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Quantification of Mass Concentrations Aerosols $PM_{2.5}$ in Primary Schools. A Case Study: Tiaret City (Algeria)

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For the study purposes, 23 primary schools have been selected in Tiaret city, and the collection of $PM_{2.5}$ was performed in the morning, afternoon and evening, in the presence and absence of students. The results showed a gradient of concentrations of $PM_{2.5}$ by site typology. Low and average concentrations are recorded in the areas close to forests (23.32 ± 2.77 µg/m^3) and high concentrations are observed in the sites exposed to road traffic (33.57 ± 3.27 µg/m^3) in winter. However, concentrations recorded in the urban sites are lower in the summer (25.33 ± 2.85 µg/m^3 in sites exposed to road traffic, and 23.78 ± 1.92 µg/m^3 in sites close to the forests).

We also noticed that the dominance of $PM_{2.5}$ was observed in the vicinity of the major axes of movement. The dispersion of these particles is illustrated by detailed maps. The maps present information obtained by hierarchical classification. They aim to answer the need for spatial knowledge of the problem of particulate pollution in urban areas in the city of Tiaret.

The hierarchical classification allowed distinguishing three groups of schools: urban schools, urban schools highly subject to dense road traffic and schools close to green spaces and forests. The results obtained revealed a high contamination of the atmospheric environment of the city of Tiaret by $PM_{2.5}$ aerosols, taking into account the results recorded in primary schools. Mass concentration of $PM_{2.5}$ in the first period (autumn and winter) is higher than that of the second period (spring and summer). Indeed, the highest concentrations are recorded in the presence of students in winter.

Keywords: Air pollution, $PM_{2.5}$ aerosols, mass concentrations, cartography, Tiaret, Algeria.

Introduction

Since the nineteenth century industrial revolution, the composition of the Earth's atmosphere has changed significantly, both globally and regionally, mainly by a significant increase in anthropogenic emissions. The impact of these emissions on the chemical atmospheric composition and on climate is complex and variable in time and space scales.

In Algeria, the problems of air pollution accumulated over decades are just like in all big cities with industrial development, automobile traffic and household waste, which suffocate their environment (Maizi et al., 2011). In the atmosphere, aerosols are among the main routes of pollutant transfer. Particles with a characteristic size of less than few microns make up the majority of the atmospheric aerosol and are, therefore, the most likely long-distance transfer route (Forster et al., 2007; Pierre, 2011). $PM_{2.5}$ fine particles have a median aerodynamic diameter of less than 2.5 µm (progressing deeper in the respiratory tract). They form in particular as a result of shocks between smaller particles and by condensation of gas on the particles. Emissions from these particles are mainly due to residential and tertiary emissions, followed by manufacturing and road transport (Alvarez et al., 2013; Benaissa et al., 2014). The difficulty of determining the size of the particles like the diameter implies that they have a spherical form, which is not always the case. Therefore, we talk about an equivalent diameter, applicable to all particles regardless of their shape. The most often used diameter is the aerodynamic average diameter corresponding to a sphere having the same speed of fall as the particle and a density equal to 1 $g.cm^{-3}$ (Magali, 2008). During the last decade, many of the world's resident particles have been affected by fine particles with aerodynamic diameters less than 2.5 µm ($PM_{2.5}$), disrupting air quality and promoting increased respiratory morbidity rates among infants and young children (Ward et Ayres, 2004; Pope et Dockery, 2006; Henschel et al., 2012; Dunea et al., 2016).

Aerosol air pollution occurring in urban areas is related to both the concentration of industries and households, and the growth of the density of motor vehicle traffic (Chan & Yao, 2008; Kharytonov et al., 2016). $PM_{2.5}$ is subject to special attention because of its potential for human health and the dangers associated with its persistence in ecosystems (Benselhoub et al., 2016).

