

## AIR QUALITY STUDY IN URBAN CENTERS: CASE STUDY OF OUAGADOUGOU, BURKINA FASO

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### Abstract

*In this work, a study on air quality in the city of Ouagadougou (Burkina Faso) was carried out. The concentration levels of NO<sub>2</sub>, SO<sub>2</sub>, BTEX and PM<sub>10</sub> in the city have been quantified. The results show that NO<sub>2</sub> concentrations (range from 22 to 27 μg m<sup>-3</sup> on average) in the city remain below the limit set by the WHO standard, except for downtown where values often exceed this standard. The average concentrations of SO<sub>2</sub> (range from 0.5 to 10.5 μg m<sup>-3</sup>) remain low in general throughout the city. The concentrations of BTEX (e.g. benzene: 27.9 μg m<sup>-3</sup>) are high in the city. PM<sub>10</sub> concentrations are very high in the city in general; they exceed the limit set by the WHO standard by a factor of 3 to 4. These PM<sub>10</sub> are mostly composed of dust from the desert and the re-suspension of dust particles related to vehicles traffic on unpaved roads. Two daily peaks for PM<sub>10</sub> are observed at heavy traffic hours. Finally, the study showed that the values of PM<sub>10</sub> concentrations observed are in the same order of magnitude of those generally observed in the Sahelian region (range from 119 to 227 μg m<sup>-3</sup>).*

**Keywords:** Air quality, pollutants, dust, concentration and passive diffusion.

### Introduction

Air pollution has become a major concern in the current issues because of its adverse effects on the environment (climate change) and humans (health problems). The World Health Organization (WHO) estimates that urban air pollution contributes to approximately 800,000 deaths per year in the world (WHO, 2002). Many studies have been published on the health impacts associated with urban air pollution (Cohen et al. 2005; Delfino et al., 2006, Curtis et al., 2006). In the past 30 years, the level of some air pollutants such as particulates matters, sulfur oxides, carbon monoxide have decreased in many cities in the United States and Western Europe because of emission control on vehicles, heating systems, power plants and industries (WHO, 2000; Godish, 2003; Defra, 2003). In these cities, networks for air quality monitoring are available to continuously monitor pollution levels. However, problems of air quality still remain in developed countries and the air quality can get worse further because of the growing use of motorized vehicles and the chemical industry.

About developing countries, serious problems of air pollution exist mainly in large cities such as Beijing, Shanghai, Bombay, Karachi, Cairo, Sao Paulo and Mexico City (Mage et al. 1996; Mayer, 1999; Akimoto, 2003; Gurjar et al., 2008). The study on air quality is recent and there is a lack of data about air quality in these countries. Most of these countries do not have specific regulations on air quality. Where such regulations

exist, they are not always enforced. There is no air quality monitoring agency in most of developing countries. In West Africa, studies based on mathematical modeling of traffic, made in Dakar, Ouagadougou and Cotonou (Tractebel, 1999, BM 1999; Worou, 2005) show that most of these cities are polluted. According to these studies, that pollution will increase in coming years due to the rapid growth of urban population especially. An increase of urban population is often accompanied by an increase of the fleet. In recent years, there is also a massive importation of used cars in these countries that are great sources of air pollution because of their very old ages and lack of regular and appropriate maintenance. This phenomenon is generally observed in developing countries (WHO / UNEP, 1992). In the case of Burkina Faso and in particular the city of Ouagadougou, the study led by Tractebel (1999) (which was updated in 2003 (MECV, 2003)) in the framework of clean air initiative project in Sub-Saharan Africa (project funded by the World Bank) has the following conclusions: The level of pollutants in downtown exceeds emissions standards set by WHO. The motorized two-wheeled (70% of urban traffic) are responsible for 77% carbon monoxide (CO) and 95% of unburned hydrocarbons (HC). On the other hand, the motorized vehicles with four wheels are responsible for 91% of nitrogen oxides emissions (NO<sub>x</sub>). This study shows that air pollution in the city is mainly due to urban transport. Indeed, urban transport consumes more than half the oil bill. The study shows that the concentration levels of sulfur dioxide (SO<sub>2</sub>) are low, due to a low share of industrial fabric in Ouagadougou and the number of diesel vehicles lower compared to gasoline vehicles. Another concern regarding the air quality in Ouagadougou is the problem of particulates matters due to dust carried from the Sahara (haze) and re-suspension of particles associated with road traffic on unpaved roads. The study also shows that if nothing is done the air pollution in Ouagadougou will continue to grow in coming years. Unfortunately there are very few experimental data on air quality in Ouagadougou. It is therefore necessary to have experimental data to control such pollution.

