Original Paper

Ambient Air Quality Assessment in the Grand Casablanca Area (Morocco): Impact of Road Traffic Emissions for the 2013-2016 Period

Manal Inchaouh[1*], Kenza Khomsi[2] & Pr. Mohamed Tahiri[1]

[1] Department of chemistry, Faculty of Science Ain Chock, University Hassan II of Casablanca, Morocco

[2] Direction de Météorologie Nationale, Casablanca, Morocco

[*] Manal INCHAOUH, E-mail: inchaouhmanal@gmail.com

Abstract

Air Pollution is a serious hazard worldwide especially in urban areas. Road traffic is the main cause of pollution in agglomerations that are confronted to an excess of pollutants due to traffic intensity and the dominance of diesel cars. This paper presents the assessment of road traffic pollution in the Grand Casablanca area. Data used are the result of simultaneous measurements at thirteen sites located in the Grand Casablanca. Available data cover 4 years period (2013–2016). Traffic-related air pollutants are reviewed in order to assess their impact on the local air quality. It include nitrogen dioxide (NO_2), particulate matter (PM_{10}), carbon monoxide (CO) and Benzene (C_6H_6). Annual evolutions are presented and compared to national air quality standards; NO_2 annual trends are also evaluated. The [NO]/[NO_2] emissions ratio calculation allows then to characterize the measurement sites against road traffic. The paper focuses on determining the contribution of road traffic emissions on air quality modifying; we found spatial variability in traffic pollutants. The results pointed out that road traffic and conditions are the main causes of air pollution in the area and the analysis provide a quick view of the relatively critical areas that need more action to reduce this pollution.

Keywords

Air quality monitoring, measurements, urban air pollution, traffic intensity, road traffic pollution

1. Introduction

The urban environment has nowadays the wider population; this generates a perpetual growth of

activities that adversely affect environment, public health, well-being, and quality of life. Population increase is accompanied with proportional increase in emissions while higher urbanization rate and lower average household size increase emissions as well (Cole & Neumayer, 2004). The ever-changing transport sector is exacerbating the phenomenon of pollution and contributing to the overall balance of gas emissions. The transition from massively industrial pollution to a pollution where transports have a predominant share has gradually been accompanied by a major transformation of monitoring systems, while industrial pollution has significantly declined in recent years, transport pollution has been steadily increasing, with the main cause being the increase of cars traffic and the vehicles fleet. Air pollution parameters demonstrates a strong correlation with the traffic intensity. The highest correlation indicators established are from CO and NO_2 pollution (Zariņš, 2014). Moreover, it is in cities that the situation is most sensitive, because while the pollution depends on topography and weather conditions, the consumption of a car in the city is four times higher than on the highway, and the highest pollution levels globally occurs in winter and summer (Cichowicz, Wielgosiński, & Fetter, 2017; Dadhich, Goyal, & Dadhich, 2017). A study on the urban population exposure to air pollution during their travels in the Paris agglomeration highlighted that the highest exposure levels are obtained in the passenger cars (Delaunay, Goupil, Ravelomanantsoa, & Person, 2012). Air pollutants are known or suspected to cause harmful effects on human health, traffic-related pollution proved to be significantly associated with respiratory symptoms in children (Kim et al., 2004), moreover, many studies showed that pollution increases mortality and pointed out the causal link between short-term exposure to air pollution and mortality (L. Pascal, 2009), (Dab et al., 2001). The Grand Casablanca , Morocco's biggest agglomeration and economic capital, is currently affected by year-round air pollution (Khatami, Ponche, Jabry, & Mirabel, 1998).

This study has made the first attempt to define the possible influence of road traffic emissions in ambient air quality over a large urban agglomeration from Morocco: the coastal area of the Grand Casablanca. The work carried out in this study focuses on:

- Presenting the main indicators of air pollution originating from road traffic (NO_x, PM_{10}, CO and C_6H_6), in particular through their effects on health and the environment;

- Present the main associated air quality standards.

- Investigating the temporal trends of NO2 concentrations for the period 2013-2016

- drawing up a temporal average profiles of sites with the highest levels of pollutants

- Identifying the most affected areas by road traffic pollution by the calculation of $[NO]/[NO_2]$ emissions ratio of each measurement site.

- Analyzing and exploiting data through the Boxplots representation of the average cycles

- Determining how meteorological parameters (wind direction and speed) affects the dispersion of pollutants

This study can be used in a more general reflection on atmospheric pollution during the implementation of Urban Travel Plan for example.

