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Air quality assessment in Algiers city

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Abstract
Very few studies related with the assessment and research of air pollutants have been initiated in Algiers, which is the political and economic capital of Algeria. This lack of studies is mainly due to the non-access and insufficiency of data, and also the failure of the air quality monitoring stations during the last years. For those reasons, the use of modeling tools can be useful to assess the air pollution levels and compare different control options. The main aim of this paper is to identify anthropogenic emission sources (road traffic, industrial, residential, and waste) which are considered key sources of air pollution in the greater Algiers, and to estimate the concentration levels of suspended particles with diameter < 10 μm (PM10) and nitrogen dioxide (NO_2) over the studied area during 2012. For this purpose, The Air Pollution Model (TAPM) was used. The results indicate that meteorology statistical measures present a perfect agreement between measured and predicted values. The index of agreement (IOA) for wind speed and its components is above 0.65, for temperature is 0.99, while for the air pollution, the comparison of predicted concentrations with measured ones shows similar results. The maximum concentration levels for PM10 (122 μg/m^3) and for NO_2 (91 μg/m^3) are higher than the values established by national and international legislation, and the industrial districts are more affected by air pollution than the urban areas.

Keywords Air quality · Emission inventories · PM10 · NO_2 · Algiers

Introduction

Algeria is the largest country in Africa with an area larger than 2 million km^2, which is about one-twelfth of the total area of Africa. Since the independence in 1962, the economy has developed rapidly as a result of the growth of oil production and the implementation of an important industrial infrastructure based on the development of hydrocarbons and mineral resources, namely the oil and gas refining complexes, the steel industry, the chemical and petrochemical industries, the fertilizer manufacturing, the cement plants, and building materials production (Safar Zitoun and Tabti-Talamali 2009).

According to the Ministry of Energy and Mines (MEM 2013), Algeria's fuel consumption has grown by 9% over the past decade. The use of energy in different sectors (road traffic 44%, residential 34%, industrial 14%, agriculture 2%, and others 5%) is the main source of atmospheric emissions in the country (Safar Zitoun and Tabti-Talamali 2009).

Algiers city, the political and economic capital of Algeria, is located nearby the Mediterranean Sea, in the northern part of the country, covering an area of approximately 120 km^2. In 2012, Algiers had a population of 3.7 million representing 10% of the total Algerian population (NOS 2012). In addition to the intense road traffic with 1.1 million vehicles, Algiers has many industrial activities (some of them concentrated on industrial areas) and many landfills. The National Observatory for Environment and Sustainable Development is the only organization that controls and continuously measures major pollutants in some areas of the country by its automatic stations named SAMA SAFIA (Arabic term literally means: Clear Sky). Air quality levels were exceeding the guidance values fixed by the World Health Organization (Boughedaoui et al. 2004; Kerbachi et al. 2006; Kerchich and Kerbachi 2012).

According to the Algerian legislation, the annually averaged limit values for particulate matter with aerodynamic diameter lower than 10 μm (PM10) and nitrogen dioxide (NO_2)

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are 80 and 40 μg/m^3, respectively (JORADP 2006). Boughedaoui et al. (2004), Kerbachi et al. (2006), Oucher and Kerbachi (2012), Talbi et al. (2017), and Petkova et al. (2013) have demonstrated that particulate matter concentration levels frequently exceed the Algerian air quality annual standard in the metropolitan region of Algiers; they also found various heavy metals in the suspended matters.

Both pollutants have negative impacts on the human health, especially when their limit values are exceeded as reported by the Word Health Organization (WHO) (WHO 2006, 2016). Unfortunately, since 2009, all SAMA SAFIA stations have been out of service; consequently, no official measurements of pollutants are done nowadays (Talbi et al. 2017) and only some intermittent data collected by researchers and experts are available (Boudehane et al. 2016; Kerbachi et al. 2006; Kerchich and Kerbachi 2012; Talbi et al. 2017; Terrouche et al. 2016), but they are not optimal to assess the air quality in Algeria and particularly in the Algiers city.

Air quality modeling can help assessing the air quality of the city providing spatial and temporal patterns of pollutants levels in the air. The Air Pollution Model (TAPM) that predicts meteorology and air pollution concentrations could be an important tool to assess the urban air quality (Pollard et al. 2015; Wahid et al. 2013). It was developed by CSIRO (Commonwealth Scientific and Industrial Research Organization) (Hurley et al. 2001). TAPM is oftenly used in Australia, New Zeeland, Portugal, Greece, and other countries for prediction of meteorological data (Dehghan et al. 2014a; Hurley et al. 2003) and air pollution dispersion studies in different areas, like coastal (Luhar and Hurley 2004; Relvas et al. 2017; Wiegand et al. 2011), rural, and urban (Luhar and Hurley 2003; Miranda et al. 2016) and even in mountainous complex terrain area (Aidaoui et al. 2015; Matthaios et al. 2017, Matthaios et al., 2016). The performance of TAPM for meteorology and pollution under different conditions was evaluated by several authors and regions over the world (Borrego et al. 2012; Dehghan et al. 2014b; Duque et al. 2016; Hurley et al. 2003; Luhar and Hurley 2004; Matthaios et al. 2017).

