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STATE OF AMBIENT AIR QUALITY IN MARRAKECH CITY (MOROCCO) OVER THE PERIOD 2009 – 2012

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ABSTRACT: The strong urbanization and the socio-economic development of a city cause serious effects on its environment and its population; our study focuses on the air quality of Marrakech city in Morocco, it's the first integral study done for that city. We will give a synthesis of air pollutants measurement results; conducted in the city over the period 2009-2012; in order to determine the spatial and temporal variations of major pollutants (NO_x; SO_2; O_3; PM_{10}) measured at the air quality monitoring stations; as well as the weather parameters which are essential to understand the dispersion of this pollution. The results showed that the NO_x levels are depending on the local emissions density and the nature of the road network. The concentrations of SO_2 are low compared to the admitted Emission Limit values (ELV); this is owing to the weak industrial activity of the city and the use of less polluting fuel (350 ppm diesel).As of particles (PM_{10}); related to road traffic; industry and natural sources; their levels exceed the thresholds limits over all sites. The city is also subject to photochemical pollution mainly due to its geographical location (strong sunlight). During the spring and the summer; the concentrations of O_3 reaches an alarming levels with significant overshoot periods of the permitted limits. This study allows us to establish a first approach on the state of the air quality of Marrakech without assessing the contribution of each source; which requires a further study to identify the phenomenon.

Keywords: Atmospheric Pollution; Marrakech City; Morocco; Air Quality; Atmo-Maroc Index

1. INTRODUCTION

Man introduces directly or indirectly several substances in the atmosphere (gas or dust);that create a disturbance in the chemical balance of the air components. Air pollution is a sensitive issue; since it affects the health; the environment and economic interests. Morocco's socio-economic development has resulted from the increase of its gross domestic product (GDP); population growth and modernization and extension of cities that required the increase of the industrial fabric; sustained energy consumption and intensification of transport. This situation creates serious impacts on the air quality. Air pollution is also a complex issue; firstly; the various pollutants have heterogeneous sources;different effects and requires different solutions and; secondly; their sources and locations are inherently variable. Marrakech city known for its pleasant climate; begins to suffer from the problem of air pollution; the emissions generated on the main roads; by industrial or craft units; is increasingly feeling; pollution peaks are often recorded in some neighborhoods. This study aims to assess the overall state of air quality in Marrakech using the available databases of the air quality monitoring datasets including the air pollutants measurements and trhe meteorological parameters ,the results are then compared to the national ambient air quality standards in order to identify the main pollutants responsible for the air quality deterioration.

2. STUDY AREA

Marrakech city (31° 37 'North; 8° 02' West) ; the fourth largest city and first tourist destination in Morocco (official population of 1070838 people in 2010); is located in the central Haouz plain bounded by the mountains of the High Atlas in the south; the province of Safi north; Chichaoua and Safi in the east and El Kelaa des Sraghna west. The area represents uniform moderate altitude topography; the only reliefs are formed by the hills of Gueliz and Koudiat Al Abid north. The average altitude is at about 465 m. the climate is semi-arid; Annual average of temperature is 22°C with ranges of -7°C and 46.6°C observed over several years. The height of annual rainfall is estimated at 240 mm with an uneven distribution (related to reliefs). Relative humidity is of 73% in January and 33% in July and may cancel during this month when dry winds blow. Winds are usually calm; from the west and northwest. In summer; there is drying winds Chergui and Sirocco from the east and the south; with an annual cumul of about 39 days centered on July. Known for its golf courses; parks and monuments; the city experience rapid industrial expansion and population growth due to rural exodus. The economy of the region is mainly based on the agriculture and livestock; tourism (550000 tourists in January 2013); craft (45% of national handicrafts exports) and the industrie mainly composed of agro-industries; chemical; Para chemical and processing industries.

4.1. Fuel Consumption

Table 1 and 2 represents annual consumption of different fuels and the volumes distributed by the service stations in Marrakech city. Gasoil represent more than 74% of fuel consumption in the city.

