Volume 3, Number 1, 2010. pp. 1-8

Jordan Journal of Physics

ARTICLE

# Study of Black Carbon Levels in City Centers and Industrial Centers in Jordan

**K. M. Hamasha**[a], **M. S. Almomani**[b], **M. Abu-Allaban**[c] and **W. P. Arnott**[d]

[a] *Department of Physics, Yarmouk University, Irbid, Jordan.*
[b] *Department of Educational Administration and Foundation, Yarmouk University, Irbid, Jordan.*
[c] *Department of Water Management and Environment, Hashemite University, Zarqa, Jordan.*
[a] *Department of Physics, University of Nevada Reno, Nevada, USA.*

*Received on: 19/10/2009;     Accepted on: 15/3/2010*

**Abstract:** Light absorption coefficients of black carbon ($B_{abs}$) were measured at several urban and industrial locations in Jordan during the summer of 2007 and the winter of 2008 using the photoacoustic instrument at a wavelength of 870 nm. Black carbon mass concentration (BC) was calculated using $B_{abs}$. Black carbon levels at urban locations in the summer of 2007 were higher than those obtained at industrial centers. Zarqa had the highest value of BC in summer (29.24μg/m$^3$) and in winter (13.27μg/m$^3$). Ibbeen and Irbid city center had relatively high values of BC in winter: 11.75μg/m$^3$ and 12.48μg/m$^3$, respectively.

**Keywords:** Black carbon; Absorption coefficients; Urban air pollution.

## Introduction

Jordan is located between 29°10′ N - 33°45′ N and 34°55′ E - 39°20′ E. The discovery of oil in the Arabian Peninsula has resulted in a fast growth and a social and economical development in the Gulf States and their neighboring countries, including Jordan which provides skilled workers. The social and economic development in Jordan has been accompanied by an increase in the consumption of oil for different needs, including residential, commercial, industrial, transportation and power generation. According to figures published by the Department of Statistics (DOS), Jordan imported about six million tons of crude oil in 2005 [1].

Emissions from motor vehicles account for 50–90 percent of air pollution in urban centers [2,3]. There are just over 750,000 vehicles licensed in Jordan, of which 77.5% are registered in the capital, Amman [4]. More than 31% of the vehicles in Jordan are diesel-powered. Vans and trucks represent 33% and 42.7% of the total diesel-powered vehicles, respectively. Most public transportation vehicles work inside cities, especially Amman and Zarqa. Particles emanating from motor vehicles contain sulfate, carbonaceous particles and a large number of chemicals [5].

Other sources of air pollution in Jordan include: power generation which uses heavy oil and natural gas; cement production which uses oil shale; cooking; home furnaces fueled by diesel, natural gas or kerosene; in addition to wood stoves. The unexpected jump in oil prices experienced during the winter of (2007/2008) has forced people with low income in the countryside and mountainous

**Corresponding Author:** K. M. Hamasha. **Email**: khadeejehh@yahoo.com

areas to switch to wood stoves because they use either olive husk or wood, which are available at low, or no cost in their immediate surroundings.

The negative health impact of air pollution on humans and animals has been widely studied. Findings of several epidemiology studies pointed out that high level of air pollution may result in several health problems, including eye irritation, skin irritation, asthma, lung cancer, cardiovascular problems, high blood pressure, lung tumors and increasing mortality rate [6-10]. Over 300,000 cases of chronic bronchitis, 500,000 asthma attacks and 16 million cases of activity loss recorded in Europe were blamed on vehicle emissions [7]. Exposure to high levels of $SO_2$ causes the impairment of the respiratory function and aggravates existing respiratory and cardiac illnesses [11]. Long-term exposure to $NO_2$ lowers the resistance to respiratory infections and aggravates existing chronic respiratory diseases. In addition to its adverse impact on humans, air pollution has adverse impacts on animals and vegetation, in addition to loss of crops.