This work aims to model air pollution in particular PM10 and NO_2 levels in the Algiers city using the TAPM, for a better understanding of air pollution phenomenon in Algiers and for helping decision making towards air quality improvement strategies.

This paper presents in section "Methodology" the methodology adopted for the study area and the model setup as well as the construction of the emission inventories. The obtained meteorological and air pollution results and their discussion are given in section "Results and discussion." Finally, section "Conclusion" provides the general conclusions.

Methodology

The air quality study was made considering the pollutants emitted by several sources (point, line, and area) in the Algiers city. The modeling setup, the simulation domains, and emissions of different sources are detailed in this section.

Modeling setup

The TAPM was applied with three nested domains with horizontal grid resolutions of 10, 3, and 1 km^2, considering 2012 as the reference simulation year. The innermost domain centered over Algiers city had an extension of 50 km × 50 km, whereas the outermost domain covered 500 km × 500 km. Figure 1 summarizes the simulation domains, the location of point, and line sources and of the meteorological station.

The lowest ten of the 25 vertical levels were 10, 25, 50, 100, 150, 200, 250, 300, 400, and 500 m, with the highest model level at 8000 m. The TAPM default databases of soil properties, topography, and the monthly sea-surface temperature and deep soil parameters were used.

TAPM directly assesses to datasets of terrain, land use, sea-surface temperature, and synoptic meteorological analyses of any region around the world. Based on its meteorological results, it estimates pollutant concentrations simulating transport, dispersion, and different processes such as wet/dry deposition, photochemistry, aqueous chemistry, and gravitational settling of aerosols in the region of interest (Hurley et al. 2005).

Meteorological model predictions for wind and temperature were extracted at the nearest grid point of Ain-Bessem meteorological monitoring station (NOM 2012) in the inner grid (3-km grid spacing) at the lowest model level (10 m above the ground). Ain-Bessem meteorological monitoring station is one of the 79th monitoring stations of the National Office of Meteorology. It is located about 76 km of Algiers, towards the southeast of the region.

For the pollution simulation, TAPM was run (with the mode chemistry and deposition) for the small nested domain of 50 km × 50 km with a horizontal grid resolution of 1 km × 1 km, representing Algiers and some municipalities of Wilaya of Blida. Unfortunately, there are no measured data to compare with air quality simulated values. Different types of sources around Algiers region and other municipalities of Wilaya of Blida were considered: point (such as cement plants, refineries, power plants), line, and area.

Some statistical indicators were used to evaluate TAPM performance by comparing predicted values and measured ones. Proposed statistics (Schlünzen and Sokhi 2008) for the meteorological components of TAPM were average value; correlation coefficient (r) between observed (O) and predicted (P) values; average difference (BIAS); root mean squared error (RMSE); standard deviation of error (STDE); skill variance