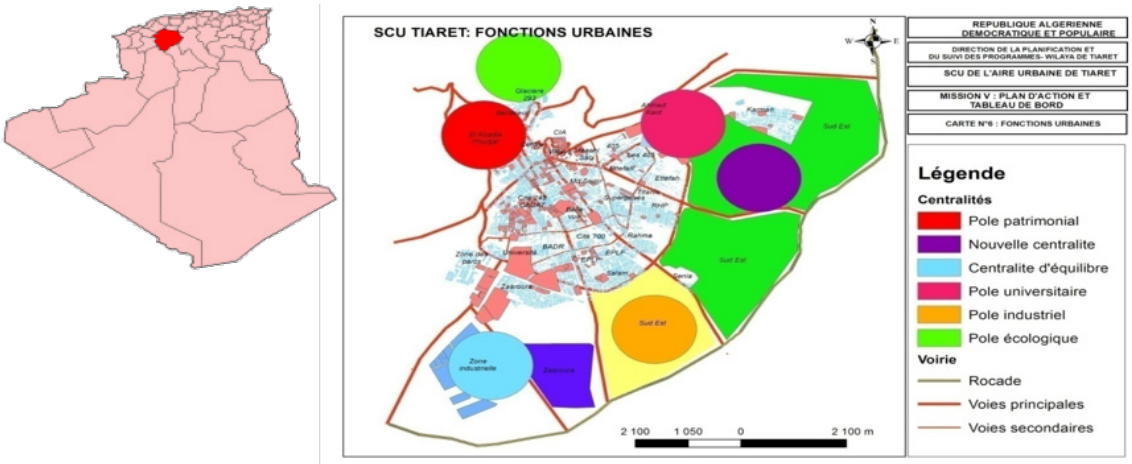
The objective of this work is to quantify particulate pollution by aerosols $PM_{2.5}$ in educational establishments in Tiaret city (Algeria).

Materials and Methods

Study area

The study was carried out in the city of Tiaret. This city is located in the North-West of Algeria between the Tellian range in the North and the Atlassien chain in the South. The climate is Mediterranean semi-arid with a mean annual rainfall of 400 mm. The region of Tiaret is located in an isolated state on the slopes of the mountains with an average altitude of 990 m (Fig. 1).

Fig. 1
Location of the study area



The prevailing winds come from the West and North-West, their average speeds vary from 3 to 4 m s^{-1}. The city of Tiaret has more than 200 km of urban road network. The city fleet consists of 156,900 vehicles, all types combined, and 71.33% of these vehicles are gasoline cars and 26% diesel cars.

This fleet is very heterogeneous because of the variety of vehicles that make it up (private or utility vehicle, gasoline or diesel, recent or old, etc.). Of this total, new cars (from 0 to 5 years) represent only 12% of the fleet, while cars over 10 years old account for 75%. However, it is precisely these older vehicles that are most polluting.

Selection of sampling sites

The 23 randomly selected primary schools are spread throughout the city (Fig. 2).

Fig. 2
Mesh and sampling sites (Google Earth, 2017)

The $PM_{2.5}$ collection consists of placing the impactor in the middle of the school yard one meter high, away from any source of contamination from the ground. Three samples were taken daily for each school, in the morning (7 – 9 am), at noon (11 am – 1 pm) and in the late afternoon (3:30 – 5:30 pm). $PM_{2.5}$ collection was conducted in the presence and absence of students in the school yard. The collection time was 30 minutes; for each sample, a total of six samples per day per school was collected. The study sites were chosen either at the intersection of the meshes, or in the middle of each mesh (mesh size of 0.5 km × 0.5 km). A total of 138 samples were collected for eight months, from November 2016 to June 2017.

Quantification of $PM_{2.5}$ aerosols in primary schools in the city of Tiaret was made using a Dekati® PM10 impactor (ISO23210, www.dekati.com, 2017). It will also be used to determine the dispersion of these particles by mapping to prevent the expected health consequences. Calculation of $PM_{2.5}$ concentrations, in $\mu g/m^3$, is performed according to a calculation model, on an Excel programme (PM10 30LPM calculation sheet ver1.51), delivered with the impactor, taking into account the values of the meteorological conditions outside the harvesting area (Marjamaki et al., 2000). The temperature and humidity were measured by a Multimetrix D53, the wind speed was measured by a branded anemometer. The data obtained were processed by R statistical and mapping tool.