In spite of the fast growth of urban areas and industrial activities in Jordan, air pollution has not received due attention. Air quality is not routinely monitored anywhere except at Al-Hashemeyyah (located in the Zarqa governorate to the northeast of Zarqa city) which experiences high levels of sulfur oxides and particulates. There have been a few studies that tackled air pollution in Jordan, but they have been limited to three stations only: Downtown and Shmeisani areas in Amman, as well as Al-Hashemeyyah. Those studies have pointed out that local air quality is poor, where concentrations of criteria pollutants (NOx, SOx, CO, PM10, TSP, lead and hydrogen sulfide) exceed the National Air Quality Standards [12,13]. The Jordanian Ministry of Environment has recently launched a project to establish an air quality monitoring network throughout the country, but actual steps towards that goal have not been taken yet.

In light of the above discussion, it is therefore clear that there is a real need to investigate the air pollution problem in Jordan. In this study, air pollution is investigated through measuring black carbon light absorption coefficients at different locations in Jordan. Black carbon, the main constituent of soot, is almost exclusively responsible for aerosol light absorption at long wavelength visible radiation and near infrared wavelengths. This type of pollution is sometimes referred to as black carbon pollution. The exhaust from burning fuels in automobiles, homes and industries is a major source of pollution in the air. Even the burning of wood and charcoal in fireplaces and barbeques can release significant quantities of soot into the air.

## Theoretical Background

Black carbon aerosol is a component of air pollution that is emitted by combustion sources including vehicles, especially those with diesel engines. Black carbon and organic carbon are the most efficient light-absorbing aerosol species in the visible spectral range. Organic carbon is strongly wavelength dependent, with increased absorption for UV and short wavelength visible radiation, but hardly at all at 870 nm. Black carbon is very likely to dominate at 870 nm [14-16]. Thus the measurement of aerosol light absorption at wavelengths in the long wavelength visible radiation is correlated to the measurement of black carbon. Light absorption by particles depends on the wavelength of the incident light [17-19]. The relationship between the aerosol absorption coefficient, $B_{abs}$, and the corresponding black carbon mass concentration (BC) is established by the aerosol specific mass absorption efficiency $\alpha_a$ via the relationship [21]:

$$B_{abs}(Mm^{-1}) = BC(\mu g/m^3) \times \alpha_a(m^2/gm) \qquad (1)$$

The magnitude of $\alpha_a$ ranges from 2 to 20 $m^2/g$ [20]. Black carbon mass concentrations (BC) are calculated from $B_{abs}$ using the light absorption efficiency for black carbon, $\alpha_a$, such that [21]:

$$BC(\mu g/m^3) = B_{abs}(Mm^{-1}) / \alpha_a(m^2/gm) \qquad (2)$$

and,

$$\alpha_a = 10 m^2/gm \text{ for } \lambda = 532nm \qquad (3)$$

Since $B_{abs}$ is proportional to $1/\lambda$ [19]; then $\alpha_a$ is also proportional to $1/\lambda$. Therefore,

$$\alpha_a(870nm) = \alpha_a(532nm)(870/532)^{-1} = 6.11 m^2/g \qquad (4)$$

Substituting back in equation (2) yields

$$BC(870nm) = B_{abs}(870nm) / 6.11 \quad (5)$$

## Methods

### Sampling Sites

Jordan is divided into 12 governorates: Ajlun, Amman, Aqaba, Balqa, Irbid, Jerash, Kerak, Ma'an, Madaba, Mafraq, Tafilah and Zarqa (Figure 1) [22]. Table 1 provides statistics about targeted governorates, including their areas, rural population, urban population and population density [1]. $B_{abs}$ coefficients were measured at selected cities taking into consideration population density, number of motor vehicles, winter heating devices and industrial impact. A summary of the characters of measurement sites is given below:

TABLE 1. Statistics of Jordan governorates according to 2008 estimate [1].

| Province | Total Population (2008 est.) | Area ($km^2$) | Population Density (person/ $km^2$) | Urban Population (%) | Rural Population (%) |
|---|---|---|---|---|---|
| Ajlun | 118,496 | 412 | 287.1 | 67.4 | 32.6 |
| Amman | 1,939,405 | 8231 | 246.3 | 91.4 | 8.6 |
| Balqa | 349,580 | 1076 | 324.9 | 63.9 | 36.1 |
| Irbid | 950,700 | 1621 | 570.3 | 76.4 | 23.6 |
| Zarqa | 838,250 | 4080 | 205.5 | 95.3 | 4.7 |


FIG. 1. Map of the Governorates of Jordan (from the United States Agency for International Development (USAID) regional website (http://jordan.usaid.gov/images/map1copy.gif.). Retrieved at 4:05 p.m, on 19/10/2008).