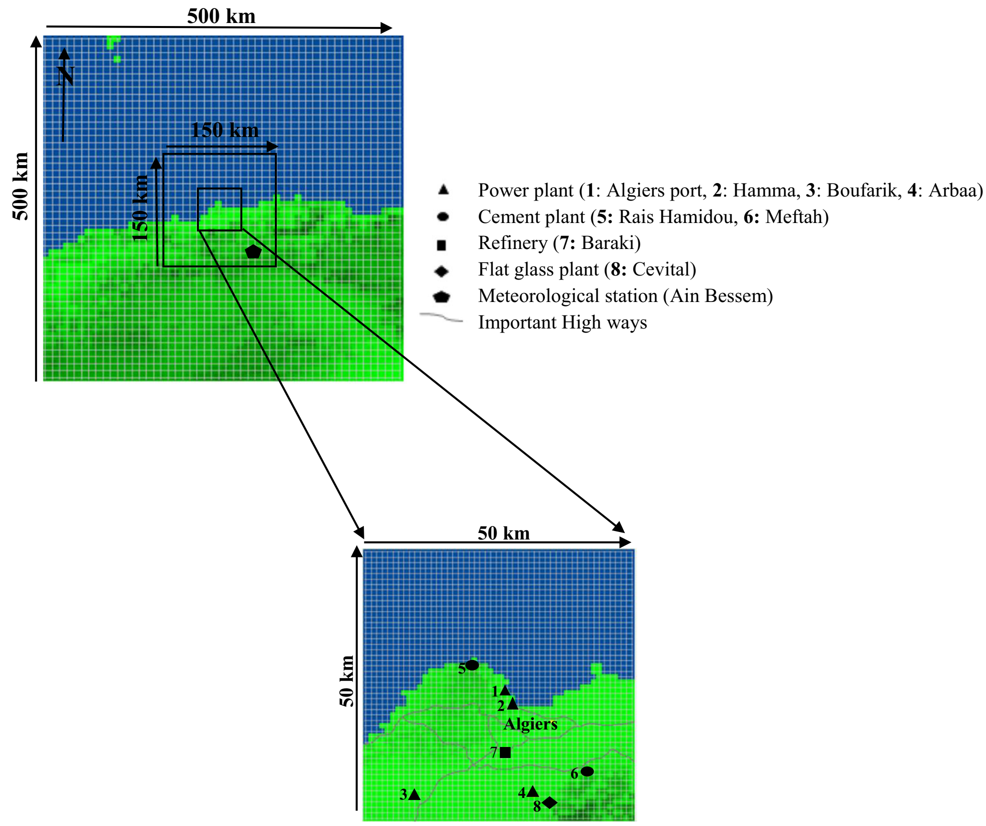


Fig. 1 Simulation domains, the location of point, and line sources and of the meteorological station

(SKVAR); and index of agreement (IOA). The main statistical parameters are presented as quality indicators in Table 1.

For an ideal forecast, correlation coefficient, SKAVR, and IOA should be one; BIAS, RMSE, and STDE should be zero.

Emissions inventories

TAPM was applied using local emission inventories for industry, road transport, residential, and waste sources as detailed in the next sections. Several studies (Baldasano et al. 2008; Cros et al. 2004; Martinet 2004) describe methodologies to estimate emissions that need a considerable amount of data. However, Ho and Clappier (2011) proposed a methodology requiring fewer data, which is the best approach for a developing country like Algeria, where there is a big lack to collect and assess data.

Table 1 Statistical parameters for meteorology (Schlünzen and Sokhi 2008)

Quality indicators	Acceptable values	Ideal value
Correlation coefficient (*r*)	(0, 1)	1.0
Fractional bias (BIAS)	(− 2, 2)	0.0
Root mean squared error (RMSE)	n.a.	0.0
Standard deviation of error (STDE)	n.a.	0.0
Skill variance (SKAVR)	(0, 1)	1.0
Index of agreement (IOA)	(0, 1)	1.0

n.a. not applicable

Point sources emissions

For the Algiers simulation domain, eight point sources with stacks taller than 60 m were considered: the power plants of Algiers port, Hamma, Boufarik, and Arbaa; the cement plants of Rais Hamidou and Meftah, the Beraki refinery, and the Cevital flat glass plant. These facilities are located at different locations outside the industrial areas, as shown in Fig. 1.

The emissions for each industry and each pollutant were calculated by Eq. 1 which is based on activities production and fuel use data (Rahal et al. 2014):

$$E_{ip,a,t} = A_{a,t} \times EF_{ip,a} \tag{1}$$

where:

- E emission related to the pollutant "ip" and the activity "*a*" for the time "*t*";
- A quantity of activity "*a*" during the time "*t*";
- EF emission factor for the pollutant "ip" and activity "*a*."

The air pollutant emission inventory Guidebook 2016 (EEA 2011) was the basis for the used emission factors.

Road traffic emissions

The Energy and Air Pollution Laboratory, Saad Dahleb University of Blida, Algeria (LPEA 2008), estimated the road traffic emissions in Algeria from the independence 1962 year until 2025. These are based on several surveys of vehicle characteristics, such as number of vehicles in each category, age, consumed fuel, and using the COPERT III Model (Ntziachristos and Zissis 2000). Information from the National Statistics Office was also used. Approximately 26% of the national automobile park is concentrated on Algiers (NOS 2012).

Road traffic emissions were considered as line (important highways) or area (secondary and tertiary roads) sources in Algiers.

According to the Ministry of Public Works and Transportations, Algeria, the distribution of the flow vehicles on Algiers highways shown in Fig. 1 was used as emission distribution keys as follows (Table 2):

Area sources emission

In Algiers region, there are important industrial districts situated in several locations. Many factories are active in these areas, including a big factory of buses and trucks, pharmaceutical industries and plastic recycling, and several small manufacturers of foodstuff. Total emissions from industrial processes for Algeria were published by Sahnoune et al. (2013) for the year 2012. The emissions from each zone were calculated using their size as a distribution keys (Table 3).

In addition to industrial areas emissions, landfill emissions were estimated for the Ouled Fayet landfill (40 ha), which represented about 70% of the total capacity of waste in Algiers; it has received around 800 ton/day. In 2013, Ouled Fayet landfill was closed in order to transform it into a public garden (SWEEP-Net.GIZ 2014).

Landfill emissions were estimated applying the air pollutant emission inventory Guidebook 2016 (EEA 2016) methodology. Emission factors for waste, total capacity, and treatment type of the landfill were used.

