

Implementation of the Air Quality Monitoring Network at Agadir City in Morocco

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Abstract

Air pollution is a major global issue with widely known harmful effects on human health and the environment. This pollution is a very complex phenomenon given the diversity of pollutants that may be present in the atmosphere. The air quality in urban areas is of a great concern for residents living in cities and represents a current issue that requires an adequate management. So that air quality policy is driven by health concerns. In this paper, we present an overview on the experience of Agadir city to establish the air quality management policy, local authority on the whole have developed a good understanding of air quality in the area. Indeed for several years, efforts have been made to monitor the air quality in this city, this translated by air quality assessment since 2006 using mobile laboratory and fixed station. Our goals in this study were to review the operation of Local Air Quality Management (LAQM) making better use of available resources to improve its outcomes and make recommendations with a view to improving air quality issues. This work highlights the requirement to revise periodically the LAQM for generating priority for air quality issues within local authority and the need to implement the optimizing Air Quality Monitoring Network (AQMN).

Keywords

Air Pollution, Air Quality Management, Air Quality Regulations, Emission Inventory, Air Quality Monitoring, Air Quality Modeling, Ambient Air Quality Standards

1. Introduction

For several years, air pollution has become for decision makers a topic of major concern. Indeed it's one of the factors with major impact on the health of people

and ecosystems. [1].

Exposure to important air quality indicators such as nitrogen dioxide (NO₂), sulfur dioxide (SO₂), fine particulate matter (PM_{2.5}), ground level ozone (O₃) and carbon monoxide (CO) is of potential concern due to their chronic and acute health effects. Epidemiological studies suggest associations between short-and long-term exposure to NO₂, SO₂, PM_{2.5} and O₃ and increased morbidity, mortality, and emergency hospital admissions for cardiovascular, cerebrovascular (stroke) and pulmonary diseases including acute myocardial infarction, arrhythmias, ischemic heart disease as well as diabetes and neurological disorders [1]-[10]. A part of their potential deleterious effects on public health, they are also implicated with acidic deposition, photochemical smog and visibility [11] [12].

Monitoring pollution levels in the atmosphere are of fundamental importance because it provides guidance on the effectiveness of control actions and indicates where greater effort is needed. Large agglomerations which experience intense road traffic and a large number of industrial and energy units are often exposed to poor air quality. Often, terrain and meteorological conditions complicate air quality issues in the area. The observation sites that make up air quality monitoring networks can have very different characteristics (topography, climatology, distance to emission sources, etc.).

Air quality at the surface is strongly heterogeneous, due to variable surface fluxes (emissions, surface deposition, etc.), meteorological conditions, and diverse local configurations (city buildings, valleys, etc). Depending on the purpose of the measurements, monitoring sites have been located in very diverse environments, from highly populated areas (to estimate exposure), to remote areas (to assess background conditions and contribution of long range transport of pollutants). In each region, the sites are categorized on the basis of criteria that are largely subjective [13]. In recent decades, many experimental and modeling studies have been conducted to obtain information on pollutant dispersion for monitoring and assessing possible long-term strategies to reduce air pollution in cities or measure their related health impacts [14].

In the case of Morocco, the environmental degradation costs 4% of the GDP and the costs of air quality degradation represent about 1.03% of GDP according to the Ministry Delegate in charge of Environment. To remedy to this situation even if Morocco is not an industrial country, it gives more attention to the problems of air pollution. In this context, it decided to make the fight against the degradation of air quality a priority of the national environmental protection policy and health. By taking the air quality monitoring measures, strengthening the legal arsenal and reducing air pollution. The major pollutants in urban areas include PM₁₀ (particulate matter with aerodynamic diameter less than or equal to 10 μm), ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, etc...

The Region of Souss Massa has an area of 53 789 sq-km (7.6% of the national territory). 15% of this area is lowland and 85% is mountain. The region is limited by the Atlantic Ocean from the West and mountain from the East. The popula-

tion of the region is about 2.7 million. The region holds significant economic potential based on its natural resources. In agriculture, an agricultural area of 616,500 hectares (30% is irrigated), which their annual production exceeds generally 50% of the national total. The region has a large forest area forming a natural barrier to agricultural areas against desertification and erosion. But despite the diversity of species (cedar, oak, juniper, etc...), The Argan tree is the main shaft of the region covering more than 64% of the regional forest and erecting get essential support any environmental action and socio-economic. Fishing is also a key sector in the region and is an asset to national. It employs a hand of important works and attracts investments and currencies. The region has a large offshore and inshore fishing port in Agadir, in addition to a number of small fishing ports reserved for artisanal fishing boats. Thanks to its climate, its diverse topography, its historical and cultural heritage and its wide beaches, the region of Souss Massa is one of unique international tourist area destination. This socio-economic development in the region is accompanied by the growth of pollution caused by industrial human activities. That's why the need of implementing an air quality monitoring network in the city.

Our goals are to review the operation of Local Air Quality Management (LAQM) making better use of available resources to improve LAQM outcomes and make recommendations with a view to improving air quality issues. This work highlights the requirement to revise periodically the LAQM for generating priority for air quality issues within local government. LAQM program in greater Agadir area, the Wilaya of the Region Souss Massa in collaboration with various partners has initiated the establishment of a local network for the tracking and monitoring of air quality. Hence, the following actions were taken:

- ✓ Performing two campaigns for air quality measurement in greater Agadir area in 2006 and 2010 using the national mobile laboratory.
- ✓ Acquiring, in 2008, the fixed measurement stations for measuring the main pollutants (NO, NO₂, SO₂, PM₁₀, O₃) located in the centre of Agadir with the aim of monitoring the rate of population exposure.
- ✓ Acquiring, in 2012, a mobile station for measuring the main pollutants. The station will be used on demand for large as well as punctual time monitoring, as follows:
 - a) Measurement of air quality nearby industrial sites;
 - b) Measurement of traffic emissions which are, in general, predominant in urban areas;
 - c) Measurement of background pollution
 - d) Measurement of pre-urban pollution
- ✓ Establishing a system for odour continuous monitoring in Agadir city based on the electronic nose technology.
- ✓ The setting in January 2014 of a specific organization for air quality management in the region of Souss Massa through the establishment of the permanent regional committee for the control and monitoring of the air quality, according to Law 13 - 03 and its implementing decree No. 2-09-286 of 8 De-

cember 2009 . In fact, this law states air quality standards and monitoring procedures and stipulates the creation of a standing committee for air quality control and monitoring, under the presidency of the Wali of the Region whose mission, among others, is :

- To identify the places and locations for setting up fixed or mobile stations which are representative of the general exposure to pollution by population and to ensure the proper working of these stations;
- To collect data on the air quality;
- To permanently inform the population on the air quality, on the basis of the air quality index;

In the last decade, much information and awareness campaigns on air quality and its monitoring were conducted among the general public within environmental events, exhibitions and seminars. Also, since 2007, several master courses were offered and some master projects supervised on topics such as:

- ✓ Modelling of air pollution with tools such as EPA's Industrial Source Complex (ISC3), Screen 3, AERSCREEN and AERMOD;
- ✓ Inventory of air pollutant emissions from car traffic using Copert;
- ✓ Study of the Urban Heat Island;
- ✓ Inventory of greenhouse gases in the area of water and sanitation.