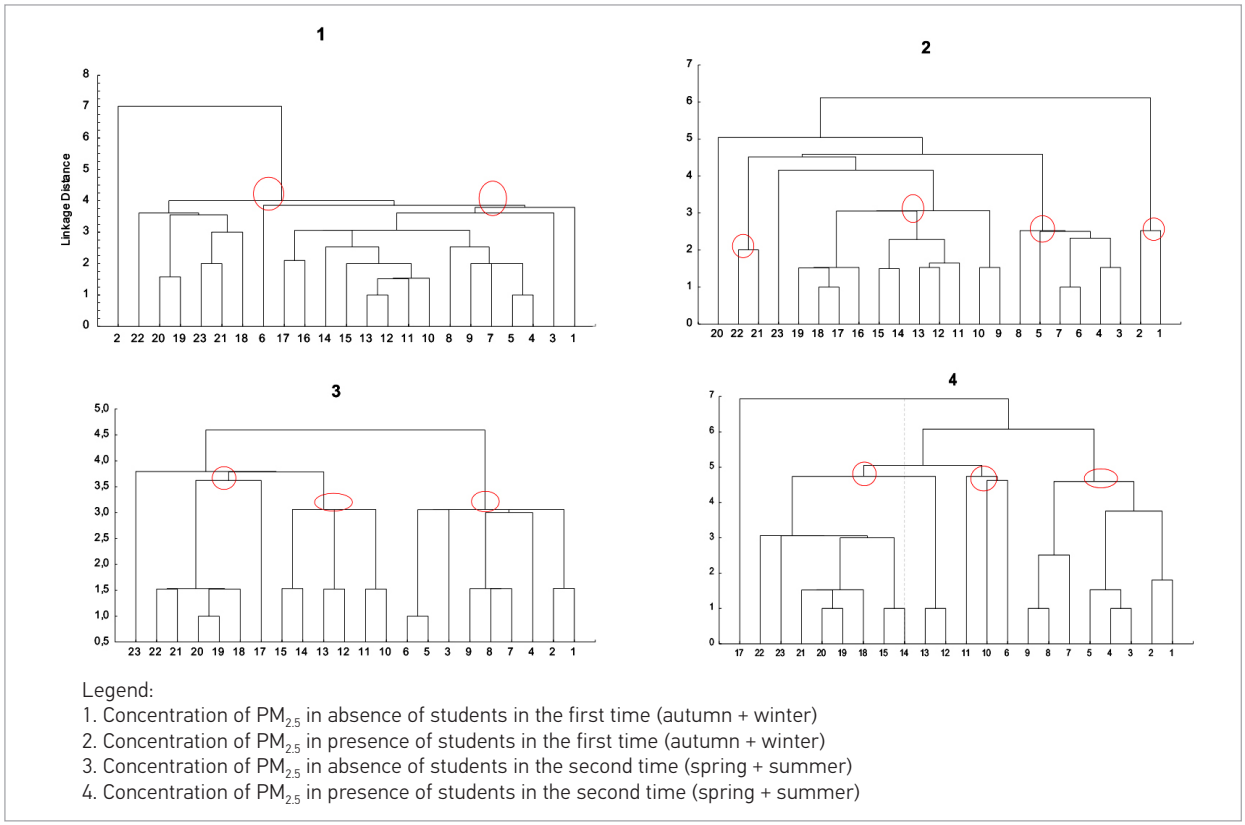
Results and Discussion

Classes of pollution and mapping

The $PM_{2.5}$ mass concentrations for each school were calculated for the 138 samples that were divided into two periods: the first was winter and fall, and the

Fig. 3

Classes of $PM_{2.5}$ aerosol pollution according to the automatic classification



Legend:
1. Concentration of $PM_{2.5}$ in absence of students in the first time (autumn + winter)
2. Concentration of $PM_{2.5}$ in presence of students in the first time (autumn + winter)
3. Concentration of $PM_{2.5}$ in absence of students in the second time (spring + summer)
4. Concentration of $PM_{2.5}$ in presence of students in the second time (spring + summer)

second was spring and summer. In the beginning, we sought to group the concentrations that were most similar to each other. To achieve this goal, we submitted the data from each period to automatic hierarchical classification. The results of this classification are shown in Fig. 3.

The automatic classification allows individualising pollution classes of each period, which are mentioned in Table 1.

Table 1

Basic statistics of pollution classes obtained by automatic classification

		Unit (µg/m³)					
	Variable	N	Mean	Min	Max	Std.Dev	Coef.Var(%).
	1	2	3	4	5	6	7
First period	Class 1 P	11	25.56	22.99	27.78	1.69	6.61
	Class 2 P	6	30.67	27.77	32.41	1.76	5.74
	Class 3 P	2	32.69	31.82	33.56	1.23	3.76
	Class 4 P	2	39.35	38.19	40.51	1.64	4.17
	Class 1 Abs	16	19.19	12.04	24.31	3.50	18.25
	Class 2 Abs	6	21.23	17.36	25.46	2.89	13.59
Second period	Class 1 P	3	18.90	15.04	21,99	3.54	18.72
	Class 2 P	10	27.19	24.31	30.09	2.20	8.08
	Class 3 P	8	30.90	27.72	34.72	2.54	8.22
	Class 1 Abs	6	17.94	13.89	21.99	3.17	17.67
	Class 2 Abs	6	20.45	16.20	23.14	2.39	11.69
	Class 3 Abs	9	20.83	16.20	24.31	2.59	12.44