Table 1 Annual consumption of fuel in Marrakech

Fuels	Annual consumption
Propane	5.29 Ktoe*
Butane	64 Ktoe
Fuel oil	58.6 Ktoe
Wood	360 000 T

*Ktoe: Thousand tons of oil equivalents

Table 2 Volumes distributed by service stations

consumption (m^3)	Afriquia	Total	Shell	ZIZ	Petrom	Total (m^3)
Unleaded	15329	9072	9166	96	3650	37313
Gasoil	40800	24408	26560	1940	13381	107089

4.2. Road infrastructures

Table 3 Road network in Marrakech

National roads	Regional roads	Provincial roads
152.706	67.786	313.715

Table 4 Distribution of vehicles by type

Type of Vehicle	Number
motorcycle	236
Passenger car	6104
Commercial vehicles	2486

Source: Regional transport Delegation

3. MATERIALS AND METHODS

3.1 Monitoring network Description

Air quality monitoring network in Marrakech has three permanent fixed stations; ST_1 (Jamae Lafnae) located in the center of the town; ST_2 (Mhamid) located at about 2km from Marrakech-Menara Airport and ST_3 (Daoudiat) located in a residential area. These stations are equipped with automatic physical-chemical analyzers enable to provide real-time concentrations of pollutants in hourly time steps. The information is transmitted to the central station and processed in the air quality data base through the XR software.

The following figure (Fig.1) shows the location of the monitoring air quality stations in Marrakech city; as well as the urban areas with high population density and large human activities.

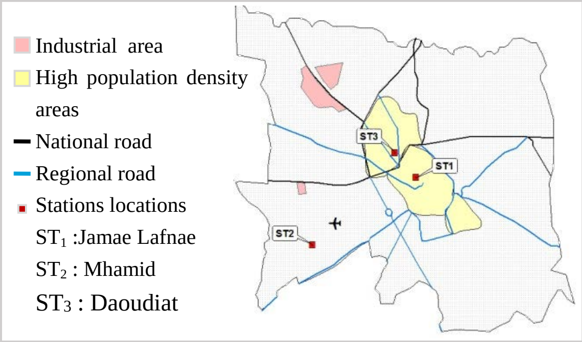


Fig1. Location of the air quality stations in Marrakech

3.2 Pollutants studied

To assess the impact of emissions on air quality; we consider the following pollutants: NO_2; SO_2; PM_{10} and O_3; these latter are regulated by the decree setting down the air quality standards and air monitoring arrangements. The developments of pollutants will be represented by temporal profiles for each pollutant and the air quality index (Atmo-Maroc index) of each site over the period 2009-2012.

4. RESULTS AND DISCUSSIONS

4.1. Meteorological Data

The dispersion of pollutants depends on weather conditions. The strongest winds favor the dispersion of pollutants and low winds favor their accumulation at local levels [1]. Figure 2 represents the average of the wind frequency and speed over the period 2009-2012. Wind roses shows a clear predominance of westerly winds with a high speed (above 9 m/s); which are the most dispersive winds; followed by medium-speed winds (4-9 m/s) and moderate-speed winds (2-4 m/s) mainly from the east and which promotes the accumulation of pollutants.

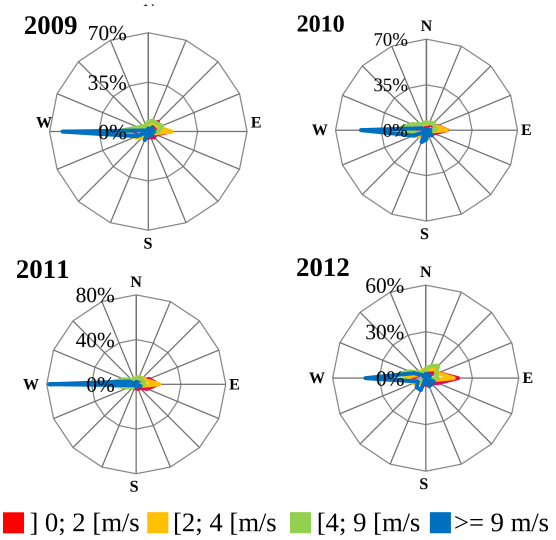


Fig. 2 Wind roses of Marrakech city (2009 – 2012)

Temperature influences the vertical dispersion of pollutants. When the air in the ground becomes colder than at altitude then it is a "thermal inversion" situation; cold air remains trapped under the warm air mass that forms an atmospheric cover and prevents the vertical dispersion of the pollutants and favors their concentrations near the ground [2]. Temperature also affects the chemistry of pollutants; the cold reduces the volatility of some gases and the summer heat promotes the photochemical formation of ozone. Humidity plays an important role in the formation processes of some pollutants such the sulfuric and nitric acids (acid mist) and their elimination (wet deposition). a study results [3] showed that the highest concentrations of ions SO_4^{2-}; NO_3^-; NH_4^+ and H^+ are observed during the high humidity periods. Figure 3 represents the monthly evolution of temperature and relative humidity. Overall sites; the temperature increases gradually to a maximum during the summer, while relative humidity decreases. The highest values are shown in Daoudiat site; it's given to its geographical nature (elevation of about 450 m).