2. Local Air Quality Management Perspective on Greater Agadir Area

Air pollution is a great threat to public health and the environment essentially in urban areas. It is important to design an air quality management system as part of urban planning and management. Effective air quality management must therefore be based on a good understanding of local air pollution problems and solutions in a broad Public Health context [15]. Local air quality management (LAQM) is a system for the design and implementation of monitoring network, management and policies within air quality in urban areas [16].

LAQM can be used to make an action plan for improving air quality through urban management and development. It needs to address the complexity of the relationship between sources and exposure. Essential components of such a system are the setting of ambient air quality standards, an emission inventory, ambient air quality monitoring, gathering appropriate meteorological data, air quality modeling, Source emission limits and an integrated regulatory system as demonstrate in **Figure 1** below.

The management of air quality in an urban area like Agadir city requires the monitoring of pollution levels, the inventory of emissions and the simulation of air quality. For the establishment of a monitoring protocol and for a continuous measurement of the concentrations of key pollutants (so as to deliver results every hour) in different parts of the city, other fixed stations must be acquired. These stations must be located primarily in the urban area and close to major sources allowing to be informed about the maximum of primary pollutants. Moreover, measurements at peripheries can also be very useful for quantifying

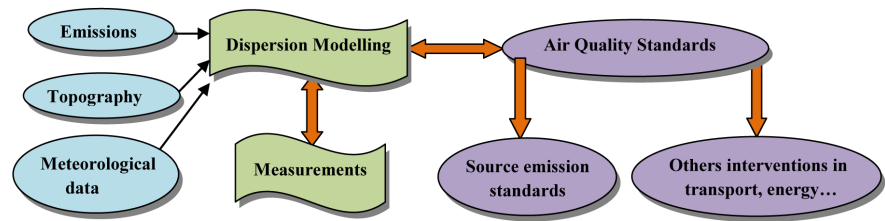


Figure 1. Schematic diagram of an air quality management system.

the levels of secondary pollutants, given that their maxima usually appear outside the cities [17]-[19].

The implementation of the emission cadastre is necessary for estimating the levels of pollutants from all emitting sources (point, area and mobile), this emission inventory allowed the collection of data including the chemical identity of the pollutants, a quantification of the human or natural activity responsible for the emission, the emission factors or the information needed for their calculation, the location and the temporal variation of the emissions for each activity. The amount of emissions from the various source categories provides an initial estimate of their contribution to air pollution in an area. The atmospheric emission inventories most of the times appeal at representative emission factors studied by means of measurements for various categories and types of sources coming from different areas of activity. At the same time, they use surrogate statistics such as the density of population, the fuel consumption, the distance travelled by vehicles or the levels of industrial production. Emission estimates are usually calculated by applying an emission factor to an appropriate activity statistic. Emission factors are generally derived from measurements made on a number of sources representative of a particular emission sector [20] [21].

Emissions from road vehicles for example, relay on a number of influencing factors and require fairly detailed models to take them all into account. These include the age and composition of the fleet, the size or weight of the vehicle, the emission standards the vehicles complied with when sold new, abatement technologies used to reduce emissions, the type and quality of fuel used, the way the vehicle is driven, trip characteristics and temperature conditions. This cadastre should necessarily cover the city and its surroundings with a spatial resolution of one kilometer and a temporal resolution of one hour of different emission categories, the great point sources, the surface sources and the linear sources [22] [23].

Thereby, the collected data will contribute to the development of simulation which consists of using the emissions inventory together with weather patterns and air quality models to predict future pollution levels. Urban concentration levels depend on the atmospheric phenomena that occur at different spatial scales, namely from international scales of thousands of km to street levels of a few meters [24].

Additionally, these levels present complex interactions with a large variety of chemicals in the atmosphere. Up to now, no single model can describe these

processes consistently so a combination of models is needed to address such description. Moreover, the choice of the model is basically dependent on the purpose of the simulation [25].

Modeling is an essential tool for the development of atmospheric emission abatement measures and Air Quality Plans (AQP). Frequently, these plans are related to urban environments where the emission sources as well as the exposed population are concentrated [26].

Developing a set of reliable tools for air quality modeling at urban scale is a very challenging task due to the fact that urban environments are particularly complex. The environments are characterized by the presence of several pollutants emitted from multiple sources. Moreover, a series of different spatial and temporal scales are involved in the chemical transformation and transport processes of such pollutants. The inherent complexity of urban environments requires simulation tools to assess air quality levels to be able to support the analysis and evaluation of a variety of policies and emission abatement measures [27].

The dispersion models are therefore calculation tools that, through equations and algorithms, allow describing in simplified way the phenomena (much complex) of the pollutant dispersion in atmosphere. The inputs of the dispersion models are the meteorological data (opportunedly processed) acquired from the weather stations, and the polluting emission (from inventory); the output will be the concentration of the same pollutant in a specified point of the territory object of the simulation. The choice of the models to use for the simulation of the pollutant dispersion in atmosphere depends on various factors, the main ones are: the detail and the accuracy of the available database (emission inventory, meteorological factors, air quality data), the morphological complexity of the area under investigation, the characteristics of the emissive sources that are simulated, field of application (urban, rural or industrial area), the detail of the results that are desired to obtain [21] [28].

These simulations must first be validated by comparing their results with the experimental measures. They can then be used to develop emission reduction scenarios and predict their effectiveness.

For the implementation of this program, close collaborations have been established between the various local partners, namely the administration represented by the Wilaya, the Region of Souss Massa and the Ibn Zohr University. Hence, the action plan is defined as following:

- a- Monitoring the evolution of the air quality
- b- To fight against all sources of air pollution
- c- Publication of monthly newsletters on the quality of air
- d- To develop an inventory of the air quality situation
- e- To assess the impact of atmospheric pollution on the health of the population
- f- To make proposals for reduction of pollutant emissions
- g- Achieving a first rough cadastre of traffic emissions, and other sources: Then, as first step, some methodologies freely available from the internet could be

used for the calculation of traffic emissions (COPERT a software tool developed by the European Environment Agency and is used widely to calculate emissions from road transport in Europe). Other necessary data are available from the competent authorities. Finally, the use of GIS systems is needed to manage the spatial inventory. To complete this latter, other emission sources (factories, commercial, residential...) should be integrated with the possibility of using appropriate emission factors.

- h- The simulation of air quality in Agadir city: This requires the use of a meteorological model and one or more air quality models to simulate the evolution of pollutants on its area. To implement this step, free models are available on the internet (EPA USA). After running the model, we can interpret the results and test various emission reduction scenarios. The purpose of the establishment of models and simulation of air quality in Agadir city is to establish air quality models that can operate continuously. This step requires collaboration between academia and administration sectors.

Because the problems involved in the atmospheric processes are very complex. Numerical models are the only existing tools able to predict air quality concentrations. These problems depend not only on the emissions of pollutants and their reactivity in the atmosphere, but also on the meteorological conditions, our attention was focused on environmental studies related to the industrial and urban emissions. It consisted in modelling these emissions and to simulate their dispersion specifically two cases for Agadir city are treated, the first is a industrial unit and the landfill. For that, we are developed a code in previous work for the modeling of atmospheric pollution which are validated using the American model screen3. Dispersion model developed is designed for analyzing single sources in simple terrain, we can use it to prepare an initial analysis in order to establish the worst case estimate of short term air quality impacts from a specific source, the model address a dispersion in rural and urban areas but it cannot account for the effects of building downwash and cannot incorporate the effects of inversion breakup and shoreline fumigation. For meteorological data a matrix of 54 combinations of wind speed and stability class is included.