### Amman

Amman is the capital and the commercial center of Jordan. It spans over an area of nineteen hills. Amman Downtown is characterized by a U-shaped basin surrounded by three mountains. Amman's climate is moderate, where air temperatures range between 20 °C and 30 °C with moderate humidity and frequent westerly breeze for most of the year. Temperatures seldom fall below freezing during winter, which is the rainy season, during which different types of precipitation (rain, snow and frost) take place. There are more than 300,000 motor vehicles (gasoline and diesel) registered in Amman serving 1,140,000 persons [4].

### Zarqa

Zarqa is a growing industrial city with a population of about a half million persons (2008 estimate) [1]. It hosts about 35% of the heavy industry in Jordan, including the only oil refinery, an oil-based power plant, steel factories, a pipe factory and a wastewater treatment plant, to mention a few. A total of 2400 industrial activities are registered in the Zarqa Industrial Chamber. Motor vehicles are also a major source of $PM_{10}$. As a result of such concentrated anthropogenic activities, the air quality in Zarqa is of concern. Residents of Zarqa often complain about odors from the oil refinery and from Alkherbeh Alsamra, where a domestic wastewater treatment plant is located. It is not difficult for travelers passing by Zarqa to notice that there is a real air pollution problem. A clear gray plume emanating from the oil refinery, odors from Alkherbeh Alsamra, in addition to morning haze are easily noticeable in the area.

Information about air pollution in Zarqa is scarce. Few studies were conducted to assess the air quality in the area. The Royal Scientific Society monitored $PM_{10}$ in the area of Al-Hashemeyyah, where most of the Zarqa industries are concentrated. $PM_{10}$ measurements taken by Asi et al. (2001) between March, 2000 and February, 2001 showed that $PM_{10}$ concentrations were higher than the Jordanian 24-hour standard of 120 $\mu g/m^3$ for 20 of the 50 days sampled [12]. No chemical analyses were conducted on the $PM_{10}$ samples collected in that study.

### Irbid

Irbid is the second largest city in Jordan. It is located 90 km to the north of Amman on the northern ridge of the Gilead. The population of Irbid is about 650,000 citizens (2008 estimate [1]). Irbid is the center of Irbid Governorate. The city has a bustling community and is a major ground transportation hub between Amman, Syria to the north and Mafraq to the east. No previous attempts were made to assess air quality in Irbid. In addition to motor vehicles, the main source of air pollution during summer, home heating is a potential source of air pollution in winter. Irbid's residents depend on fossil fuels, including kerosene, diesel and natural gas for heating and other household needs.

### Ibbeen

Ibbeen is located in Ajlun Governorate. The population of Ibbeen is 8363 inhabitants according to a 2008 estimate [1]. Ibbeen is known for its high altitude, which makes it among the coolest cities in Jordan. Maximum temperatures during January hardly exceed 8.2°C, while minimum temperatures often fall below 0°C. Snow is common in winter, which extends from early November to early May. Several snow storms hit Ibbeen every year, often producing a snow layer as thick as one meter over the highlands in the governorate. The high cost of traditional heating fuel compels people to burn wood, olive cake, agricultural residues and any available combustible materials, including tires. Also, diesel-fueled vehicles (small trucks and mini vans) are very common in Ibbeen.

### Fuhais

Fuhais is a city in the Balqa Governorate, situated 15km west of Amman, with about 20,000 residents [1]. Between Amman and Salt (center city of the Balqa Governorate), Fuhais is situated on several freshwater streams that run through the forested area 20 km west of Amman. Fuhais is home to the first constructed cement factory in Jordan, which has been in operation since the fifties of the past century. On several occasions, the factory uses crude oil shale for fuel. People often complain of the environmental problems associated with the factory activities, which are considered a potential air pollution source in Fuhais. Among the substances which emanate from the factory are soot, sulfur compounds, hydrocarbons, PM10, PM2.5 and TSP, in addition to other carbon compounds. RSS is monitoring TSP and PM10 in Fuhais, but fine particles have not been monitored anywhere in the town.