2. Materials and Methods

2.1 Study Area

The Grand Casablanca area (Figure 1) is located on the Atlantic coast in the north-west of the country, with an area of 1 615 km² and a population of about 4 million inhabitants (RGPH 2014). The Grand Casablanca hosts different activities, a large industrial environment (the thermal power station, Mohammedia refinery and Ain Sebaa-Bernoussi industrial zone) characterizes the North-East part, the urbanized part is bordered by the Bouskoura forest in the south and rural agricultural lands in the South-East and South-West, the southern parts are less urbanized. It is also a major transport hub for the whole country; railway lines and several major roads and highways connecting the city with the rest of the country cross it: the N1 and N11 National Roads, South Ring Road, Coastal Road, Expressway, R315 Regional Road and the A7, A3 and A5 Highways.
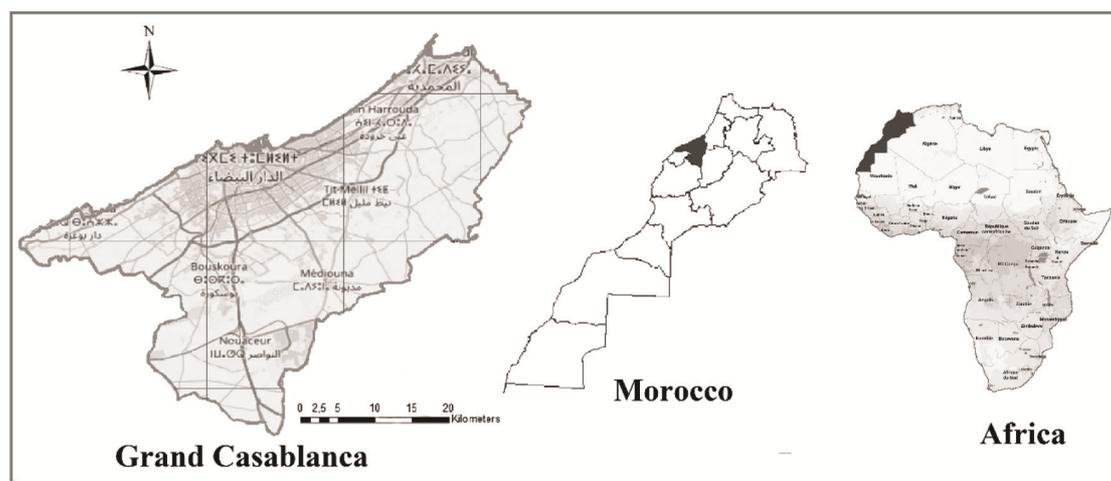

Figure 1. Location of Morocco in Africa (right map) and Location of the Grand Casablanca in Morocco

Source: haut-commissariat au plan; Google maps 2018

2.2 Studied Parameters and Their Health Impact

Air pollution parameters considered here (NO_2, PM_{10}, CO and C_6H_6) are the main indicators of road traffic pollution especially in urban areas. The exhaust (fuel combustion), evaporation, abrasion of vehicle equipment (brakes, tires, etc.) as well as road wear and the resuspension emit these pollutants. Nitrogen dioxide (NO_2) is a motor traffic tracer (L. Smith et al., 2015), it forms during the combustion of fossil fuels from the reaction of Nitrogen monoxide (NO) with oxygen or ozone in the air. NO_2 causes a range of harmful health effects, a short-term exposure to NO_2 is associated with adverse health effects and increases hospital admissions and mortality especially for susceptible populations (children, elderly, and asthmatics) and long-term exposure is associated with adverse health effects (respiratory symptoms/diseases, hospital admissions, mortality, etc.) (Latza, Gerdes, & Baur, 2009). Particulate matter 10 micron or less (PM_{10}) comes from iron and steel industry, cement factory, wastes incineration

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and automobile traffic and the smaller they are, the more dangerous they are (Ropeik & Gray, 2002). According to a public health study in France, fine particles pollution causes 48,000 deaths per year, which is as much as alcohol, and reduces life expectancy by up to two years (M. Pascal et al., 2016). Ultra-fine particles provoke alveolar inflammations, with release of mediators capable, in susceptible individuals (elderly, diabetics, or those with known coronary artery disease) of causing exacerbations of lung disease and increasing blood coagulability, thus also explaining the increases in cardiovascular deaths associated with urban pollution episodes (Martinelli, Olivieri, & Girelli, 2013; Seaton, MacNee, Donaldson, & Godden, 1995). Carbon monoxide (CO), an odorless, colorless and flammable gas, results from the incomplete combustion and motor vehicles is the absolutely dominant source (Fenger, 1999). Numerous studies showed that prolonged exposure to CO has health consequences: headaches and dizziness (Raaschou-Nielsen, Nielsen, & Gehl, 1995) and elderly hospitalizations for cardiovascular disease (Hoek, Brunekreef, Goldbohm, Fischer, & Van Den Brandt, 2002). Benzene (C_6H_6) is a volatile organic compound belonging to the family of hydrocarbons that mainly comes from the residential and tertiary sector, in particular from woods combustion, and road transport. Benzene has effects on the nervous system, blood cells and platelets that can cause loss of consciousness and the major health risk associated with exposure to low concentrations has been shown to be cancers risk and leukemia (Duarte-Davidson, 2001; M. T. Smith, 2010; WHO, 2000).

