

# **Ambient Concentrations and Chemical Composition of PM<sub>2.5</sub>: A Regional Source Apportionment Study**

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## I. Executive Summary

The term fine particulate matter 2.5 (PM<sub>2.5</sub>), refers to small particles in the air of two and half microns or less that, at high enough levels, are known to have adverse health effects on human populations. Though monitoring and reducing fine particulate matter is a serious issue in nearly every industrial or developing region, to date, only a small amount of PM<sub>2.5</sub> monitoring data for the Israel-Palestine-Jordan region exists.

The M23-20 PM<sub>2.5</sub> study represents a significant and pioneering contribution to scientific knowledge of PM<sub>2.5</sub> composition and concentration within the Israel-Jordan-Palestine region. By conducting a long-term, wide-ranging measurement campaign and by quantifying key chemical species present in PM<sub>2.5</sub>, a unique dataset with high spatial and temporal resolution was obtained, thus enabling regulatory efforts to focus on effective control measures.

In addition to the scientific-regulatory objective, the project aimed to:

1. Conduct research jointly as a model of regional cooperation.
2. Use the research conducted as a platform for building local capacity in the field of environmental monitoring.

PM<sub>2.5</sub> was measured over twelve months—from January to December 2007—at 11 sites located in Israel, Jordan, and the Palestinian Authority. At each selected sampling site, 24-hour integrated PM<sub>2.5</sub> samples were collected every six days (~ 5 samples per month) for the characterization of PM<sub>2.5</sub> mass concentration and chemical composition.

The average PM<sub>2.5</sub> mass concentration for all sites was 28.2  $\mu\text{g m}^{-3}$ . The highest annual average concentrations were recorded in Amman at 40.3  $\mu\text{g m}^{-3}$ , and the lowest levels were recorded in the Aqaba, Eilat, and Rahma regions, with averages in the range of 20 to 25  $\mu\text{g m}^{-3}$ . Even the lowest averages recorded are above international standards considered to be the limit for avoiding adverse impacts of fine particulate matter on human health: the World Health Organization, for example, has 10  $\mu\text{g/m}^3$  as its standard; the U.S. Environmental Protection Agency has 15  $\mu\text{g/m}^3$ . The study results show that the contribution of annual average dust to total PM<sub>2.5</sub> concentrations ranges from 13 to 25% at all sites. Secondary inorganic ions, including ammonium sulfate ((NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>) and ammonium nitrate (NH<sub>4</sub>NO<sub>3</sub>), which largely arise from atmospheric oxidation of sulfur dioxide and nitrogen oxide gas emissions, contributed together an annual average of 7.5  $\mu\text{g m}^{-3}$  to total PM<sub>2.5</sub> mass concentrations. This level of inorganic PM<sub>2.5</sub> content is comparable to, or in some cases, lower than, levels seen in many urban regions in Europe and North America.

Carbonaceous material (organic matter and elemental carbon) was the dominant contributor to PM<sub>2.5</sub> mass in the region, comprising, on average, about 50-60% of the PM<sub>2.5</sub> mass. Strong spatial differences were observed for both organic and elemental carbon, indicating the significant influence of source location on PM<sub>2.5</sub> measurements.

The major objectives of the project have been deemed completely fulfilled. The three research teams plan to continue sharing a common database, and they plan to issue joint publications based on the analyzed results of the project soon, as well. The results of the study will be published in English, Arabic, and Hebrew, and will be brought to the attention of the government of each respective research team.

## II. Research Objectives

Fine particulate matter - PM<sub>2.5</sub>, is a well known air pollutant which is clearly associated with adverse health effects. Numerous studies have documented the associations between high ambient PM<sub>2.5</sub> concentrations and a wide variety of cardio-respiratory health concerns, including lung cancer and premature mortality. The development of effective air pollution regulations in the Middle East has been heretofore impeded by a lack of knowledge about the sources and composition of PM<sub>2.5</sub> in the region. Furthermore, the existing dataset on PM<sub>2.5</sub> consists of mass concentration only, thus giving very limited clues about the PM<sub>2.5</sub> pollution origin. Chemical analysis of PM<sub>2.5</sub> composition quantifies chemical tracers, the knowledge of which helps estimate different PM<sub>2.5</sub> source contributions and thereby also provides new insight into the development of effective control PM<sub>2.5</sub> measures.

The M23-20 PM<sub>2.5</sub> study represents a significant and pioneering contribution to the scientific knowledge of PM<sub>2.5</sub> composition in the region. By conducting a long-term, wide-ranging measurement campaign consisting of more than 60 day-long measurements in each of the selected 11 sites over the course of one year and then by quantifying key chemical species present in PM<sub>2.5</sub>, a unique dataset with high spatial and temporal resolution was obtained. Applying source apportionment techniques on the collected dataset provides a strong foundation for identification of the appropriate PM<sub>2.5</sub> sources, which thus enables regulatory efforts to focus on effective control measures.

In addition to the described scientific-regulatory objective, the project also aimed to:

1. Conduct research jointly as a model of regional cooperation.
2. Use the research conducted as a platform for building local capacity in the field of environmental monitoring.

The most recent MERC project on transboundary air pollution (MERC M18-054) studied the transboundary air pollution effects of urbanization on the Israeli-Gaza Mediterranean Coast. For MERC M18-054, Israeli and Palestinian researchers measured and modeled photochemical air pollution in the West Bank, Gaza, and Israel, as well they analyzed relevant meteorological data. Both the design and the goals of the M18-054 research are complementary to the PM<sub>2.5</sub> monitoring project M23-020, as these two projects focus on the two most challenging air pollution problems of the USA, Europe and Eastern Mediterranean regions: particulate matter and photochemical smog. Together, these projects provide valuable data to aid in the creation of regulatory measures that would manage a spectrum of air pollution problems.

### **Support from additional organizations:**

1. PM<sub>2.5</sub> monitoring in the Haifa area was performed in active partnership with the Haifa District Municipal Association for the Environment (HDMAE). The organization purchased, placed, and operated one URG PM<sub>2.5</sub> sampler in one of their air quality monitoring stations, and they participated in data assimilation and analysis tasks throughout the duration of the project.

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2. *Yad Hanadiv* (the Rothschild Foundation) granted the project full support for the creation of a clean laboratory room, which included the purchase of precise balance for conducting the majority of the gravimetric analyses.

### III. Methods and Results

Methods and Design: Measurements were taken for twelve months (January 2007-December 2007) at 11 sites located in Israel, Jordan and the Palestinian Authority.

The sites—four in Israel, four in Jordan and three in the Palestinian Authority—were selected to represent varied background concentrations, urban development sources and trans-political as well as physical boundaries. A listing of the specific sites and their characteristics are listed in **Table 1: Sampling Sites and their general characteristics**. A map noting the location of the sites within the region can be seen in **Figure 1**.

At each selected sampling site, 24-hour integrated PM<sub>2.5</sub> samples were collected every six days (~ 5 samples per month) for the characterization of PM<sub>2.5</sub> mass concentration and chemical composition.