This work is based on air quality campaign of measurement in the city of Ouagadougou. The main aim of this work is to evaluate the concentration level of air pollutants in the city. The air pollutants studied are nitrogen dioxide (NO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>), benzene, toluene, ethyl-Benzene, xylene (BTEX) and particulate matter smaller than 10 μm (PM<sub>10</sub>).

### **Materials and methods**

The campaign of measurement was conducted in two steps: the first step was a preliminary campaign which aimed to determine the current level of air pollution and to have the map of air pollution of the city. This campaign was held in Ouagadougou from November 28 to December 5, 2006. The pollutants studied in this campaign were NO<sub>2</sub> (which reports pollution by motorized vehicles) and SO<sub>2</sub> (which reports pollution from diesel vehicles and some industries). The second step consisted of a measurement campaign which lasted five months: from February to June 2007. The objective of this campaign was to assess seasonal variation of air pollutants concentrations during measurement period. The pollutants measured in this campaign were NO<sub>2</sub>, SO<sub>2</sub>, BTEX and PM<sub>10</sub>.

### **Materials**

Passive samplers for NO<sub>2</sub>, SO<sub>2</sub> and BTEX NO<sub>2</sub>, SO<sub>2</sub> and BTEX were measured using passive diffusion tubes made by Passam ag (Passam, 2010). Several types of passive samplers have been developed since Palmes and Gunnison (1973) published the

principle of passive sampling. Passive samplers operate on the principle of diffusion of gases from the atmosphere along a sampler of defined dimensions on to an adsorbing or absorbing (a solid base impregnated with a chemical reagent) medium. The gas molecules are transferred from the ambient air into the sampling device by molecular diffusion, which is a function of temperature and pressure (Delgado-Saborit and Cano, 2006). The mean concentration of the sampled gas is computed according to Fick's first law on the exposure period (Palmer and Lindenboom, 1979).

The type of adsorbent used depends on the pollutant and the manufacturer. For NO<sub>2</sub> sampling, the most commonly adsorbent used is Triethanolamine (TEA). NO<sub>2</sub> is trapped by the TEA as nitrite ions (NO<sub>2</sub><sup>-</sup>) whose color is pink. The absorbance of the solution is then determined by spectrophotometry. This absorbance is then converted into equivalent mass. We finally get the concentration of pollutant in the air through the diffusion coefficient and the duration of exposure. Passam ag tube for NO<sub>2</sub> use Triethanolamine as adsorbent.

The sampling of SO<sub>2</sub> is done by passive tubes of Ferm type (Ferm, 1991) provided by the company Passam ag. To minimize the influence of wind, a Teflon filter is placed at the top of this tube and is attached by a steel grille. The sampling is based on the principle that SO<sub>2</sub> diffuses through a filter impregnated with a mixture of sodium carbonate and glycerol (adsorbent). Once at this level, the sulfur dioxide is trapped as sulfate ions. The analysis of sulfate ions is done by chromatography/conductivity associated with a cations suppressor.

The adsorbent used for BTEX in the case of Passam ag tubes is the active carbon (Passam, 2010). BTEX are absorbed on an active carbon and desorbed by carbon disulfide in laboratory and then analyzed by gas chromatography.

Table 1 gives the specifications of passive diffusion tubes of Passam ag type, for NO<sub>2</sub>, SO<sub>2</sub> and benzene according to Passam manual (Passam, 2010).

### **Thermo-Andersen ADR1200S for PM<sub>10</sub>**

The instrument used for particles measurements is an automatic analyzer of particles, the Thermo-Andersen ADR1200S. It has two main modules: a nephelometric analyzer of dust, the personal DataRAM of ADR-1200 type and a sampling pump branded pDR-PU. A computer software allows to gather the measurements on a PC connected to the unit: pDR-COM.

The device samples the air through an omni-directional head of DR-OSI model. The air sampling is done through an inlet cyclone. This cyclone stops particles which aerodynamic diameter is larger than the opening of the cyclone. For each opening of cyclone the corresponding flow can be fixed. For PM<sub>10</sub>, the flow is 1.2 L.min<sup>-1</sup>, for PM<sub>2.5</sub>, the flow is 4 L.min<sup>-1</sup>. Then the air goes through the optical measurement cell (the nephelometric unit) where the intensity of light scattered by the particles is converted into mass concentration.