First period: autumn and winter, second period : spring and summer.
P: presence of students, Abs: absence of students

First period: autumn and winter

In the presence of students, we observed a concentration gradient by site typology (Table 1), with low concentrations recorded in the sites close to the forest (25.65 ± 1.69 µg/m³) in class 1. Slightly elevated concentrations were recorded in the urban sites (30.67 ± 1.76 µg/m³) indicating class 2. The dominance of aerosols $PM_{2.5}$ appeared in class 4 with a concentration of 40.51 ± 1.64 µg/m³during this period. This class includes two schools located in an urbanisation zone with dense road traffic.

In the absence of students, there were two classes of pollution, ranging from an average of 19.19 ± 3.50 ug/m³ in sites close to the forest (class 1), and 21.23 ± 2.86 µg/m³ in urban sites exposed to road traffic (class 2); these values are still lower than the daily standard set by the World Health Organization (WHO, (2005) of 25 µg/m³.

Those values were confirmed by Ait Bouh et al. (2012), where $PM_{2.5}$ averages increased strongly in winter (between 17 and 27 µg/m³), particularly for two urban sites invaded by intense road traffic. However, cold can lead to an increase in air pollutant emissions from the combustion (Aurelien, 2003; Aurelien, 2017).

These observations make it possible to highlight the deterioration of air quality in these sites, especially in the presence of students, where $PM_{2.5}$ concentrations far exceed the daily norm (25 µg/m³) set by the WHO (2005). Dunea et al. (2016) found significant correlations ($p < 0.01$) between the locations of children with respiratory problems and the multi-year

average $PM_{2.5}$. These results support the hypothesis that increased $PM_{2.5}$ levels directly influence wheezing symptoms and asthma attacks in children.