2.3 Data Collection

Hourly data were obtained from the air quality monitoring network of the Grand Casablanca (13 stations) (see Figure 2) from January of 2013 to December of 2016, except for the PM_{10} that are daily data. The fixed stations are generally located in public places and measures continuously and in real time the concentrations of a number of ambient air pollutants including those quoted above, as well as the meteorological parameters allowing the transformation and dispersion of the pollutants (wind speed and direction, ambient temperature, atmospheric pressure and relative humidity). Air pollution parameters studied here are subject to specific regulations in Morocco (Table 1). In order to perform a relevant statistical analysis, basic data are analyzed according to the requirements of the ADEME Guide: "Rules and Recommendations on: Data Validation, Aggregation Criteria and Statistical Parameters" (2003), and the "Guide of Air Quality Data Aggregation for the Application of the European Directives 2004/107/EC and 2008/50/CE on ambient air quality" (2015). Only sites that meet the criteria mentioned in these guides are evaluated here.
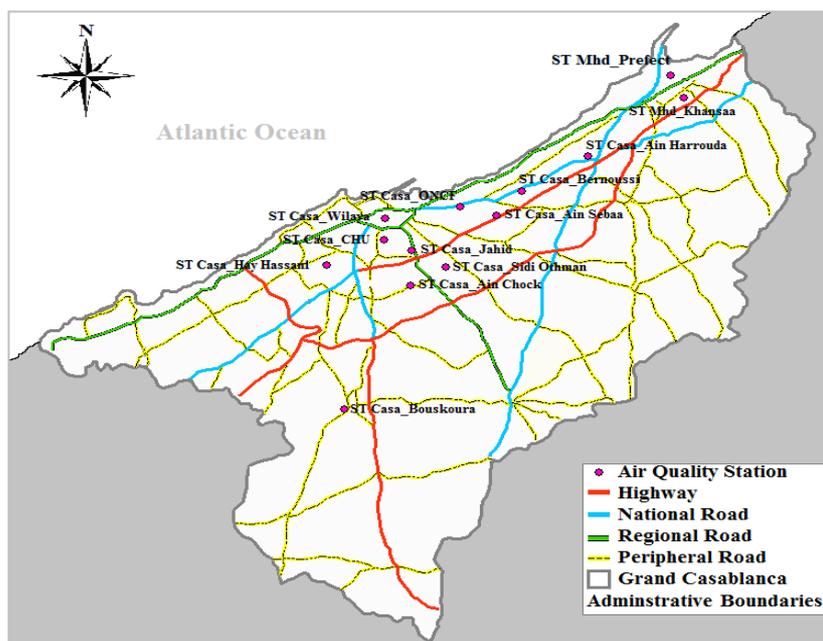
Figure 2. Location of the Air Quality Stations and Road Infrastructures of the Grand Casablanca

Table 1. National Ambient Air Quality Standards

Pollutant	Nature of the threshold	Limit values
NO$_2$ (µg/m^3)	Limit values for health protection	**50**; Annual Average **200**; Percentile 98 of Hourly Averages
	Limit value for the protection of vegetation	**30**; Annual Average
SO$_2$ (µg/m^3)	Limit values for health protection	**125**; Percentile 99.2 of the Daily Averages
	Limit value for the protection of ecosystems	**20**; Annual Average
CO (mg/m^3)	Limit values for health protection	**10**; Daily Maximum of 8-hour running average
PM$_{10}$ (µg/m^3)	Limit values for health protection	**50**; Percentile 90.4 of the Daily Averages
C$_6$H$_6$ (µg/m^3)	Limit values for health protection	**10**; Annual Average

2.4 Data Analysis

For each site of the monitoring network, the mean annual of the traffic pollution indicators: NO$_2$, PM$_{10}$, CO and C$_6$H$_6$ were calculated and compared to the Moroccan legislated air quality standards, for the entire period 2013–2016. Temporal trends of NO$_2$ concentrations were then evaluated for stations with a minimum data coverage of 75% of valid data per year for at least three out of the 4-years period. The non–parametric method proposed by Thiel (1950) and Sen (1968) for estimating the slope of a linear trend was used. This approach involves computing slopes for all the pairs of ordinal time points and then using the median of these slopes as an estimate of the overall slope. Since Sen's slope is robust against outliers, it is widely used for the estimation of trending magnitudes of climate series (Deo,

McAlpine, Syktus, McGowan, & Phinn, 2007; Guentchev & Winkler, 2010; Hidalgo-Muñoz, Argüeso, Gámiz-Fortis, Esteban-Parra, & Castro-Díez, 2011; Tramblay, El Adlouni, & Servat, 2013). The statistical significance of the obtained trends is then tested using the modified Mann–Kendall test proposed by Hamed and Rao (Hamed & Ramachandra Rao, 1998), for testing the presence of a monotonic increasing or decreasing trend. EPA's ProUCL5.1.002 software (US EPA Statistical Software for Environmental Applications for Data Sets with and without Non detect Observations) was used here and the test is performed at significance level of 5 %.