The model calculates maximum concentrations that can be compared to the maximum ambient air quality criteria in order to determine acceptability. In the event that the maximum predict values are greater than the criteria, the model can be rerun with modified source parameters to determine operating parameters that will meet the objectives.

3. Air Quality Regulation

Air pollution is one of the biggest environmental problems in cities throughout the world. Humans can be adversely affected by exposure to air pollutants in ambient air. In this sense the World Health Organization (WHO) and the United Nations Environment Program (UNEP) have highlighted outdoor air pollution as one of their key strategic focus areas to tackle root causes of death and disease globally. The WHO states in a 2011 press release that for 2008, the esti-

mated mortality attributable to outdoor air pollution in cities amounts to 1.34 million premature deaths. Air pollution in urban environments is primarily a result of the burning of fossil fuels and the key sources are the transport sector, electricity generation, the industrial and manufacturing sector and domestic fuel use for heating/cooling and cooking. Activities which are contributing to an increase in emissions include uncontrolled land-use and transport planning, use of poor fuel quality, energy-intensive productive activities, and limited air quality management capacity. Exposure to air pollutants is generally higher around high trafficked and congested roads, as well as industrial areas and regions reached by secondary pollutants formed downwind such as tropospheric ozone. As stated by the American Lung Association, ozone and particle pollution are the most widespread air pollutants and among the most dangerous.

To address these risks, the WHO air quality guidelines (AQGs) are designed to support and guide countries in development of their own national air quality standards. In addition to the guideline values, interim targets are given for each pollutant. These are proposed as incremental steps in a progressive reduction of air pollution and are intended for use in areas where pollution is high. These targets aim to promote a shift from high air pollutant concentrations, which have acute and serious health consequences, to lower air pollutant concentrations. The WHO states that progress toward the guideline values should, however, be the ultimate objective of air quality management and health risk reduction in all areas [29].

In response, an extensive body of legislation has been developed which establishes health based standards and objectives for a number of pollutants in air, several countries at Europe, North America and Asia set different National Ambient Air Quality Standards (NAAQS) for pollutants considered harmful to public health and the environment. These NAAQS provided public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly and provided also public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings.

The main objective of most air quality standards is to protect human health without imposing unacceptable economic and social costs. The intended application of these standards is to act as benchmarks against which the ambient air quality can be assessed. The responsibility for their implementation rests with the setting of air quality standards is a complex task and involves contributions from a wide range of disciplines. The scientific techniques used to assess the risks of air pollution to human health include meta-analysis techniques, toxicology, epidemiology including longitudinal analysis, air modeling and monitoring, dose-response and exposure assessment. [30].

As previously written, air pollution is a worldwide problem with widely known Harmful effects to human health and the environment [31] [32], another example, Numerous studies have pointed to the detrimental effects of traffic pollution on commuters and residents who live close to major roads [33] [34]

[35] [36]. To minimize this trend, multiple joint efforts concerning government entities, organizations and citizens have been made. The strategy to reduce these negative effects is to define air quality improvement policies. In this sense, Morocco pays a special attention to air pollution. Indeed, the cost of environmental degradation in Morocco is estimated at 4 per cent of the gross domestic product. Biodiversity is at risk, with 2.5 per cent of the inventoried fauna, 23 per cent of flora faced with threat of extinction and the cost of degradation of air was valued at almost 368 Million Dollars per year, representing approximately 1.03% of GDP. Climate change is already underway in Morocco; the average yearly temperature has risen 1.8 degrees and rainfall has declined 30 per cent. Morocco imports nearly 90 per cent of its energy and pays a high price for imported crude oil, oil products, coal and electricity.

To deal with this situation and in order to overcome the legal and regulatory shortcomings in the fight against air pollution, the legal arsenal is strengthened.

Legislation to protect air started to develop in 2003 with the enactment of Law No. 13-03 on Combating Air Pollution. The Qualit'Air Program, initiated by the Mohammed VI Foundation for Environmental Protection in 2002, set up monitoring stations in a number of cities and introduced a few relevant laws. The Qualit'Air program is still the only official program recognized at the national level and able to mobilize various ministries and partners to work together towards common goals.

In this sense, a number of laws have been promulgated for a better protection of air. These include:

- ✓ Law No. 13-03 on air pollution.
- ✓ Law No. 11-03 on the Protection and Conservation of the Environment;
- ✓ Law No. 12-03 on Environmental Impact Assessment;
- ✓ Decree No. 2-97-377 on the traffic police and rolling.
- ✓ Decree No. 2-09-286 setting standards for air quality and the procedures for air monitoring.
- ✓ Decree No. 2-09-631 fixing the emission limits release or discharge of pollutants into the air from stationary pollution sources and methods of their control.
- ✓ Decree No. 2-12-172 establishing the technical requirements for the disposal and the methods of the recovery of waste by incineration.
- ✓ Order No. 3750-14 of 29 October 2014 establishing the information thresholds, alert thresholds and rules for applying emergency measures regarding the monitoring of air quality.

In the case when the level of concentration of one or more pollutants reaches the information threshold, the Standing Committee of control and air quality monitoring shall take all available measures to inform the public. When an alert threshold exceeded its limit according to Decree N°3750-14 (see **Table 1**), the standing committee of control and air quality monitoring proposes to the Wali or concerned Governor to take all necessary emergency measures in order to limit the scope and effects of the laying of pollution on the population, according

to Decree No. 2-09-286 mentioned above. The information thresholds and alert threshold are considered achieved when these are recorded simultaneously by at least two stations, of which one has background pollution.

The National Ambient Air Quality Standards are summarized in the **Table 1**. The **Table 2** show the information and alert thresholds, these apply over differing periods of time because the observed health impacts associated with the various pollutants occur over different exposure times, the units of measure for the standards are parts per million (ppm) by volume, parts per billion (ppb) by volume, and micrograms per cubic meter of air ($\mu\text{g}/\text{m}^3$). In this study, the Moroccan legislative framework could be completed by the European recommendations in the cases of need.

This limit values exposed in **Table 1** are considered the minimum requirements that air quality should meet in order to protect human health and the environment. Where air pollution levels exceeded limit values, emission reduction strategies were to be implemented to improve air quality environment, according the mentioned regulations. This Moroccan limit values or guidelines

Table 1. Moroccan air quality standards, EU air quality standards (2010) and WHO air quality guideline values.

