Environment Protection Engineering

Vol. 44 2018 No. 1

DOI: 10.5277/epe180106

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ANALYSIS OF PM CONCENTRATIONS IN THE URBAN AREA OF BEJAIA

The particulate matter (PM_{10}, PM_7, PM_4, $PM_{2.5}$ and PM_1) mass concentrations in Bejaia City, Algeria, over the course of one week, from July 8 to July 14, 2015, have been presented for the first time. The study covered eight urban sampling sites and 169 measurements have been obtained. The average city-wide PM_{10} and $PM_{2.5}$ concentrations measured during this sampling were 87.8±33.9 and 28.7±10.6 μg/m^3, respectively. These results show that the particulate matter levels are high and exceed the World Health Organization Air Quality Guidelines (WHO AQG) and European 24-hour average limit values (50 μg/m^3 for PM_{10} and 25 μg/m^3 for $PM_{2.5}$). The PM_1, $PM_{2.5}$, PM_4 and PM_7 fractions accounted for 0.15, 0.32, 0.56 and 0.78, respectively, of the PM_{10} concentrations. The analysis revealed that variations of PM concentration in the study region were influenced primarily by traffic. Lower PM_{10} concentrations (21.7 and 33.1 μg/m^3) were recorded in residential sites, while higher values (53.1, and 45.2 μg/m^3) in city centers.

1. INTRODUCTION

Among air pollutants, suspended particulate matter is extensively recognized as the most important air pollutant in term of human health effects considering that many epidemiological studies substantiate significant associations between concentration of PM in the air and adverse health impacts [1]. However, the toxicological properties of particles depend on their size [2] and chemical composition [3]. Factors which may influence the toxicity of airborne particulate matter include the following: bulk chemical

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composition [4], trace element content [5], strong acid content, sulfate content, and particle size distribution [6].

By the aerodynamic diameter, PM can be divided into coarse (2.5 μm < *Di* ≤ 10 μm), fine (*Di* ≤ 2.5 μm), ultrafine (0.01 μm < *Di* ≤ 0.1 μm), and nanoparticles (*Di* ≤ 0.01 μm) [7, 8]. The composition and size distribution of particles depend strongly on particle formation processes, i.e., the sources of the particles, and this has been explored in numerous studies with respect to PM_{10} and $PM_{2.5}$ [9–11].

Traffic was the main contributor to urban ambient PM in several regions [12–14]. In the study conducted by Weijires et al. [15], the highest particle numbers were measured near congested traffic or behind heavy diesel-driven vehicles. Vehicle PM emissions are the result of a series of variables: fuel [16], vehicle type, drive cycle [17], traffic conditions, road characteristics [18] and climate conditions [19, 20]. As in other Algerian cities, the primary source of air pollution in Bejaia is traffic. A correlation has been found between road traffic and air pollutants concentrations. Alkama et al. [21, 22], measured concentrations of three pollutants (CO, NO_x and SO_2), however no measurements of particulate matter (PM) mass concentrations were conducted.

In this paper, we present an analysis of PM (PM_{10}, PM_7, PM_4, $PM_{2.5}$ and PM_1) and total suspended particle concentrations in Bejaia for one week, from July 8 to July 14, 2015. PM mass concentrations were analyzed by days, hours and locations. The characterization of traffic fleet composition was also described.

2. MATERIALS AND METHODS

The city of Bejaia is a port city along the Mediterranean Sea with a population upwards of 200 000 people. The PM samples were collected in eight sampling sites: six urban stations (Ville (Vl), Aamriw (Aw), Daouadji (Dd), Ihaddaden (Id), Sidi Ahmed (SA), Irreyahen (Ir)) and two residential stations (Targa Ouzamour (TO) and Boukhiama (Bk)) (locations shown in Fig. 1). Three samples per day were collected for each site: in the morning (8:00–9:00), at noon (12:00) and in the evening (4:00–5:00). PM measurements were also taken continuously at the Daouadji site in 15/07/2015, for three hours (from 10:20 to 13:23). A total of 169 mass concentration measurements were obtained from all sites combined.

Fine (PM1 and PM2.5) and coarse (PM4, PM7, PM10) PM concentrations were measured using a portable sampler (Aerocet 531S Particle Mass Profiler & Counter). The Aerocet 531S is a full-featured, battery operated, handheld particle counter or mass monitor. In the mass mode, the unit will measure PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10} and TSP mass concentration levels. The Aerocet 531 was chosen because there are no monitoring stations in Bejaia.