In order to study temporal behaviors of pollutants, temporal profiles are presented in different time steps (monthly, weekly &daily) for sites recording the highest levels of NO_2, PM_{10} and CO.

The most affected sites by road traffic emissions are determined by the method of the NO/NO_2 ratio calculation for characterizing the measurement sites against traffic intensity. A hierarchical classification is carried out and the monitoring sites are grouped according to their profiles.

Statistical data analysis of pollutants for the site representing the highest $[NO]/[NO_2]$ratio was performed using the Boxplot presentation method for different temporal cycles. Boxplot graphic is good for showing trends in the distributions of data (Mintz, Fitz-Simons, & Wayland, 1997). We represent the evolution of the minimum, 25th percentile (P25), median, mean, 75th percentile (P75) and the maximum.

Meteorological data are used for the interpretation of the pollutant concentrations observed at the urban-traffic station representing a traffic pollution hot-spot. Meteorological parameters analyzed here include wind direction (°) and wind speed (m/s).

3. Results

3.1 Annual Mean Concentrations Compared to the Annual Guideline

3.1.1 Nitrogen Dioxide NO_2

The evolution of NO_2 annual averages (Figure 3 (a)) allows the differentiation of the thirteen study sites; it shows that the NO_2 levels respect relatively the sanitary standard. A prioritization seems to be in place with three sites recording the highest values and exceedances of the limit value for the protection of vegetation (30 μg/m³): Ain Harrouda, Ain Sebaa and Bouskoura sites. The 98 Percentile evolution (Figure 3(b)) allows the estimation of peak levels, the measured values are all below the health protection limit value (200μg/m³) except for the Ain Harrouda site that exceeded this value in 2013.
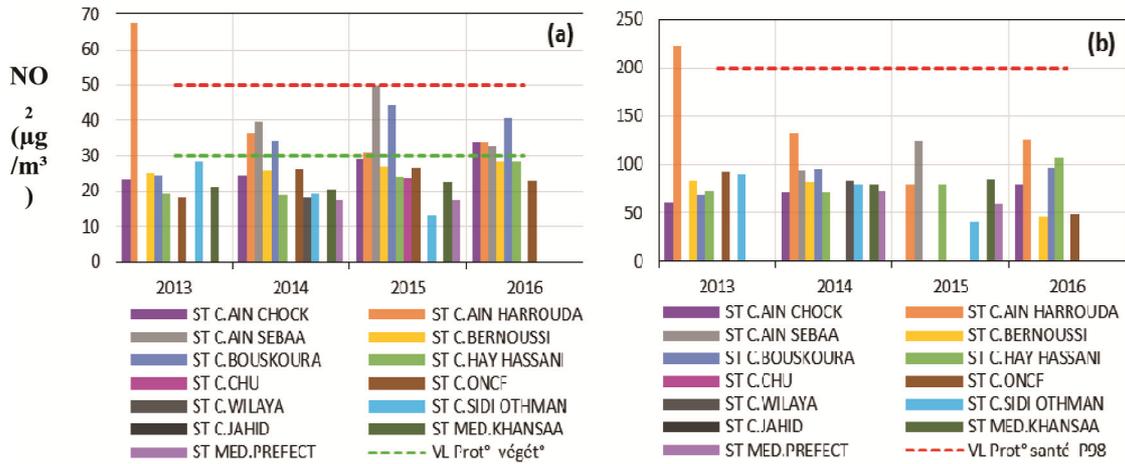
Figure 3. Evolution of: (a) Annual Average Concentrations & (b) 98% Annual Percentile of Nitrogen Dioxide regarding the Moroccan Standards in the Thirteen Monitored Sites (2013-2016)

3.1.2 Particulate Matter PM_{10}

For the Particulate pollution, figure 4 illustrates the annual evolution of the 90.4 daily percentiles of PM_{10}; most of the represented sites experienced exceedances of the daily PM_{10} standard. Table2 represent the number of days where the PM_{10} standard was exceeded for the sites presenting exceedances of the health protection. The results shows exceedances of the sanitary standard, and a largest number of overruns recorded in 2014.
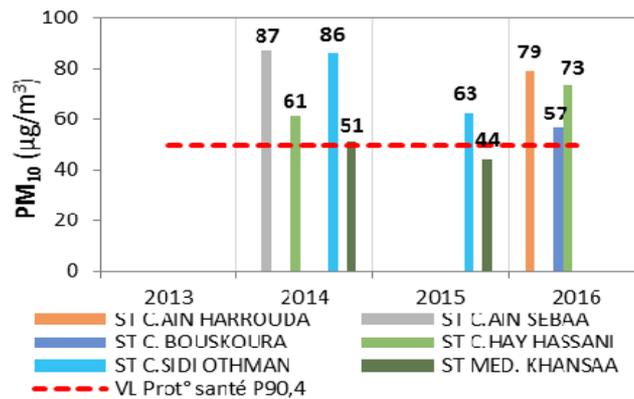