Polluants	Moroccan limit values	EU limit values 2010	WHO guideline values
Sulphur dioxide (SO_2)	99.2 percentile of daily mean values of $125 \mu\text{g}/\text{m}^3$	$350 \mu\text{g}/\text{m}^3$ 1-hour mean	$20 \mu\text{g}/\text{m}^3$ 24-hour mean $500 \mu\text{g}/\text{m}^3$ 10-minute mean
Nitrogen dioxide (NO_2)	98 percentile of daily mean values of $200 \mu\text{g}/\text{m}^3$ $50 \mu\text{g}/\text{m}^3$ annual mean	$40 \mu\text{g}/\text{m}^3$ annual mean $200 \mu\text{g}/\text{m}^3$ 1-hour mean	$40 \mu\text{g}/\text{m}^3$ annual mean $200 \mu\text{g}/\text{m}^3$ 1-hour mean
Carbon monoxide (CO)	$10 \mu\text{g}/\text{m}^3$ daily maximum running 8-hour mean	$10 \text{mg}/\text{m}^3$ maximum daily 8 hour mean	$10 \text{mg}/\text{m}^3$ maximum daily 8 hour mean
Particulate matter (PM_{10})	90.4 percentile of daily mean values of 50	$50 \mu\text{g}/\text{m}^3$ 24-hours mean $40 \mu\text{g}/\text{m}^3$ annual mean	$50 \mu\text{g}/\text{m}^3$ 24-hours mean $20 \mu\text{g}/\text{m}^3$ annual mean
Ozone (O_3)	$110 \mu\text{g}/\text{m}^3$ 8-hour daily max mean	$120 \mu\text{g}/\text{m}^3$ 8-hour daily max mean	$100 \mu\text{g}/\text{m}^3$ 8-hour daily max mean

Table 2. Information and alert thresholds according to Decree N° 3750-14.

Polluants	Information threshold	Alert threshold
Sulphur dioxide (SO_2)	$350 \mu\text{g}/\text{m}^3$ of sulphur dioxide average measured in an hour	$550 \mu\text{g}/\text{m}^3$ of sulphur dioxide average measured in 3 consecutive hours
Nitrogen dioxide (NO_2)	$250 \mu\text{g}/\text{m}^3$ of nitrogen dioxide average measured in an hour	$400 \mu\text{g}/\text{m}^3$ of nitrogen dioxide average measured in an hour
Particulate matter (PM_{10})	$150 \mu\text{g}/\text{m}^3$ of PM_{10} average measured in 24 hours	$200 \mu\text{g}/\text{m}^3$ de PM_{10} average measured in a 24 hours
Ozone (O_3)	$200 \text{g}/\text{m}^3$ average ozone measured in an hour	$260 \mu\text{g}/\text{m}^3$ average ozone measured in an hour

were formulated following processes that reflected well-debated national and international best practice and knowledge.

4. Materials and Methods

To characterize the air quality in Agadir City, the use of a Regional mobile laboratory which advantages and versatility of monitoring have been discussed in other studies in Beijing [37], Helsinki [38], Zurich [39] and Las Vegas [40]. And a fixed station, which is the lonely one installed for the moment in the city, were used for air quality monitoring. The mobile laboratory allows flexible and rapid response for estimating the air quality in areas not yet equipped with fixed stations. It can also be used to characterize air pollution on a given site and for punctual campaigns. Furthermore, it can help in the selection of a proper site for future location of fixed stations.

The mobile laboratory and the fixed station include the following instruments for air quality measurement:

- ✓ Auto-sampler-Analyzer of PM₁₀ fine particulate matter suspended in the air. Its measuring principle is based on the element oscillating microbalance (the absorption of beta-rays).
- ✓ Automatic measurement analyzer of sulphur dioxide (SO₂) whose measurement principle is based on the UV fluorescence.
- ✓ Automatic analyzer measuring carbon monoxide (CO) whose measurement principle is based on the infrared correlation.
- ✓ Automatic analyzer for measuring the ozone (O₃) whose measurement principle is based on UV absorption.
- ✓ Automatic analyzer measurement of nitrogen oxides (NO-NO₂-NO_x) whose measurement principle is based on chemi-luminescence.
- ✓ Automatic analyzer measurement of volatile organic compounds (COV and BTEX) whose measurement principle is based on.

Furthermore, these two stations include instruments for measuring weather parameters, the calibration system, the local acquisition system, and the transmission and data acquisition system to manage, analyze and process the data in real time.

Location of Mobile Laboratory and the Fixed Station

The mobile laboratory was installed in a residential area located in the grounds of the administrative district and specifically in the Wilaya Park during 2013 and then, it was installed in near industrial site of Anza town between 2014 and 2015; while the fixed station was located in a primary school situated in a residential district in the city centre, as presented below in **Figure 2**.

5. Results and Discussion

5.1. Meteorology

The mobile laboratory reports meteorological parameters for temperature, relative humidity and speed and wind direction.

In this study, we present pollution and metrological data gathered from mobile monitoring surveys and the fixed station conducted over a 3-year period, to investigate the pollution levels of different pollutants across the Agadir city. At first, we present the metrological data, over the period of 2013 to 2015 as shown in **Figure 3** and **Figure 4**. This weather conditions affects the propagation and dispersion of the pollutants.

In **Figure 4**, we present the daily average temperatures measured over a year. During 2015, the data of measurement wasn't available during the sex first months of the year because of some technical problems.

As we note, from the **Figure 3** and **Figure 4**, that there is a difference of temperature between the two sites of monitoring during the same measurement period which could affects the levels of pollution. In previous work, it was highlighted that the varied topography and temperature inversions coupled with



Figure 2. Location of the mobile laboratory and the fixed station between 2013 and 2016.

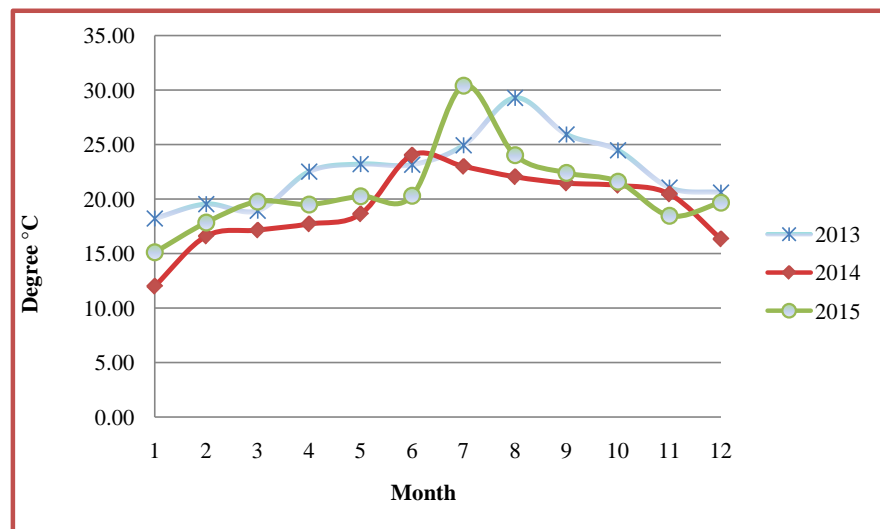


Figure 3. Monthly temperature variation on fixed station on the period 2013-2015.