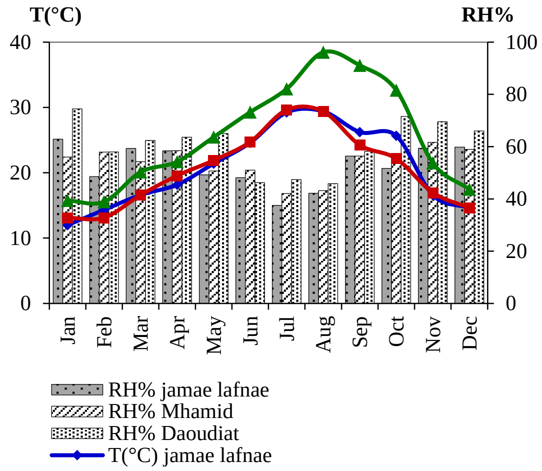


Fig. 3 Monthly mean of Temperature and Relative Humidity for the period (2009- 2012)

Precipitation allows atmospheric leaching of soluble particles and gases by folding them down to the ground and diminishing the concentrations of pollutants [4]. When rainfalls are short and intense; the leaching effects is reversible and the levels of pollutants increase rapidly when the rain stops. However; when it rains for several hours this effect is quite significant and pollutant levels remain low long time before recovering. The chemical composition of rainfalls can provide valuable informations of the air quality state in the concerned area [5]. The recorded values of precipitation in Marrakech city represents a strong variability ; the annual accumulation (Fig.4) experienced a very significant drop (about 40%) in 2012 compared to 2009 (339,4mm).

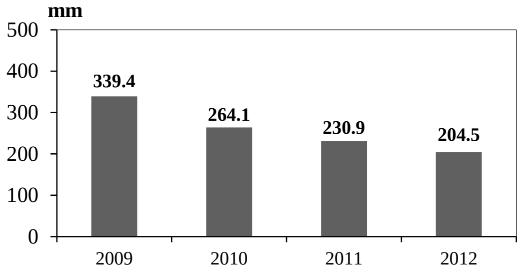


Fig. 4 Total annual Precipitations

4.2. Pollutants data analysis

4.2.1. Nitrogen oxides (NO_x)

NO_x includes nitrogen dioxide (NO_2) and nitrogen monoxide (NO); these precursors of photochemical smogs come mainly from combustion processes (industry; transport…); it is generally accepted that 70-75% of emissions in urban areas comes from vehicles [6]. Near the emission sources the concentrations of NO are larger than those of NO_2 but NO is rapidly oxidized into NO_2 here the emissions are expressed as NO_2-equivalent. Figure 5 (a) and (b) demonstrates that the situation has evolved during the study period. In Jamae lafnae sites directly affected by vehicle emissions and Mhamid affected by Marrakech-Menara Airport traffic; annual levels have increased since 2009; local weather conditions; especially in winter; may explain the most significant changes. Limit values for health protection in Mhamid and the annual limit value P98 (200 ug / m^3) in Jamae lafnae are exceeded in 2012.The Daoudiat site is the least polluted site given its distance from major roads.

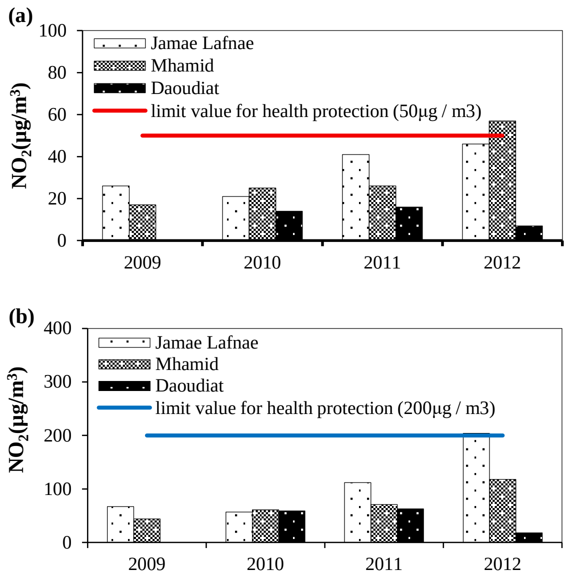


Fig. 5 NO_2 - Annual trends of **(a)** hourly averages and **(b)** 98 percentile of hourly average

In normal situations; NO_2 levels increases during the cold season; this is due to many emissions (heating + frequent use of vehicles). The seasonal averages (Fig.6) are significantly higher during the winter; with low and variable winds. And also during the summer because of the importance of traffic and tourist activities over the area; associated with the increase of temperature and solar radiations that promotes NO_2 formation.