The study sampling sites were located in Haifa (HF), Tel-Aviv (TA), West Jerusalem (WJ), East Jerusalem (EJ), Eilat (LT), Hebron (HB), Nablus (NB), Aqaba (AB), Amman (AM), Zarqa (ZA) and Rahma (RM). Each site was equipped with a URG-3000ABC medium volume particulate sampler for PM<sub>2.5</sub> collection. This sampler is designed to remove coarse particle fractions (>2.5 microns) via a special cyclone separator to enable the collection of PM<sub>2.5</sub> only.

The URG fine particle sampler was configured to collect particulate matter onto filters in three out of four channels (two 47mm Teflon filters, one 47mm Quartz filter) via two separate air flow inlets of ~16.7 liter per minute (lpm) passing through the PM<sub>2.5</sub> cyclone. This was followed by a manifold used to split each individual flow into two 8.35 lpm flows that were collected on the one Quartz filter, two Teflon filters, and one bypass stage that was not used for sample collection.

Flow rates were controlled by critical orifices located upstream of a vacuum pump and were measured periodically throughout each sampling day with a calibrated rotometer.

Operators at each of the 11 sampling sites were carefully trained in filter handling and storage. After each sampling period, filter samples were sealed in Petri dishes and stored in a freezer to minimize contamination and the loss of volatile species.

Samples were later transported in batches in ice-packed coolers to the project's central depot at the Hebrew University in West Jerusalem, as well as to the Weizmann Institute in Rehovot, for gravimetric mass concentration measurements and Elemental Carbon \ Organic Carbon (EC\OC) analyses, respectively. The filters were subsequently sent to Reno, Nevada, and Madison, Wisconsin, for additional chemical measurements: water soluble ions by Ion Chromatography (IC) and trace elements by X-Ray Fluorescence (XRF).

In order to track any possible contamination from sample preparation during field and laboratory handling, 12 field blanks (one per sampling month) were taken at each site. The blank filters were stored and transported alongside the 24h samples.

Gravimetric analysis was performed using a 5 digit accuracy Sartorius ME 5-F gravimetric balance. The balance was placed in a humidity-controlled glove box inside a clean, temperature-controlled room.

EC/OC analysis was performed using a Sunset Laboratory Inc. thermal-optical carbon analyzer and the US NIOSH 5040 protocols. Trace elements, including trace metals, were analyzed by X-Ray Fluorescence (XRF) using protocols also used by the US EPA for its fine particle chemical speciation trends network. Water soluble ions, including sulfate, nitrate, ammonium, chloride, sodium and potassium, were analyzed by extraction of the samples from high purity water and analysis by an Ion Chromatograph (IC).

Table 1: Sampling Sites and their general characteristics

<b>SITE</b>	<b>SITE CODE</b>	<b>LOCATION</b>	<b>SITE DESCRIPTION</b>
Haifa	HF	Israel	Urban
Tel-Aviv	TA	Israel	Urban
W.Jerusalem	WJ	Israel	Urban
Eilat	LT	Israel	Urban
Nablus	NB	Palestinian Authority	Urban
E.Jerusalem	EJ	Palestinian Authority	Urban
Hebron	HB	Palestinian Authority	Urban
Zarqa	ZA	Jordan	Urban
Amman	AM	Jordan	Urban
Rahma	RM	Jordan	Rural/Background
Aqaba	AB	Jordan	Urban