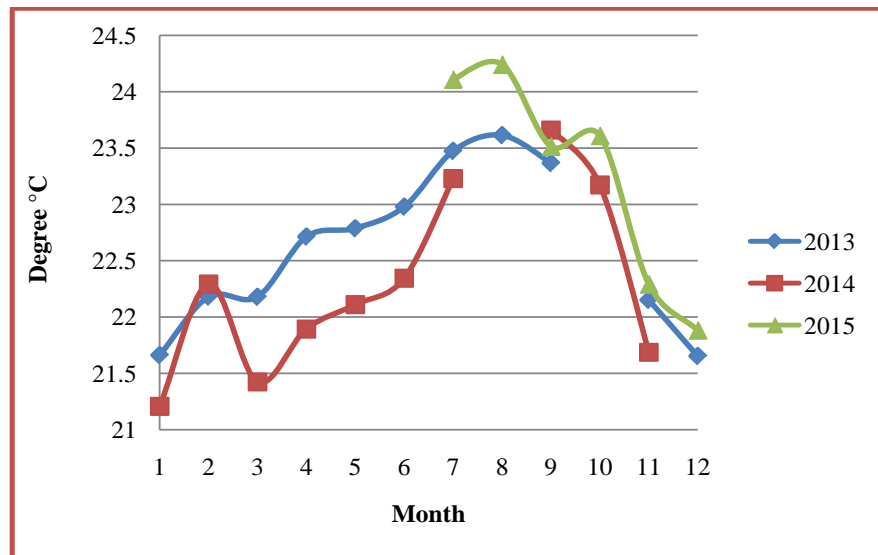


Figure 4. Monthly temperature variation on mobile laboratory on the period 2013-2015.

winds increase the levels of pollution [41]. So, the impacts of these meteorological parameters should be investigated in the case of Agadir region because of its irregular topography from the cote of the Atlantic Ocean to the mountains of the big and anti-Atlas, and the variation of the temperature and wind across it.

To have a clear idea about the temperature variation between the two sites, we resume in the following table the maximum and the minimum values presented in each year either in the fixed station or in the mobile laboratory.

Analyzing the presented data in **Figure 3** and **Table 3**, we remark that the temperature varies less than 2°C between the tree years and about 6°C through the year from the minimum value to the maximum value, with an average temperature of 23°C at the mobile laboratory. However, at the fixed station, there is a large variation about 20°C between summer and winter (from the minimum value to the maximum value) with an average temperature of 22°C .

The winds also affect air pollution as we mentioned below [41]. From the **Figure 5** and **Figure 6**, prevailing winds recorded during the measurement period is part of a Northern general flow of North-West, East, and West and in few cases flow from the South-East.

The large frequencies are associated with the most unfavourable wind conditions on odour dispersion. They are about 50.6% for 1 to 4 m/s of them and 2.4% for 4 to 9 m/s respectively, which correspond to low dispersive conditions and limited periods into which are slightly unstable, respectively, as shown in the winds rose plots in **Figures 5-7**.

We note that the wind speed into the Anza and Wilaya sites is less important than the one into the fixed station which is highly related to the topography and the surrounding of the measurement site.

As we see from the rate humidity variation during the period 2013 to 2015 there is slight difference between the fixed station and the mobile laboratory measurement as exposed in the **Figure 8**. The relative humidity detected on the



Figure 5. Wind Rose at the Wilaya during 2013.



Figure 6. Wind Rose at Anza area during 2014.

mobile laboratory was less than the one detected at the fixed station. In some cases, we could not present the value detected of the rate humidity due to the lack of data. In general, we observe a slight increase of the rate humidity detected between June and October with a maximum value during August.

5.2. Air Quality Data

Campaigns for air quality measurement in Greater Agadir Area are carried out in 2006 using the national mobile laboratory, the **Figure 9** below shows the sites concerned by the control of air pollution. The choice of the three sites was not arbitrary but based on legislative and scientific criteria taking into account the



Figure 7. Wind Rose at downtown during 2014.

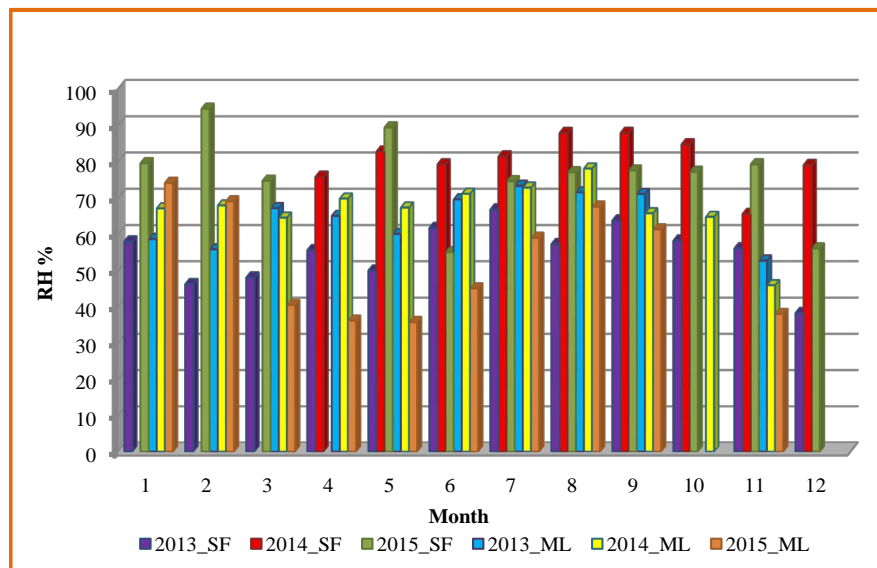


Figure 8. Humidity variation on the period 2013-2015. (SF. fixed station; ML. mobile laboratory).

zoning of the city into residential, commercial and industrial areas. As following, the result will show a difference between the levels of pollution in each area.

Air quality data for the years 2006-2015 was compiled and analyzed, based on records from the air quality monitoring station and mobile laboratory

Details of continuous measurements are shown in **Table 4** below.

These campaigns made it possible to characterize the level of air pollution at some sites in Greater Agadir Area from this table we can conclude that many sites have high levels of ozone and other pollutants meet national air quality standards. And also air pollution may be different in other seasons, so it is recommended to carry out other campaigns at different seasons. The national



Figure 9. Map of the sites location of the campaign. Anza; Abattoir and Almassira Airport.

Table 3. The maximum and the minimum values of temperature on the period 2013-2015

		2013	2014	2015
Fixed station (SF)	Minimum value	10°C	11°C	12.2°C
	Date	7 January	10 January	28 January
	Maximum value	35.5°C	30.8°C	37.7°C
	Date	14 August	13 August	29 July
Mobile laboratory (ML)	Minimum value	20°C	20.43°C	19°C
	Date	29 December	1 January	28 October
	Maximum value	26.9°C	25.9°C	27.7°C
	Date	16 August	30 October	29 July

Table 4. Concentration values of different pollutants on different sites of the campaign.

Pollutant	Period of campaign	13/04 to 20/04/2006	20/04 to 27/04/2006	27/04 to 09/05/2006
		Airport	Abattoir	Anza
SO ₂ (µg/m ³)	Average	1.4	49	37
	Maximum hourly	54	203	215
NO ₂ (µg/m ³)	Average	1.3	14	11
	Maximum hourly	7	44	65
O ₃ (µg/m ³)	Average	141	158	191
	Maximum hourly	199	245	312
PM ₁₀ (µg/m ³)	Average	15	20	30
	Maximum daily	20	39	55
CO(mg/m ³)	Average	0	0	0
	Maximum hourly	1	0.5	0.3
NO(µg/m ³)	Average	1.5	3	2
	Maximum hourly	10	35	17

standards requires that 8-h ozone concentrations should remain below 110 $\mu\text{g}/\text{m}^3$ while the WHO advises that this concentrations should remain below 100 $\mu\text{g}/\text{m}^3$ in order to satisfactorily protect humans from the harmful effects of ozone. Elevated surface ozone concentrations can cause harm to human health and agricultural productivity.

