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ANTIQUITY IMPACT OF AIR POLLUTION AT GADARA, JORDAN

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ABSTRACT

Several recent studies have pointed out that the northern parts of Jordan are exposed to high levels of ground ozone. North Jordan is a wealthy reservoir of ancient heritage including six out of the ten Decapolis Cities. It is alleged that air pollution-via acid deposition- has led to the deterioration and erosion of buildings, structures, statues, and monuments. Therefore, this research is conducted to assess air quality at Gadara, the capital of the ancient Decapolis and to come up with mitigation measures that have to be adopted in order to save the ancient heritage from further deterioration. Measurements revealed that most criteria air pollutants including sulfur dioxide, nitrogen dioxide, and carbon monoxide attain corresponding national ambient air quality standards. However, ground ozone, which is believed to expedite the deterioration rate of rocks in the presence of acids as they act as a catalytic agent, exceeds the limit recommended by the World Health Organization of 50 ppb.

KEYWORDS: Decapolis, Gadara, air pollution, sulfur dioxide, nitrogen oxides, carbon monoxide, and ground ozone

INTRODUCTION

In addition to its adverse health impact (Dockery and Pope, 1994; Pope, 1995; Laden et al., 2000; Pope, 2002; WHO, 2007; Knox, 2008), air pollution has a devastating impact on the environment including destruction of forests and vegetation; acidification and eutrophication of lakes; deteriorating of metals, structures, and statues and monuments; and cracking of leather and rubber (Boubel et al., 1994). Air pollution usually affects buildings in two ways: decay and soiling. Soiling is the discoloration of a building, whereas decay results in the destruction of the building fabric (Massey, 1998).

Airborne substances such as acids, oxides, and ground ozone alter chemical composition of rocks outer surfaces and make them susceptible to rain wash. This process caused severe destruction to ancient invaluable antiques worldwide. Recent studies have pointed out that northern Jordan is influenced by air pollutants that are transported from south Europe and eastern Mediterranean coast (Wanger et al., 2000; Kallos et al., 2006; Asaf et al., 2008). In addition, there are several natural and anthropogenic sources of air pollution in North Jordan. Hot springs around Lake Tiberias are potential-natural sources of sulfur compounds. Anthropogenic sources of air pollution in North Jordan include motor vehicles, open burning, and pesticides.

North Jordan has five out of the ten Decapolis (a group of ten cities on the eastern frontier of the Roman Empire in Jordan and Syria) including Gerasa (Jerash), Gadara (Umm Qais), Pella (Almasharea'), Capitolias (Beit Ras), and Raphana (Hartha). Most ancient statues and monuments at the Decapolis are made of marble and limestone, which are basically calcium carbonate ($CaCO_3$) that reacts with acid deposition to form calcium sulfate, carbon dioxide, and water. When calcium sulfate is exposed to wet acid deposition or to pure water, it simply dissolves.

Air pollution has the potential to expedite deterioration rate of rocks. Thus, it has a devastating impact on ruins and antiques. Consequently, the main objective of this paper is to address air pollution impact on the structures, statues, and monuments in the capital of the Decapolis (Gadara) and to draw up a remedial plan to protect this fascinating ancient city.

HISTORY OF GADARA

Gadara is the site of ancient Greco-Roman town of Gadara which was one of the cities of the Decapolis. It is situated 110 km north of Amman. Its strategic location was an important factor in its prosperity: River Yarmouk and Golan Heights are visible in the north, while looking south provides an amazing sight of the southern forested hills of Ajloun. Fertile Horan plateau borders Gadara from the East, whereas Jordan valley and the Sea of Galilee form the west border.

Greeks were the first people to marvel at the breathtaking view and established their acropolis. Later on, the Roman Byzantines and ottomans would follow suit leaving their own marks in the city. Although the intensive successive occupation during the rich past of the city has deposited gigantic cultural hallmarks therein, demolishing earthquakes destroyed several constructions and forced inhabitants to flee the city during the Umayyad period which extended from 661 AD till 799 AD (Mershen, 1992). During the Ottoman rule of the region, Gadara restored its significance and emerged as an important crossing town in south Syria and north Jordan, and it was given a modern name which is Um Qais (Weber, 1989).

THE NATURAL AND CULTURAL CONTEXT OF UMM QAIS

Umm Qais as a whole can be divided into two main parts. The first part is the ancient city of Gadara which includes the Greco-Roman, Byzantine, and the Ottoman establishments, whereas second part is the modern town which incorporates rural landscape.