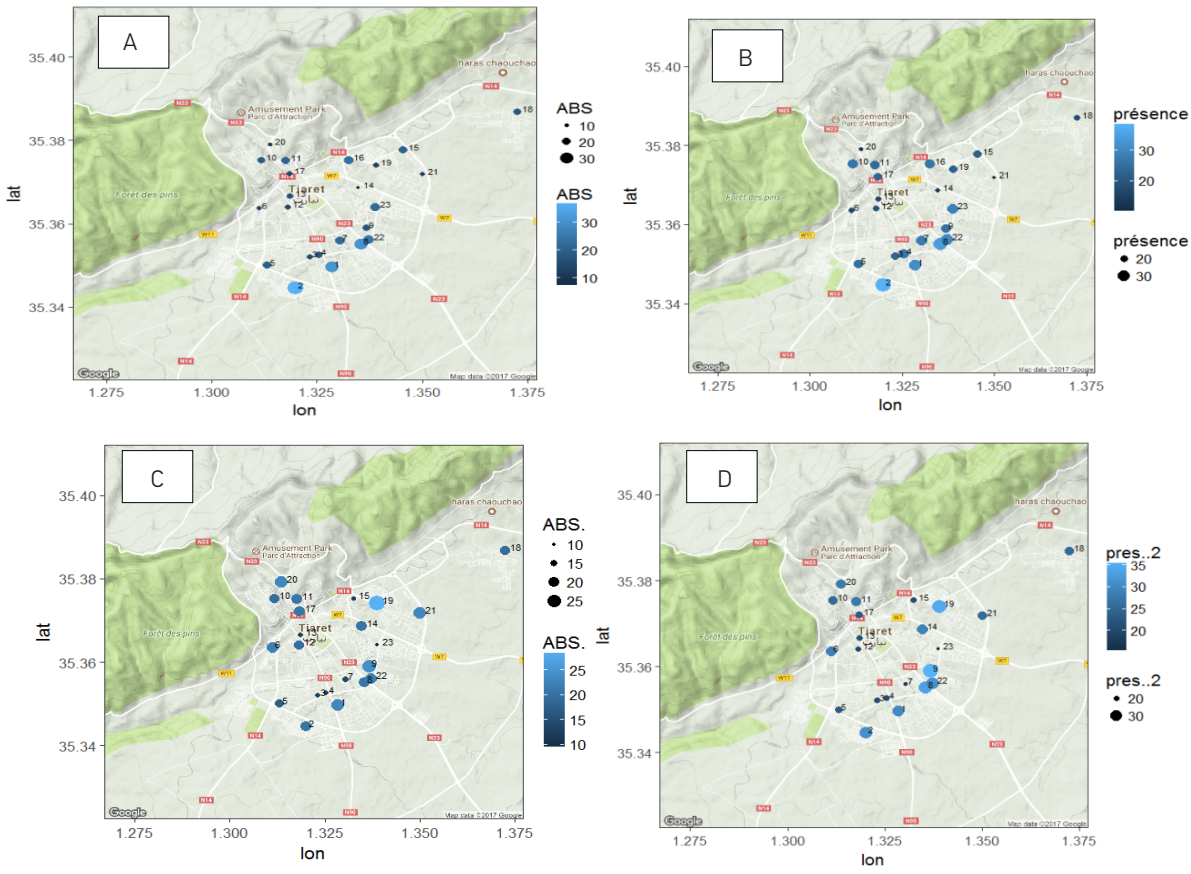
Second period: spring and summer

The same typology of $PM_{2.5}$ aerosol concentrations was observed during this period, with a maximum value of 30.90 ± 2.54 ug/m^3, observed in class 3 of sites located in a highly urbanised area with dense road traffic (Fig. 4). Low concentrations, which are close to the limit allowed by the WHO, were recorded in class 1 and class 2, 18.9 ± 3.54 µg/m^3 and 27.2 ± 2.2 µg/m^3, respectively, in the presence of students.

In the absence of students, class 3, which includes 9 schools located in urbanised areas close to road traffic, recorded a concentration of 20.83 ± 2.59 µg/m^3. However, Yves et al. (2013) found that the mass concentrations of $PM_{2.5}$, near the Fuveau road (France), were of the order of 14 µg/m^3, slightly exceeding the annual value (10 µg/m^3) of the WHO (2005). On the

Fig. 4

Mapping mass concentrations of $PM_{2.5}$ in both periods in the presence and absence of students



Legend:
A: absence of students in period I; B: presence of students in period I; C: absence of students in period II; D: presence of students in period II.
Relation: mass concentrations of PM2.5 vs environmental meteorological factors

other hand, Mi et al. (2016) reported that the highest concentrations of $PM_{2.5}$ were marked in winter, especially in urban sites. $PM_{2.5}$ showed a distinct seasonality of high concentration in winter and similar levels in other seasons (Yuan Chen et al., 2017). For Wei et al. (2012), the mean mass concentration of $PM_{2.5}$ was 101.6 ± 27.5 μg/m^3 in winter and 32.7 ± 19.7 μg/m^3 in summer (China). These results show the seasonal effect that is clearly visible on all sites. These high values are mainly explained by the impact of weather conditions (humidity, temperature, wind speed), which are more favourable to the accumulation of pollutants during the winter period.

Mapping

$PM_{2.5}$ mass concentration mapping was performed by R in two states: in attendance and absence of students, for both periods. The R package used is *ggmap* (2017). The low concentrations are shown in dark blue, unlike the high concentrations which are in light blue. Each point, indicated on the map, represents the school, the dimension of the circle defines the value of concentration, and the higher concentration is a larger circle.

The results of this mapping are shown in the following maps (Fig. 4).