Each measurement consisted of 1-min average concentrations of TSP, PM_{10}, PM_7, PM_4, $PM_{2.5}$ and PM_1 and was recorded on a data storage card. The 3-hour and 24-hour average concentrations were then calculated from the 1-min readings.

Fig. 1. Map of sampling sites within Bejaia City: Vl –Ville, Aw – Aamriw, Dd – Daouadji, Id – Ihaddaden, SA – Sidi Ahmed, TO – Targa Ouzamour, Ir – Irreyahen, Bk – Boukhiama

Before sampling, the Aerocet-531 monitor was tested with a zero filter and flow meter to ensure proper functioning of the monitor. During sampling, the sampler was placed at a height of 1.5 m from the ground and at a minimal distance of 4 m from the road. The Aerocet 531S counts and sizes particles in 8 different size ranges then uses a proprietary algorithm to convert count data to mass measurements (µg/m3). Our analysis focused mainly on the measurements of $PM_{2.5}$ and PM_{10} for comparative reasons, as they are the quantities most often measured and covered in the literature.

3. RESULTS AND DISCUSSION

Analysis of the fleet is an important element of determining the content of air pollution generated from automobiles. For example, diesel fuel is a much larger source of PM than standard unleaded fuel. However, obtaining a precise description of any fleet is difficult and uncertain.

During the period 1970–2014, the traffic fleet of this city has increased approximately by a factor of 26, from 11 000 registered vehicles in 1970 to 256 000 registered vehicles in December 2014. During this time, the average age of the automobile fleet has increased from about 5.5 to 8.5 years, thus increasing the likelihood of vehicles with poorly functioning emission control systems. Figure 2 shows the distribution of heterogeneous traffic fleet composition (different categories and fuel) and vehicle classification (age) in the region of Bejaia.

The heterogeneous traffic characteristics in the study region in 2014 indicated dominance of cars (63.6%) followed by vans (21.4%), lorries (7.4%), buses (2.8%), construction vehicles (2.2%), trailers (1.7%), and motorcycles (0.6%) (Fig. 2).

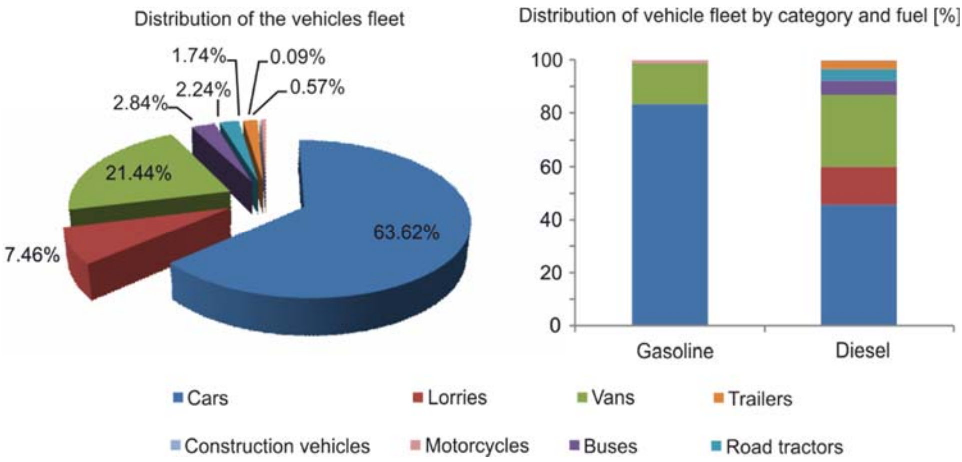

Fig. 2. Distribution of the composition of heterogeneous traffic fleet
and classification of vehicles at the study region in 2014

Bejaia is characterized by a strong dieselization of its fleet. The share of diesel vehicles has increased steadily during the period 1999–2014 from 43.17% in 1999 to 53% in 2014. Gasoline vehicles represent the remaining 47%.