Figure 4. Evolution of the 90.4 Percentile of Daily Averages of PM_{10} regarding the Moroccan Standards over 2013-2016 Period

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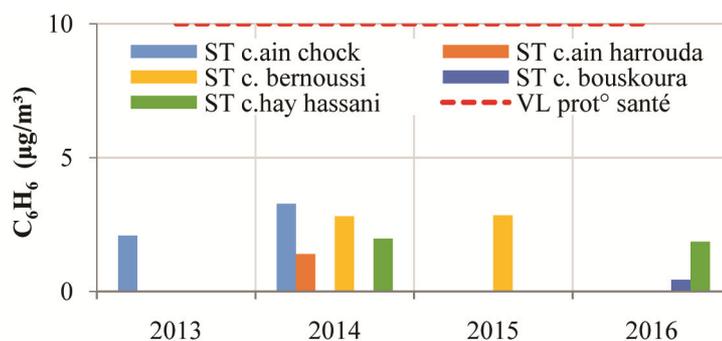**Table 2. Number of Days Exceeding the Limit Value for Health Protection of the PM$_{10}$ (90.4 Percentile)**

	St C. Ain Chock	St C. Ain Harrouda	St C. Ain Sebaa	St C. Bernoussi	St C. Bouskoura	St C. Hay Hassani	St C. Chu	St C. Oncf	St C. Wilaya	St C. Sidi Othman	St C. Jahid	St Med. Khansaa	St Med. Prefecture
2013	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	-	-	40	-	-	35	-	-	-	95	-	37	-
2015	-	-	-	-	-	-	-	-	-	43	-	14	-
2016	-	13	-	-	6	16	-	-	-	-	-	-	-

3.1.3 Carbone Monoxide CO

Table 3 record the exceedances of the standard for stations with carbon monoxide analyzers. In 2013-2016 period, the measuring stations showed no exceedances of the 8-hour sanitary standard: 10 mg/m³ (Daily maximum of the running average over 8 hours), but in 2016 the station of Ain Harrouda exceeded the above-mentioned value 17 days.

Table 3. Number of Days Exceeding the 8-Hour CO Standard (Limit Value for Health Protection)

	St C.Ain Chock	St C.Ain Harrouda	St C.Ain Sebaa	St C. Bernoussi	St C. Bouskoura	St C.Hay Hassani	St C.ONCF	St C.Sidi Othman
2013	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0
2016	0	**17**	0	0	0	0	0	0

Figure 5. Annual Average Concentrations of Benzene regarding the Sanitary Standard

3.1.4 Benzene C$_6$H$_6$

Figure 5 shows the evolution of the annual averages of benzene for sites with benzene analyzers. A lack of data probably due to equipment failures for some sites, did not allow to compare the measurement

results or to study the evolution of annual concentrations. However, we found that the recorded levels are all below 10 μg/m^3, the annual limit value.

3.2 Trends in Annual NO$_2$ Concentrations Average

Trends in data for nitrogen dioxide (NO$_2$) were investigated over the period 2013 to 2016 at the Grand Casablanca monitoring stations. Table 4 summarizes the coefficients of variation of Theil and Sen of the average annual NO$_2$ concentrations. The record for six monitoring stations (Casa.Ain Saba; Casa.CHU; Casa.ONCF; Casa.Wilaya; Casa.Jahid; Media Prefect; and Media Khansaa) was less than three. This period is considered too short to offer a meaningful understanding about concentration trends. Therefore, results for these stations are not presented in table 4. Results indicates statistically significant increasing trends of annual concentrations of NO$_2$ at the Casa.Ain Chock; Casa.Bernoussi; Casa.Bouskoura; Casa.Hay Hassani and Casa.Sidi Othman stations.Trends in Casa.Ain Harrouda station are not statistically significant.

Table 4. Annual Trends in Nitrogen Dioxide (NO$_2$) in the Studied Area; Significance Level=0.05

Station	Trends
	Average Nitrogen dioxide (NO$_2$)
ST C.Ain Chock	0.215
ST C.Ain Harrouda	0.405
ST C.Bernoussi	0.0595
ST C.Bouskoura	0.247
ST C.Hay Hassani	0.202
ST C.Sidi Othman	0.381

3.3 Intercycles Analysis: Average Profiles of Sites with the Highest Levels of Pollutants

Figure 6 provide the evolution of automobile pollution indicators studied here, at various time scales (seasonal/monthly, weekly and daily) for sites recording the highest levels of pollution (Ain Harrouda, Ain Sebaa and Bouskoura). This allows evaluating the temporal evolutions and highlight the occurrence of exceptional air pollution events (pollution peaks, weekend effect, seasonality, etc.) as well as the specificities of this pollution according to the typologies of the measurement sites. Temporal profiles enable to differentiate the selected sites and globally shows homogeneous behavior for all pollutants. Seasonal/monthly profiles are marked by a maximum in winter (december-february) and minimum values at the end of summer (august-September). Weekly profiles shows higher concentrations on workdays and a decline on weekend with peaks in the middle of the week. As for the daily profiles, hourly evolution shows, for NO2, the presence of two peaks corresponding to the hours of intensification of car traffic during the day. NO$_2$ level increases in the morning from 07:00 to 09:00, a second peak is formed in the late afternoon (19:00-22:00), beyond these hours, levels are stable and