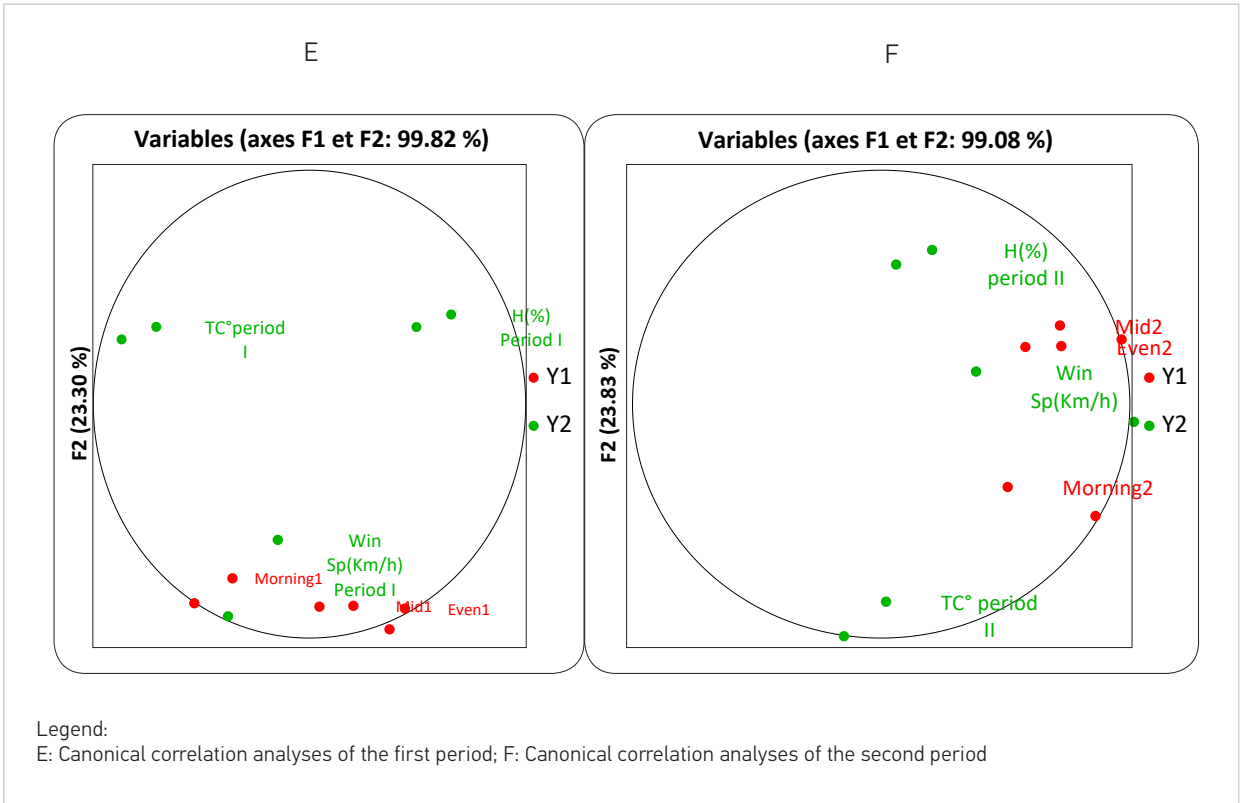
To examine possible correlations between some meteorological parameters and $PM_{2.5}$ concentration, we performed a canonical correlations analysis (CCA). The result of this CCA is illustrated in Fig. 5.

Two factorial plans are likely to be interpreted; they represent about 99% of point clouds for both periods.

The analysis shows a difference between the two periods. $PM_{2.5}$ concentrations are positively correlated with wind speed, which plays an important part in the dispersion of PM (r = 0.31 **). On the other hand, a

Fig. 5

Correlations between some meteorological parameters and $PM_{2.5}$ concentration



Legend:
E: Canonical correlation analyses of the first period; F: Canonical correlation analyses of the second period

weak correlation is observed between the temperature (r = 0.011), the humidity (r = 0.136 **), and the concentration of $PM_{2.5}$. On F2 axis (23.30% of information can be interpreted according to the axis), we find that the wind speed is correlated with sampling times (morning, noon and evening). In the first period, we notice a strong correlation between the wind speed and the "morning" sampling time. This is shown by the concentrations found in two different sites. On the other hand, a strong correlation between the wind speed and the three sampling times in the second period was observed for F1 (75.25%). This correlation is statistically significant (especially at noon). The $PM_{2.5}$ concentration is closely related to moisture in the 3 sampling times, whereas Yile (2017) points out that a lower wind speed in the lower atmosphere reduces transport he dispersion of aerosols increases the accumulation of aerosols near their sources and increases the local concentrations of aerosols. Dumka et al. (2013, 2015) note that in addition to seasonal variability, mass concentrations of $PM_{2.5}$ also exhibit pronounced diurnal patterns, strongly related to the combined effects of local emissions, meteorology and boundary layer dynamics. However, the effect of wind dynamics is identified as the main actor of dust uplift (Tiwari et al., 2017).