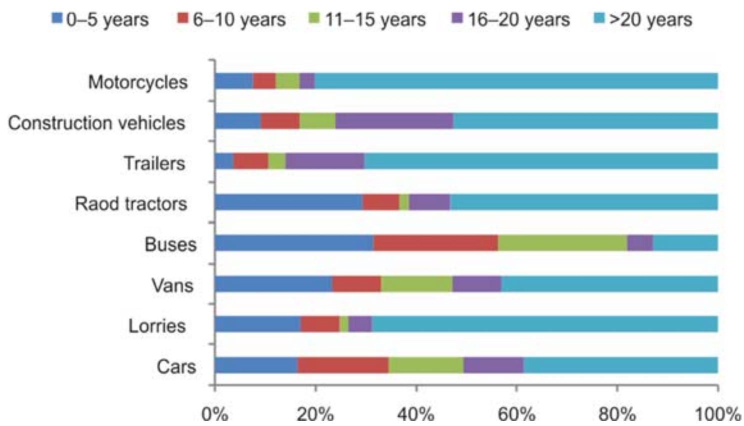

Fig. 3. Percentage distribution of the traffic fleet of Bejaia by age in 2014

The analysis of traffic fleet (in 2014) showed that 37%, 25% and 14% of the total vehicles (256 000) were older than 20, 10 and 5 years, respectively. Only 24% of vehicles were less than 5 years old (Fig. 3).

While the average life time of a vehicle in France is only 14 years, according to National Consumer Council, the average age of the Bejaia traffic fleet exceeds 20 years. These characteristics of traffic fleet indicate traffic as a main source of emissions.

We observed a weekly fluctuation of PM concentration on top of daily fluctuations. Lower levels were recorded during the weekend (10 and 11 of July, 2015). PM_{10} and $PM_{2.5}$ concentrations reached a maximum during weekdays, as expected. Figure 4a presents the time series of 24-hour average of PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10} and TSP concentrations at all sites except the Daoudji site during the period of study. Figure 4b shows the measurements taken over a 3-hour period at the Daoudji site and Table 1 provides a summary of the PM 3-hour averages.

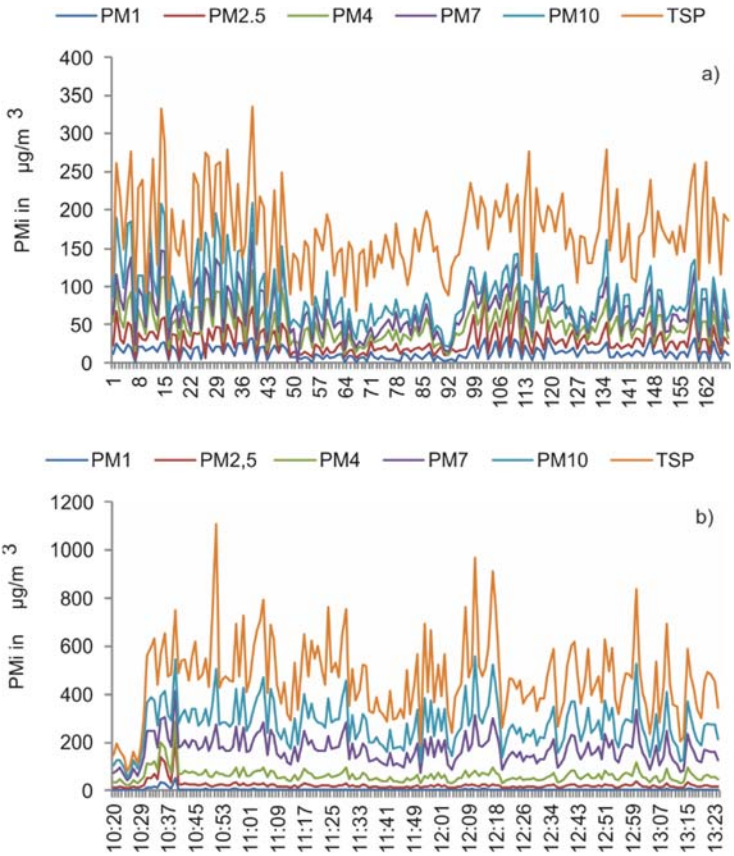

Fig. 4. A time series of 24-hour averages for PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10} TSP concentrations at various sites during the period study (a), and at the site Daoudji during a 3-hour period (b)

Table 1

Average PM_i and TSP concentrations during a 3-hour period at the Daouadji site [µg/m^3]

Particles	PM_1	$PM_{2.5}$	PM_4	PM_7	PM_{10}	TSP
Mean value±SD	3.6 ±1.8	15.4±5.8	41.1±12.9	98.8 ± 31.4	158.6±61.9	246.0 ±94.4

Determined from the average of the three daily measurements, the 24-hour average PM_{10} concentrations exceed the European Union (EU) limit value and the WHO guideline of 50 µg/m^3. Figure 5 shows average particle concentrations for each monitoring site for the period of study.