**Sahab**

Sahab is an industrial/residential town in Amman Governorate, located 20 km to the south east of Amman, the city. The population of Sahab is about 53,000 residents according to 2008 estimate [1].

**Sampling Procedure**

A DRI photoacoustic instrument [21] was used at a wavelength of 870 nm to measure the black carbon light absorption coefficients at different locations in Jordan. The experimental procedure is to install the setup of the photoacoustic spectrometer instrument, then collect data. The instrument is controlled by a Labview program. Before installation, the instrument should be located in a well-ventilated area, where the air could be brought in. When it is ready to sample air, the instrument inlet flexible tubing is connected to the inlet of copper tubing, so that an air sample can be pulled in. This copper tubing was fixed to some stable wall with its inlet open all the time during the sampling.

The light absorption measurements were performed approximately every two minutes during the observational periods (from 7:00 am to 6:00 pm) at the selected sites. The selected sites were:

1) The city centers of the three largest cities in Jordan; Amman, Irbid and Zarqa. Measurements at these locations were carried out twice: once in summer 2007 and the other time in winter 2008. The chosen locations for the three cities were close to main streets that have very crowded traffic. The inlet tubing was two meters high from the ground and about three to four meters away from the street.
2) Locations at industrial centers; Jordan Cement Factories at Fuhais, Jordan Petroleum Refinery in Zarqa and Jordan Industrial Estates Corporation at Sahab. Measurements at these locations were conducted in summer 2007. These measurements were made inside the parking lots of these industrial centers.
3) A location in a town that heavily use wood heaters during winter; Ibbeen town center. This measurement was conducted during the winter of 2008. The measurement site was close to the main street (no heavy traffic at this town compared with the three big cities) in the town center.

Since there is just one instrument, and the simultaneous measurements in different cities are impossible, the measurement days were chosen to have very similar weather conditions for each type of measurement (summer and winter measurements).

Table 2 summarizes the results of all the measurements, showing for each location the dates of the measurements, the average black carbon light absorption coefficient for that day ($\overline{B}_{abs}$), the average relative humidity for that day ($\overline{RH}$) and the average temperature for that day ($\overline{T}$).

## Results and Discussions

For the summer measurements, $\overline{B}_{abs}$ is higher for the locations in the city centers than for the locations in the industrial centers. Zarqa city center had the highest value of $\overline{B}_{abs}$ (178.68±27.300) $Mm^{-1}$ during a summer day and (81.07±4.860) $Mm^{-1}$ during a winter day. The measured $\overline{B}_{abs}$ at the industrial locations had very low values. A measurement at Ibbeen town center shows that this location had a high value of $\overline{B}_{abs}$ during a winter day.

The BC values calculated using equation (5) are shown in Table 2. As can be learned from Table 2, city centers experience high values of $\overline{B}_{abs}$. Measurements carried out at Zarqa downtown gave the highest levels of black carbon concentration during summer as well as during winter, because of numerous air pollution sources concentrated in the city.

TABLE 2. Measured parameters and measurement locations.

| Measurement Location | Date | $\overline{B}_{abs}\,[Mm^{-1}]$ | BC[μg/m$^3$] | $\overline{RH}$ % | $\overline{T}[C^0]$ |
|---|---|---|---|---|---|
| Irbid City Center | 9/7/2007 | 61.24±2.748 | 10.02 | 36.47±0.519 | 32.25±0.139 |
| Irbid City Center | 3/2/2008 | 76.24±4.430 | 12.48 | 86.26±0.317 | 15.58±0.072 |
| Amman City Center | 14/8/2007 | 67.26±2.418 | 11.00 | 30.24±0.640 | 31.31±0.149 |
| Amman City Center | 5/2/2008 | 22.74±1.666 | 3.72 | 68.08±2.63 | 15.61±0.163 |
| Zarqa City Center | 16/8/2007 | 178.68±27.300 | 29.24 | 27.35±0.477 | 33.00±0.180 |
| Zarqa City Center | 27/1/2008 | 81.07±4.860 | 13.27 | 85.75±0.442 | 19.64±0.338 |
| Ibbeen Town Center/Ajlun | 28/2/2008 | 71.79±8.840 | 11.75 | 21.22±0.394 | 24.85±0.215 |
| Jordan Cement Factories/Fuhais | 12/8/2007 | 7.36±0.564 | 1.20 | 31.99±0.432 | 31.50±0.104 |
| Jordan Industries Estates/Sahab | 13/8/2007 | 13.18±0.969 | 2.16 | 30.41±0.433 | 32.12±0.131 |
| Jordan Petroleum Refinery/Zarqa | 15/8/2007 | 9.7±1.142 | 1.59 | 30.24±0.797 | 29.46±0.265 |