Effect of sampling time on the distribution of $PM_{2.5}$

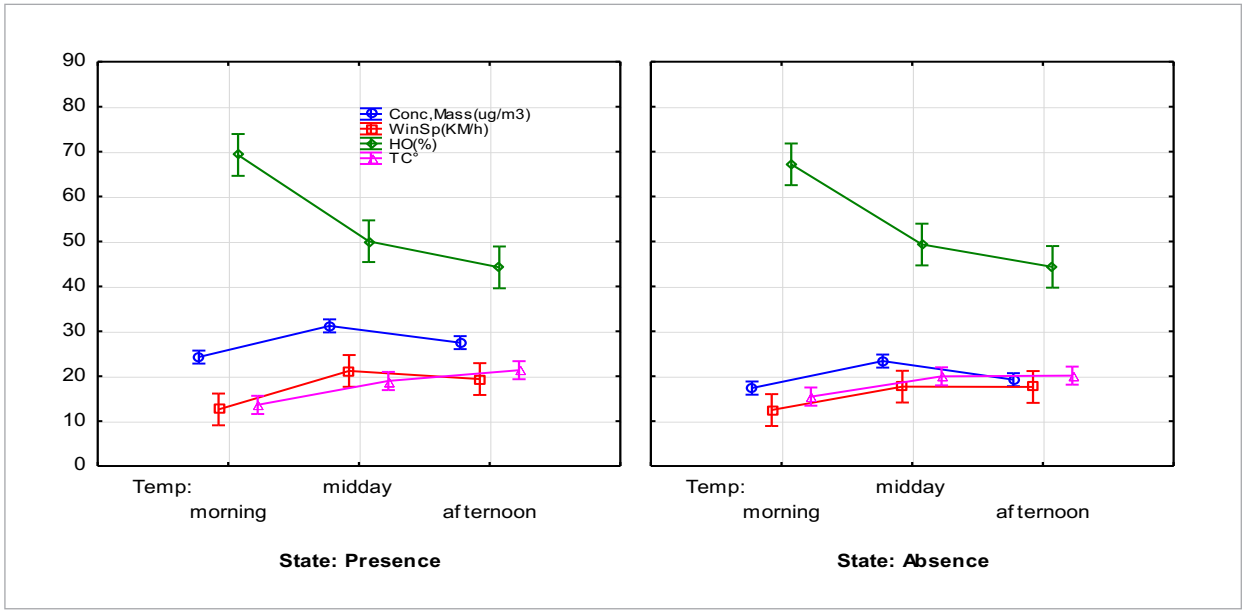
In this part, and in order to study the temporal distribution of $PM_{2.5}$, we performed a factorial analysis of variance. The factors selected are the three periods: morning, noon and evening. Fig. 6 represents the factorial analysis of $PM_{2.5}$ variance in the presence and absence of students.

There is a highly significant difference between the three sampling times (p = 0.001). This difference was observed in the mass concentrations at noon 27.37 µg/m^3 compared with morning and evening, 20.80 µg/m^3 and 23.56 µg/m^3, respectively.

Indeed, the dominance of $PM_{2.5}$ in winter was recorded in the sites N° 01.02, and 22, respectively, 33.25 µg/m^3, 35.88 µg/m^3 and 29.5 µg/m^3. These schools are located in the main sights in the city centre and are exposed to the traffic lanes of dense road traffic, coinciding with increased human activities in the city.

Fig. 6

Factorial analysis of two periods in the presence and absence of students in the morning, noon and evening



The $PM_{2.5}$ emissions at noon are higher compared with other times (Fig. 6), which means that the source of this emission is increasing especially at this time. However, Tiwari et al. (2017) found that the lowest value of $PM_{2.5}$ (36 ± 30 μg/m^3) was observed between 14:00 and 17:00. In Guwahati (India), they found that the cause was the proximity to road traffic and human activities in the markets and the sites located near the most polluted sites.

Similar diurnal profiles of $PM_{2.5}$ have been observed in several urban sites in India (Badarinath et al., 2009; Jain et al., 2010; Tiwari et al., 2017) showing the important role of weather on atmospheric diurnal variability of the aerosols. Bo et al. (2015) showed a daily change in $PM_{2.5}$ and daily values higher than night-time measurements in Beijing (China). In Ile-de-France near automobile traffic routes, the concentrations of fine particles can be up to twice as high as those found in the background (Petite et al., 2013). In 2012, Host et al. found a value between 30% and 45% of the $PM_{2.5}$ recorded at the measurement stations near the traffic as a consequence of the direct impact of the traffic with diesel vehicles being responsible for 90% of these emissions.

However, it is important to point out that a significant number of schools are located in road traffic locations next to construction sites and that pollution may be a health hazard to students.

Particle pollution is of particular concern during the winter because of the use of heaters and temperature inversion situations. However, the share of vehicle traffic through diesel vehicles is steadily increasing. We find that natural and anthropogenic emissions also have a significant influence on increases in aerosol concentrations in winter, with important implications that need to be addressed. This has been demonstrated by Yuesi (2011) who found that during autumn and winter burning fossil fuels produced heavy loads of aerosols in mode, smoke and soot.