**Figure 1: A map of the region and the study locations**

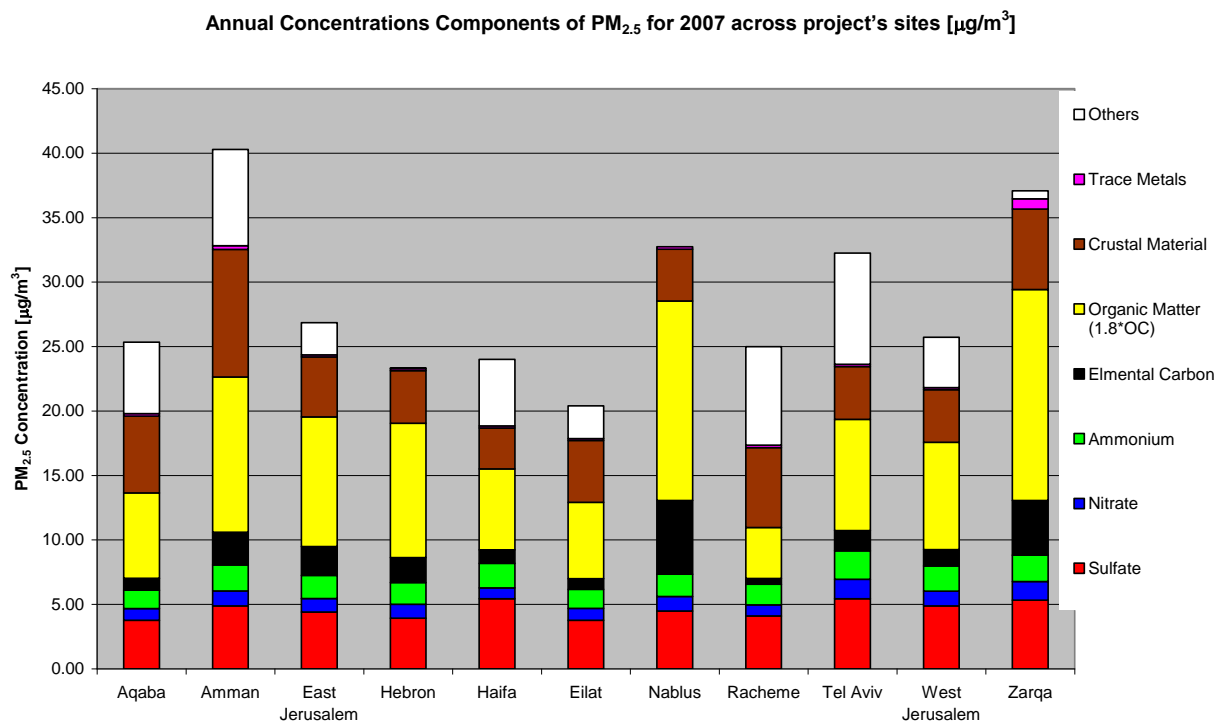


### Study results and discussion:

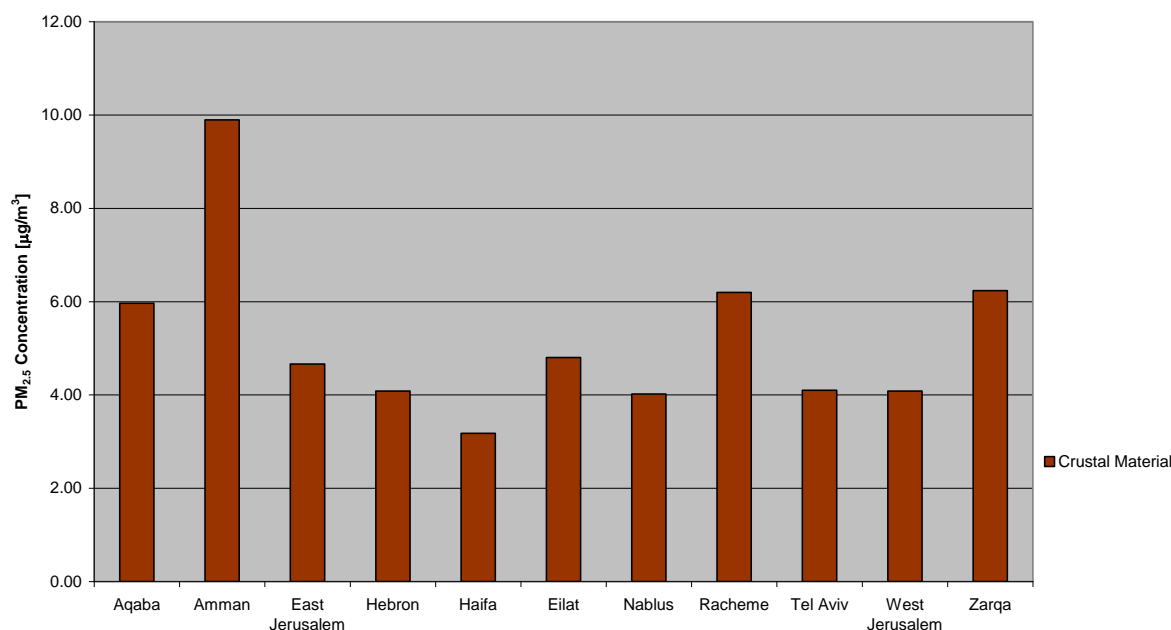
Although the 11 sampling sites in the study seem to cover only relatively small portion of the region, in the context of PM<sub>2.5</sub> and air pollution transport, the sites are impacted by quite different sources and meteorology. As a result, the 11 sites have PM<sub>2.5</sub> trends and concentrations that share some characteristics similar to data from other regions of the world, but these sites capture features that are uniquely associated with the locations in the Middle East.

The average PM<sub>2.5</sub> mass concentration for all sites was 28.2  $\mu\text{g m}^{-3}$ . The highest annual average concentrations were recorded in Amman at 40.3  $\mu\text{g m}^{-3}$ , and the lowest levels were recorded in the Aqaba, Eilat, and Rahma regions, with averages in the range of 20 to 25  $\mu\text{g m}^{-3}$ . Bulk annual average concentrations in all sites can be seen in Figure 2.

**Figure 2: Graph of PM<sub>2.5</sub> Concentration in 2007**



Compared to virtually all existing PM<sub>2.5</sub> standards in Europe and North America (for example, World Health Organization has a standard of 10  $\mu\text{g/m}^3$ ; the U.S. Environmental Protection Agency's standard is at 15  $\mu\text{g/m}^3$ ), these levels are considered to be too high to protect against adverse health impacts on humans. There have been some assertions that PM<sub>2.5</sub> in the Middle East may have different risk factors than in other parts of the world due to the potential for high contributions of re-suspended dust to particulate matter concentrations. These study results show that the annual average dust contributions to the total PM<sub>2.5</sub> concentrations was in the range of 13 to 25 percent at all sites. The fine particle crustal material observed in this research project is shown in Figure 3. It is important to note that crustal material is the main component of desert dust.

**Figure 3: Crustal Fraction Concentration in 2007**Annual Concentrations Components of PM<sub>2.5</sub> for 2007 across project's sites [ $\mu\text{g}/\text{m}^3$ ]

The highest crustal dust contributions to PM<sub>2.5</sub> were found in the Aqaba, Eilat and Rahma regions, as well as in Amman. The high dust levels in Amman are believed to result from the extensive construction taking place in the city during the study period. At all other sites, the annual average dust contribution to PM<sub>2.5</sub> mass was in the range of 13-18 percent, which is not very different from the levels measured in most European and North American urban areas.

Secondary inorganic ions, including ammonium sulfate and ammonium nitrate, which largely arise from atmospheric oxidation of sulfur dioxide and nitrogen oxide emissions, contributed together an average of  $7.5 \mu\text{g m}^{-3}$  to the total PM<sub>2.5</sub> mass concentrations on an annual average basis at the study sites. This level is comparable to, or lower than levels seen in many urban regions in Europe and North America.

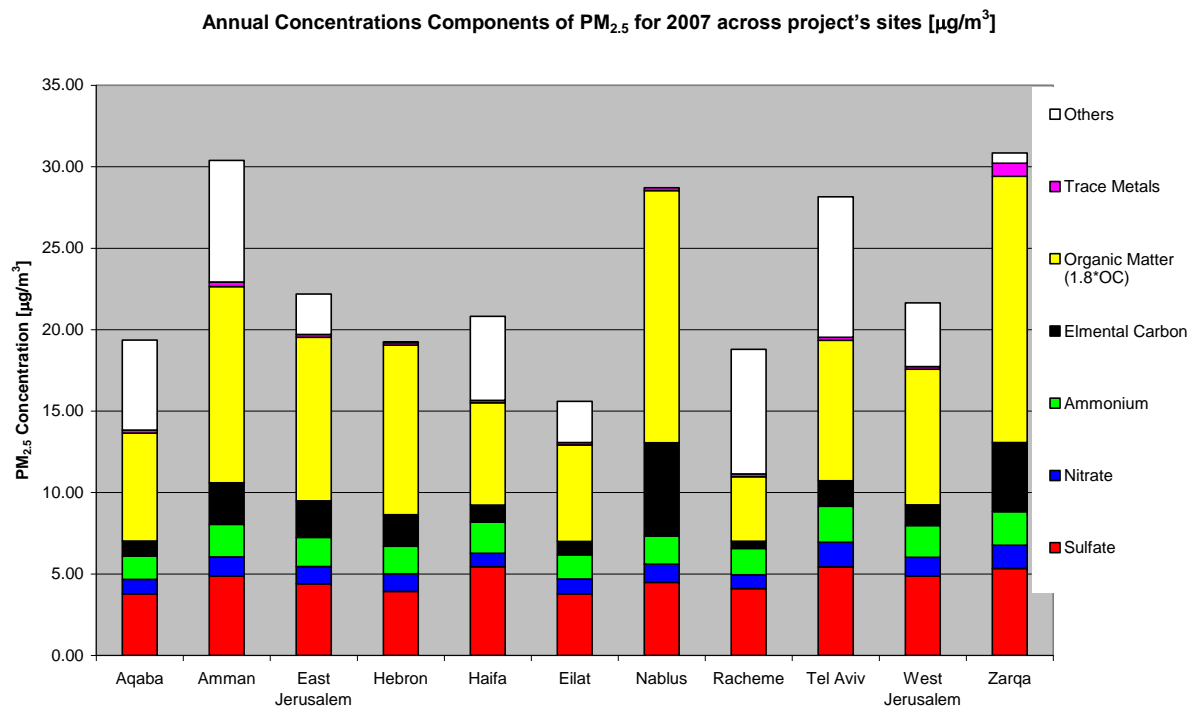
Although the annual average concentrations of these species are relatively consistent for all study sites, different trends in the monthly average concentrations, naturally clustered by geographic region, were observed. Tel Aviv and Haifa had a distinct sulfate peak concentration in early spring, while all other sites, with the exception of Amman and Zarqa, showed peaks in late summer or early fall. Amman and Zarqa showed no strong seasonality in sulfate concentrations. These results indicate the connectivity of the secondary inorganic components in Jordan Valley.