Measurements performed near industrial complexes indicate low values of black carbon. During summer, $\overline{B}_{abs}$ values were 7.36±0.56 Mm$^{-1}$, 9.70±1.14 Mm$^{-1}$ and 13.18±0.97 Mm$^{-1}$ at Fuhais Cement Factories, Zarqa Petroleum Refinery and Sahab Industrial Complex, respectively. Low black carbon concentrations in the vicinity of industrial zones are attributed to the efficiency of tall stacks in reducing ground level concentrations of emitted substances. However, tall stacks do not really make air cleaner; they only carry black carbon and other pollutants to distant locations as seen from the results at the location in Zarqa downtown.

Values of $\overline{B}_{abs}$ obtained during winter were 22.74±1.67 Mm$^{-1}$, 76.24±4.43 Mm$^{-1}$ 81.07±4.86 Mm$^{-1}$ at Amman downtown, Irbid downtown and Zarqa downtown, respectively. It is evident that winter values of $\overline{B}_{abs}$ were lower than summer values at Amman and Zarqa downtowns. Winter value of $\overline{B}_{abs}$ at Irbid downtown was higher than its summer value. Throughout the sampling locations, air temperatures were thirteen to seventeen Celsius degrees lower in winter than in summer, while relative humidity was 38 % to 58% higher. This means that airborne particulates have a better chance to settle down through wet or dry deposition, resulting in lower black carbon concentrations in winter, such as the case in Amman and Zarqa. Higher values of carbon concentration during winter in Irbid indicate that there is a winter-associated source of black carbon. Irbid residents use kerosene heaters, gas heaters, diesel heaters and wood heaters. All of these types of heaters can add a lot of black carbon particles to the environment. In Irbid city, people use more kerosene and wood heaters than other types of heaters. Both types have chimneys outside that could add a lot of black carbon to the air as seen from the measurements on winter days. People in Amman and Zarqa use more gas heaters than other types of heaters. Gas heaters do not have chimneys outsides, and the black carbon released from the incomplete combustion in this type of heaters is normally less than that in the other types of heaters.

As can be learned from Figure 2 and Figure 3, BC increases with population during summer, but the trend is reversed during winter. This is likely due to the fact that people in small towns use primitive heating methods that emit greater amounts of black carbon.

Measurements at Ibbeen town center on a winter day (28/2/2008) show that the city had relatively high levels of black carbon (about 71.79±8.840 Mm$^{-1}$) for such a small town that is not crowded with automobiles, especially during winter. Ibbeen is very cold in winter, and people usually use wood heaters. These heaters have chimneys outside that release significant amounts of black carbon particles as well as other polluting gases.