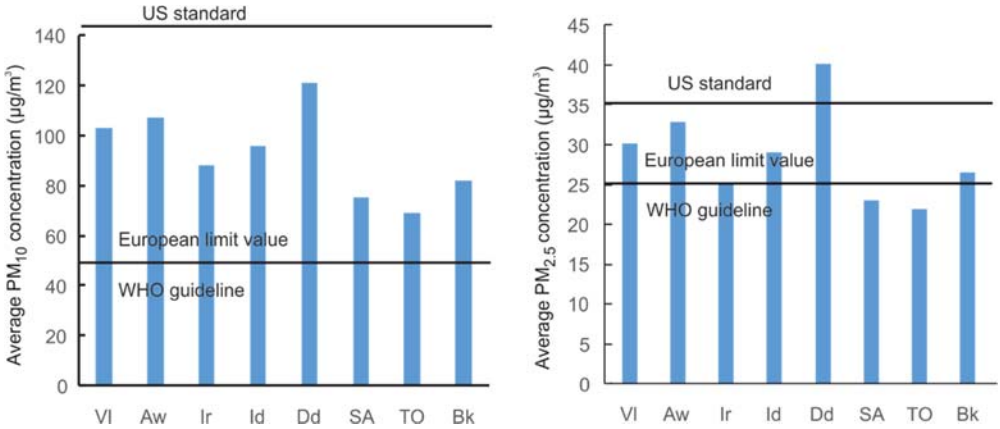

Fig. 5. 24-hour average concentrations of PM_{10} and $PM_{2.5}$ compared with the current air quality guidelines: Vl – Ville, Aw – Aamriw, Ir – Irreyahen, Id – Ihaddaden, Dd – Daouadji, SA – Sidi Ahmed, TO – Targa Ouzamour, Bk – Boukhiama

The results obtained for fine particles ($PM_{2.5}$ and smaller) also show high levels, exceeding recommended concentrations by the WHO and EU (25 µg/m^3), as well as US guidelines (35 µg/m^3) for the site Dd.

Table 2 shows the correlation between different PM sizes. Good correlation was found between PM_{10} and PM_4, PM_7 and TSP concentrations (R^2 = 0.89, 0.90 and 0.73, respectively). The correlation between PM_{10} and smaller particles, such as PM_1, however, is not satisfactory. This result suggests that the fine particles ($PM_{1–2.5}$) and very fine particles (PM_1) may have the same origin of traffic. PM fractions 2.5–10 are strongly enriched in land-based particles and suspension of dust may be included.

Table 2

Correlations between PM fractions of various sizes in Bejaia during the period of study

	PM_1	$PM_{2.5}$	PM_4	PM_7	PM_{10}	TSP
PM_1	1					
$PM_{2.5}$	0.903	1				
PM_4	0.856	0.872	1			
PM_7	0.815	0.803	0.975	1		
PM_{10}	0.788	0.772	0.944	0.954	1	
TSP	0.754	0.715	0.861	0.861	0.858	1

The PM_1/PM_{10}, $PM_{2.5}/PM_{10}$, PM_4/PM_{10} and PM_7/PM_{10} mass ratios contributing to the total mass contribution of PM_{10} are similar for all sites. When compared with European cities, where the ratio $PM_{2.5}/PM_{10}$ ranged from 0.61 to 0.84 [23], the ratio of 0.32 found in this study is small and fine particles cannot be considered as dominant in PM_{10}. PM_1, $PM_{2.5}$, PM_4 and PM_7 constitute 0.15, 0.32, 0.56 and 0.78, respectively of the mass contained with the PM_{10} measurement.

Although monitoring sites were located next to streets and were designated as traffic air pollution monitoring stations, the concentrations of TSP could not be considered primarily traffic-attributable because they arose extensively from road works. The average annual concentration of PM_{10} was estimated at 51% of the average annual concentration of TSP (which is the average across all monitoring sites). The analysis of 24-hour average PM_{10} and $PM_{2.5}$ showed minimum values in the residential stations of Boukhiama (Bk) and Targa Ouzamour (TO) (21.7 μg/m^3 and 33.1 μg/m^3, respectively) and maximum values in the road stations of Daouadji (Dd), Aamriw (Aw) and Ville (53.1 μg/m^3, 49 μg/m^3 and 45.2 μg/m^3, respectively). Figure 6 shows a representation of the overall distribution of PM by location for both PM_{10} and $PM_{2.5}$.

