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Road Traffic and PM10, PM2.5 Emission at an Urban Area in Algeria: Identification and Statistical Analysis

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ABSTRACT: Air quality in greater Algiers, in Algeria was assessed analyzing aerosol particulate matter (PM10 and PM2.5) at a site influenced by heavy road traffic. Particulate matters were collected using a Gent sampler to characterize the atmospheric aerosol of Algiers. An Energy dispersive X ray spectrometer (EDXRF) was used to determine the heavy metal concentrations in the PM2.5 and PM10 size fractions. Principal Component analysis and Enrichment factor were used to identify the major sources of air pollutants for PM10 fraction in the studied area. Backward trajectories were calculated in order to identify potential distant sources that contribute to particulate pollution in our site. Significant concentrations of PM 2.5 and PM10 as well as associated heavy metals have been documented. The mean concentrations of heavy metals contained in PM10 and PM2.5 were, in descending order, Fe>Zn>Ni>Pb>Mn>Co>Cr; Pb>Mn>Co>Fe>Zn>Ni>Cr respectively. The contribution of road traffic to the levels of fine (PM2.5), and coarse (PM10) particles were studied.

Keywords: Aerosol, Particulate matter, Heavy metal, EDXRF, Enrichment factor.

INTRODUCTION

Particulate matters (PM) are nowadays one of the most serious pollutants in urban areas due to their known adverse effects on human health. The severity of the health impact is linked to particle size (Nuria et al., 2011; Massey et al., 2016).Fine particles PM2.5 (with aerodynamic diameter less than 2.5 μm) result from fuel combustion from motor vehicles, power generation, and industrial facilities, as well as from residential fireplaces and wood stoves. Coarse particles PM10 (less than 10 μm in diameter) are generally emitted from sources such as traffic on unpaved roads, materials handling, and crushing and grinding operations, as well as windblown dust (Vitor et al., 2008; Massey et al., 2013).Epidemiological studies have shown an association between exposure to elevated PM10 and PM2.5 concentrations and increased mortality and morbidity

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(Segala et al., 2008; Neuberger et al., 2007; Massey et al., 2016).Countries with low or medium socioeconomic levels now face a deterioration in air quality due to many factors, the most important being rural exodus, rapid industrialization and the development of parking. Many countries in Africa are not currently in a position to have the reliable data needed to measure the effects of particulate matter pollution (Laid et al., 2006).

Algeria, a country located in North Africa, is a good model of the situations currently observed in countries at the medium socioeconomic level due to population explosion, strong urbanization and rapid industrialization. In recent years, a number of studies in Algeria have been carried on trace elements in respirable fraction of particulate matters (Ahmed et al., 2016; Hocine et al., 2008; Mohammed and Khaled, 2009; Rabah et al., 1999; Rabah et al., 2000; Nassima et al., 2015; Mohammed et al., 2017). Nassima et al. (2012) have shown that the capital of Algeria, Algiers is confronted with severe air pollution problems.

Road traffic is particularly important in Algiers; the motorization rate is 200 vehicles per 1000 inhabitants, with an average age of 9 years for light vehicles and 14 years for heavy vehicles (Laid et al., 2006).The few occasional measurements of the levels of pollution carried out in the city of Algiers by the air quality monitoring network showed that the particles of automobile origin seem to predominate (Aoudia et al., 2005).

This work included the detailed characterization of the concentrations of PM10 and PM2.5 and selected heavy metals carried by these airborne particles and their distribution by size sampled at a site directly influenced by road traffic and characterized by high population density using a non destructive technique XRF.

MATERIALS AND METHODS

The study was carried out at the nuclear research center (CRNA); on the heights of Algiers (Fig. 1).The site is located in a busy urban area and is adjacent to a road. The campus is surrounded by high traffic vehicle density (with about100000 cars per day) (Mohammed, 2010), but no other prominent pollution sources. The sampling site is situated at an altitude of 200 m about the sea level. The climate of the surrounding area is rainy and cold during winter, but hot and dry in summer.

