Identification of anthropogenic and natural sources of atmospheric particulate matter and trace metals in Constantine, Algeria

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Abstract

The purpose of this study was to identify the different Sources of PM10 and some metallic elements (Pb, Cu, Zn, Fe, K, Ca, Na, Mg) at a traffic site at Zouaghi, in the south of Constantine, using factor analysis (FA) to categorise the different trace elements according to their origin and the enrichment factor (EF) to identify terrigenous elements and those having a marine origin. We also used back-trajectories clustering to identify potential distant sources that contribute to particulate pollution and metallic elements in our site. Sources of coarse particles are the most important due to the significant contribution of resuspended coarse particles and Saharan dust intrusions. Anthropogenic, soil resuspension, sea salt and traffic were identified as the main PM10 sources. Enrichment factors in relation to soil and seawater average concentrations indicate that Mg is of marine origin and K originates mainly from the soil while Pb, Cu and Zn are derived from anthropogenic sources. Results point at the Sahara desert as a major source of PM10 and Fe.

Keywords: Traffic site, factor analysis, back-trajectories, enrichment factors.

1 Introduction

Motor vehicles strongly affect air quality within urban areas (Pastuszka et al. 2010). Several studies have provided evidence that the exposure to high concentrations of aerosols is associated with adverse health effects (Pateraki et al. 2012). Multi-city extensive studies conducted in the United States and in Europe

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reported positive associations between PM10 and death. In a multicentre study involving four European cities, consistent positive associations were found between coarse particles central sites concentrations and prevalence of respiratory symptoms. Another particulate matter health study in China revealed a 10-μg/m^3 increase in 2-day moving-average PM10 was associated with a 0.35% increase of total mortality, 0.44% increase of cardiovascular mortality and 0.56% increase of respiratory mortality (Chen et al, 2012). In a study that examines the relation of lung cancer incidence with long-term residential exposures to ambient particulate matter, it was established that a 10-μg/m^3 increase in 72-month average PM10 was positively associated with lung cancer. Moreover, adverse health effects may be caused by mineral dusts originating from the Sahara.

Lim et al. (2012), in the framework of the WHO driven evaluation of the Global Burden of Disease (GBD), evidenced that particulate atmospheric pollution is the 4th cause of worldwide mortality in developing countries and the 11th one in central Europe. REVHIHAAP (Review of evidence on health aspects of air pollution) (WHO 2013) evidenced that mean life expectancy of European citizens is reduced by 9 months due to increase on premature mortality due to cardiovascular, respiratory and cerebro-vascular causes. These reports also indicate that atmospheric particulate matter (PM) is the main pollutant causing these health outcomes.

Studies on traffic-related airborne particulate matter, are scarce or even not available in many cities in the developing world and particularly in Africa. This is in spite of the high levels of atmospheric particulate pollution observed in African cities.

In the developing countries, the particulate matter forms the major contributor to air pollution and hence the pressure to understand its sources better. Emissions from combustion of fossil fuels are expected to increase significantly in African cities in the near future. Atmospheric particulate pollution is more severe in developing countries than in developed countries because of rapid urbanization and a sudden expansion in the number of vehicles. It was reported that annual PM levels in Northern Africa exceeded annual and 24-h WHO guidelines, with annual PM10 levels exceeding 150 μg/m^3 in different sites of Cairo while mean PM10 levels across a network of four monitoring stations that was established in Algiers ranged from approximately 38 to 129 μg/m^3 between 2002 and 2003.

The Mediterranean area is also affected by natural mineral dust transport from the Sahara (Rodriguez et al. 2007).

The main objectives of this study were: 1) to assess the temporal variations of atmospheric particulates and associated metallic elements; 2) to identify distant sources of PM10 by calculating 3-day back trajectories; 3) to identify potential

pollution sources of PM10 and metallic elements based on factor analysis and cluster analysis (CA).

2 Methods

The paper must include in order: the title, author(s), address, an English abstract, keywords in English, if possible a French abstract and keywords in French, the introduction, a limited number of sections (e.g: 1. the method; 2. the results; 3. discussion), and then the conclusion, acknowledgements and references. Main sections will be numbered 1, 2, 3. The titles of sub-sections will not be referenced.

Site description

The sampling site was located at the entrance to the campus of the Faculty of Earth Sciences located at Zouaghi, Constantine, nearby National Road 79, which is one of the busiest traffic highways in the city of Constantine, (36°22'N, 6°40'E, 640 m.a.s.l), Algeria. The sampling device was placed about 5 m above the ground, and about 6 m from the road. The position of the sampling site was such that it could be considered a traffic station because it is directly influenced by vehicular emissions. Sampling was scheduled at midnight.