Carbonaceous material (organic matter and elemental carbon) was the dominant contributor to PM<sub>2.5</sub> mass in the region, with an overall average of about 50-60% of the PM<sub>2.5</sub> mass. Strong spatial differences were observed for both organic and elemental carbon, indicating the importance of local sources.

The highest levels of PM<sub>2.5</sub> organic carbon were observed in Zarqa, Nablus, and Amman. Although secondary organic aerosol, which is mainly particulate matter

formed from the oxidation of gas-phase volatile organic compounds, is an important source of organic material in the region, the data demonstrate the importance of local, including mobile, sources. The OC/EC concentrations in Tel Aviv are 38% and 50% higher than those measured in Haifa. The importance of mobile sources was quantified for all sites using the measurement of organic compound tracers or molecular markers. Organic and elemental carbon concentrations, with the possible exceptions of Eilat, Aqaba and Rahma, represent the most important contributors to PM<sub>2.5</sub> in the region in the context of Europe and North America PM<sub>2.5</sub> pollution. The study also revealed that toxic metals in PM<sub>2.5</sub> varied significantly across the sites, with the highest concentrations in Haifa and Zarqa. Haifa had significantly higher concentrations of nickel and zinc compared to the other sites; this higher level is suspected to result from the combustion of residual oils used by ships, the stationary combustion of fuel oil, or by industrial activity. Likewise, Zarqa had significantly higher concentrations of lead in the PM<sub>2.5</sub> samples than any other site, including Aqaba and Amman, suggesting that the high level of lead in Zarqa is not the result of leaded gasoline fuel, a type of fuel still used in Jordan during the study period. Annual concentrations of the abovementioned fractions, excluding the crustal fraction, are presented in **Figure 4**

**Figure 4: PM<sub>2.5</sub> components concentrations in 2007**



As can be seen in **Figure 4**, PM<sub>2.5</sub> concentrations, even after subtraction of the crustal fraction, and thus leaving mainly anthropogenic species, still do not meet the 15  $\mu\text{g}/\text{m}^3$  annual level maintained by the U.S EPA.

The spatial and temporal variability of the measured PM<sub>2.5</sub> and its chemical components were further examined on a subset of seven sites using summary statistics, correlation analysis, and coefficient of variation (COV). The sites included in this sub-analysis (ordered geographically from west to east) were Tel Aviv, Haifa, Hebron, W. Jerusalem, E. Jerusalem, Nablus and Amman. Factor analysis was

conducted on the total PM<sub>2.5</sub> mass as an initial data reduction tool. Results from the factor analysis conducted for PM<sub>2.5</sub> mass on all 11 sites indicated that the four sites not included in the current sub-analysis had unique and dominant local sources of PM<sub>2.5</sub> and, hence, are not included in the present report.

Since a primary objective of this study was to compare PM<sub>2.5</sub> and its major components across sites, summary statistics as well as the other analyses were conducted using data collected on days when results from all seven sites were available for a given pollutant species ('matched data'). Three dates were removed from the comparative analyses due to the occurrence of extreme events that substantially influenced PM<sub>2.5</sub> concentrations throughout the entire region. Dust storms occurred twice on sampling days, leading to extremely elevated levels of total PM<sub>2.5</sub> and its crustal component. Also, sampling was conducted on the Jewish holiday known as Lag B'Omer (the 33<sup>rd</sup> day of the Omer period), which is celebrated throughout Israel with bonfires and corresponding highly elevated PM<sub>2.5</sub> concentrations and particulate components associated with biomass burning. All three of these sampling days provide little relevant information concerning the typical spatio-temporal relationships for PM<sub>2.5</sub> in this region, and were, therefore, removed.

Results showed considerable variability among the sites in mean total PM<sub>2.5</sub> concentrations, with values ranging from 19.8 µg/m<sup>3</sup> in Haifa to 34.9 µg/m<sup>3</sup> in Amman (again, these values do not include days when extreme PM<sub>2.5</sub> episodes occurred). While annual PM<sub>2.5</sub> standards had not been set forth by any of the local governments at the time of this analysis, it is worth noting that all sites exceeded internationally-accepted air quality standards for annual PM<sub>2.5</sub> mass concentrations even after the results of the three extreme days were removed.

PM<sub>2.5</sub> concentrations in Tel Aviv and Amman were the highest among the cities examined, with levels that were 2-3 times that of international standards. Despite differences in absolute concentrations, correlations for total PM<sub>2.5</sub> mass among the sites were moderate to strong (> 0.50). Of the 21 possible pairwise correlations for PM<sub>2.5</sub>, the mean correlation coefficient was 0.64, with Haifa and Amman pair having the only correlation lower than 0.50 (r = 0.35).

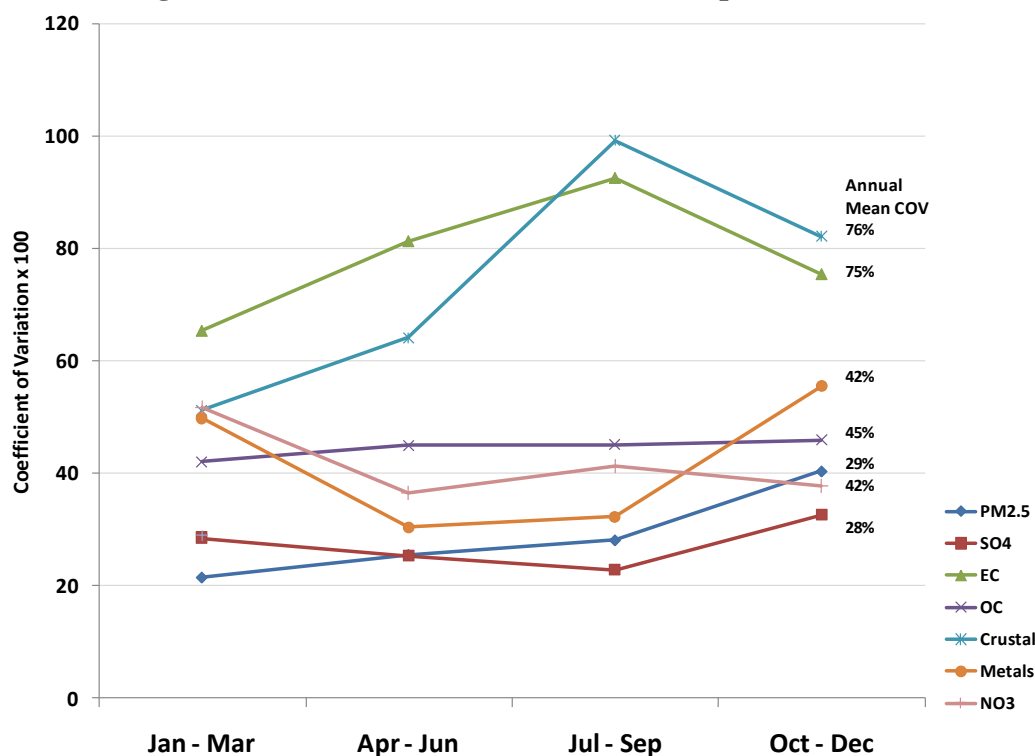
**Table 2: Mean pairwise correlation coefficient between a given site and six other sites**