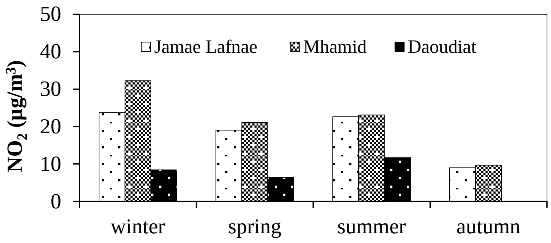


Fig.6 NO_2- Seasonal profile (2009-2012)

Figures 7 and 8 shows respectively ,the weekly and daily profiles of NO_2. Levels are rather higher on weekdays than weekends; with a pollution tip in midweek. On the daily profile; the morning peak observed between 8 and 10am is characteristic of the human activity resumption. The decline in the afternoon could be explained by the formation of ozone from the interaction of NO_2 with solar radiations. A second peak is observed between 7 and 9pm corresponding to the evening returns.

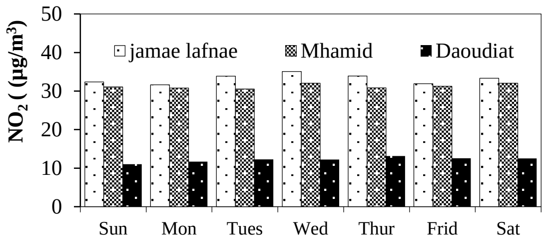


Fig.7 NO_2 - Weekly profile (2009-2012).

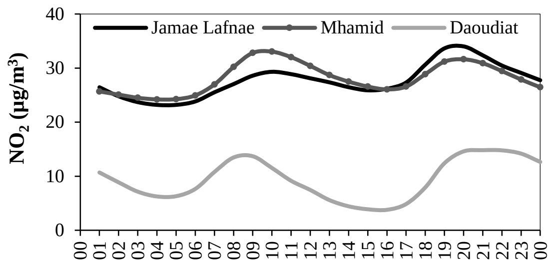


Fig.8 NO_2 - Daily profile (2009-2012)

4.2.2. Sulfur dioxide (SO_2)

SO_2 is mainly emitted by using sulfur-containing fossil fuels and some industrial processes. Emissions of SO_2 in fossil fuels burning represent around 70 to 80 million tons per year at the world level [7]. This gas is transformed in contact with air humidity into sulfuric acid and contributes to the acidification; the depletion of natural environment and deterioration of buildings. Figure 9 (a) and (b) represent the annual evolution of SO_2; levels tend to increase since 2009 over all measurement sites but remain relatively low compared to the regulatory thresholds.

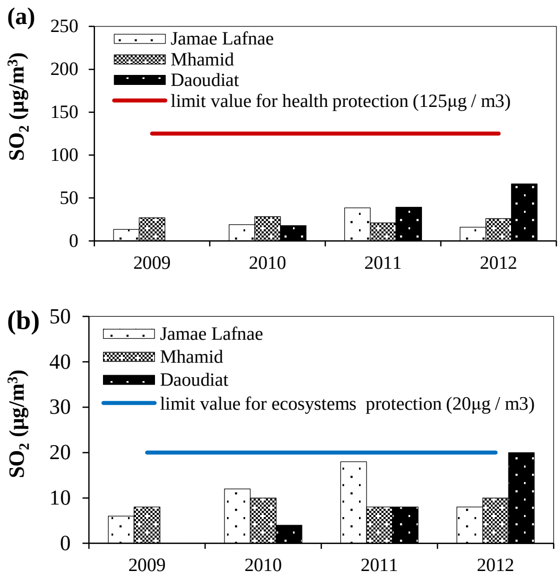


Fig. 9 SO_2 - Annual trends of **(a)** hourly averages and **(b)** 99;2 percentile of hourly average

The levels of SO_2 vary with the seasons; seasonal profile (Fig.10) show increases levels during the cold season. Episodes of high concentrations are usually met in winter ; firstly; the weather conditions are less dispersive and; secondly; energy needs and therefore emissions are higher (domestic heating…).