Table 2 Distribution of the flow vehicles on Algiers highways

Highways and secondary and tertiary roads	Rate (%)
Southern ring road highway: Dar El Beida-Ben Aknoun-Zéralda	8.5
Highway: Boudouaou-Dar El Beida-Blida	6.5
Sheeplike road: Dar El Beida-Alger centre	5
Bir Khadem-Birtouta	4
Birtouta-Zeralda	2
Secondary and tertiary roads	74

Table 3 Distribution keys of industrial emissions depending on the size of each industrial zone (ME 2017)

Industrial districts in Algiers	Area (ha)	Rate (%)
Rouïba–Reghaia	1.000.00	67.65
Oued Smar	400.00	27.06
El Harrach	78.00	5.27

According to the census data of 1998, updated by the National Statistical Office (Algeria) in 2004, Algiers region was divided into four different sub-areas (hyper center, center, first, and second crowns) in function of the population density. This administrative division allows taking into account the evolution of urban dynamics, in particular, the extension phenomenon of peripheral areas located to the east of the main agglomeration. The hyper center and the center represent 8 and 20% of the Algiers population, respectively, while 34 and 38% of the population are leaving in the first and the second crowns (Safar Zitoun and Tabti-Talamali 2009).

Because of missing data, residential PM10 and NO_2 emissions delivered by the European Monitoring and Evaluation Programme (EMEP 2017), which include the Algiers region, were spatially disaggregated by population density using a top-down methodology. Figure 2 shows the land use distribution of the different considered area sources.

Total Algiers emissions

Emissions of pollutants from point and line sources (important highways in the Algiers city) were allocated to the place of each industry and road line, while emissions from industrial areas, residential, waste, and secondary and tertiary roads' traffic were considered as area sources.

Not just the old vehicles are contributing to air pollution, but also recent vehicles imported from developed countries (France, Japan, Germany etc.…), are not emitting in accordance with the origin countries standards and emit the same quantity of pollutants as the old ones (Chikhi et al. 2014). In addition to the vehicle emissions, industrial, residential, and waste sectors are contributing to the degradation of life quality in the city (Rahal et al. 2014) and are responsible for respiratory diseases. A significant relation was found between air pollution by particulate matter and human health in an urban area in Algiers (Laïd et al. 2006).

Total emissions for each activity and pollutant were temporally disaggregated using the temporal emission profile to characterize emission evolution over the time (Rahal et al. 2014). The relative emission of pollutants from all sources used in this work is summarized in Fig. 3.

As shown in Fig. 3, road traffic mainly contributes to NO_2 emissions, followed by industry, residential, and waste sectors, 82% of NO_2 emissions are from road traffic origin and