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the lowest values are observed at night (23:00-06:00). CO daily profile follows the same trend as for NO_2 but with less intense peaks. For all temporal profiles, the Bouskoura site seems to be intermediate to the other sites for all the studied pollutants.
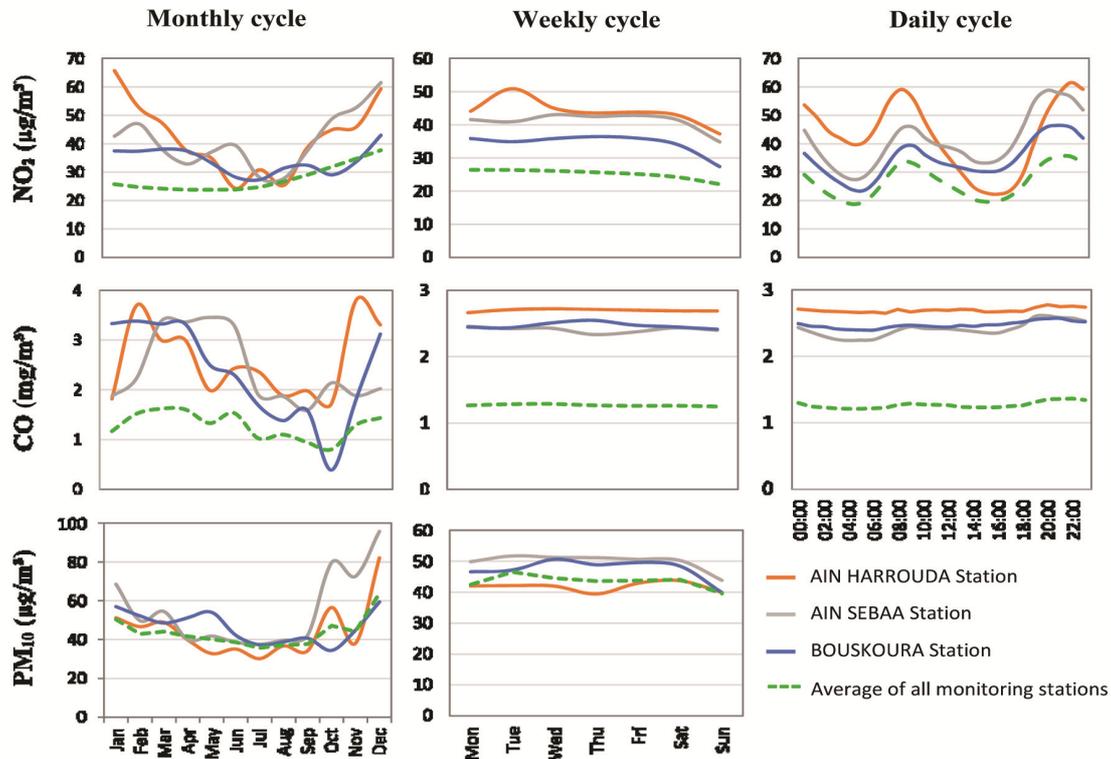

Figure 6. Average Cycles (Monthly, Weekly, Daily) of Road Traffic Indicators for Sites with the Highest Levels

3.4 Identification of Typical Traffic Sites: [NO]/ [NO$_2$] Ratio

Considering the results, the[NO]/[NO$_2$]ratio differs greatly from one site to another (Table 5). The resulting values allows to draw a distinction between the sites and to group them in three categories:

• Ain Chock, Bernoussi, Hay Hassani, CHU, Med Khansaa and Med prefecture sites are the least influenced by traffic vicinity with an [NO]/[NO$_2$]ratio lower than 1. These sites could be defined as urban background sites, with an NO concentrations mainly lower than NO_2 and less characteristic of road transport effect.

• Ain Sebaa and ONCF sites appears intermediate (moderately affected by road traffic), with an NO/NO_2 ratio of between 1 and 1,5. However, those of Ain Harrouda, Wilaya and Sidi Othman have more scattered ratios. Indeed, in 2013-2014, the sites had ratios lower than 1, then as of 2015, the influence of road traffic emissions seems to have increased to values beyond 1.

• Finally, Bouskoura site stands out as the most affected site by road traffic emissions with an [NO]/ [NO$_2$] ratio higher than 1.5 for most of the time.