The specifications of the device are given below:

- The instrument measures particles concentrations between 0.001 and 400 mg.m<sup>-3</sup>; its resolution is 0.1% of the reading or 1 µg m<sup>-3</sup>.
- Accuracy: ± 0.2% of the reading or 0.5 µg m<sup>-3</sup> for a recording mean time of 60s.
- Accuracy compared to the standard gravimetric method: ± 5% of the reading ± precision.

**Table 1: Specifications of the passive diffusion tubes (Passam, 2010).**

Pollutant	Sampling rate	Working range	Sampling time	Detection limit	External influences			Expanded uncertainty	
					Wind speed	Turbulences at kerbsites	Temperature		Humidity
<b>NO<sub>2</sub></b>	0.8536 ml min <sup>-1</sup> corrected to 9°C	1-200 µg m <sup>-3</sup>	1-4 weeks	0.3 µg m <sup>-3</sup> for 1 month exposure ; 0.64 µg m <sup>-3</sup> for 2 weeks	influence of wind speed < 10% up to 4.5 m s <sup>-1</sup> using protection shelters	may rise uptake rate, membranes recommended	no influence between 5 to 40°C	no influence between 20 to 80%	18.4 % at concentration levels of 20-40 µg m <sup>-3</sup>
<b>SO<sub>2</sub></b>	11.9 ml min <sup>-1</sup> at 20°C	0.5-240 µg m <sup>-3</sup>	2-4 weeks	0.2 µg m <sup>-3</sup> for sampling periods of four weeks	influence of wind speed < 10% up to 4.5 m s <sup>-1</sup> using protection shelters	-	no influence between 10 to 30°C	no influence between 20 to 80%	22.1 % at concentration levels of 20-40 µg m <sup>-3</sup>
<b>Benzene</b>	6.44 ml min <sup>-1</sup> at 20°C	0.5-50 µg m <sup>-3</sup>	2-4 weeks	0.2 µg m <sup>-3</sup> for a sampling time of 1 month	influence of wind speed < 10% up to 4.5 m s <sup>-1</sup> using protection shelters	-	no influence between 10 to 30°C	no influence between 20 to 80% caution under tropical conditions	27.1 % at concentration levels of 1 - 5 µg m <sup>-3</sup>

## Methods

For the preliminary campaign, 43 measurement sites were selected including four sites based on the criteria “peak site” and 39 sites based on the criteria “background site”. The peak site reports the pollution at the source, that is, the traffic of vehicles in our case. These sites were chosen because a certain class of people was exposed directly by emissions from traffic. A background site reports the exposure of people in offices or in residences in downtown. Fig. 1 shows the 43 sites selected to cover the whole city.

The samplers were placed at height between 1.5 and 2 meters. This height corresponds to the respiratory height. The passive diffusion tubes were exposed during one week and then they were collected and sent to the Passam ag laboratory in Switzerland for analysis.

For the second measurement campaign (lasted from February 2007 to June 2007), two sites of measure were chosen in the city, a background site and a peak site (Fig. 2). For all measures in the peak site, instruments are placed about 10 meters close to the road. The chosen site is the courtyard of an agency of “Société Nationale Burkinabé d’Electricité (SONABEL: society of electricity in Burkina Faso), locate at “Cité an II” (area of Ouagadougou) close to “Avenue Bassawarga”. Avenue Bassawarga is one of the avenues where the traffic flow is very important (Tractebel, 1999; MECV, 2003). The background site chosen is the backyard of the “Ministère de l’Environnement et du Développement Durable” (ministry of environment in Burkina Faso), behind the offices, on the ground floor and away from the discharge of air conditioners. In both measurement sites, the instruments are placed at height between 1.5 and 2 meters as in the preliminary campaign. The passive samplers are exposed for two weeks. At each site and each month, two tubes are exposed during the campaign (5 months) for NO<sub>2</sub> and SO<sub>2</sub>. For BTEX in both sites, 3 measurements with passive tubes were made during the follow weeks: 1st, 8th, and 15th. The tubes were kept away from the sun’s light and sent to laboratory for analysis twice during the campaign (mid-season and end of the campaign).