Research must be conducted to understand the evolution of ozone within the city very important compared to what is found in the pre-urban. To understand this phenomenon previous research has argued that tropospheric ozone is one of the leading photochemical pollutants in the atmospheric boundary layer. Because of the photochemical nature of ozone production, the largest concentrations typically occur during the early to mid-afternoon hours when incoming solar radiation is maximized [42]. Reciprocally, the lowest concentrations generally occur during the overnight hours due to scavenging of ozone through reactions with nitrous oxide and volatile organic compounds [43].

Many studies, including [44], have shown that monthly average ozone concentrations reach a maximum between March and August and a minimum during the winter. In general, an increase in surface temperature and a decrease in wind speed are both associated with higher ozone values [42] [45] [46].

One of the primary formation mechanisms for ozone is via photochemical processes. Therefore, the presence of sunlight and the amount of available radiation are important in determining the rate of ozone formation [45] [47].

Furthermore, an increase in relative humidity is usually associated with an increase in cloud cover and a decrease in atmospheric stability, which in turn reduces the photochemical processes that are vital to the formation of ozone [45].

Many study showed how urban air quality is affected by a change in meteorological parameters, indeed, it was found that an increase in summertime heat and a decrease in summertime precipitation will lead to a substantial increase in both the minimum and maximum ozone concentrations as well as an increase in the total number of exceedance days. During the hotter, drier years, the number of days with ozone concentrations above the legal regulatory limit increased nearly threefold. The length of time in which humans and crops are exposed to these unsafe levels was also doubled. Furthermore, a significant increase was noted in the overnight minimum ozone concentrations [48].

In this study, air quality data for the years 2013-2015 based on records from the air quality monitoring station and mobile laboratory, was compiled and analyzed in terms of the legal limits compliance, namely on the maximum hour exceedances and maximum daily exceedances allowed per year.

a. Nitrogen dioxide (NO_2):

The concentrations are averaged per month in the **Figure 9**. They remain low limit values and no exceedances were observed for NO_2 for fixed station site. However, into measurements sites of the mobile laboratory, it was detected an exceedances of the information threshold on February 2014. **Figure 10** presents the average concentrations per day of the profile variation during a week of NO_2 .

For the daily profile, concentrations decrease on Saturday and Sunday as

shown in **Figure 11**. For the time profile, the highest concentrations are recorded during heavy traffic hours (time expressed in universal time). The information threshold ($200 \mu\text{g} / \text{m}^3$) has been exceeded 3 times into the measurement site of the mobile laboratory 4; 10 and 19 February 2014 July. In city centre, the fixed station recorded no exceedance of the information threshold.

b. Sulfur dioxide SO₂:

SO₂ is by far the pollutant the less present among the substances taken into account in the calculation of the air quality index. The low concentrations of SO₂ are observed nationwide except around areas of high industrial density, emitting this pollutant. In general, SO₂ concentrations of the monitored sites remained very weak before the limit values according to the Moroccan air quality standards as shown in **Figure 12**.

Any remaining low, the profile of the monthly average SO₂ concentrations

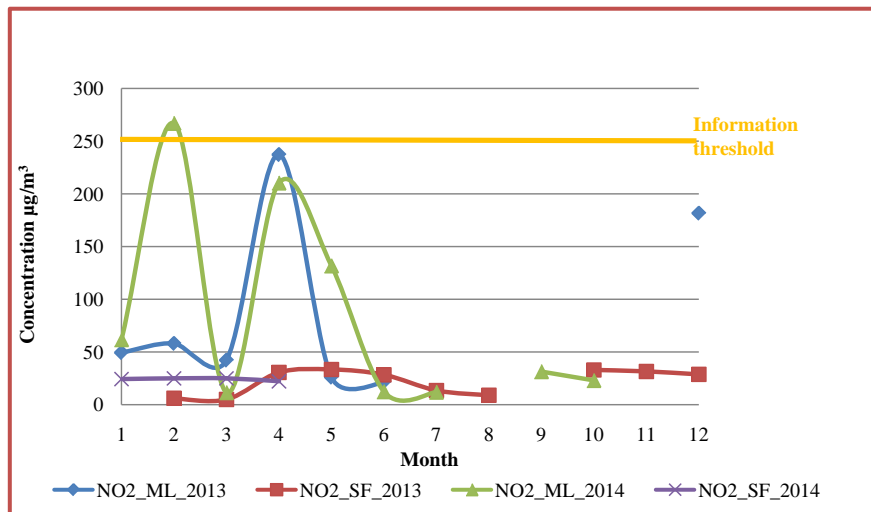


Figure 10. Monthly NO₂ variation into monitoring stations on the period 2013-2015. (SF. fixed station; ML. mobile laboratory).

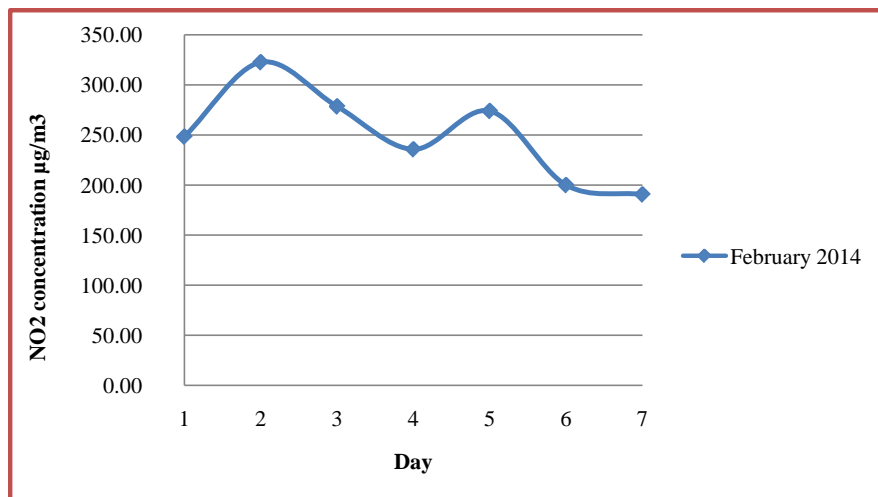


Figure 11. Daily average profile of NO₂ during February 2014 into the sites measurements of the mobile laboratory.

well mark an annual cycle similar to those of primary pollutants generally observed on the background of sites (winter concentrations are higher than summer concentrations).

c. Suspended particles (PM₁₀):

The annual average concentrations of PM₁₀ on sites are largely below to the limit value sites as shown in **Figure 13**. The fixed station is located downtown is the busiest site with an annual average of 2 µg/m³. The highest daily concentration is recorded on Anza town and Wilaya sites with about 87 µg/m³ in January and December, respectively.