Given Site	PM <sub>2.5</sub>	Sulfate	EC	OC	Metals	Crustal	Nitrate
<b>Tel Aviv</b>	0.64	0.76	0.49	0.63	0.54	0.60	0.54
<b>Haifa</b>	0.58	0.75	0.39	0.54	0.51	0.60	0.51
<b>Hebron</b>	0.69	0.73	0.36	0.66	0.50	0.65	0.60
<b>W. Jerusalem</b>	0.72	0.81	0.51	0.66	0.63	0.74	0.62
<b>E. Jerusalem</b>	0.64	0.68	0.33	0.49	0.52	0.60	0.64
<b>Nablus</b>	0.64	0.79	0.30	0.62	0.54	0.64	0.64
<b>Amman</b>	0.55	0.56	0.48	0.64	0.38	0.48	0.61

Among the  $PM_{2.5}$  components, sulfate ion<sup>-</sup> was the most homogeneously distributed among the sites, with a mean annual COV of 0.28 (Figure 5). Pollutant covariance differed by pollutant and time of year. There was noticeably greater variation among sites in  $PM_{2.5}$  crustal and EC components during the summer months of July through September, whereas mean variability among sites for the other components were typically lowest during this time period.

Correlation among sulfate ion concentrations among the sites was also the highest of all the chemical components measured, with a mean across-site correlation coefficient of 0.73 (Table 2). These results are consistent with those from other parts of the world, and are to be expected from a regional pollutant like sulfate, which is formed through secondary processes in the atmosphere. Sulfate in Amman provided the only exception to the uniform sulfate concentrations exhibited across the study area, with concentrations that were weakly correlated to all of the other sites (mean  $r_s$  between Amman and the other sites = 0.56) (Table 2). It is possible that this finding is due to local emissions from the numerous industrial sources in the Zarqa area, although this interpretation should be viewed as speculative and warrants further research to address definitively. It is also worth noting that  $PM_{2.5}$  aggregate metal concentrations were also substantially higher in Amman than in other sites, and Amman's results were only weakly correlated with particulate metal concentrations at the other six sites (mean  $r_s$  = 0.38). It is believed that this should be summed metals or dominated elements.

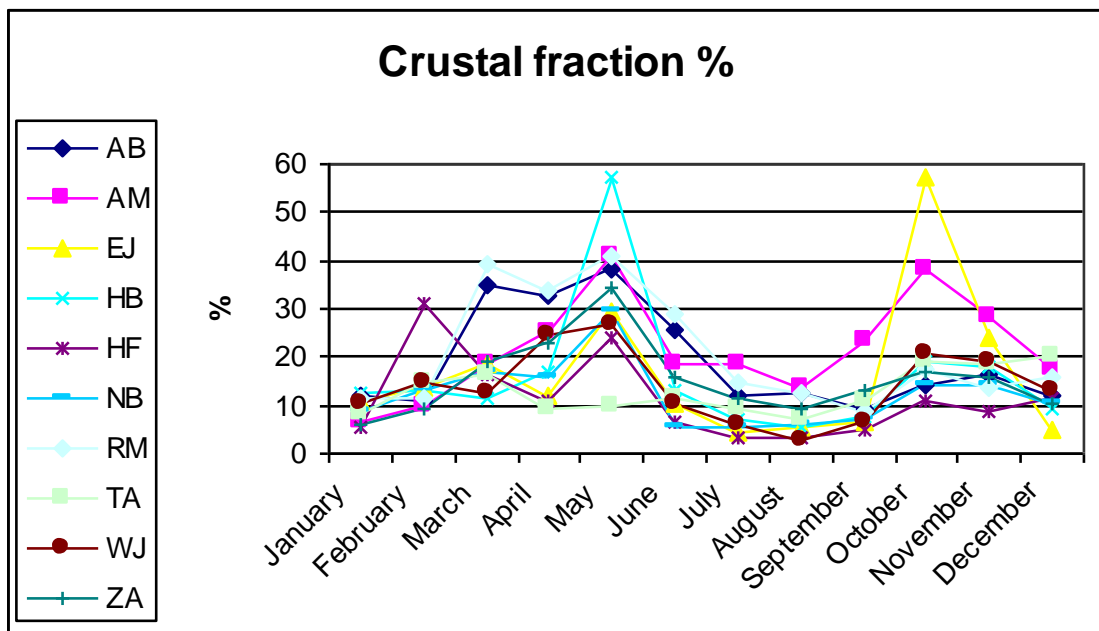
The spatial pattern of EC (elemental carbon) among the sites was also notable. EC is typically emitted from diesel engines and exhibits high intra-urban spatial heterogeneity given its local, primary source contributions. The present findings showed moderate to strong correlations ( $r > 0.65$ ) in EC concentrations among the large urban sites of West Jerusalem, Tel Aviv and Amman. Moreover, the correlation was high despite absolute differences in EC concentration measured in the  $PM_{2.5}$  in each of these cities. The high EC correlations in these urban centers may be due to synoptic conditions (i.e., the influence of stagnation episodes) and commuter activity patterns occurring in these urban areas. Similarly, weaker EC correlations among the other sites may point to the impact of specific EC sources beyond those of traffic-related emissions.