In addition to its distinctive type of basalt rocks, the outstanding importance of Greco-Roman ruins stems from the primary features of an integrated Roman city in terms of its planning, monuments, and artistic works, in addition to its distinctive type of basalt stone. The Byzantine part of the city is renowned for the octagonal church which was built at the side of the Cardo Street (Fig. 1). The church is marked by its fabulous style.

Figure 1. Columns of the octagonal church in Gadara. Image is courtesy of Holy Land Photos.

The Ottoman village is the most interesting part of the city. Umm Qais, on the road from Damascus to Tiberias and hence to the Palestinian seaports, overlooking Lake Tiberias and the Golan Heights, attracted the people during the Ottoman period to settle in the town (Fig. 2) as it provided numerous jobs (Mershen, 1992).

Figure 2. A typical dwelling at Um Qais during late Ottoman Reign.

GADARA IN ANTIQUITY

Gadara has a wealth of remarkable antiques including the Hellenistic wall which was constructed after the conquest of Gadara by Antiochus the third in the early second century AD to enclose the ancient Acropolis hill (Mershen, 1992). Capitals, pedestals, drums, and columns are scattered at different parts of the city especially along both sides of the colonnaded Decumanus Maximus street. The capitals are categorized into two types: Ionic, and Corinthian (Segal, 1988).

Ionic capitals are found under the frieze of the Germani tomb dated to the early second century AD. Another Ionic capital discovered at the north mausoleum dated to the end of the third century AD. Corinthian capitals recur to the late second and early third century AD. The complete column at ancient Gadara is composed of the pedestal as a base, the drums (two, three or four above each other) and finally the Corinthian capital on the top of them (Segal, 1988).

A large portion of the western Roman Theater (Fig. 3) has survived historic upheavals (Segal, 1988). A vaulted passageway supports its rows of seats. Built of hard basalt stones, a row of elaborately carved seats for dignitaries stand near the orchestra, and in the center is a large headless white marble statue of Tyche, the Goddess of fortune of the city, which is now displayed at a nearby museum.

Figure 3. The Western Roman Theater (Brent MacDonald of http://www.bibleistrue.com/qna/pqna63.htm)

The north theatre in Gadara is larger than the west one. The diameters of its orchestra and its exterior diameter are 45 meters and 77 meters, respectively. The west theatre is smaller, it was built with a diameter of 53 meters. Both theatres were built in the second century AD for various purposes such as tragic and comic plays, religious processions, and poetry in honor of the city's gods (Weber, 1989).

Across from the theater is the main colonnaded street (Cardo) which was in all likelihood the town's commercial center. Also, there are a terrace near the black basalt theater, ruins of the Nymphaeum along the east-west colonnaded street (Decumanus), a bath complex, and a well-preserved roman mausoleum can be seen (Segal, 1988). The word Nymphaeum is derived from the sacred water pools dedicated to the nymphs (water goddess) who lived near water sources. Baths of Herkleides Thermae (public baths) were named after a Gadarene nobleman whose name appeared into a Greek inscription within a wreath on a mosaic floor. Romans tapped water to Gadara from Ain Trab (aqueduct) which was 13 kilometers east of Gadara. Two tunnels with a depth of 15 meters run under the Acropolis were part of the aqueduct (Frevel, 2005).

The Decumanus Maximus is the paved and colonnaded long street in ancient Gadara. It is regarded as the main thoroughfare which divided Gadara into two areas, a small northern part, and a big southern one. The Decumanus Maximus is oriented into east- west direction with 1,7 km, and is colonnaded on both sides by limestone columns, and paved with basalt slabs (Frevel, 2005).

The Roman Zeus temple is located to the northwest of the north theatre. It had been built in the second century BC during the reign of the Seleucid king Antiochos the fourth who founded sanctuaries in different towns for his favorite god, Zeus Olympios. The Propylaeum of the Roman temple lies on the southern side of the Decumanus Maximus (Nielsen, et a., 1993). The Basilica Terrace (the Octagonal church and its Atrium) comprises two coherent parts: the basilica octagonal church to the south and its rectangular atrium. Basalt and limestone Corinthian capitals and columns were transported during the Byzantine period from a Roman building, and re-used to erect the basilica Terrace (Kerner, 1989-1994).

Cave of Issa (Jesus or Issos) is located about four kilometers to the west of GADARA. It is believed that Jesus Christ visited Gadara where he cured two mad men by transforming their evil souls into a herd of pigs which were frightened and sank into the Sea of Galilee (Mathew 8:28; Holy Bible, 2011).

