of tailpipe emission can be accomplished by the following:

1- Reduction of traffic volume near the historic buildings
2- Improving traffic access to and from the city center
3- Improve traffic flow through the city
4- Place more restrictions on tailpipe emission
5- Subsidize a reliable public transit system within the city
6- More restricted enforcement is needed to make vehicles comply with emission requirements in the city of Al-Salt.

The study team recommends further detailed investigations to be conducted to better preserve and stop the unnecessary and unacceptable level of damage inflicted on our treasures

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