For PM<sub>10</sub>, in each site, the instrument is exposed during 24 hours by week. For each month, two series of measure were done in each site. Measurements were recorded for a time interval of 60 seconds, so 1440 values are recorded during 24 hours. To appreciate better the daily concentrations, we have chosen an hourly average to represent the results.

	A	B	C	D	E	F	G	H	I	J
1										
2						F2	G2			
3		B3-4	C3	D3	E3	F3	G3	H3		
4			C4	D4NO	D-E4	E4NE	F4NO	G4 O	H4 O	I O
5				D4-5	D-E4-5	E4-5	F4-5			
6				D5SO	D-E5	E5SE	F5SO	G5 O	H5 O	I5 O
7		B-C6-7		D6	E6	F6	G6	H6		
8				D7	E7	F7	G7			
					E-F8					

Fig. 1. Mesh of the city of Ouagadougou.

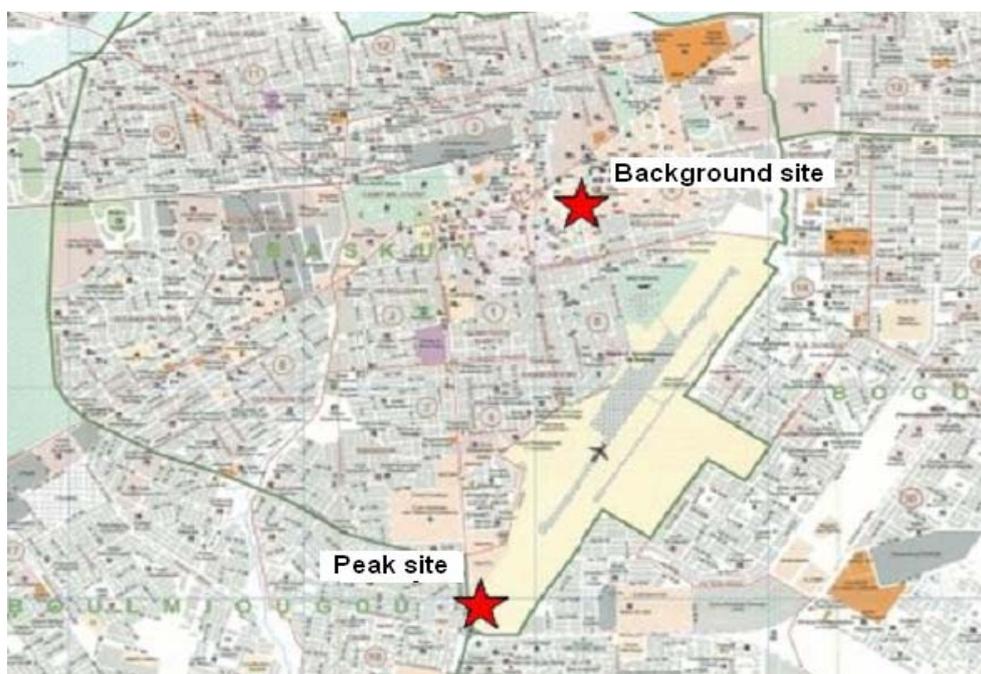


Fig. 2. Observation sites during the five months campaign.

### Results and discussion

NO<sub>2</sub> concentrations

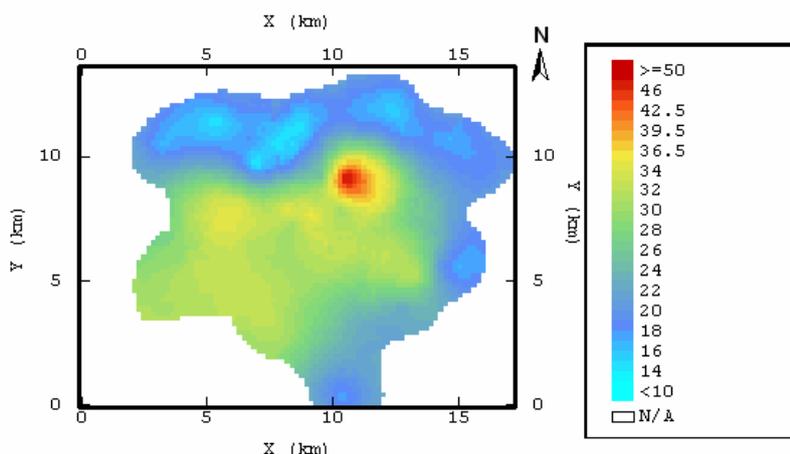
NO<sub>2</sub> concentrations in the city for preliminary campaign

Table 2 gives a summary of the results for NO<sub>2</sub> in the preliminary campaign. NO<sub>2</sub> concentrations obtained in the peak sites in downtown (Place du 2 October, Rond-point des Nations Unies, Avenue Kwame N’Kruma) exceed the limit set by the WHO standard (for one year), but this value is close to the standard at one peak site outside downtown (Boulevard Charles De Gaulle). At the background sites, the average concentration which is 27 μg m<sup>-3</sup> is less than the WHO standard (40 μg m<sup>-3</sup>).