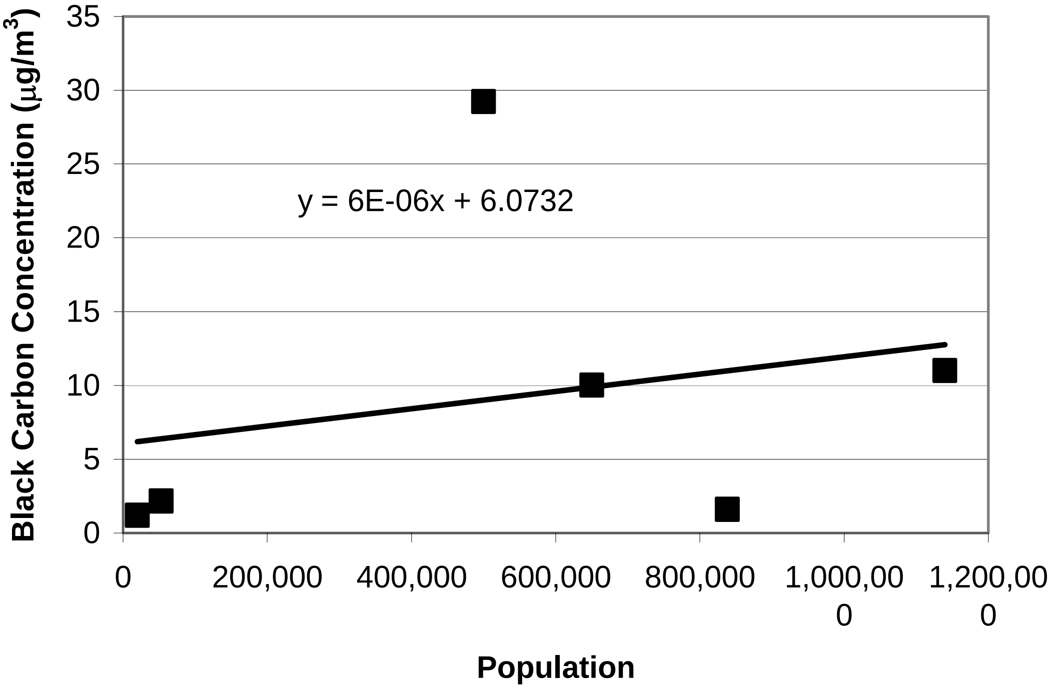


FIG. 2. Dependence of BC on population during summer time.

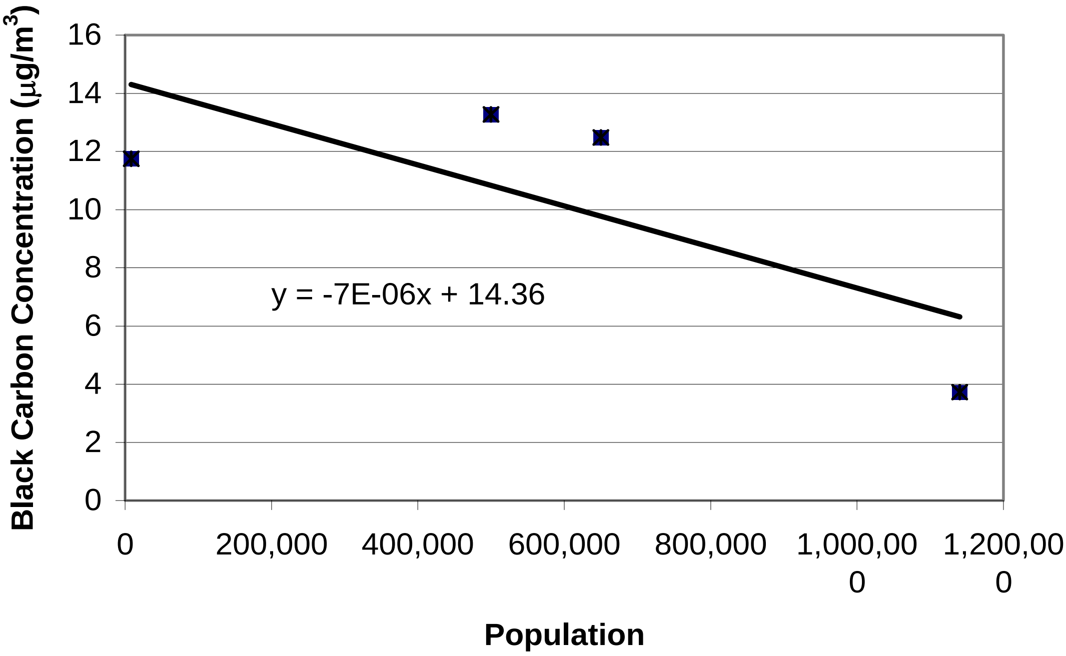


FIG. 3. Dependence of BC on population during winter time.

## Conclusions

This study showed that the city of Zarqa had the highest black carbon levels in summer and in winter. Black carbon levels at the sampling sites in industrial centers are the measure of how these centers add the pollutant black carbon to the environment. Measurements in winter showed that black carbon levels are higher at locations where people heavily use wood heaters. In addition to the local impact of this pollutant on the local environmental quality, it also contributes to the global environmental pollution problem.