**Figure 5: Mean annual COV for PM<sub>2.5</sub> components in 7 sites**

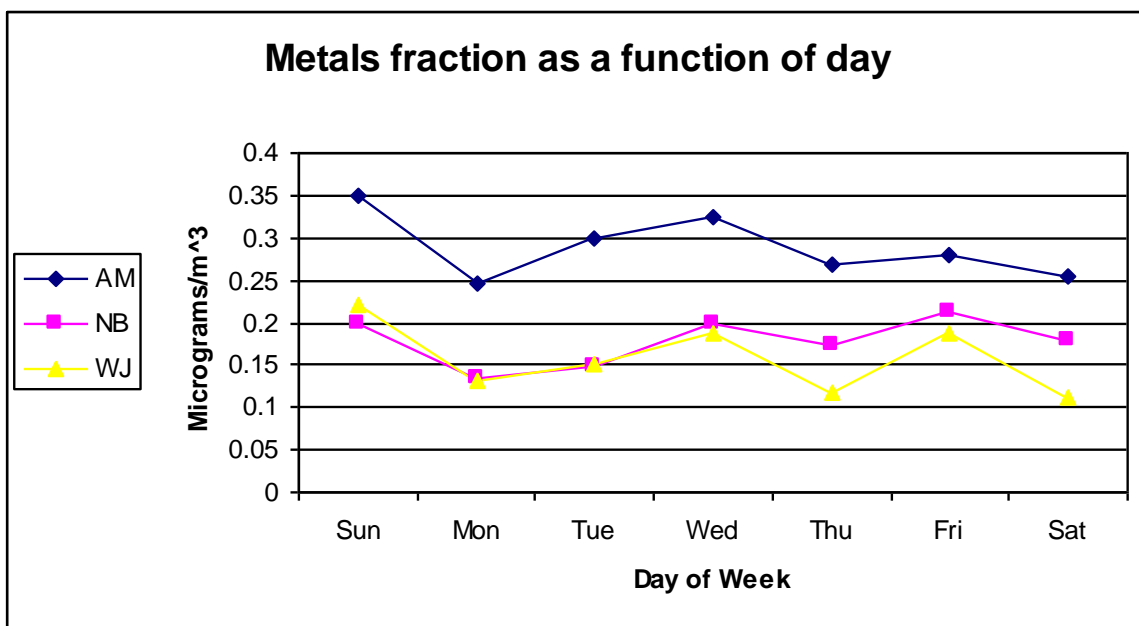
As for the temporal variability: seasonal variability showed PM<sub>2.5</sub> peaks in May and October, which was pivoted by crustal fraction peaks reaching ca. 60% of PM<sub>2.5</sub> mass in East Jerusalem and Hebron. This observation can be explained by the high probability of synoptic conditions leading to elevated dust concentrations that occur in the region in April-May and in October, for example, the Red Sea Trough and Sharav-Hamsin Saharan Cyclone. A further synoptic analysis is needed as a complementary source apportionment analysis aid to resolve anthropogenic and non-anthropogenic fractions as a function of place and time. Such resolving analyses would be vital to any future recommendations regarding PM<sub>2.5</sub> regulation in the region. Monthly variability of PM<sub>2.5</sub> concentrations, crustal fraction concentrations and crustal fraction mass percent are given in Figure 6, 7 and 8, respectively; and day of week variability for metal and organic fractions is shown in Figures 9 and 10, respectively.

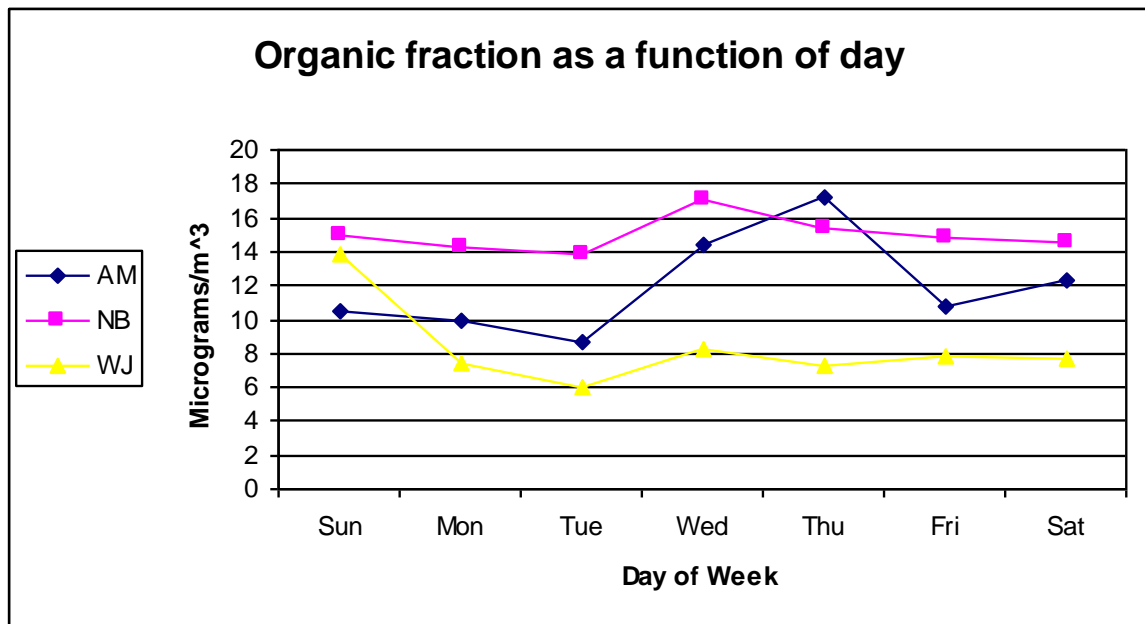


**Figure 8: Crustal fraction monthly average mass percent**



**Figure 9: Metal fraction average as a function of day of week**



**Figure 10: Organic fraction average as a function of day of week**

Figures 9 and 10 show no distinct variability as a function of day of week as was reported in the literature for organic fraction in several locations around the world. Further analysis is needed to discern which specific PM<sub>2.5</sub> components correlate with primary air pollution gases, such as NO<sub>x</sub> gases, which show reduced concentrations over weekends, and are thus thought to be linked to transportation sources. Further source apportionment aiding techniques--such as CMB model calculations and synoptic analyses—are planned to be performed prior to peer reviewed paper submission, which is expected during 2009.

## IV. Impact relevance and Technology transfer

The data of this project are a pioneering, wide, and unique set in their high spatial, temporal, and chemical resolution. The use of these data by all parties of the project will continue jointly and/or separately long after the project is finished. Some of the potential activities that will make use of these data are:

1. **Scientific paper writing.**
2. **Continued fine analysis of data:** analyses of spatial and temporal variability, trends and correlations of a broad set of chemical tracers have yet to be done, as current analyses were based on chemical groups of PM<sub>2.5</sub> components, not on specific chemical elements or compounds.
3. **Relating PM<sub>2.5</sub> concentrations and compositions to specific sources of pollution:** future research of source emission profiles (e.g. stack emission sampling, fuel composition measurements, etc.) may be combined with the current data in order to better assess major source shares in PM<sub>2.5</sub> in the air.
4. **Relating PM<sub>2.5</sub> concentrations and compositions to health outcomes:** although this project had planned to relate the results of its research to PM<sub>2.5</sub>'s impact on human health, accomplishing this huge task in the allotted timeframe proved to be beyond the project's ability. In a future analysis, health records can be compared to the current dataset in order to study the relationships between PM<sub>2.5</sub> concentrations and compositions and human health.
5. **Relating PM<sub>2.5</sub> concentrations and compositions to synoptic conditions:** synoptic records in the PM<sub>2.5</sub> measurement dates can also be used to study the synoptic conditions leading to elevated PM<sub>2.5</sub> concentrations. Combining meteorological trajectory models and source apportionment models can further constrain the origin of PM<sub>2.5</sub> in the region.
6. **Improving PM<sub>2.5</sub> regulations:** applying source apportionment techniques on this dataset could provide a strong tool for identifying PM<sub>2.5</sub> sources, which would enable more focused, and thereby effective, regulation efforts.