**Table 2: Measurement results for NO<sub>2</sub> during preliminary campaign.**

	NO <sub>2</sub> ( $\mu\text{g m}^{-3}$ )	Standard deviation
WHO standard 2005	40 (1 year)	
Boulevard Charles De Gaule	36	
Place 2 Octobre	55	
Rond point des Nations Unies	56	
Avenue Kwamé N’Kruma	62	
<b>Average in the peak sites</b>	<b>52.2</b>	<b>9.75</b>
Minimum of background site	14	
Maximum of background site	49	
<b>Average in the background sites</b>	<b>27</b>	<b>7.8</b>

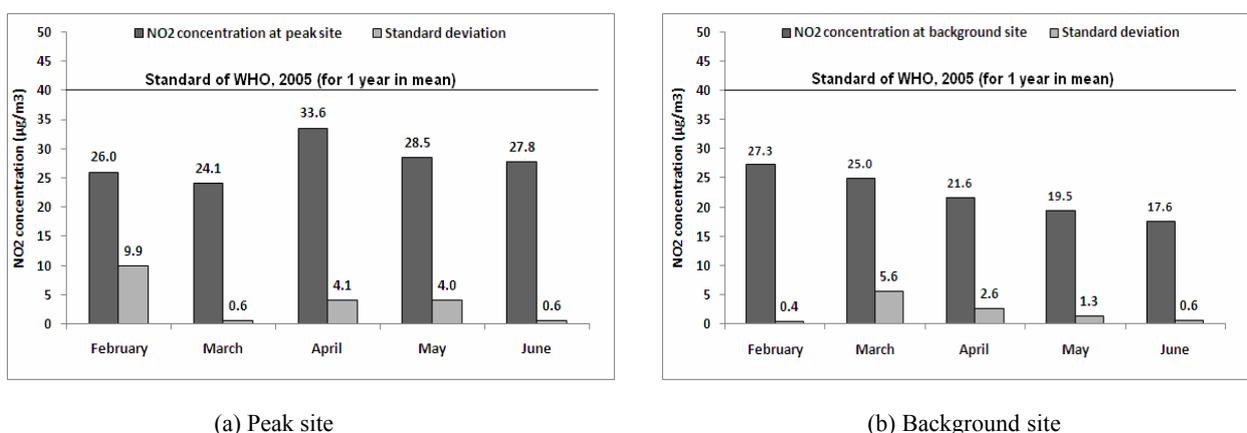
Fig. 3 shows the spatial distribution of NO<sub>2</sub> concentrations in the city of Ouagadougou. On this map, NO<sub>2</sub> concentrations are high in downtown and they fall when we get away. This result is in agreement with other studies conducted in big towns that led to similar observations (Lewnes et al. 2004; Carslaw and Beevers, 2005; Chaloulakou et al., 2008). The place where the concentration is the highest is at the “Rond-point des Nations Unies” in downtown. This roundabout is the intersection of several roads including “Avenue Kwame N’Kruma”. NO<sub>2</sub> is a pollutant linked to the traffic, its concentration is higher in downtown where the traffic is the most important, and it decreases when we get far from downtown.