## Acknowledgements

The authors acknowledge the financial support provided by the Deanship of Scientific Research and Graduate Studies at Yarmouk University through grant number 2006/25. Many thanks extend to the Department of Driving and Vehicles Licensing and the Department of Statistics, Amman-Jordan for providing necessary data used in this project.


## References


[1]Department of Statistics, Amman, Jordan. http://www.dos.gov.jo/dos_home_a/main/index.htm

[2]Cooper, C.D. and Alley, F.C., Sci. Total Environ. 146/147 (1996) 27.

[3]Gillies, J., Abu-Allaban, M., Gertler, A., Lowenthal, D., Jennison, B. and Goodrich, A. JJEES, 1(1) (2008) 1.

[4]Department of Driving and Vehicles Licensing. Amman, Jordan.

[5]Kassel, R., “Dump Dirty Diesel: The Health and Air Quality Benefits of Cleaner Diesel Engines”. Diesel Retrofit Workshop, Oct. 21 (2003).

[6]Pope, C.A., Thun, M.J., Namboodira, M., Dockery, D.W., Evans, J.S., Speizer, F.E. and Health Jr., C.W., American Journal of Respiratory Critical Care Medicine, 151 (1995) 669.

[7]Künzli, N., Kaiser, R., Medina, S., Studnicka, M., Chanel, O., Filliger, P., Herry, M., Horak, F., Puybonnieux-Texier, V., Quénel, P., Schneider, J., Seethaler, R., Vergnaud, J.C. and Sommer, H., The Lancet, 356(9232) (2000) 795.

[8]Pope, C.A, Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K. and Thurston, G.D., Journal of American Medical Association, 287(9) (2002) 1132.

[9]Takano, H., Yanagisawa, R., Ichinose, T., Sadakane, K., Yoshino, S. and Yoshikawa, T., Am. J. Respir. Crit. Care Med. 165(9) (2002) 1329.

[10]Sanjay, R., “Exposure to Bad Air Raises Blood Pressure”, Study Shows. ScienceDaily. (Ohio State University (2008). http://www.sciencedaily.com /releases/2008/07/080728114026.htm

[11]Andre, N.E., Diaz-Sanchez, D. and Li, N., Current Opinion in Pulmonary Medicine, 7(1) (2001) 20.

[12]Asi, R., Anani, F. and Asswaeir, J. “Studying Air Quality in Al-Hashemeyyah Area/Zarqa”. A report prepared by the Royal Scientific Society (RSS) for the general institution for the protection of the environment, Amman, Jordan, (2001).

[13]Hamdi, M.R., Bdour, A. and Tarawneh, Z. Environmental Engineering Science, 25(9) (2008) 1333.

[14]Rosen, H., Hansen, A. D. A., Gundel, L. and Novakov, T., Applied Optics, 17 (1978) 3859.

[15]Lindberg, J.D., Douglass, R.E. and Garvey, D.M. Applied Optics, 32 (1993) 6077.

[16]Lewis, K., Arnott, W.P., Moosmüller, H. and Wold, E., Journal of Geophysical Research, 113 (2008) D16203.

[17]Moosmüller, H., Arnott, W.P., Rogers, C.F., Chow, J.C., Frazier, C.A., Sherman, L.E. and Dietrich, D.L., J. Geophysics. Res., 103(D21) (1998) 28149.

[18]Horvath, H., Catlan, L. and Trier, A., Atmos. Environ. 31(22) (1997) 3737.

[19]Kirchstetter, T.W., Novakov, T. and Hobbs, P.V., J. Geophysics. Res. 109(D21) (2004) D21208.

[20]Liousse, C., Cachier, H. and Jennings, S.G., Atmospheric Environment, 27A, (1993) 1203.

[21]Arnott, W.P., Moosmüller, H., Rogers, C.F., Jin, T. and Bruch, R., Atmospheric Environment, 33 (1999) 2845.

[22]United States Agency for International Development (USAID) (http://jordan.usaid.gov/images/map1copy.gif.). Retrieved at 4:05 p.m. on 19/10/2008).