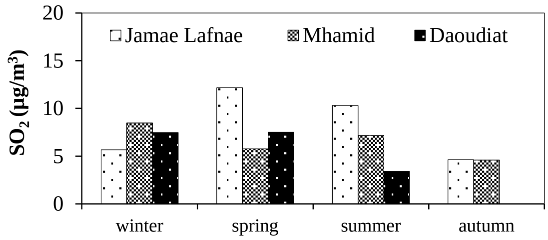


Fig.10 SO_2 - Seasonal averages (2009-2012)

SO_2 levels could be compared to the relative humidity and temperature trends, or the highest levels are obtained when the relative humidity trends exceed 40% (Fig.11) and temperature between 20°C and 30°C (Fig.12) .
However no correlation can be really made on the basis of these indicators, relative humidity and temperature may themselves be influenced by other meteorological factors which are not estimated in this study (hygrometry, sunshine levels, surface radiation, atmospheric pressure…)

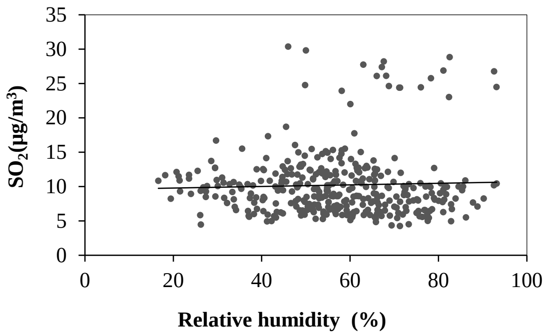


Fig.11 SO_2 evolution in terms of relative humidity (Mhamid site in 2010)

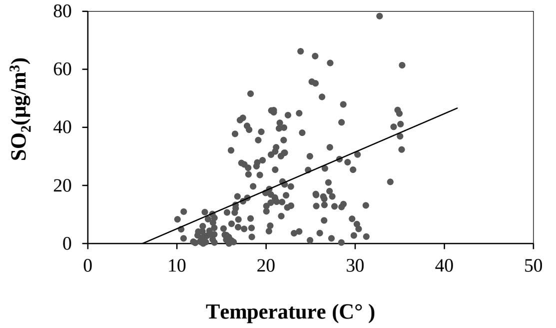


Fig.12 SO_2 evolution in terms of temperature (Daoudiat site in 2012)

On the weekly profile (fig.13); a slight decrease is observed during the weekend similarly to the reduction of traffic. The daily profile (fig.14) reveals morning and evening increases related to human activity. Morning peak is observed between 8 and 10 am and a second strongest peak between 8 and 9pm.

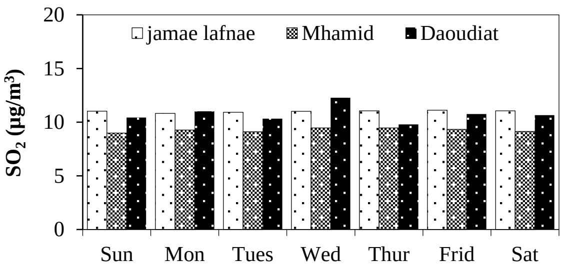


Fig.13SO$_2$ - weekly profile (2009-2012)

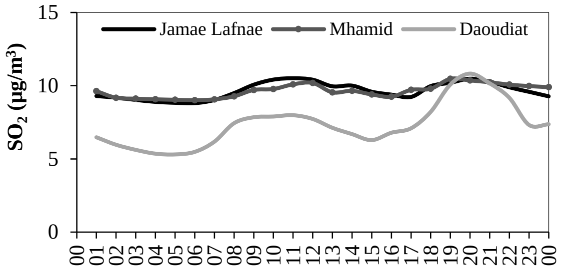


Fig.14SO$_2$ - Daily profile (2009-2012)

4.2.3. Ozone O3

O_3 is a secondary pollutant that depends in its formation and evolution on both of the state of the original primary pollution in the atmosphere and ambient weather conditions [2]; O_3 is formed from precursors during the movement of polluted air masses under the effect of solar radiations; it follows that in general; the highest values are not recorded in areas where primary pollutants are emitted (cities and industrial areas); but in the surrounding and the near rural areas and downwind of agglomerations [8;9]. This pollutant is harmful for the health it causes in high concentrations inflammation and bronchial hyperactivity;irritation of nose and throat usually occur; accompanied by breathing difficulty. Eye irritation is also observed. Sensitive subjects (children; chronic bronchitis; asthma ...) are more sensitive to ozone pollution [10]. The annual average of O_3 presented in Figure 15 reveals that the levels decrease gradually in 2010 and 2011; the year 2012 saw a significant increase; this is mainly due to climatic variations; particularly to sunlight (high temperatures). Table 6 presents; in chronological order; overtaking reference values for O_3.