**Fig. 3.** Spatial distribution of NO<sub>2</sub> in the city of Ouagadougou.

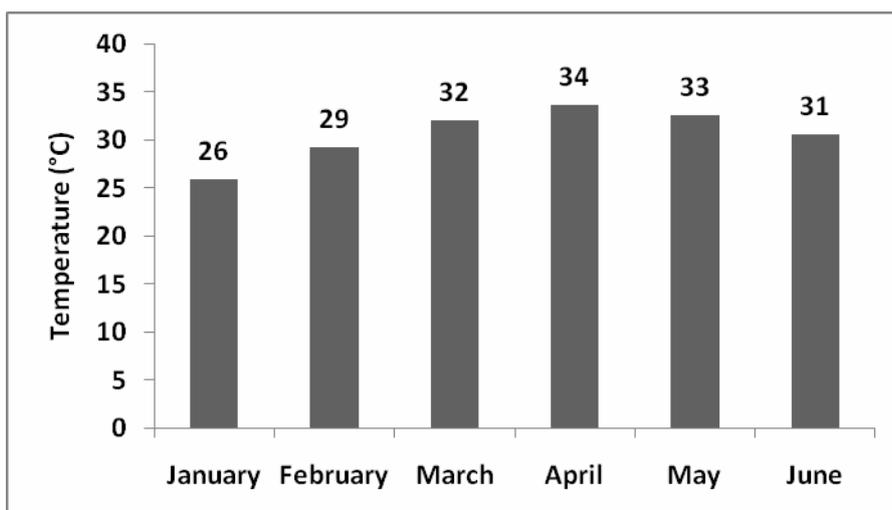
### Evolution of NO<sub>2</sub> concentrations during the 5-month campaign

Fig. 4 shows the evolution of NO<sub>2</sub> concentrations measured for 5 months. In general, the concentrations observed at the peak site ( $28 \mu\text{g m}^{-3}$  in average) are higher than those observed at the background site ( $22 \mu\text{g m}^{-3}$  in average). For both sites (peak site and background site), NO<sub>2</sub> concentrations are below the limit set by the WHO standard. Here the peak site is not located in downtown, but in a place where the traffic is important. At the peak site (Fig. 4.a), there is no significant difference in concentrations observed for the different months, except in April. It is difficult to draw a conclusion on the relative high value of NO<sub>2</sub> at the peak site in April because of the proximity of the traffic which can induce turbulence that will influence the tubes response (Plaisance et al., 2004). Similar concentrations at the peak site can be explained by the fact that the flow of vehicles is virtually the same in all months, as

observed by Stevenson et al. (2001). At the background site (Fig. 4.b), a downward trend from February to June is observed. The works of Stevenson et al. (2001) and Afif et al. (2009) have shown that high values of NO<sub>2</sub> are observed in winter (low temperature) and low values are observed in summer (high temperature). This observation can be explained by the fact that high temperatures promote destruction of NO<sub>2</sub> through chemical reactions with other chemical species that contributes to its removal from the atmosphere in summer (Gupta et al., 2003). Fig. 5 shows an increase of the temperature from February to April, then, a fall, from April to June, which corresponds to the beginning of rainy season. However, for this last period, we notice a decrease of NO<sub>2</sub> concentration, which is different of Gupta et al., (2003) observation. That observation can be explained by the removal because of the humidity. Indeed, water (from the rain) and NO<sub>2</sub> can react, leading to nitric acid formation.