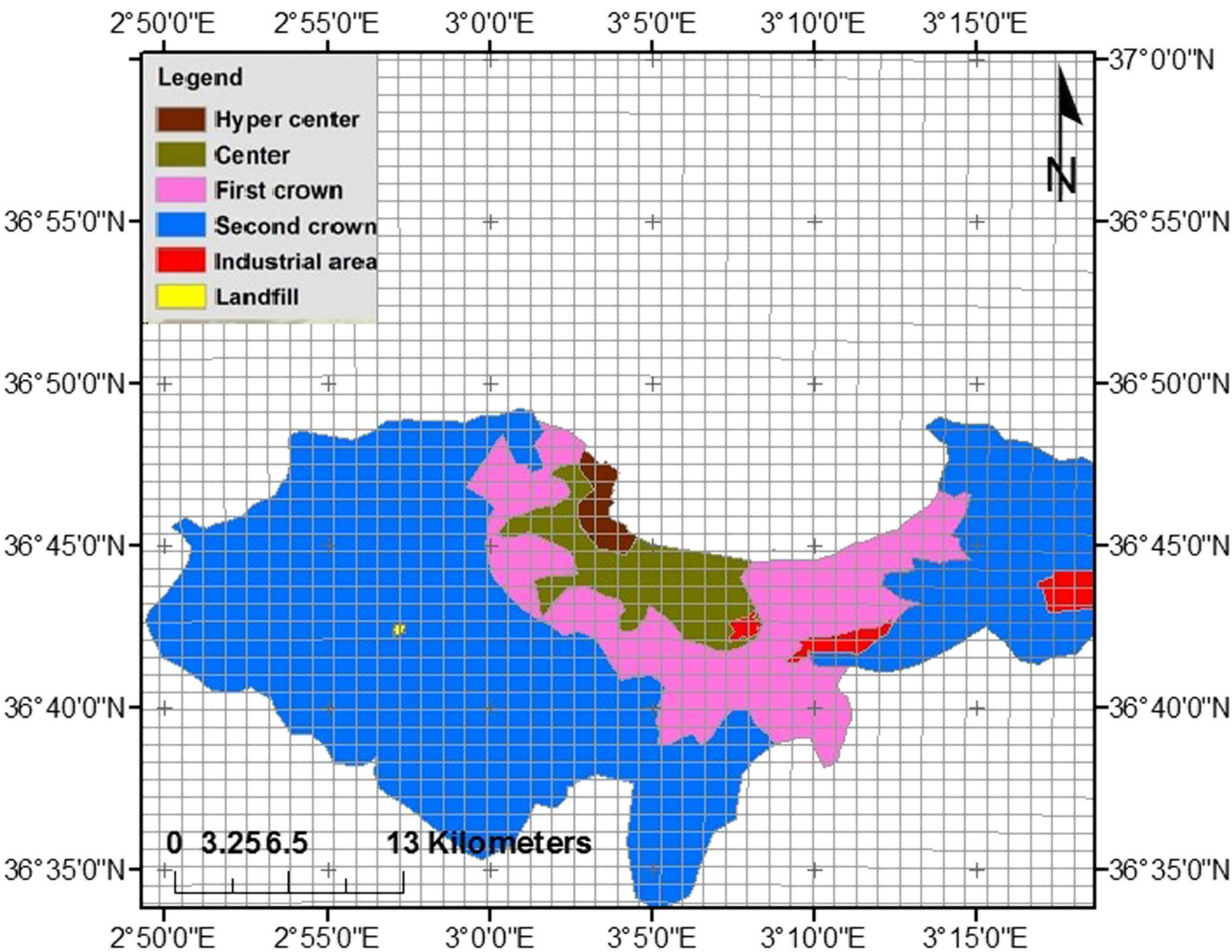


Fig. 2 Area sources distribution

12% from the industry. Around 90% of PM10 emissions are from the industrial sector. These percentages are similar to those delivered in 1995 by the Ministry of Territory Planning and Environment, Algeria, with 69% of NO_2 emissions from road traffic and 29% of NO_2 and 98% of PM10 emissions from the industrial sector (MATE 2001).

Results and discussion

Meteorological and air quality results are presented and discussed, including those from the validation of the meteorological component.

Meteorological validation

Figure 4 shows measured and predicted wind roses and time series of hourly averaged temperature at 10 m above ground level (AGL) at the Ain-Bessem meteorological station along the entire year of 2012.

In general, there is a similarity between measured and predicted data for meteorological variables at the same location, although for some periods, there are some differences.

Dominant winds measured at Ain-Bessem are from the South-east, West, and North-east. Predicted dominant winds also blow from the South-east and North-east with a clear contribution from westerly winds. Measured winds tend to be stronger than predicted ones.

Measured and predicted values of temperature are very similar. The higher temperatures were registered in the summer period especially during the months of July and August.

The performance statistical indicators obtained using the hourly averaged model predictions for wind speed ($\overline{U}$), horizontal wind components (U and V), and temperature (T) are shown in Table 4.

According to Table 4, the statistics show some differences between the predicted and measured values of the wind speed and its components. The model wind speed performance with a correlation coefficient of 0.68 is well comparable to values found in other studies (Yu et al. 2008; Zhong and Fast 2003).

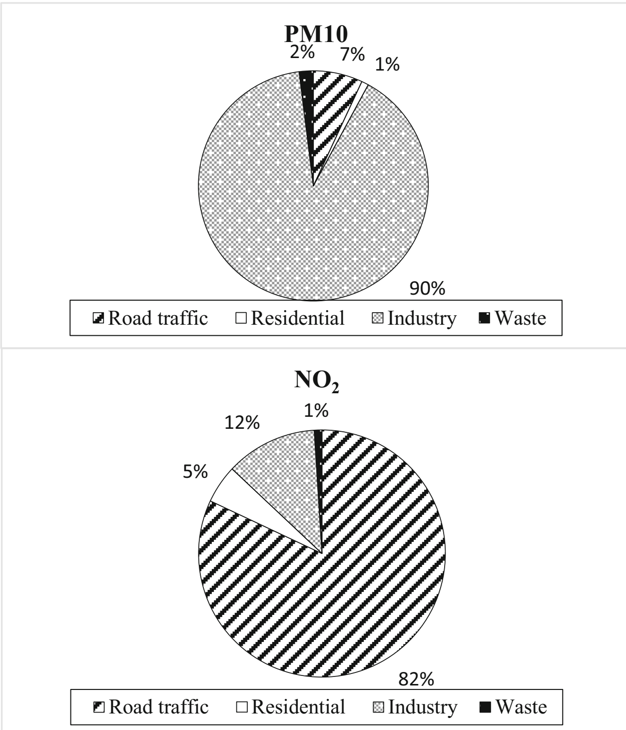


Fig. 3 Relative NO_2 and PM10 emission of pollutants from all sources in Algiers in 2012

The IOA (a measure of the skill of the model in predicting variations about the measured mean), for wind speed and its components, is higher than 0.65. Based on numerous other modeling study (Hurley et al. 2001; Zawar-Reza et al. 2005), an IOA value greater than 0.5 represents a good model performance.