Measurement of fine particulate matter

A portable low volume air sampler Model Minivol TAS with a rate of 5 liters/minute was used. Ambient air particulates were trapped by a quartz filter (47 mm in diameter with a porosity of 0.2 microns). After each sampling interval, the collection media were returned to the weighing laboratory and allowed to equilibrate for 24 h in a dessicator before weighing to a precision less than ± 0.01 mg using a Shimadzu balance (model AUW120D). The initial weights were determined after a similar period of desiccation.

Analysis of trace elements

Each filter was digested according to the method of Kuvarega and Taru (2008). A Shimadzu-7000 AAS supporting an acetylene flame was used to analyse metallic elements Fe, Na, Mg, Ca, Zn and K, while Pb and Cu were analysed using polarography (VA Computrace797). To minimize the effects of matrices, the standard addition technique was used for the determination of all metals. The results of the analysis of ten blank samples were used to estimate the element concentration produced by the filter and sample preparation. Factor analysis attempts to identify underlying variables, or factors, that explain the pattern of correlations within a set of observed variables. The primary interest of this type of analysis is to replace the original variables, generally correlated with more easily treated uncorrelated variables (Dagnelie, 1975). This technique tries to explain a

set of data in a number smaller than the number of starting dimensions. The technique is to summarize the data-matrix with minimal and controlled loss of initial information by a reduced number of factors as differentiated as possible. This is a linear transformation whose general pattern is written in the form:

$$X_i = A_{i1}F_1 + A_{i2}F_2 + \cdots + A_{ik}F_k + U_i$$

with X: variable.

F: the common factor.
U: single factor.
A: coefficient used to combine k factors.

The data were processed using IBM SPSS Statistics 20.0 software. The main sources of PM10 were identified by performing a varimax rotation which has reduced the initial number of variables to a lesser number of independent variables (factors), and which estimated values of the factors (factor score) for each sample.

3 Results

Contribution of local Traffic to PM10 Levels

Figure 1 shows the evolution of the difference in concentration of PM10 between the traffic and background sites. Daily concentrations of roadside PM10 are almost always higher than those of background site (positive days), but for 9 days (of 116 days), background pollution exceeds the pollution along road (negative days) and for 22 days, the levels of PM10 in the background and roadside sites are identical.
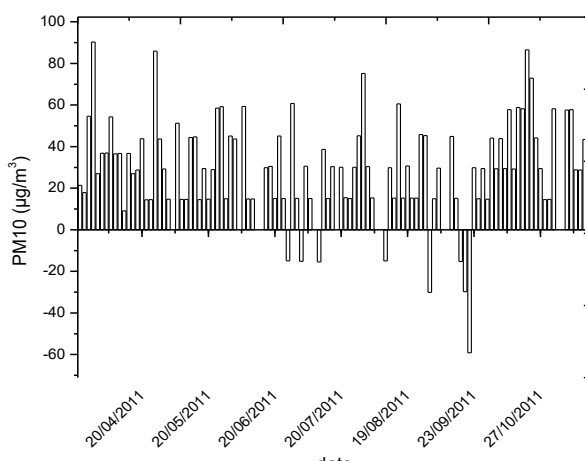

Figure 1. Time variation of the difference in PM10 concentrations between traffic and background sites

Several studies (Charron & Harrison, 2003) reported the influence of weather conditions on levels of particulate emitted by vehicles. To well understand this phenomenon we analyzed the meteorological data during the positive and negative days (Table 1, Figure 2).

In the positive days, the temperature and humidity are different from those observed during the negative days (Table 1). These two parameters have a significant influence on the number and size of particles. A rise in temperature favors the formation of finer and thus more mobile particles. In addition, a high temperature and a high air humidity effectively reduce the density of air causing a reduction in the oxygen content in the air and thus influence the air-fuel ratio of the burnt mixture resulting in elevated levels of particle emissions (Jamriska et al., 2008).

We also observe that the average wind speed is higher during the negative days than during the positive days (1.4 and 1.2 m/ s respectively). The wind speed is greater than 3.6 m/s in 12% of the time during the negative days (Fig. 2) and only in 5% of the time during the positive days (Fig. 2B). High wind speeds promote the dispersion of the particles and eliminate the difference between traffic and background sites. The predominance of light winds at measurement sites promotes the accumulation of dust from transportation on the roadside leading to higher pollution than in the background site.

We also note that for the positive days, prevailing winds are westerly and tend to bring dust from arid lands situated to the west of National Road 79.