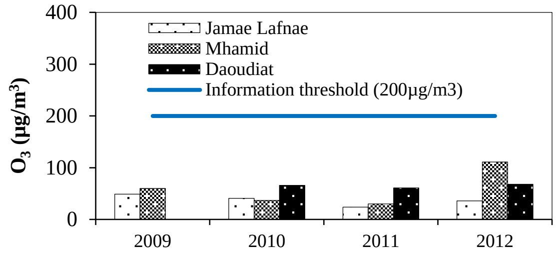


Fig. 15 O_3 - Annual trends (2009-2012)

	Number of days exceeding averages on 8 hours (1)			Number of 3 consecutive days exceeding the daily average(2)		
	jamae lafnae	**Mhamid**	**Daoudiat**	**jamae lafnae**	**Mhamid**	**Daoudiat**
2009	**8**	**42**	**-**	**14**	**62**	**-**
2010	**4**	**1**	**58**	**14**	**20**	**58**
2011	**-**	**-**	**7**	**-**	**20**	**91**
2012	**12**	**118**	**26**	**11**	**112**	**54**

Tab 6. Number of accidence of regulatory values

(1) Limit value for health protection: 110µg / m^3
(2) Limit value for vegetation protection : 65µg / m^3

O_3 levels depends on the weather conditions (temperature and irradiation; prolonged sunshine; low humidity and wind speed). these conditions are met in summer. The seasonal profile (Fig.16) shows that the ozone levels exhibit strong seasonality, with a seasonal maximum occurring during spring and minimum levels in winter for all the sites studied. This implies that high temperature and relative humidity besides the intense solar radiation in summer are responsible for the formation of high O_3 concentrations. The levels of ozone were observed in order of decreasing abundance as follows: spring, summer, autumn, and winter. O_3 has a life span of a few days; so it can be transported far from its production area; during the weekend O_3 accumulates significantly in the lower troposphere where it reaches a maximum of about 10% more than during weekdays. This phenomenon; known under the term "Sunday effect" was already mentioned in some studies; including one on Long Beach in Los Angeles [11]. O_3 levels in air layers near the ground is always determined by the formation-degradation process. Figures 17 and 18 illustrates the weekly and daily profiles ; the week is marked by an increase of O_3 during the weekend while the daily profile shows a single typical peak as "bell" in the afternoon (around 2 pm) that persists at high levels for several hours before decreasing at 5 pm. The diurnal evolution is generally less pronounced because of the absence of night degradation processes.

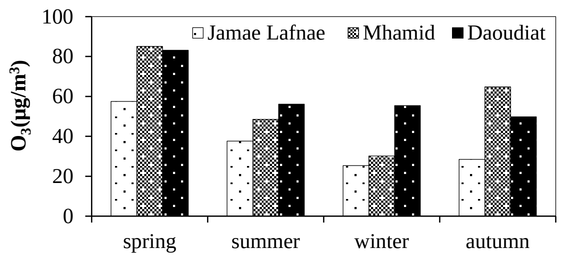


Fig.16 O_3 - Seasonal averages (2009-2012)

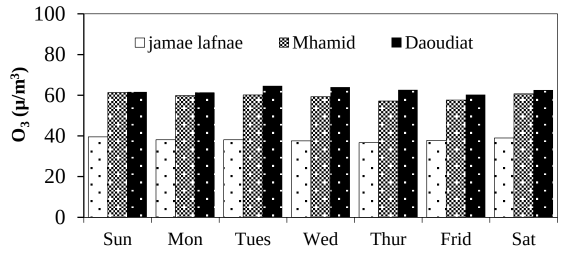


Fig.17 O_3 - Weekly profile (2009-2012)

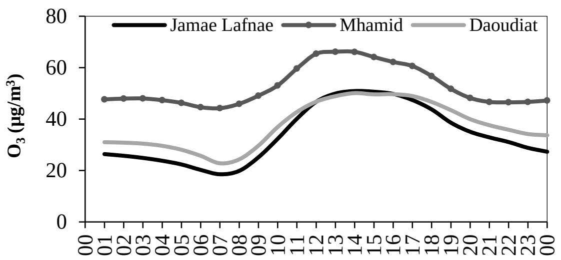


Fig.18 O_3 - Daily profile (2009-2012)