Moreover, the statistics of temperature present very good results, with a correlation coefficient and an IOA larger than 0.98. The RMSE (2.14) is in the same level than statistics found by Wiegand et al. (2011).

BIAS and SKVAR, for all variables, are within the range of acceptable values shown in Table 1. Overall, all the statistics presented in Table 4 indicate a good agreement between measured and predicted values.

Assessment of the air quality

Even without measured data during 2012, we decided to compare results with some data measured by four monitoring stations (namely Beb El Oued, Hamma, Ben Aknoun, and 1er Mai) situated in several locations in Algiers from 2003 to 2007, the period when monitoring stations were functioning (Safar Zitoun and Tabti-Talamali 2009). The results are illustrated in Fig. 5.

Annual averaged concentrations of PM10 and NO_2 predicted in 2012 are slightly higher than the other averaged

Fig. 4 Measured and predicted wind roses and temperatures for the Algiers region for the year 2012

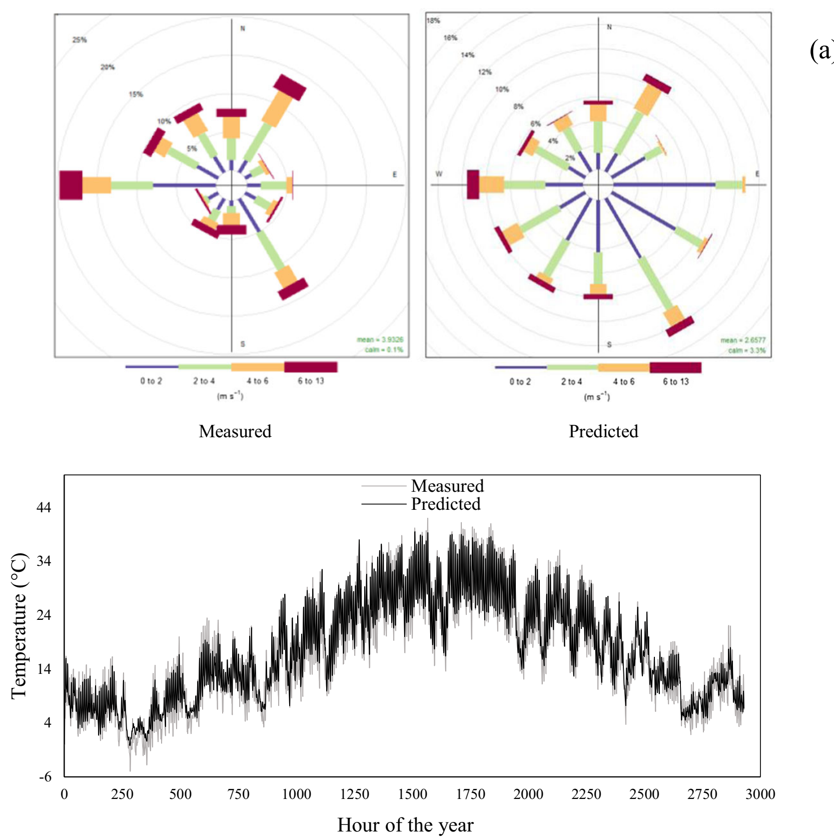


Table 4 TAPM performance statistics indicators for Algiers for wind speed ($\overline{U}$) in m s^{-1}; the west-east component of the wind (U) in m s^{-1}; the south-north component of the wind (V) in m s^{-1}, and temperature (T) in °C

Variable	Wind speed		West-east component of the wind		South-north component of the wind		Temperature	
	$\overline{U}_m$	$\overline{P}_P$	U_m	U_p	V_m	V_P	T_m	T_P
Average value	3.40	2.90	0.40	0.74	0.49	0.33	16.70	17.60
r	0.68		0.71		0.75		0.98	
BIAS	− 0.45		0.35		− 0.16		− 0.80	
RMSE	2.06		2.07		2.25		2.14	
STDE	1.92		2.04		2.25		1.99	
SKVAR	0.80		0.79		0.84		0.97	
IOA	0.68		0.73		0.79		0.99	

$\overline{U}_m$, U_m, V_m, and T_m are the modeled wind speed, west-east component of the wind, south-north component of the wind and temperature, respectively
$\overline{U}_p$, U_p, V_p, and T_p are the predicted wind speed, west-east component of the wind, south-north component of the wind and temperature, respectively

values measured by the monitoring stations of SAMA SAFIA, from 2003 to 2007; this difference is probably due to the higher intensity of human activities and/or road traffic emissions in 2012. These data are in good agreement with results from previous studies; Abderrahim et al. (2016) prove that 48% of PM10 values evaluated in different periods from 2002 to 2006 exceed the limit target value of air quality (≤ 50 μg/m^3) in Hamma area (Algiers), whereas Talbi et al. (2017) show that the level of PM10 in Algiers can reach more than four times the limit threshold of air quality fixed by the local air quality standard regulations (≤ 80 μg/m^3).