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3.5 Analysis of the Cycle Structure: Boxplots Representation

Table 5. [NO]/ [NO$_2$] Ratio during the Study Period (2013-2016)

	Ain Chock	Ain Harrouda	Ain Sebaa	Bernoussi	Bouskoura	Hay Hassani	CHU	ONCF	Wilaya	Sidi Othman	Jahid	Med. Khansaa	Med. Prefect
2013	0.83	0.25	--	0.56	1.35	0.67	--	1.13	--	0.61	--	0.60	--
2014	0.63	0.86	1.11	0.54	**1.94**	0.50	--	1.01	1.08	0.59	--	0.75	0.65
2015	0.55	1.16	0.98	0.56	**2.03**	0.65	0,63	1.41	1.69	1.06	--	0.70	0.78
2016	0.50	1.39	1.11	0.63	**2.02**	0.49	--	1.42	--	--	--	0.86	--

The box-plot representation of the average cycles allow analyzing the dispersion of the concentration data against the average. It is therefore necessary to analyze the representativity of the average cycles over the considered period. For the Bouskoura site, which represents the highest NO/NO$_2$ ratio, considering the figure, the data are more dispersed in winter than in summer, during the weekly peak (midweek) and peak hours (09:00 and 20:00). The dispersion of the NO$_2$ data seems to be better than the CO and PM$_{10}$ data. This observation is illustrated, in part, by the difference between the median and the mean of the extracted cycles (represented by the curve in Figure 7). Indeed, for the NO$_2$ data these are relatively close, whereas for the CO and PM$_{10}$ data the means are sometimes below the median values. The CO and PM$_{10}$ means appear accordingly smoothed by the low extreme values and the NO$_2$ extreme values are higher than the high border. A specificity is noted with regard to NO$_2$ data for the daily cycle, the interquartile gap is larger for hours from 7am to 10am. This can be explained quite simply by the alternation of the road attendance that can vary according to peak hours.
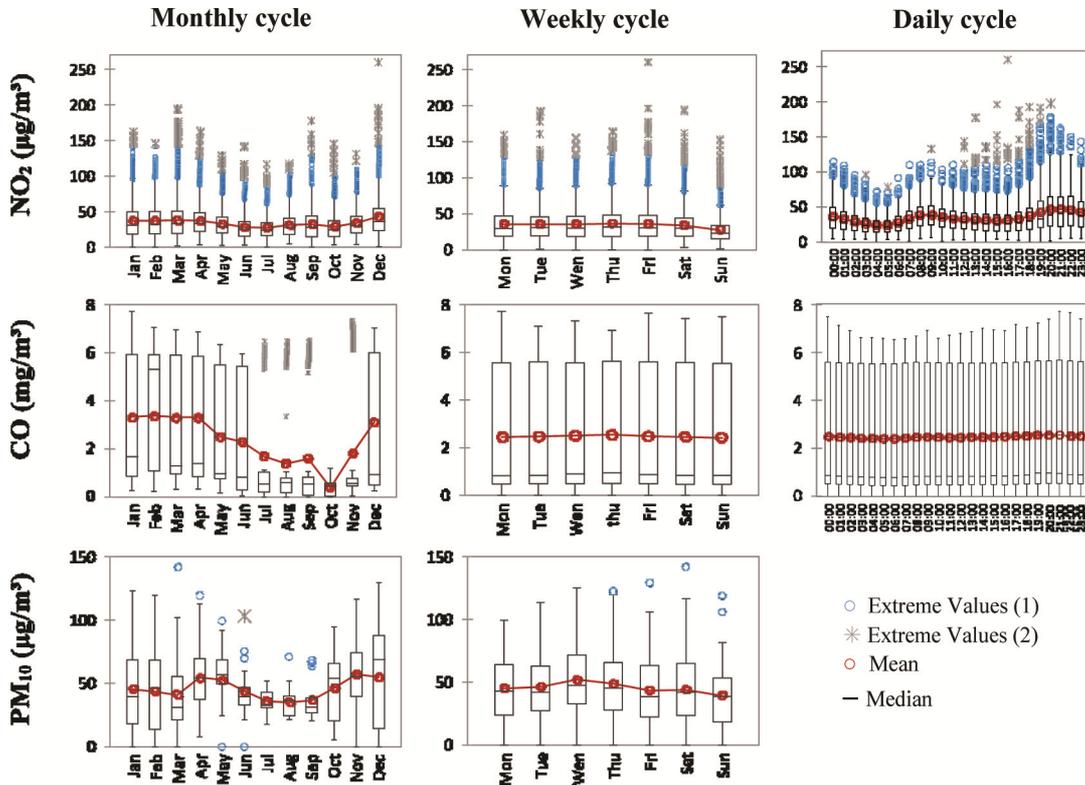
Figure 7. Average Cycles (at Monthly, Weekly, Hourly Intervals) for the Traffic Indicator Pollutants (NO$_2$, CO and PM$_{10}$) of the BOUSKOURA Site over the 2013-2016 Period