Fig. 1. A map of sampling site in the study area (Algiers, CRNA)

Particulate matter (PM10, PM2.5) samples were collected from June to December simultaneously every third day for 24h, using a low volume air sampler (Gent model) with a flow rate of 1.29 m^3/h through polycarbonate filters. Mass concentration was determined gravimetrically, using a microbalance and all filters were weighed twice before and after being exposed. The difference of weight of the filter before and after sampling was used to calculate PM10 and PM2.5 concentration expressed in $\mu g/m^3$.

After collection, samples are stored until processing and analysis in sealed Petri dishes and stored in desiccators. For analytical purposes, we have prepared chemical standards from products of known purity, by acid or aqueous dissolution, depending on the sample to dissolve, then, we make the necessary dilutions. The concentration of the stock solutions is once diluted mixtures to make compatible and non-interfering; we find the desired concentrations in 20µl (Mohammed and Khaled, 2009).These are collected using a micropipette and deposited onto uncontaminated filters of the same kind as the filters used for picking, then left to dry.

The elemental analysis of aerosol samples was performed by means of X-ray fluorescence spectrometer (Epsilon 3 Model).

For statistical analysis, Pearson's correlation coefficient and principal components analysis (PCA) were performed, to identify the relationship among heavy metals in particulate matter and their possible sources. The correlation coefficient measures the strength of interrelationship between two heavy metals (Lu et al., 2010). PCA widely used to reduce data and to extract a smaller number of independent factors for analyzing relationships among observed variables (Tokalioglu and Kartal, 2006), starts with the correlation matrix describing the dispersion of the original variables and extracting the eigen values and eigen vectors.

PCA was conducted by the Varimax rotated factor matrix method, based on the orthogonal rotation criterion with Kaiser Normalization.

Air mass backward trajectories have been calculated with the HYSPLIT 4 model to identify external sources and their geographical origin.

RESULTS AND DISCUSSION

A total of 52 pairs of coarse and fine filters, were collected and analyzed. Mass concentrations results for PM10 and PM2.5 are shown in Fig.2.