This comparison between measured and predicted concentrations is not representative of the real validation, it is made as an indication to have an information about the pollution magnitude in the study area.

The annual spatial atmospheric PM10 and NO_2 distributions provided by the air quality modeling system, for the Algiers region for the entire year of 2012, are displayed as dispersion maps in Figs. 6 and 7.

Figures 6 and 7 show that concentration levels of PM10 and NO_2 reach values above 120 and 90 μg/m^3, respectively. Highly pollution peaks for PM10 are around Oued Smar, Rouiba, and Reghaia regions, where the big industrial areas, Beraki refinery and high flow highways, are located. However, NO_2 dispersion reaches high levels near the industrial areas, Meftah cement plant, Ben Aknoun highway, and also as the hyper center of Algiers, where the most population and big flow traffic are concentrated.

By contrast, the other regions could be regarded as unpolluted regions since both PM10 and NO_2 concentrations are much lower even lower than the WHO human health protection guidance values. Ladji et al. (2009a, 2009b) also mention that industrial areas were more polluted than the urban ones, whereas that the forest mountains area is cleaner.

The modeling results show that Algerian annually averaged limits (80 μg/m^3) for PM10 and (40 μg/m^3) for NO_2 have been exceeded in some Algiers areas; by consequence, air quality guidelines fixed by the WHO (20 and 40 μg/m^3)

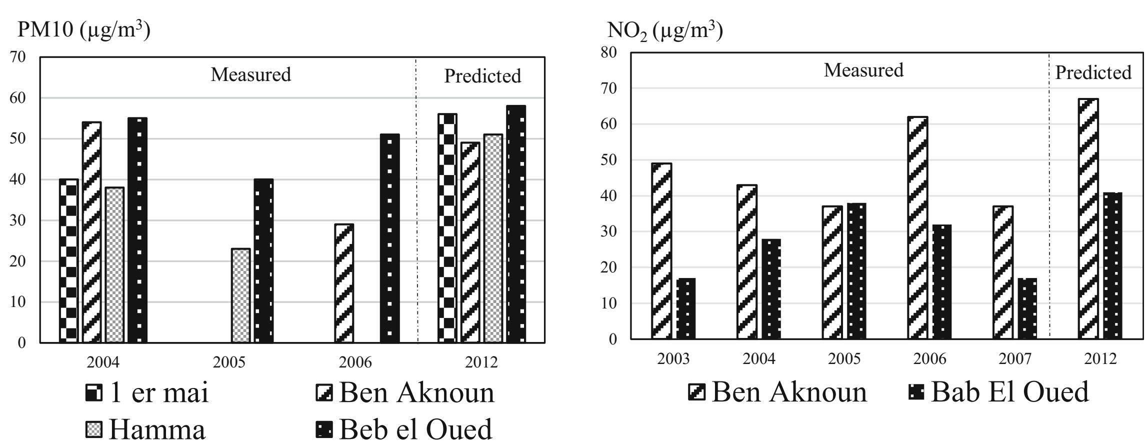
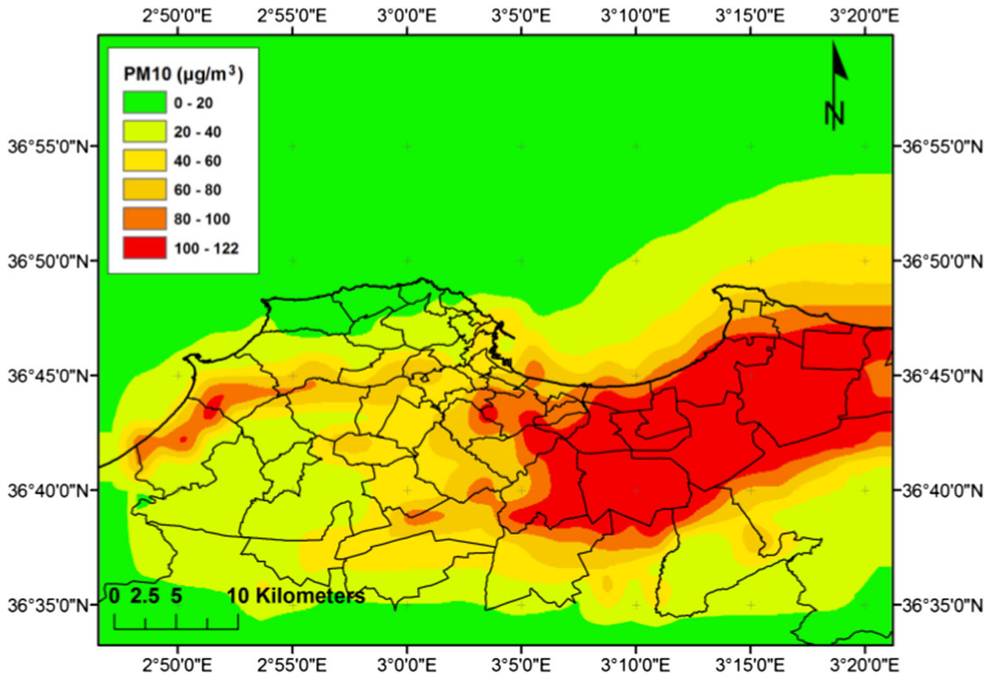