Suspended particles are also measured on the Wilaya site. Concentrations are

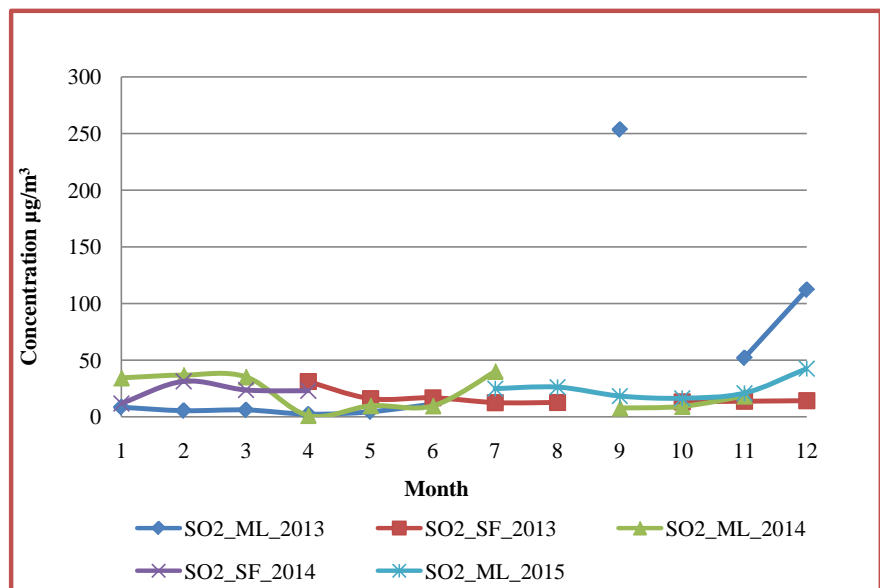


Figure 12. Monthly SO₂ variation into monitoring stations on the period 2013-2015. (SF. fixed station; ML. mobile laboratory).

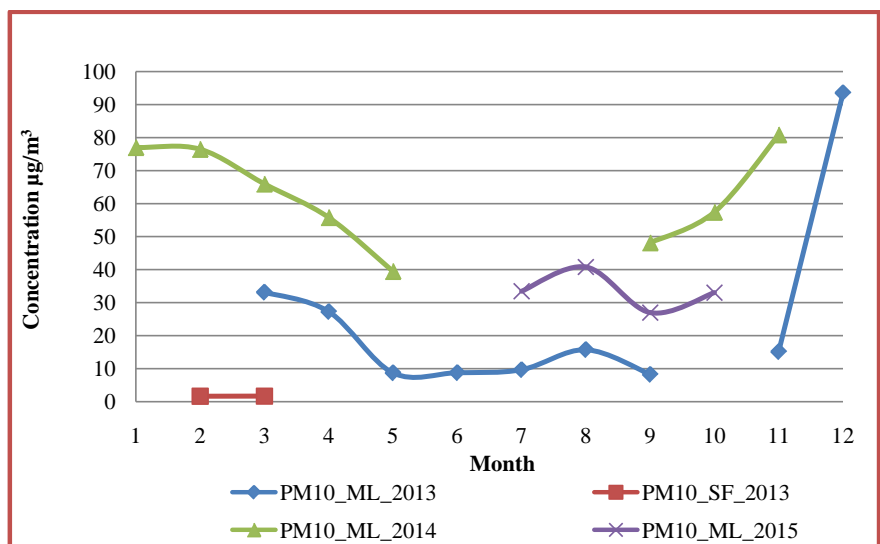


Figure 13. Monthly PM₁₀ variation into monitoring stations on the period 2013-2015. (SF. fixed station; ML. mobile laboratory).

somewhat higher than those observed in the background sites while remaining the same order of magnitude. Levels of particulate into Wilaya site respect different values and limit quality objective.

d. Carbon monoxide (CO)

CO is monitored at the tree sites. CO levels have largely respected the quality objective on stations measuring sites as shown in **Figure 14**. Mean concentrations (over 8 hours) maximum recorded on the Wilaya and Anza sites are respectively 51% $\mu\text{g}/\text{m}^3$ and 68% $\mu\text{g}/\text{m}^3$. These concentrations are the highest than those recorded in 2013 and 2014.

e. Ozone (O_3)

The alert threshold for ozone, set at 260 $\mu\text{g}/\text{m}^3$ over an hour, has never been surpassed on measurement sites as shown in **Figure 15**. However, the most important ozone levels are observed when weather conditions are favourable for

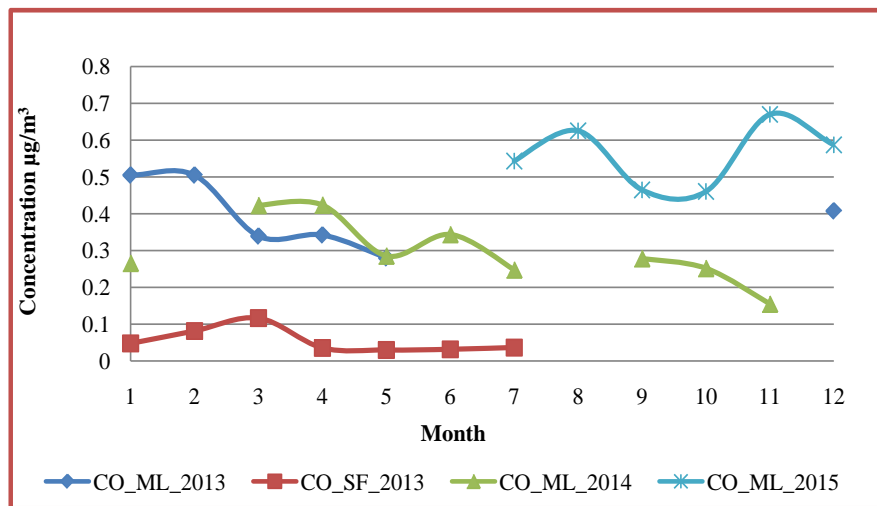


Figure 14. Monthly CO variation into monitoring stations on the period 2013-2015. (SF. fixed station; ML. mobile laboratory).

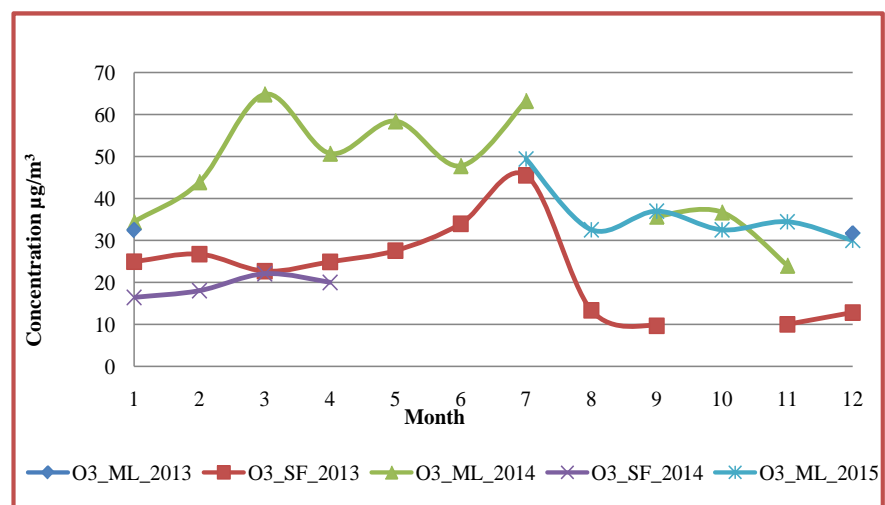


Figure 15. Monthly O₃ variation into monitoring stations on the period 2013-2015. (SF. fixed station; ML. mobile laboratory).

its production, the conditions are generally characterized by strong sunlight, high temperatures and low wind speed. Thus, the most important concentrations are generally recorded during summer periods.