Table 1. Average values of some meteorological parameters

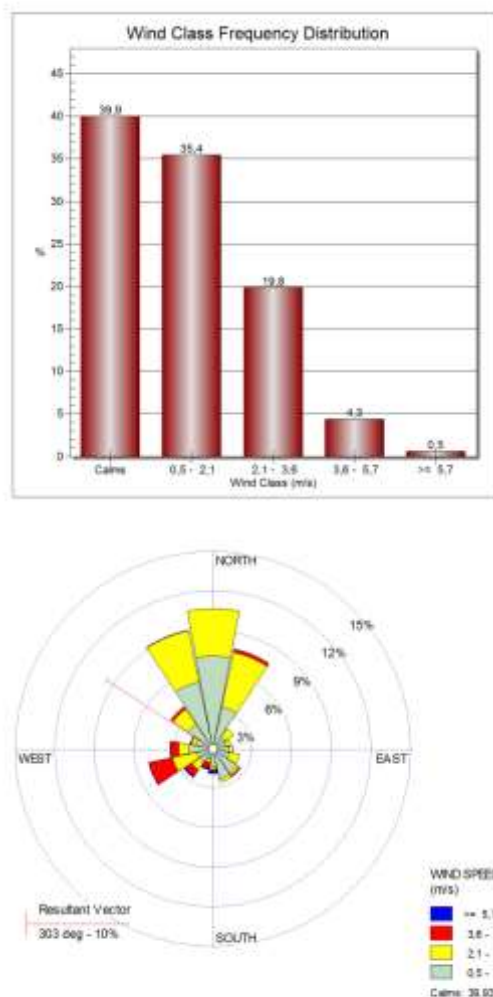|	Negative days	Positive days
Wind speed	1.4	1.2
Rainfall	0.7	2.2
Temperature	22.6	19.4
Humidity	31.8	41.4
Pressure	948	968.2

A
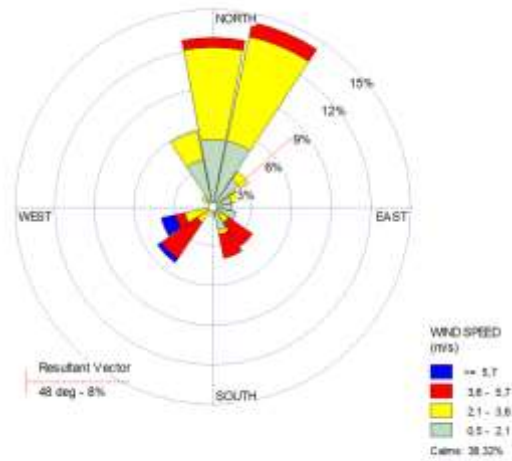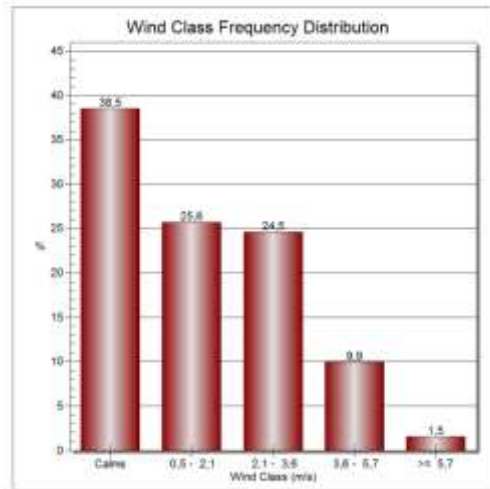
B

Figure 2. Wind roses in Zouaghi, Constantine (A) Negative days (B) Positive days

Table 2 shows the contribution of road traffic to PM10 and some metal elements. Traffic contributes 39.8% to PM10, either by direct emissions such as Pb (62.4%), Zn (50.3%), Cu (55.6%), and/or the resuspension of soil dust originating from earth such as Fe (57.9%), Ca (65.1%), K (56.8%) and from marine elements like Na (29.5%) and Mg (49.6%). It is assumed that traffic emits Pb, Zn and Cu by a single channel (direct emission) and the other elements are resuspended by vehicle movement. The direct emission and resuspension contribute up to 55.49% and 49.55% respectively to PM10 levels.