4.2.4. Particulate matter PM10

PM_{10} comes mainly from combustion. In urban areas it comes from traffic (emissions ; tires wear..) and domestic heating; their levels are also linked to physical mechanisms such as resuspension (strong wind) or accumulation during stable weather periods. In Marrakech city ; the resuspension is responsible for a large share of PM_{10} emissions owing to the dry and windy atmosphere of the area. Due to their small size; fine particles are able to penetrate deep into the respiratory tract and reach the lungs. Short exposures may cause coughing ; bronchial irritation and inflammation. Particles can also affect lung function and suddenly worsen diseases such as asthma and cardiovascular events [12]. The Annual average (Fig.19) shows very high values over all sites. Limit value for health protection (50µg/m^3) is greatly exceeded. This increase is associated to road traffic emissions and also to meteorological conditions that are preventing the dispersion of particles overall measurement sites. Daoudiat site records the highest concentrations in particles .

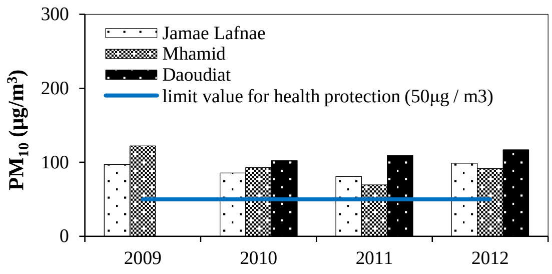
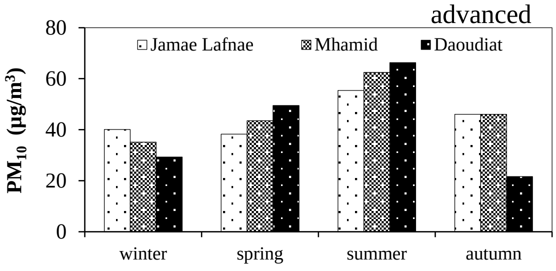


Fig. 19 PM_{10} - Annual trends of 99;2 percentile of hourly average

Seasonal evolution of PM_{10} (Fig.120) shows a great difference between the cold and warm seasons .in winter the rain allows the leaching of the atmosphere causing a drop of the levels; while the dry and hot summer favors the accumulation and formation of secondary particles. This often results in reduced visibility; the atmosphere becoming more "opaque". Wind also promotes the dispersion of the pollution but depending on its strength; can recover the suspended particles in the air. The weekly profile (Fig.21) is characterized by a decline on the weekend related to the reduction of traffic ; an advanced



pollution is also observed on Thursday.

Fig.20 PM_{10} - Seasonal averages (2009-2012)

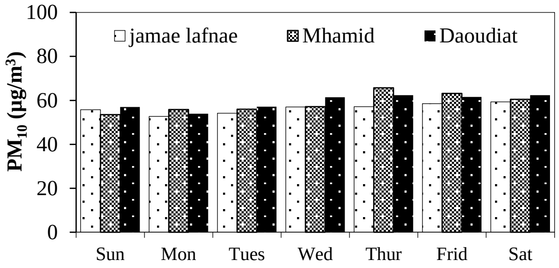


Fig.21 PM_{10} - weekly profile(2009-2012)

The daily profile (Fig.22) is marked by a "double-hump curve"; morning peak (from 9 to 11am) and evening peak (from 6 to 8pm). At Daoudiat site the peaks are shifted by about 2 hours from those of other sites; it seems that other sources of pollution than traffic are attributable to this observation (Industrial activity in surrounding areas).

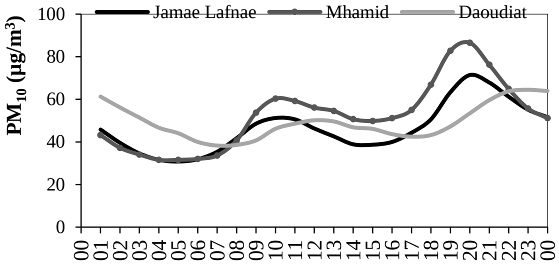


Fig. 22 PM_{10} - Daily profile (2009-2012)

4.3. Atmo-Maroc Index

Air pollution can result from a several substances; which often makes more complex the issue and the understanding of synthetic or accessible informations. air quality Index is a function that transforms the air quality data (expressed as concentrations of several pollutants measured over different times; in different stations) into a single value and generally single dimensionless which represents or characterizes the air quality of a homogeneous area [13]. Atmo-Maroc Index is an air quality indicator developed by the national meteorological service of Morocco; in order to provide a synthetic information of air pollution in towns with over 100 000 inhabs.This index is compiled from the daily concentrations of four typical pollutants for air pollution phenomenon : SO_2; NO_2; O_3 and PM_{10}.