3.6 Wind Roses

Figure 8 present the wind roses for the Bouskoura site. The wind roses have been created using the hourly data from the four years 2013-2016. The results of this station located in the background of the Grand Casablanca suggest that the predominant winds come from the northern sector with a velocity mostly between 0 and 2 m/s, followed by the westerly winds; this situation is favorable to the accumulation and stagnation of pollution plumes loaded with air pollutants. The site was therefore influenced by the emissions of pollutants from the center of the agglomeration and the neighboring road network.
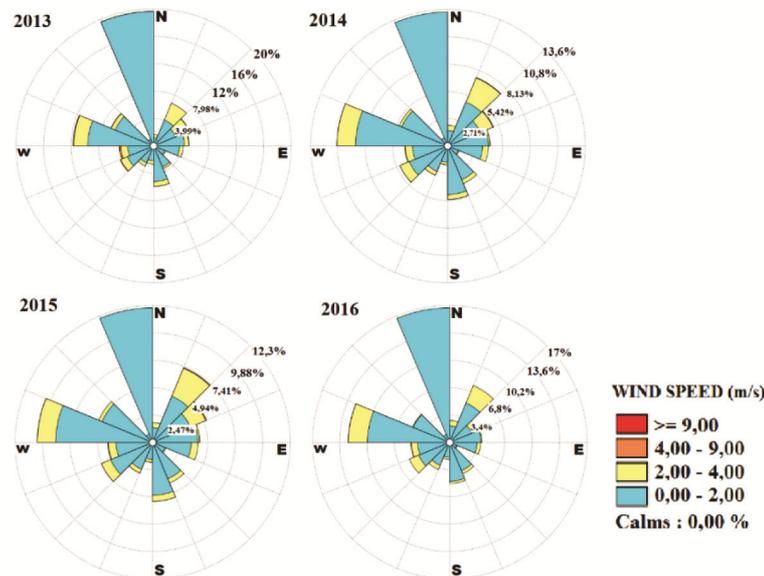
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Figure 8. Wind Roses of Bouskoura Site from 2013 to 2016

4. Discussions

The purpose of this study is to examine the role of road traffic in modifying air quality in a large urban agglomeration, the Grand Casablanca. Over all measurement sites, the measured concentrations result from different contributions: background pollution, transregional contribution (imported via air mass flows), urban contribution mainly related to traffic and meteorological factors impact. NO_2 Annual means showed a significant increase for some monitoring sites. The absence of statistical significant tendencies in time series for some monitoring sites is due to the shortness of the period used for this study. The high annual value of NO_2 in Ain Harrouda (67.51 μg / m³) can be explained by the exposure of the site to the prevailing winds of the SAMIR oil refinery of Mohammedia, and the decrease is probably due to the significant decline of refining activities and their definitive cut by the end of 2014. As for PM_{10}, the majority of sites experienced limit values exceedances most of the time; a large proportion of the particulate pollution can result from road dust resuspension (Amato et al., 2009) , and rise with the vehicles speed (Nicholson, Branson, Giess, & Cannell, 1989). The benzene and CO respects the recommended thresholds except for the station of Ain Harrouda that exceeds the sanitary standard 17 times in 2016. In order to determine the most affected sites by road traffic emissions, we studied the temporal evolutions of the sites with the highest values of road traffic pollutants, including NO_2, the analysis of temporal profiles (monthly, weekly and daily) has enabled to understand the evolution of these pollutants over time and highlight the periods with the highest emissions. The NO/NO_2 ratio allowed to set up a hierarchical classification and to determine the most affected sites by the road traffic emissions. The results revealed that the Bouskoura site have the highest values and turned out to be the most impacted site by the NO_2 emissions. This finding may reflects the direct influence of road traffic emissions on the air quality in this site. However, several other factors may be behind these results; in addition to emission levels, meteorological parameters also highly influence the

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pollution levels by their transport or transmission (Mayer, 2015), a low wind speed (less than 3 m/s) favors the accumulation of the pollutants (Latini, Grifoni, & Passerini, 2002). The analysis of the wind roses in the Bouskoura site reveals that the site is mainly subject to the prevailing northern winds, which turns the pollution plumes formed downtown to this site. That can explain the strong values recorded.

5. Conclusion

Urban air quality is getting worse; road traffic in the Grand Casablanca is largely responsible for the local emissions of nitrogen oxides and particles, and thus contributing to the degradation of its air quality. Some air pollutants are present in high concentrations, often above the recommended guidelines. In addition to emissions, air pollution levels also depend on weather conditions. This study allowed us to understand the spatio-temporal distribution of pollutants, particularly those emitted by road traffic in the Grand Casablanca and to identify the most affected areas by this type of pollution. This work suggests that road traffic plays an important role in the air quality modification, especially in areas with heavy road traffic or close to major traffic routes. The Improvement of local air quality requires therefore additional controls and the application of reduction strategies for the vehicular emissions to reduce the alarming pollution levels.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

Acknowledgements

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