Table 2. Difference inpollution between traffic and the background sites

	Traffic site µg/m³	Background site	Increment* µg/m³	Contribution due to traffic** %
PM₁₀	81,71	49,23	32,48	39.75
Pb	1,09	0,41	0,68	62.39
Cu	0,63	0,28	0,35	55.56
Zn	1,47	0,73	0,74	50.34
Direct emission	**3.19**	**1.42**	**1.77**	**55.49**
Fe	4,11	1,73	2,38	57.90
Ca	3,93	1,37	2,56	65.14
K	5,93	2,56	3,37	56.83
Mg	2,34	1,18	1,16	49.57
Na	6,92	4,88	2,04	29.48
Resuspension	**23.23**	**11.72**	**11.51**	**49.55**

*Increment = concentration in traffic site - concentration in background site
**Contribution = [(concentration in traffic site – concentration in background site) / concentration in traffic site]* 100

4 Conclusion

PM10 concentrations were measured at a sampling traffic site situated at Zouaghi, Constantine between 23 March 2011 and 22 November 2011. The results presented in this work allow us to conclude that PM10 concentrations are excessive in light of the WHO and the EU standards. The latter seem hardly feasible in view of the contribution of natural aerosols to ambiant PM levels. The average daily concentration of PM10 (80,42 µg/m³) was observed for the period extending from 23 March 2011 to 22 November 2011. During the study period implying the sampling of PM10, the average concentration of PM10 was 105.2 µg /m³. Sources of PM10 particles are related to the significant contribution of resuspended coarse particles and Saharan dust intrusions.

In this work some statistical techniques have been successfully used to identify and characterize PM10 sources. The application of Varimax rotated factor

analysis, a multivariate technique, has allowed us to qualitatively identify anthropogenic, soil resuspension, sea salt and traffic as the main PM10 sources, at a traffic site in Constantine (Algeria).

Enrichment factors in relation to soil and seawater average concentrations indicate that Mg is of marine origin and K originates mainly from the soil while Pb, Cu, Zn are derived from anthropogenic sources.

To identify external sources and their geographical origin, air mass back-trajectories have been calculated with the HYSPLIT 4 model. Results point at the Sahara desert as a major source of PM10 and Fe. The contribution to Na results from long-range transport of air masses originating from the North (Mediterranean sea) or from the South (salt marshes).

On the other hand, salt marshes located south of the study station are identified as the path followed by dust plumes originated in the desert region. They have been derived for Na.

The mediterranean sea has been identified as the major source of Na, Mg, K and Ca. Iron is of crustal origin, either from nearby sources such as the soil surrounding the site or distant sources such as the Sahara to the south. Calcium and potassium have also an anthropogenic origin. Anthropogenic sources are related to the construction works of the tram on the other side of the road along the measurement site. Zn, Cu and Pb are derived from anthropogenic sources: traffic and industry. Traffic is the major source of the high Pb levels observed since gasoline still contains lead additives in Algeria.

Traffic contributes 39.8% to PM10, either by direct emissions or by the resuspension of soil dust originating from earth and from marine elements.

References

[1] Charron A and R M Harrison (2003): Primary particle formation from vehicle emissions during exhaust dilution in the roadside atmosphere, Atmospheric Environment, Vol. 37, p 4109–4119

[2] Rodriguez S, Querol X, Alastueya A and J de la Rosa (2007): Atmospheric particulate matter and air quality in the Mediterranean: a review. Environ Chem Lett 5, p 1–7. doi: 10.1007/s10311-006-0071-0

[3] Jamriska, M., L. Morawska and K. Mergersen,(2008): The effect of temperature and humidity on size segregated traffic exhaust particle emissions. Atmos. Environment, 42, p 2369-2382.

[4] Pastuszka JS, Rogula-Kozłowska W and E Zajusz-Zubek (2010): Characterization of PM10 and PM2.5 and associated heavy metals at the crossroads and urban background site in Zabrze, Upper Silesia, Poland,

during the smog episodes. Environ Monit Assessment 168: 613-627. doi: 10.1007/s10661-009-1138-8

[5] Chen R, Kan H, Chen B, Huang W, Bai Z ,Song G and G Pan (2012): Association of particulate air pollution with daily mortality: the China Air Pollution and Health Effects Study. Am J Epidemiol G Vol. 175, n°11, p 1173-1181. doi: 10.1093/aje/kwr425

[6] Lim SS, Vos TD, Flaxman AD, Danaei G, and K Shibuya K (2012): A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet, 380, p 2224-2260. doi: 10.1016/S0140-6736(12)61766-8.

[7] Pateraki St, Asimakopoulos DN, Flocas HA, Maggos Th and Ch Vasilakos (2012): The role of meteorology on different sized aerosol fractions (PM10, PM2.5, PM2.5–10). Sci Total Envir 419, p 124-135. doi: 10.1016/j.scitotenv.2011.12.064

[8] WHO (2013): Review of evidence on health aspects of air pollution-REVHIHAAP. WHO Regional Office for Europe.