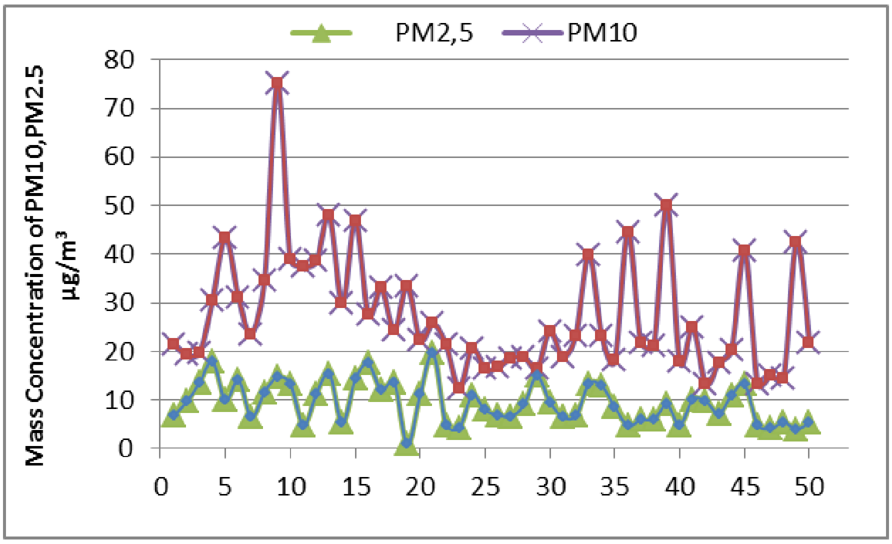

Fig. 2.Variation of levels of PM2.5 and PM10 measured in the study area

From this figure, it appears that the PM10 content is always higher than PM2.5.According to particulate matter guidelines, daily PM10, PM2.5 values of 50 and 25µg/m^3(WHO, 2000) were exceeded twice and no times respectively during the sampling period. The highest daily mass concentrations for PM10, PM2.5 were 75.10 and 19.71µg/m^3, respectively. In contrast, the lowest daily concentrations were 12.30 and 0.87µg/m^3 for PM10, PM2.5 respectively. The mass data also reveal that the mean ratio of PM2.5/PM10 is accounted for 0.377.This means that coarse particle mass was higher than that for PM2.5.When compared with concentrations recorded in other northern African cities characterizes by intense vehicles circulations, PM10 levels in the network are lower in general than those from Sfax (Tunisia) (66µg/m^3) (Imed et al., 2006), from Morocco in Kenitra (81µg/m^3)(Mustapha et al., 2009) and from Egypt (93µg/m^3) (Abu-Allaban et al., 2007). PM10 mean levels vary from one to the other according to the degree of traffic influence.

Elemental mean concentrations of seven heavy metals (Cr, Mn, Fe, Co, Ni, Zn and Pb) associated with PM2.5 and PM10 found in this study are shown in the following table.

Table 1. Elemental concentration (ng/m^3) for heavy metals associated with PM10 and PM2.5

Metal	Concentrations (ng/m^3) in:			
	PM 2.5		PM10	
	Mean	SD	Mean	SD
Cr	0.270	0.230	0.590	0.796
Mn	26.720	24.898	8.630	9.339
Fe	13.850	11.604	281.740	310.899
Co	15.050	45.026	0.930	6.208
Ni	0.845	0.758	18.720	17.372
Zn	1.040	2.640	49.040	39.547
Pb	89.130	24.541	11.730	9.523

According to Table 1 we observe that elements such as Mn, Co and Pb are more present in PM2.5 while the elements Cr, Fe, Zn, and Ni are more present in PM10.The Lowest concentrations were found for chromium with an arithmetic mean concentration of 0.27 ng/m^3 and 0.59 ng/m^{3}in PM10 and PM 2.5 respectively (Table1).The highest mean value of the concentrations of the metals associated with PM10 and PM2.5 were found for iron (Fe) (281.74ng/m^3) and lead (Pb) (89.13ng/m^3) respectively. Concerning only the metals contained in the PM10,it can be seen that average concentration of chromium (Cr) in Algiers was 0.59 ng/m^{3}while the WHO guideline value is only 0.25ng/m^3.Chromium level in Algiers was much lower than in Kenitra, Morocco (216 ng/m^3,Traffic) (Mustapha et al., 2009).The mean concentration of lead detected in the air of Algiers (11.73ng/m^3) was lower than those from: Morocco(267ng/m^3),Egypt(4800ng/m^3)(Yatkin and Bayram, 2008),Tanzania(58ng/m^3) (Mkoma et al., 2009) and Nairobi in Kenya(610ng/m^3)(Odhiambo et al., 2010).Manganese level was 8.63ng/m^3 while in Morocco and Tanzania was 43 and 16ng/m^3, respectively, the WHO value is 150 ng/m^3.Ni concentration was 18.72g/m^3, much lower than in Kenitra (Morocco) (449ng/m^3) and higher than in Dar Esaalam (Tanzania) (2 ng/m^3) ,Who guideline value is only 2.5ng/m^3.Zinc level in the network was 49.04ng/m^3 while the concentration of zinc in Morocco, Kenya and Tanzania were 2205ng/m^3, 50ng/m^3 and 370ng/m^3, respectively. The concentration of Fe in the present study was 281.74ng/m^3.This value is lower than in Kenya (3800ng/m^3), or in Morocco 3079ng/m^3.Average concentration of Co was 0.95 ng/m^3.The reference concentration for inhalation of cobalt is 5 ng/m^3(CalEPA, 1997).The highest levels of the studied metal in PM10 appeared for iron. Also, concentrations of heavy metals carried by the fine particles (PM2.5) were very low in Algiers compared with various cities in Africa except for manganese.

Table 2 shows some literature data confirming this remark. Generally elemental mean concentrations found in this study are much lower than those found in other African countries.