Jordanian, Palestinian, and Israeli researchers, field staff, and graduate students worked together on all aspects of the project, from field sampling to result evaluation and decision making.

The study was conducted with a commitment to joint research, teamwork, the transfer of available data, and operation as a single research unit. Cooperation and scientific advisory took place through constant email exchange, monthly conference phone calls, and personal meetings at the PI and managerial staff levels. PI's conducted quarterly meetings to monitor the project's progress.

The three research teams share a common database and are about to issue joint publications based on the analyzed results of the project. The results of the study will

be published in English, Arabic, and Hebrew and will be brought to the attention of the governments of each research team.

Three urban variability sub-projects (East vs. West Jerusalem, Eilat vs. Aqaba and Amman vs. Zarqa) were conducted along with the main project. The sub-projects consisted of additional continuous carbon soot monitoring. Furthermore, Palestinian, Israeli, and Jordanian MSc students who worked as field operators in the larger project were able to conduct these sub-projects as a part of their MSc thesis research. The sub-project results were reported in detail as appendices in the 6<sup>th</sup> semiannual report submitted to MERC.

The active participation of Professor Schauer from the University of Wisconsin (UW) offered a unique opportunity for the local teams to gain professional experience in a variety of source apportionment aspects: conducting of a wide field measurement campaign, combining of QA/QC considerations, laboratory work, data analysis and so on.

Professor Schauer shared valuable knowledge and contributed to the project's local capacity-building goal through his participation in imparting the most up-to-date scientific background to the local teams.

## V. Project Activities / Outputs

Listed below are the meetings attended and held during the project period.

- ◆ A joint 2-day launch meeting was held in Amman in July 2005 during which all Middle Eastern parties and US-based scientists were present.
- ◆ Telephone and e-mail contacts between Jordanian, Palestinian Authority, Israeli and US project scientists continued after the July launch meeting. These contacts involved discussions of finances, equipment purchases and orders, and siting criteria.
- ◆ During May 2006, Israeli co-Principal Investigators, Drs. Shmuel Brenner and Jeremy Sarnat, accompanied the project's Scientific Advisor, Dr. Jamie Schauer, to the proposed sampling sites in Amman, Zarqa, Aqaba, Rahma, Haifa, Eilat, West Jerusalem, and East Jerusalem.
- ◆ The second project-wide research meeting ("the May meeting") was held in East Jerusalem in May 2006. The main activities of this meeting were training on the sampling equipment and establishment field work Q/A protocol.

Additional meeting and activities held in the second half of 2006 and into 2007 include:

- ◆ Joint validation of PA and AIES samplers;
- ◆ PA training session in Haifa;
- ◆ Visit of PA project members to HUJI filter depot;
- ◆ Deployment of and on-site training for samplers in East Jerusalem by the AIES coordination manager;
- ◆ AIES MSc student meetings with JSSD project members during a visit to Amman to further the student's planned proposal comparing measurements in Aqaba and Eilat;
- ◆ A project meeting between the Jordanian and Israeli teams was held during December 2006 in Aqaba, Jordan.
- ◆ A project meeting between the Palestinian and Israeli teams was held in December 2006 at the Al Quds University building in East Jerusalem.
- ◆ The presentation: "Decoupling of Environmental Issues from the Overall Aspects of Political Disputes – Is It Possible? The Case of the PM 2.5 Study" was presented by Dr. Brenner at a NATO Advanced Research Workshop (ARW) on "Strategies to Enhance Environmental Security in Transition countries" in Sibiu, Romania, September 6-9, 2006.
- ◆ A project meeting between the Palestinian, Jordanian and Israeli teams was held during February 2007 in West Jerusalem.
- ◆ During August 2007, Dr. Brenner traveled to the US and attended the following meetings related to the progress of the project:
  1. Meetings and discussions with Prof. Schauer at the University of Wisconsin in Madison. Visits to the laboratories of the University and the Wisconsin Department of Environmental Health, focusing on the issue of the IC analysis.

2. Visit to the laboratories of the Desert Research Institute in Reno, Nevada, which focused on the metal analysis. Discussions with: Prof. Richard Tropp, assistant research scientist Ms. Dana Trimble, and Prof. Alan Gertler.
  3. Visit and discussions on overall sampling and analysis issues at the South Coast Air Quality Management District (SCAQMD) in Diamond Bar (Los Angeles), California. The visit was conducted by Dr. Philip Fine, Atmospheric Measurements Manager for Science & Technology Advancement.
- ◆ Mr. Khaled Nassar (JSSD) was invited to present the project at the conference of “Frontiers of Chemical Sciences III: Research and Education in the Middle East”, which was held in Istanbul, Turkey, from December 8-13, 2007.
  - ◆ Deployment of Aethalometer and TSI instruments in Amman and Zarqa sites by Rami Saleh (JSSD) and the Air Quality Center team (RSS) supervised by Eng. Faysal Anani.
  - ◆ Visit of Mr. Boris Goldman to Eilat site for repairing a leak found in the URG.
  - ◆ A project meeting between the Israeli PI, project manager, project coordinator and the Israeli and Palestinian BGU MSc students was held during November 2007 in West Jerusalem, during which they discussed different methods to analyze the results collected in their studies.
  - ◆ Dr. Sharf and Roei Elisha also visited the HUJI filter depot at that time.
  - ◆ Visits of Ben Cary, Dr. Schauer and Dr. Sharf to Weizmann Institute EC/OC lab.
  - ◆ Project meetings between the Palestinian and Israeli team leaders were held during July, September, October and November of 2007 in the Al-Quds University building in East Jerusalem.
  - ◆ The following paper was published:  
Brenner S., C. Lipchin, A. Amster, “Decoupling Environmental Problems from the Overall Aspects of Political Disputes: Is It Possible? The Case of the PM<sub>2.5</sub> Project” In: Strategies to Enhance Environmental Security in Transition Countries; R.N. Hull et al. (Eds.), pp. 215-224. © 2007 Springer.
  - ◆ In 2008, a data processing workshop for the project teams was held in West Jerusalem. The raw data from all project results were processed and sorted. The output of this workshop was a quality controlled dataset that served as the agreed basis for the source apportionment analysis.
  - ◆ Between May 19-26, 2008, Dr. Shmuel Brenner participated in a NATO ARW entitled "Rethinking Higher Education To Meet The New Challenges Of Environmental Security" at the Kharkiv State Municipal Academy in the Ukraine. There is a common understanding that the major global environmental problems (for example, climate change,

energy, water, desertification, diversity, ozone layer depletion, etc.) pose significant threats to world security. At the same time, local and regional problems (for example, health, poverty, waste and wastewater, air quality and soil contamination) have an enormous impact on the ability to combat both types of environmental problems.