Lead (Pb) is present in paved road dust due to exhaust emissions from leaded gasoline vehicles (Lu et al., 2014; Wei et al., 2015). In fact, the city of Tiaret car fleet consists of 71.33% of gasoline cars and 26% of diesel cars.

In the end, the use of accumulating plants with high pollutant levels above the $PM_{2.5}$ components is highly recommended. We can consider that the pairing of biological and physicochemical techniques is interesting, in the sense that the results obtained by the bioindicators are complementary and allow a better characterisation of pollution by fine particles (Maizi et al., 2012). Permeability studies have shown that the cuticle is also a means of access for different types of pollutants to plant tissues (Francoise et al., 1988). Thus, urban forest contributes to reducing the concentration of certain pollutants in the ambient air.

The vegetation refreshes microclimates, and groups of trees with a dense crown modulate the behaviour of the winds (Yann Vergriete, 2007). In addition, urban trees have a useful role of air purification. The foliage, for example, absorbs many atmospheric pollutants, in particular ozone, sulphur dioxide and carbon dioxide.

The ANOVA also shows a highly significant difference ($p = 0.001$) between the mass concentrations of $PM_{2.5}$ measured in the presence and absence of students for the 23 schools. The dispersion of aerosols is also favoured by the increase in the wind speed and the activities of students at the recreation period. That is explained by the difference of concentrations. For example, for the first site, the concentration of $PM_{2.5}$ is 38.19 μg/m^3 with wind speed = 20.67 km/h in the first period, and it is 24.31 μg/m^3 with 13.83 km/h in the second period. Thus, $PM_{2.5}$ concentrations in the presence of students are higher (27.81 ± 4.82 μg/m^3) than during their absence (20.04 ± 3.5 μg/m^3). These values are higher than the annual standard (10 μg/m^3) set by the WHO (2005). According to the study conducted in the lower air in girls' schools, Dinh Trinh (2011) found that $PM_{2.5}$ concentrations were higher in the presence of students than found in their absence. Children are at an increased risk for the effects of air pollution because of their immaturity in the lungs and their sensitive immune system (Bateson & Schwart, 2008; Sheffield et al., 201a5). Children living near heavy traffic are more likely to develop asthma (Gasana et al., 2012; Gowers et al., 2012; Newman et al., 2014; Daniel, 2016).

$PM_{2.5}$ is associated with acute and chronic health effects and is a widely used indicator of air quality (Stéphanie, 2013; Chang-Fu Wu, 2017). Evidence for these regulations comes mainly from associative studies that have consistently demonstrated a

relationship between $PM_{2.5}$ and increased morbidity and mortality. Deryugina et al. (2016) found an increase in daily $PM_{2.5}$ three-day mortality. Thus, they guess that each 1 $\mu g/m^3$ increase in $PM_{2.5}$ increases the three-day emergency visits by 2.3 per million beneficiaries.

Conclusions

This study has made it possible to know the state of $PM_{2.5}$ air quality in the educational establishments of Tiaret region, where a certain number of suspended contaminants in the air is present in the urban school environment. However, repairable suspended particles (RSPMs) are of great importance because they can significantly affect the health of occupants (Radha, 2011).

The analysis of the canonical components showed that the $PM_{2.5}$ concentration was strongly correlated with the wind speed and closely related to the humidity and temperature in the 3 sampling times. We, therefore, note that wind speed is one of the conditions more or less favourable to the dispersion of pollutants. We conclude that wind speed also has a significant influence on the increase of aerosol concentrations in winter, with important implications that must be related to occupants in the middle.

There was a highly significant difference ($p = 0.001$) between the mass concentrations of $PM_{2.5}$ measured in the presence and absence of students for the 23 schools. Ultimately, the dispersion of aerosols is favoured by the increase in speed wind and the movements of students in the course at the time of recreation.

The analysis of factorial variance in the absence and in the presence of students showed that the concentration of the $PM_{2.5}$ at noon was higher than in the morning and the evening. It is possible to note that the dominance of $PM_{2.5}$ was recorded in the sites located in the city centre streets and still exposed to heavy road traffic, and the concentration of $PM_{2.5}$ at noon wass higher than at other times; we also note that the causes of pollution are road traffic and human activities in markets and building sites located near these sites.

Tree cover and tree planting programmes are still quite rational and reasonable. Given the scale of the task, if we want to rapidly increase the tree cover in cities, we need to encourage natures and from various sources.

Finally, the typical characterisation of aerosols and their evolution in time and space are still relevant and deserve to be the subject of extensive research.

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