EXPERIMENTAL METHODS

A mobile monitoring station was placed at the southern curb of the road that passes by the historical town which connects Umm Qais with its western orchards. The road is about eight meters wide and experiences low traffic flux as it is mainly used by local residents in order to reach their olive groves. The station is equipped with analyzers (Thermo Environmental Instruments Inc.) which is capable of measuring sulfur dioxide (pulsed fluorescence method, model TEII 43C), nitrogen oxides (chemiluminescence, model TEII 42i), ozone (UV optical absorbance, model 49), and carbon monoxide (gas filter I.R. absorption, model 48i), air temperature, wind speed, wind direction and relative humidity (Table 1).

Analyzers were set to record readings every five minutes for one week- July 3 through July 10, 2012. Collected data were automatically and continuously downloaded into a companion PC. Analyzers were calibrated at the sampling site prior to starting the experiment in order to ensure proper functioning.

Table 1. Continuous monitoring analyzers, their accuracy, and lower detection limit.

Instrument Type	Measured Parameters	Accuracy	Lower Detectable Limit
Chemiluminnescence NO-NO_2-NO_x Analyzer	Nitrogen Oxides (NO_x ppb)	±0.04 ppb	0.4 ppb
UV Photometric O3 Analyzer	Ground Level Ozone (O_3 ppb)	±1 ppb	1 ppb
Gas Filter I.R. Absorption Analyzer	Carbon monoxide (ppb)	±1 ppb	1 ppb
Pulsed Fluorescence SO_2 Analyzer	Sulfur Dioxide (SO_2 ppb)	±1 ppb	1 ppb
Temperature Sensor	Temperature (°C)	±0.3 °C	0.3 °C
Humidity Sensor	Relative Humidity (%)	± 3%	3%
Wind Speed Sensor	Wind Speed (m/s)	±0.3 m/s	0.3 m/s

RESULTS AND DISCUSSION

Climatology

The climate in Gadara is semi-arid, and is characterized by hot-dry summer and mild with irregular rainfall winter. Weather patterns in the region are strongly influenced by phenomena originating in central Asia during winter and in India and Iran during summer. During winter, large scale meteorological features, which influence southern Levant, are southward extending ridges of high pressure from Siberia interrupted by depressions moving eastward from the Mediterranean Sea. Associated cold fronts can cause squalls, rain and thunderstorms. The depressions are usually preceded by southwest winds and followed by northwest winds that have the potential to produce rain during winter months. In summer, a large thermal low is formed over northwestern India and Iran. Arabia and southern Levant are on the western part of this semi-permanent low, resulting in prevailing northwest and northerly winds throughout the summer.

Meteorological data of the study area during this measurement campaign are illustrated in Table 2. The average air temperature is 26.4 °C, with minimum temperature of 16.5 °C recorded during night time and maximum temperature of 36.2 °C. The average relative humidity varies between 44.7% and 87.5%. Higher relative humidity and moderate annual precipitation at the project site multiply the wet-deposition of atmospheric pollutants which lower their concentrations in ambient air, but would likely increase the acidity of rain droplets.

Table 2. Summary of wind speed (WS) and temperature (T) observations

Parameter	Value
Min WS (m/s)	0
Max WS (m/s)	9.1
Avg WS (m/s)	3.3
Min RH (%)	44.7
Max RH (%)	87.5
AvgRh(%)	66.1
Min T (°C)	16.5
Max T (°C)	36.2
Avg T (°C)	26.4

West and northwesterly wind dominates wind direction at the study area (Figure 4) indicating that the monitoring site is potentially impacted by regional transported pollutants originating to the west or northwest of the monitoring station. During midnight and early morning period, wind tends to fluctuate between southeast-south-west and northwest directions; but west-northwest wind prevails when starting around 9:30. The maximum wind speed at Gadara was9.1 m/s occurring at 4:50 pm.

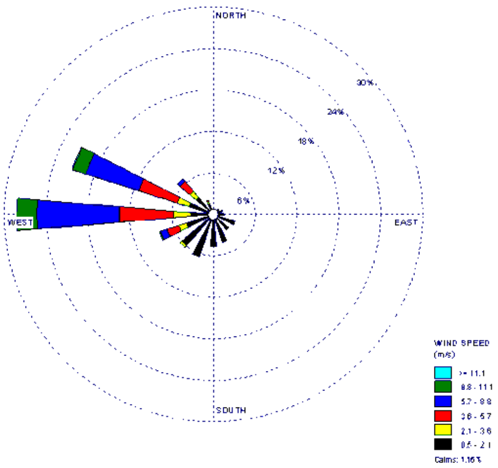

Figure 4. Wind direction and speed distribution for the study area during the period 3/7/2012 through 10/7/2012.