The Pearson's correlation coefficients for heavy metals in PM10 are presented in the following Table.

Table 2. Concentration of heavy metals associated with fine and coarse particles (PM2.5, PM10) in the present work and in other sites

Elements concentration(ng/m^3)	PM 2.5	PM 10	Site (Traffic)	Author
Cr	0.27	0.59	Algiers centre	Present work
	84	219	Kenitra(Maroc)	(Mustapha et al., 2009)
	/	/	Cairo (Egypt.)	(Abu-Allaban et al., 2007)
	/	1	Dar ES Salaam (Tanzania)	(Mkoma et al., 2009)
	/	/	Nairobi(Kenya)	(Odhiambo et al., 2010)
Mn	26	8	Algiers centre	Present work
	23	43	Kenitra(Maroc)	(Mustapha et al., 2009)
	/	/	Cairo (Egypt.)	(Abu-Allaban et al., 2007)
	2	16	Dar ES Salaam (Tanzania)	(Mkoma et al., 2009)
	/	/	Nairobi(Kenya)	Odhiambo et al., 2010)
Fe	13	281	Algiers centre	Present work
	1936	3079	Kenitra(Maroc)	(Mustapha et al., 2009)
	500	4300	Cairo (Egypt.)	(Abu-Allaban et al., 2007)
	31	610	Dar ES Salaam (Tanzania)	(Mkoma et al., 2009)
	/	3800	Nairobi(Kenya)	Odhiambo et al., 2010)
Co	15	0.9	Algiers centre	Present work
	/	/	Kenitra(Maroc)	(Mustapha et al., 2009)
	/	/	Cairo (Egypt.)	Abu-Allaban et al., 2007)
	/	/	Dar ES Salaam (Tanzania)	Mkoma et al., 2009)
	/	/	Nairobi(Kenya)	Odhiambo et al., 2010)
Ni	0.8	18	Algiers centre	Present work
	166	499	Kenitra(Maroc)	(Mustapha et al., 2009)
	/	/	Cairo (Egypt.)	(Abu-Allaban et al., 2007)
	1	2	Dar ES Salaam(Tanzania)	(Mkoma et al., 2009)
	/	/	Nairobi(Kenya)	(Odhiambo et al., 2010)
Zn	1	49	Algiers centre	Present work
	1413	2205	Kenitra(Maroc)	(Mustapha et al., 2009)
	/	/	Cairo (Egypt)	(Abu-Allaban et al., 2007)
	24	370	Dar ES Salaam (Tanzania)	(Mkoma et al., 2009)
	/	50	Nairobi(Kenya)	(Odhiambo et al., 2010)
Pb	89	11	Algiers centre	Present work
	342	267	Kenitra(Maroc)	(Mustapha et al., 2009)
	1600	4800	Cairo (Egypt)	(Abu-Allaban et al., 2007)
	39	58	Dar ES Salaam (Tanzania)	(Mkoma et al., 2009)
	/	610	Nairobi(Kenya)	(Odhiambo et al., 2010)

Table 3. Correlation coefficients between the measured heavy metal concentrations in the atmospheric PM10

Variables	Cr	Mn	Fe	Co	Ni	Zn	Pb
Cr	1						
Mn	0,441	1					
Fe	0,454	**0,975**	1				
Co	-0,048	**-0,531**	**-0,569**	1			
Ni	0,390	0,344	0,333	-0,060	1		
Zn	0,374	**0,803**	**0,837**	-0,445	0,358	1	
Pb	0,407	**0,557**	**0,585**	-0,353	**0,506**	**0,665**	1

Correlation analysis of the above heavy metals was conducted using the Pearson coefficient method.Interelement relationships provide interesting information on the sources and pathways of the heavy metals (Lu et al., 2010).obviously, there were strong positive correlations between the most contaminating heavy metals, as shown in table 3,among them Mn-Fe(0.975),Mn-Zn(0.803),Mn-Pb(0.557),Fe-Zn(0.837),Fe-Pb(0.585),Zn-Pb(0.665),Ni-Pb (0.506),this shows the coexistence of these elements and can help us to identify pollution sources (Belamri et al., 2017). We observe negative values of correlations between (Co-Fe) and (Co-Mn) meanings that the presence of one implies the diminution of the other. A weak correlation was observed between chromium and the other elements.