The physical location and topography of the city plays a crucial role for emissions and concentration changes. For example, the city of Agadir is located next to the Atlantic sea and mountain respectively, which don't provides them with a sufficient zone to disperse a large amount of the pollution coming from city sources, especially the traffic and the industries. Nevertheless the meteorological conditions influence severely in the generation and distribution of air pollutants by their transport or transmission as far as temperature and radiation favour the photochemical production of ozone [49].

5.3. Clean Air Strategy

In the last decade, Morocco developed a multiple strategies for controlling and reducing pollutants emission. The regional air pollution control strategy, in Greater Agadir Area as well as in the potential polluted cities, was the most challenging issues in pollution control. There are integrating requirements into a multiple pollutant control strategy which calls for the development of a comprehensive emission control plan, including acid deposition, ozone, fine particles, and greenhouse gases. In the immediate term, this strategy targets to start with the control of SO₂, NO_x, VOC, and fine particles, for which were establishing corresponding multi-pollutant control regulations and looking for getting a management systems as the development of clean energy sources like Nour of photovoltaic Station in Ourzazate and the eolien centres in the north and the south of Morocco. Effective decision-making support in regional air quality management based on enhancing of vehicle emission control and promoting of climate friendly air pollution control measurement which lead to a reliable regional-scale modeling that is urgently needed to have an integrated, accurate emission database which may lead to develop a preventive scenarios to fight against global warming. There are also needs to establish regional air quality monitoring networks, to develop regional air quality modelling and forecast systems, and to set up management systems.

The measurement of the regulated pollutants is devoted to a number of monitoring stations that cover a variety of environments. The stations are classified regarding the type of area (urban, suburban or rural) and also depending on the influence of the immediate surroundings (traffic, industrial or background). Furthermore, this classification is based mainly on spatial considerations like the degree of built up areas, population distribution or the influence of near sources. However, other relevant aspects linked to the concentrations of the air pollutants, such as the terrain topography and the atmospheric dispersion conditions of the area, should be also considered because stations belonging to the same category may show very different concentration levels and variability, which are, in addition, pollutant-dependent [13] [50]-[56].

The main role of air analysis and monitoring is to obtain reliable analytical

information concerning some mechanisms and processes. The first one is the identification of pollutant emission sources and assessment of the range of their influence. The second one is the assessment of the environmental quality and the investigation of the environmental fate of pollutants. Another very important aspect is the bioaccumulation in tissues of living organisms and the assessment of the ecotoxicity of pollutants. Finally, the role of monitoring involves the assessment of the environmental impact of new regulations and policies.

Various air monitoring approaches have been developed including ground stations of monitoring networks, satellite telemonitoring, the application of biomonitoring, portable monitoring device solutions which are however far from being perfect as they are usually characterized by low sensitivity and low separation efficiency. Biomonitoring, as an alternative solution, unfortunately lacks standard procedures. However, satellite remote sensing can be regarded as a complementary approach, providing information on pollutant concentrations over large areas. The approach is expected to be improved in the near future, covering different types of analytical parameters. However, the application of telemonitoring is connected with huge investment costs [57].

Monitoring networks must be designed with a balance between costs and benefits analysis. In order to maximize the benefits, the surveillance stations monitoring networks and control alarming networks are usually located in places to cover areas with large populations. The number of sampling stations in the case of air monitoring can be defined by Directive European 2008/50/EC. The selection of air sampling station locations may be done in several ways. One is the population-weighted method of sampling station land coverage [58], which gives the best output data for the assessment of individuals environmental exposure. The other model is environmental-based, designed to monitor the main emission sources, like industrial facilities or motorways. There is also the integrated, multi-objective selection system based on sustainable development principles, involving environmental, social and economic issues in the planning, location and number of monitoring stations [59].

Continuous monitoring of the air pollution with a well-designed air quality monitoring network (AQMN) is the first step in addressing this issue. Obtaining the continuously monitored data to ensure the safe levels of air quality is one of the primary objectives of AQMN, in addition to evaluating exposure hazards and implementing effective control strategies. Environmental protection agencies would be looking for an optimal design of AQMN meeting these objectives with an obvious focus on minimizing cost [60]. The methodology to design a new AQMN or evaluate an existing AQMN attracted the attention of several researchers. Maximum sensitivity of the collected data [61] [62] and maximum coverage factors such as intensity of emissions, source distance and meteorology [63] were one of the first techniques to design an AQMN. Statistical measure of information content [64] and Fisher's information measure was used to determine the optimum number and location of monitors in a network [65].

Local Air Quality Management must be improved periodically to complement

national policies, to control industrial pollution and vehicle emission standards in order to develop a general strategy for air quality, based on clear standards and targets and to establish new systems for local air quality management, based on air quality management areas and effective control of emissions, particularly from vehicles and industries.

To optimize the existent resources, it recommended that local authority must designated Air Quality Management Areas (AQMA) standards and objectives are unlikely to be achieved. Once an AQMA is declared, it requires that the authority undertake a further assessment of the nature of the problems in the AQMA and an action plan setting out what measures they propose to take in pursuit of the achievement of air quality standards and objectives. The principal purpose of review and assessment is to identify areas where air quality objectives are being or are likely to be exceeded, so that appropriate action may be taken to address the problem. The process also generates information to inform local planning decisions and to support the work that local authorities do in providing advice to the public on air quality matters. We have no doubt that these are important functions and ones that are likely to continue to fall to local authorities LAQM monitoring has a part to play in its own right and not simply as a foundation for AQMA designation and action planning. It complements and supports local authorities other air quality responsibilities. It is important not to overlook review and assessment as a self-standing function, nor to lose sight of the needs of authorities without AQMAs [66].

6. Conclusions

Air pollution is a complex issue, supplied by multiple sources ranging from Industrial gases, vehicle exhaust, dust due to vehicle movements, construction debris, garbage burning, domestic cooking and heating, and some seasonal sources such as agricultural field residue burning, dust storms and sea salt (for coastal areas). To curb these emissions and reduce ambient pollution levels, national authorities are taking necessary action and introducing interventions in varying capacities a lack of coherent policy as well as unplanned growth across sectors (construction, transport, industry) is hindering these efforts.

The aim of this study is to present a review of Local Air Quality Management (LAQM) in Agadir city, this work highlights the requirement to revise it periodically for generating priority for air quality issues within local government taking in account the better use of available resources to improve LAQM outcomes and make recommendations with a view to improving air quality outcomes. Ultimately, this work describes the sites selected for measurement based on historical data that have been conducted since 2006 through 2016 using the fixed station and mobile laboratory.

Finally, the study amongst other things shows that to have a better monitoring network we should take into account the expansion of the city and the new created industrial sites. This last point guides us to a new zoning of the area study, making a new inventory of the whole sources of pollutions in this area,

and also taking the account the metrological data during a large period of time and the topography of the region. The compellation of all this data will give us a good approach to evaluate the existing network and to have a clear idea about the critical sites and points that should have more attention.

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