AMBIENT AIR QUALITY

With the exceptions of ozone, monitored concentrations of air pollutants are found to be well below Jordanian standards of ambient air quality (JSAAQ), which are summarized in Table 3. Mean daily concentrations of sulfur dioxide (SO_2) were 5.0 ppb (Fig. 5). Mean daily concentrations of carbon monoxide (CO) were 500 ppb (Fig. 6).

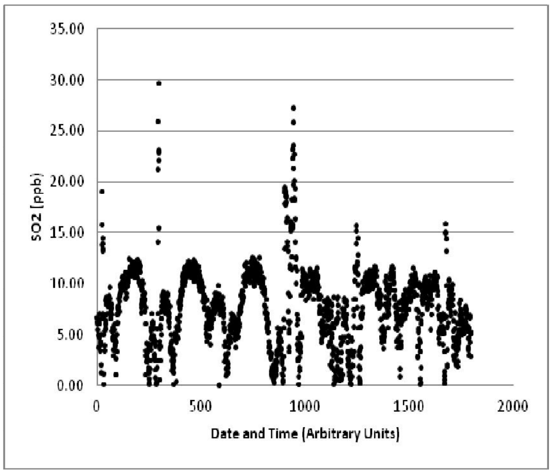

Figure 5: Average Hourly SO_2 Concentrations at Gadara.

Table 3.Jordanian Ambient Air Quality Standards (JS-1140/2006).

Duration	Pollutant	Maximum Allowable Concentration	Number of Allowable Exceedances
1-hour	SO_2	0.300 ppm	3 times/ any consecutive 12 months
24-hours	SO_2	0.140 ppm	1 time/year
Annual	SO_2	0.040 ppm	-------
24-hours	TSP	260 µg/m^3	3 times/ any consecutive 12 months
Annual	TSP	75 µg/m^3	-------
24-hours	PM_{10}	120 µg/m^3	3 times/ any consecutive 12 months
Annual	PM_{10}	70 µg/m^3	------
24-hours	$PM_{2.5}$	65 µg/m^3	3 times/ any consecutive 12 months
Annual	$PM_{2.5}$	15 µg/m^3	------
1-hour	NO_2	0.210 ppm	3 times/ any consecutive 12 months
24-hours	NO_2	0.080 ppm	3 times/ any consecutive 12 months
Annual	NO_2	0.050 ppm	------
1-hour	CO	26 ppm	3 times/ any consecutive 12 months
8-hours	CO	9 ppm	3 times/ any consecutive 12 months
1-hour	H_2S	0.030 ppm	3 times/ any consecutive 12 months
24-hours	H_2S	0.010 ppm	3 times/ any consecutive 12 months

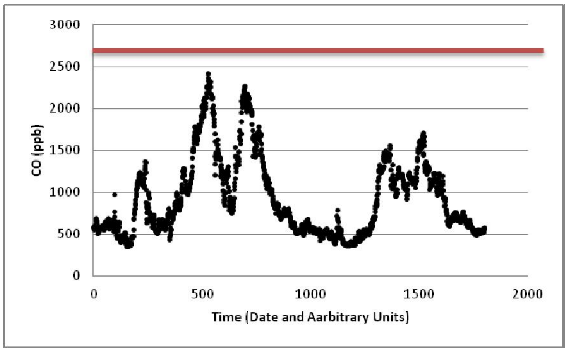

Figure 6: Average Hourly CO Concentrations at Gadara are below the Jordanian Standard which is illustrated by the red line at the top of the chart.

Concentrations of nitrogen dioxide (NO_2) during the monitoring period are illustrated in Fig. 7. Mean hourly concentrations of nitrogen dioxide (NO_2) were 12.8 ppb.