The enrichment factor (EFs) can give an insight into differentiating an anthropogenic source from a natural origin and hence, can also assist in the determination of the degree of contamination (Salwa et al., 2013).It was calculated using Fe as reference element and Mason's crustal concentration values. The comparison of the PM10 composition and the average composition of the soils may help to identify which trace elements are enriched in the aerosols with respect to the soils (Ahmed et al., 2016).

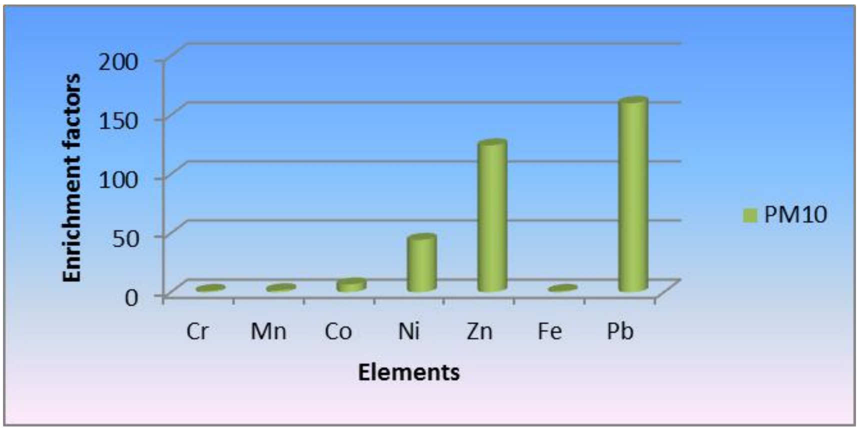

Fig. 3. Enrichment factor values of Elements in PM10 at the study area

As shown in Fig. 3, EF values of Cr, Mn and Co were less than 10 indicating that these elements, mainly originate from natural source emissions (Saliba et al., 2007), they have got the atmospheric input through winds, dust-storms and resuspension by vehicles. The enrichment factor value of Ni indicates that this element was moderately enriched (EF between 10 and 100), thus Ni originates from natural sources, as well as anthropogenic sources.Zn and Pb representing metals that originated from anthropogenic sources with traffic being a significant source, their EFs were greater than 100.

Principal component analysis with

varimax rotation and retention of principal components having eigenvalues greater than 1.0 was used to identify major elements associated with different sources in PM10. The percent of variance explained by each significant factor was calculated. Only variables with factor loading greater than 0.5 were taken into account in order to characterize the source. Table 4 shows the results of the factor loadings with a varimax rotation, as well as the eigenvalues.

Table 4. Principal component analysis values

Elements	Principal components		
	1	2	3
Cr	0.154	0.237	**0.894**
Mn	**0.852**	0.200	0.374
Fe	**0.877**	0.202	0.366
Co	**-0.826**	-0.019	0.276
Ni	0.051	**0.914**	0.187
Zn	**0.788**	0.339	0.277
Pb	**0.501**	**0.685**	0.154
Eigen value	4.3	2.2	1.8
% of cumulative	43.7	65.9	84.2
Source	Oil combustion Road dust and exhaust Earth crust	Oil combustion	Road dust and exhaust

The result indicates that there were three principal components (PC) with eigenvalue higher than one, and that three factors explain 84.2 % of the total variance. The first principal component explains 43.7 % of the total variance and is mainly composed of Mn, Fe, Co, Zn and Pb.This factor is probably related to oil combustion, wear from vehicle tires (Pastuszka et al., 2010),resuspended road dust and exhaust emissions (Young et al., 2002; Tüzen, 2003),the high loading of iron and manganese is best explained by crustal materials, braking dust and erosion (Abdelhamid et al., 2017).The second principal components is mainly consists of Ni and Pb accounts for 65.9 % of the total variance and hence is associated with oil combustion and brake linings emission (Weckwerth et al., 2001; Monaci et al., 2000). In main component 3, chromium has the highest value, accounting for 84.2 % of the total variance. The high loading of Cr is explained by road dust and exhaust. This result is consisting with the correlation coefficient analysis, which indicates that chromium is not correlated with the other elements.