For each of the above pollutants; an air quality sub-index (from 1 to 10) is daily calculated from the recorded data. NO_2, SO_2 and O_3 sub-indexes are calculated from the average of the hourly maxima and PM_{10} sub-index from the mean of daily averages for the selected measurement site.

Index	Quality
1	Very Good
2	Good
3	Good
4	Medium
5	Medium
6	Mediocre
7	Mediocre
8	Bad
9	Bad
10	Very Bad

Tab 7. Sub-indices Scale for Atmo-Maroc Index

4.3.1. General trends

Figure 23 represent the average trends of the air quality index for each site in 2012.

Air Quality in Jamae Lafnae is generally good (over 60%); in Mhamid the index reflects the observations made on the various pollutants (PM_{10} and NO_2). The year 2012 recorded much higher concentrations of NO_2 than normal and induces bad air quality (37%). at Daoudiat site the quality is mean and sometimes bad because of the high levels of particulates and photochemical pollution (O_3).

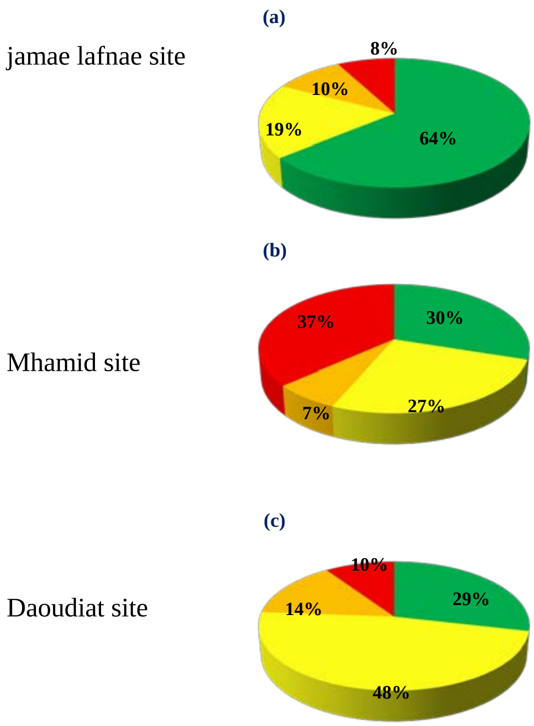


Fig 23. Air quality indexes for (a) jamae lafnae ;(b) Mhamid and (c) Daoudiat in 2012

5. CONCLUSION

We have examined the variations of major ambient air pollutants (NOx; SO_2; O_3; PM_{10}) over the city of Marrakech for the period 2009-2012; through the recorded data of the air quality monitoring network of the city .The study highlighted the pollutants mainly related to traffic. Air quality can be described as generally good for some pollution indicators (NO_2 and SO_2), but remains worrying for PM_{10} and O_3, although the traffic is not the only parameter that may affect the pollutant concentrations, it still seems to have a major impact since the difference between the measured values in the three measurement sites. Temporal trends also shows this influence especially on daily profiles where departure and returns hours are marked overall sites. This shows that the surroundings areas are subject to a very important road activity both in winter (domestic traffic) than in summer (tourist traffic). NO_2 levels increases slightly since 2009, the higher levels are met in winter due to the increased use of heating and transportation. Sulfur dioxide levels remains very low (less than 20 g / m^3) due to the absence of a sustained industrial activity in the city.

The most harmful pollutants in the city are particles (PM_{10}) and ozone (O_3), the annual and the daily limit values for PM_{10} are largely exceeded over all sites. Ozone is the second pollutant in order of importance, the levels exceed the value of the annual quality targets during the spring and the summer seasons. The results of this study highlights on the agglomeration scale, the reciprocity of background pollution and traffic proximity phenomena, particularly due to the density of the structuring road network. It also highlights the geographical areas where efforts must be particularly made in order to clip the higher levels of the air pollution.

6. ACKNOWLEDGEMENTS

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