The participants reviewed the abovementioned problems and heard several case studies regarding specific examples of such impacts in Eastern Europe, the USA, and Canada. Dr. Brenner presented the Israeli perspective with an emphasis on the Arava Institute and its unique pedagogic contribution concerning the environment and its linkage to the peace process. The MERC-funded transboundary PM<sub>2.5</sub> project was also presented in order to elaborate on the scientific merits associated with public health and capacity building, and the fruitful ongoing connections between Israelis, Palestinians, Jordanian and Americans despite troubled times.

- ◆ During September of 2008, Dr. Shmuel Brenner was invited by AIES to conduct a series of lectures describing the PM<sub>2.5</sub> project to several organizations in the USA. The main objectives of the lectures were to give an overview about the background, the structure, and the goals of the MERC-supported PM<sub>2.5</sub> project, emphasizing the project's environmental and public health aspects as well as its contribution to the peace process through transparency and capacity building in the region.

These meetings are listed in the following table:

DATE	PLACE	ORGANIZATION
Sept 8-9	Los Angeles	Friends of the Arava Institute Board of Trustees
Sept 9	Los Angeles	UCLA Law School
Sept 10	Salt Lake City	S.J. Quinney College of Law, University of Utah
Sept 11	Denver	Sturm College of Law, University of Denver
Sept 12	Boulder	Wolf College of Law, University of Boulder

- ◆ In October 2008, a conference phone call was held between all PI's to discuss the final conference.
- ◆ In November 2008, Dr. Shmuel Brenner and Dr. Arye Vanger met Mr. Khaled Nassar in Aqaba to finalize the final conference program.
- ◆ The final conference was to be held in Aqaba in January 12-13<sup>th</sup> 2009, but had to be postponed to a later date due to the sensitive situation created by the Israeli operations in Gaza. The final meeting was successfully conducted in Istanbul, Turkey, in May 2009.
- ◆ The Final Conference in Istanbul was held from May 24<sup>th</sup> through 26<sup>th</sup>. All the Principal Investigators and main staff members attended with the exception of Dr. Sarnat. In addition, Mr. Boaz Ayalon, MERC grants manager, US Embassy, Tel Aviv was a guest of honor, as was Paul E. Rohrlich, the Environment, Science, Technology and Health Officer, US Embassy, Tel Aviv. A key achievement of the Conference was the signing by all significant participants in the project of 'The Istanbul Declaration PM<sub>2.5</sub>'. This document includes, among other

statements, the intentions of the research team to continue joint, transboundary research in order to improve public health in the region. A copy of the Declaration and the schedule of the conference are included with this report.

- ◆ The following are the topics for five core, co-authored papers, and include the goals decided on by the research teams:

1. **Bulk Composition of PM<sub>2.5</sub> in the Region** - *to be led by the Palestinian team.*

This paper will focus on the analysis of the seasonal and spatial trends of the major components of PM<sub>2.5</sub> in the region, as well as secondary inorganics such as sulfate, nitrate and ammonium, organic carbon, elemental carbon, crustal material and sea spray.

2. **Toxic Metals in PM<sub>2.5</sub> in the Region** - *to be led by the Jordanian team.*

This paper will focus on the concentrations comparison of dust and anthropogenic metals in PM<sub>2.5</sub> at the 11 sites and also assess the seasonality of these concentrations. The paper will provide insight into the sources of the anthropogenic metals in PM<sub>2.5</sub> at the locations with the highest metal levels.

3. **Sub-Regional Correlations** – *to be led by Dr. Jeremy Sarnat and the Israeli team.*

This paper will compare the PM<sub>2.5</sub> concentrations and composition across Jerusalem, Tel-Aviv, Hebron and Nablus sites. The paper will provide insight on the local sources at those sites believed to be responsible for elevated PM<sub>2.5</sub> concentrations.

4. **Seasonal Source Apportionment of Carbonaceous Fine Particulate Matter at 11 sites in the Middle East** – *to be led by Professor Jamie Schauer.*

This paper will assess the seasonal and spatial contributions to organic carbon and PM<sub>2.5</sub> mass at the 11 project sites.

5. **Comparison of Monthly trends in Primary and Secondary Organic Aerosols in East and West Jerusalem** - *to be led by Professor Jamie Schauer.*

This paper will address the differences in primary and secondary sources of carbonaceous fine particulate matter at the two sites in Jerusalem.

## VI. Project Productivity

The project accomplished the majority of its original goals:

- A broad unique and unprecedented PM<sub>2.5</sub> measurement campaign was held for the first time in the region.
- Significant, high resolution data were created for basic and future advanced source apportionment analysis.
- PM<sub>2.5</sub> samplers were purchased and will be used in additional projects in the region.
- Gravimetric and EC/OC labs were built.
- Palestinian, Jordanian and Israeli field operators were trained.
- Operation and QA/QC protocols were written and delivered to all the teams.
- Three subprojects were successfully accomplished leading to further local capacity building and master degree theses.
- A special work and personal relationship was established between both the PI's and all of the research teams.
- Five co-authored peer review papers are expected to result directly from the project. One has already been submitted for consideration for publication and the other four are expected to be submitted by the end of summer of 2009.
- Two students of AIES (Israeli and Palestinian) received M.Sc. degrees from Ben-Gurion University based on their studies in the framework of the PM<sub>2.5</sub> project.

\* Upon Professor Schauer's recommendation, based on QA/QC considerations, IC and metal analyses were not done in the region.

## VII. Future Work

JSSD will build on the capacity developed by the implementation of this project to have a greater impact on the national level by disseminating the projects' results among the relevant stakeholders. In addition, JSSD will work with policy-makers on the enhancement of the national standards for  $PM_{2.5}$  in Jordan, and, if needed, they will review and discuss the study's results with the relevant policy-makers as a platform from which to upgrade national efforts in this field.

Furthermore, JSSD plans to identify the potential public health and environmental safety concerns that may arise from the information revealed by the results of this project. Such identification will be performed in the hope for greater national regulatory action.

AIES has decided to conduct future studies on particulate matter with the Air Pollution Laboratory of the Technion in Haifa (Professor Yaacov Mamane, director). The URG monitors, the balance, and the EC/OC equipment will become an integral part both of the joint research program and of the equipment belonging to the two institutes.

AIES recently acquired several new samplers for settling dust. Together with the existing researchers and equipment of the Technion, it is believed that a whole range of advanced studies related to particulate matter, its sources and the environmental and health impacts of such matter will be feasible. It was also agreed that alumni of AIES, including Jordanian and Palestinian students, will participate in the various future programs hoped for as a result of the successes of the present research project.