So, we found that the main sources of PM pollution in the studied site are vehicles exhaust and suspended soil.

In order to characterize the origin of air masses, arriving at our site, 48h back trajectories were computed for the day of 13 July with Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT-4) model using data available in NOAA’s Air Resources Laboratory (ARL) archives. The model output is a set of latitude–longitude coordinates of the air parcel estimated position for every hour. Backward trajectories for day with high mass concentration of PM10 (13 July) are shown in the following figure.

This figure shows the particles that take 48 hours from the region of El Oued passing through Hassi R'mel and Ghardaîa to arrive at the sampling site of the urban center of Algiers. Results indicate that the Sahara desert is the main source of these particles in the studied area.

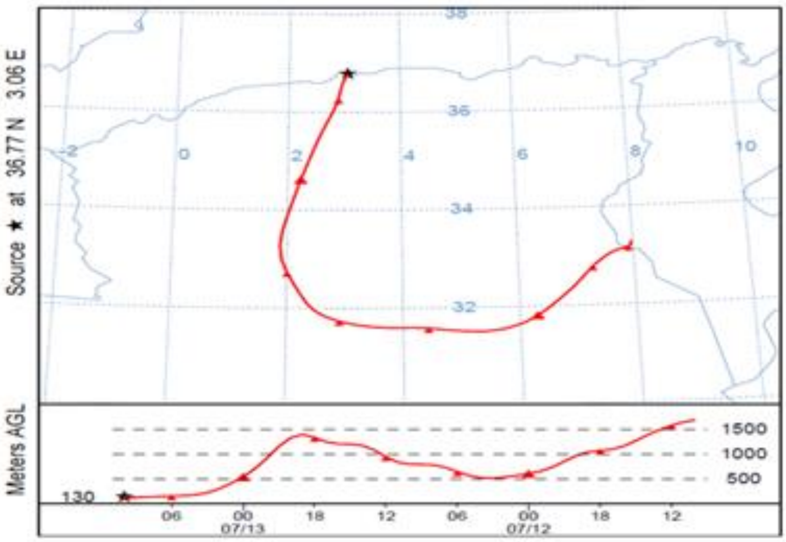

Fig. 4. Pathway of polluting particles before 48 hours of arriving at the sampling site.

CONCLUSION

The main objective of this research work was to assess the pollution levels reached by different sizes of particulate matter (PM10, PM2.5) and heavy metals associated with them in a site characterized by heavy road traffic. Quantification of PM10 and PM2.5 revealed concentrations slightly above international standards. The mean concentrations of PM10 and PM2.5 recorded during the study period were 29.28 and 10.22 µg/m^3respectively. The concentrations of the metallic elements such as chromium and nickel in PM10 are high compared to international standards reported in the literature. The sources of different heavy metals in Algiers centre were identified according to principal component analysis, correlation coefficient and enrichment factor (EF) analysis show that the airborne particles of Algiers city are divided into two kinds of sources, those originating from soil dust including Cr, Mn, Co and those originating from anthropogenic contribution, in particularly road traffic including Zn and Pb. According to the backward trajectories analysis, the air masses responsible for the highest concentrations recorded during the sampling period in Algiers center were affected by a Saharan dust.

Results suggest that soil resuspension and traffic are the most important sources of environmental pollution in the region. So, the efficient control of atmospheric pollution in an urban environment is necessary to avoid public health problems due to exposure of public to toxic heavy metals associated with fine and coarse particulate matter.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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