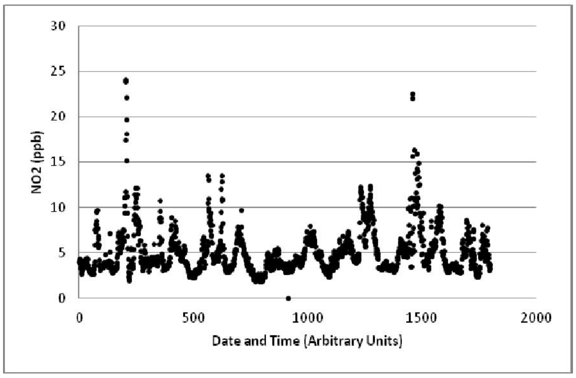

Figure 7: Hourly NO_2 Concentrations at Gadara.

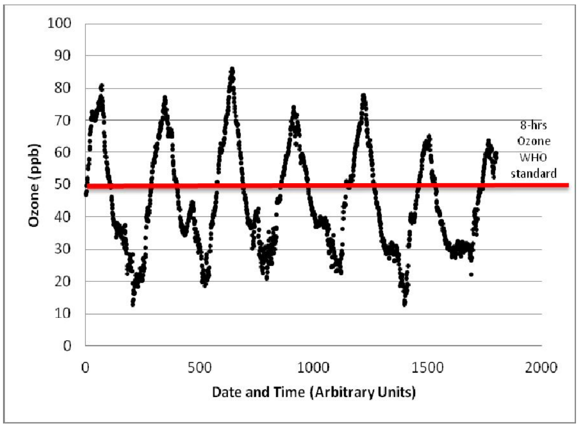

Figure 8: Hourly O_3 Concentrations at Gadara.

There are no JSAAQ for ground ozone, therefore its measured concentrations are assessed against standards recommended by world health organization of 50 ppb (WHO, 2000). It is evident that there are several incidences where ground ozone exceeded above mentioned standards (Fig. 8), which agrees with previous studies which reported high ozone values at north Jordan (Weinroth et al., 2008). Ozone is catalytic agent that expedites chemical reaction between atmospheric acids and rocks' minerals. Therefore high concentration of ground ozone at Gadara has the potential to facilitate the erosion and deterioration of ancient buildings, statues, and monuments therein.

Reaction of rocks with atmospheric acids occurs during the process of absorption onto the surface. This produces sulfite which is subsequently oxidized to sulfate in a process termed sulfation, which is accelerated by the presence of ozone (Martin 1984; Adema and Heeres,1995; Elfving et al., 1994a,b,c; Johnson et al.,1996; Massey, 1999;). The surface sulfate (gypsum for example) gradually deteriorates under humid conditions.

MITIGATION PLAN AND SUSTAINABLE PROTECTION OF THE CULTURAL HERITAGE AGAINST DETERIORATION

The preservation of the cultural heritage against serious threats, including air pollution, is the responsibility of the entire humanity. Therefore, in order to reduce the threat faced by the cultural heritage and antiquity at Gadara, collaborative efforts at the national and international levels have to be deployed. Adopted actions must ensure effective multilateral dissemination of information by developing and concentrating the scientific and technical data available in collaborative countries through existing professional international bodies, and developing practical long-term cooperation across borders or between regions.

The conservation and protection actions of the antiquity should focus on eliminating or mitigating the causes of deterioration such as negative climatic effects, pollution, and biological growth. Protective actions should also make available antiquities less vulnerable to weathering agents through identifying, eliminating, and/or mitigating intrinsic factors that accelerate deterioration.

Public awareness about the nature of deterioration and conservation concepts should be promoted at local, national, and regional levels. Awareness should also be fostered on the nature of the risk that the public themselves may impose when visiting the cultural site.

CONCLUSION

This study was undertaken in order to assess air quality in northern Jordan including seven ancient cities which formed the historic Decapolis trade center. Measurements were taken at Gadara, the capital of the Decapolis. Air pollutants; that were measured; include carbon monoxide, sulfur dioxide, nitrogen oxides, and ground ozone.

Basic meteorological parameters were also measured. Findings indicate that most detected air pollutants were below their maximum corresponding national limits that are set by Jordanian ministry of environment. However, ground ozone exhibited several incidences where it has exceeded maximum limits set by WHO. High ozone values go in line with previously published modeling results which predict high values of ground ozone in north Jordan. There is a great concern that ozone may expedite erosion and deterioration rates of rocks at Gadara, therefore, a mitigation plan has to be strictly adopted in order to protect the treasures of Gadara as well as other historic sites in north Jordan. Findings also indicate that westerly and northwesterly wind was predominant during this measurement expedition which implies that the monitoring site and the city of ancient Gadara are influenced by air pollutants that originated somewhere to the west or northwest of Gadara.

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