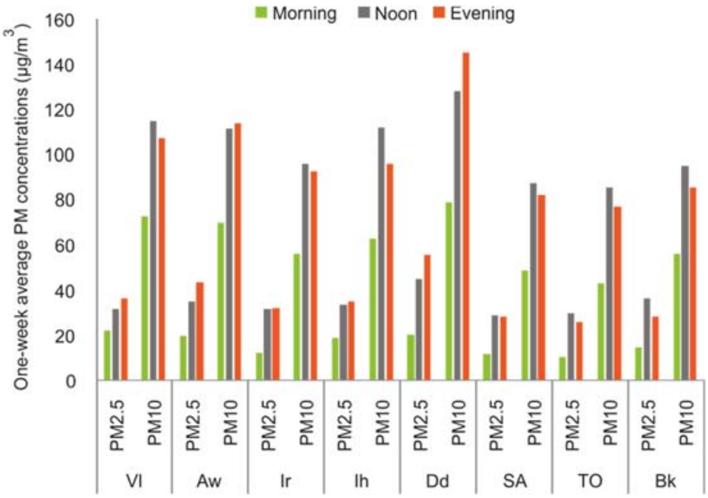

Fig. 6. Hourly Daily data variation for each PM monitoring site:
Vl – Ville, Aw – Aamriw, Ir – Irreyahen, Ih – Ihaddaden, Dd – Daouadji,
SA – Sidi Ahmed, TO – Targa Ouzamour, Bk – Boukhiama

Variations in PM concentrations are observed in all locations throughout the day. Table 3 summarizes the PM10 and PM2.5 statistics during morning, noon and evening. The PM concentrations are generally lower in the morning, high at noon and they remain high until the evening. Concentration at each station increased by a consistent amount, i.e., stations with higher morning concentrations had higher evening concentrations. The lowest PM2.5 and PM10 average values (16.2±4.6, and 60.8±12 μg/m^3, respectively) were observed in morning. The highest average value for PM10 was recorded at noon (103.7±15.1 μg/m^3) although for PM2.5 it was recorded in the evening (35.7±9.5 μg/m^3). High PM concentrations were observed during peak traffic flow hours indicating a significant contribution from vehicle emissions. The results show that in all sites daily levels vary over a wide range.

Table 3

PM concentrations measured during the period of study (8–14 July, 2015) [μg/m^3]

	PM_{10}						$PM_{2.5}$					
	[PM]	Min	Q_1	Me	Q_3	Max	[PM]	Min	Q_1	Me	Q_3	Max
Morning	60.8±12.3	42.9	53.9	59.1	70.4	78.8	16.2±4.6	10.3	11.9	16.7	20.0	22.1
Noon	103.7±15.1	85.4	92.9	103.5	112.8	128.1	34.0±5.0	29.0	31.1	32.8	35.4	44.8
Evening	99.8±22.1	76.9	84.6	94.0	108.7	145.2	35.7±9.8	25.8	28.4	33.5	38.3	55.6

Q_1, Q_3 – first and third quartile, Me – median, Min, Max – minimum and maximum values

The largest concentration levels were observed during mid-day and evening when the traffic density was the highest. The maximum concentrations were recorded at the Daouadji (Dd) site, an urban area in the center of the city with heavy traffic. Concentrations remained high all afternoon into the evening.

In future, the authors aim to assess the seasonal variations in atmospheric particulate concentrations and to characterize their chemical composition. More analysis on the influence of heterogeneous traffic characteristics on the ambient PM concentrations is also of interest for a simulation of air pollution in the region, including impacts from road conditions and meteorological effects.

4. CONCLUSION

Analysis of aerosol particle size distributions from urban Bejaia (Northern Algeria), during one summer week were investigated in this study. In the dense traffic locations of Bejaia, 24-hour average PM_{10} (87.8 μg/m^3)/$PM_{2.5}$ (28.7 μg/m^3) levels exceeded the WHO AQG and the EU limit of 50/25 μg/m^3. The PM_1, $PM_{2.5}$, PM_4 and PM_7 fraction accounted for 15%, 32%, 56% and 78% of mass of the PM_{10} concentrations, respectively.

The largest PM concentrations were during the evening and at noon when traffic density was highest. The maximum values were recorded at the Daouadji (Dd) station. Concentrations remained high all afternoon into the evening.

The lowest PM_{10} concentrations of 21.7 and 33.1 μg/m^3 were recorded at residential stations, whereas higher minimum values (53.1, 49 and 45.2 μg/m^3 were measured at the urban stations, suggesting traffic as a primary cause of particulate matter. The overall PM_{10} averages, however, were similar for all eight stations. A correlation was found between PM_{10} concentrations and other PM concentrations.

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