Fig. 5 Comparison between annual average concentrations of PM10 and NO_2 measured by monitoring stations during the years (2003 to 2007) and the predicted during 2012, for different sites in Algiers

Fig. 6 Spatial distribution of PM10 concentrations

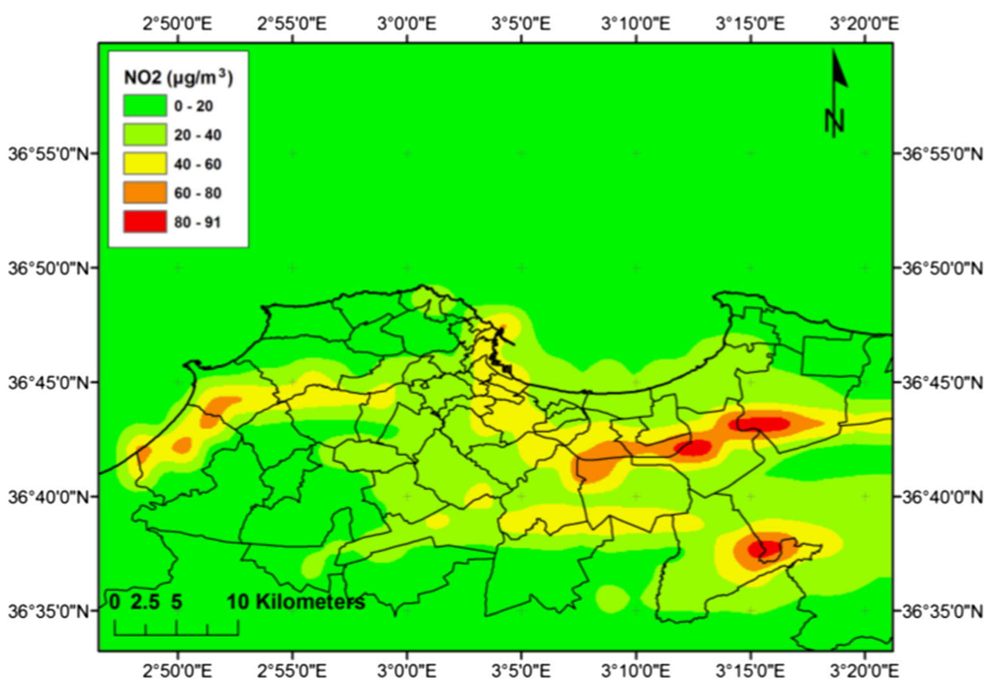


(WHO 2006) and the European Union (EU) (40 and 40 μg/m^3) (EEA 2011) for PM10 and NO_2, respectively, are also exceeded. Thus, a negative effect on the population health by respiratory problems, especially in the agglomeration situated near the highways and industrial areas where citizens are exposed chronically to air pollutants. Consequently, these results indicate a fundamental necessity for regular control of air pollutants, especially, in urban areas like Algiers city.

Conclusion

Meteorological and air quality models are important tools in various applications, such as prediction of meteorology, air pollution levels, air quality management situations, and environmental impact assessments. This paper presents results from a year-long urban simulation of meteorology and pollution by PM10 and NO_2 using the TAPM for Algiers city, to gain information about ambient concentration levels and source impacts.

Fig. 7 Spatial distribution of NO_2 concentrations



Statistical performances indicators for meteorology suggest that the model is doing well as it can simulate meteorological variables to a satisfactory degree. The IOA for wind speed is 0.65 and for temperature is 0.99. Despite the lack of air quality measures for 2012, the comparison between the predicted concentrations of PM10 and NO_2 for the year 2012 and measured ones for other years in several sites in the study area shows that the predicted results are of the same order of magnitude of the measured ones.

The predicted concentrations scored the highest values of 120 and 90 μg/m^3 for PM10 and NO_2, respectively, in the east region of Algiers, as a consequence of the high industrial activity, population, and vehicle circulation, unlike the results observed in the west region of the city. In general, the lowest levels were estimated for the background areas. It should be noted that the results exceed the national and international legislation in some areas which reflects the high pollution levels. It can be also concluded that TAPM can provide useful information to identify high-pollution impacted areas. Reducing PM10 and NO_2 emissions should be an urgent action to improve the quality of life of citizens in Algiers.

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