**Fig. 4.** Monthly variability of NO<sub>2</sub> concentrations at both sites during the campaign of five months.



**Fig. 5.** Monthly temperatures in °C (in average) from 2004 to 2006 in Ouagadougou.

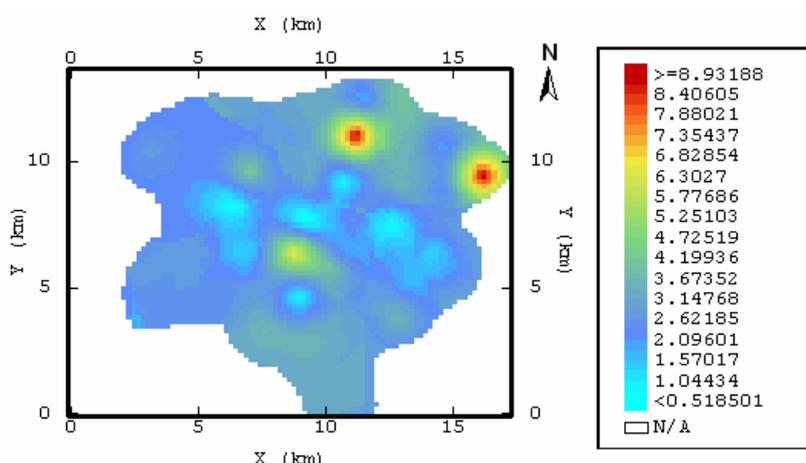
### SO<sub>2</sub> Concentrations

SO<sub>2</sub> concentrations in the city for preliminary campaign

Table 3 gives the results for SO<sub>2</sub> in the preliminary campaign. SO<sub>2</sub> concentrations are comprised between 2.7 and 10.4  $\mu\text{g m}^{-3}$  for the peak sites and between 0.5 and 9.2  $\mu\text{g m}^{-3}$  for the background sites. For all sites in Ouagadougou, SO<sub>2</sub> concentrations are low and below the WHO standard which is 20  $\mu\text{g m}^{-3}$  for SO<sub>2</sub> (for 24 hours). That can be explained by the low industrial base in Ouagadougou and the low rate of diesel vehicles compared to the rate of gasoline vehicles (which is the most important) (Tractebel, 1999). Fig. 6 shows the spatial distribution of SO<sub>2</sub> concentrations in Ouagadougou. This figure shows that the values of SO<sub>2</sub> concentration are generally low, but the higher values are observed close to the industrial sites (in particular, the power plants of SONABEL which consume domestic fuel oil, heavy fuel oil and diesel fuel; these power plants are located in industrial areas of Kossodo and Gounghin) and some parts of downtown.

**Table 3: Synthetic table of SO<sub>2</sub> during preliminary campaign.**

	SO <sub>2</sub> ( $\mu\text{g m}^{-3}$ )	Standard deviation
WHO standard 2005	<b>20</b> (24 hours)	
Boulevard Charles De Gaule	2.7	
Place 2 Octobre	5.6	
Rond point des Nations Unies	10.4	
Avenue Kwamé N’Kruma	6.8	
<b>Average in the peak sites</b>	<b>6.3</b>	<b>2.7</b>
Minimum of background site	0.5	
Maximum of background site	9.2	
<b>Average in the background sites</b>	<b>2.9</b>	<b>2.1</b>



**Fig. 6.** Spatial distribution of SO<sub>2</sub> in the city of Ouagadougou.

### Evolution SO<sub>2</sub> concentrations during the 5-month campaign

For technical problems that occurred during the campaign (5 months), we got results about SO<sub>2</sub> concentrations only for February and March. Table 4 gives the results for the two sites (peak and background). On this table it can be noted that the

concentrations of SO<sub>2</sub> are low at both sites. There is no significant difference for the two sites. However, it is difficult to draw a conclusion on these small differences between the peak site and background site due to the limited number of values. It can also be a problem of detection of SO<sub>2</sub> with regard to values close to the detection limit of SO<sub>2</sub> tubes (Table 1).

**Table 4: Variation of SO<sub>2</sub> for two months.**

Month	SO <sub>2</sub> ( $\mu\text{g m}^{-3}$ ) at peak site	SO <sub>2</sub> ( $\mu\text{g m}^{-3}$ ) at background site
February	2.2	2.8
March	4.1	4.4

### BTEX Concentrations

For BTEX, some measurements were done during the second campaign. Table 5 gives the results obtained during this campaign. These results shows that benzene concentration ( $29.7 \mu\text{g m}^{-3}$  for the background site and  $26.2 \mu\text{g m}^{-3}$  for the peak site) is very high compared to the limit set by the European Commission's standard for benzene which is  $5 \mu\text{g m}^{-3}$ , for annual average (EC, 2000). This is in agreement with the study of CREPA (CREPA, 1994), which showed that concentrations of polycyclic aromatic hydrocarbons (PAHs) including benzene, were high. Emissions of the two motorized wheels could be responsible for these high rates of BTEX (Tractebel, 1999).

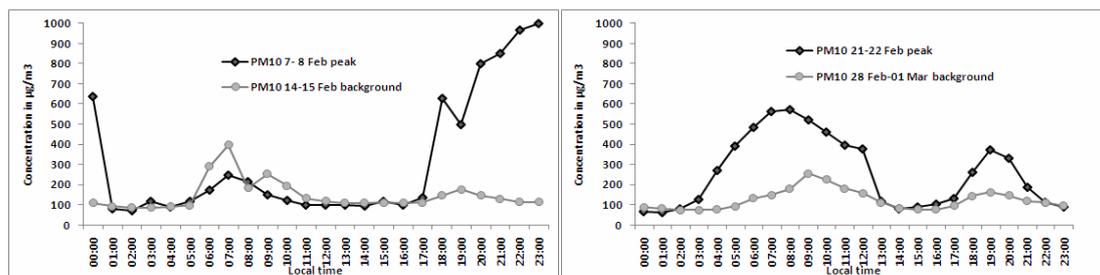
**Table 5 : Concentrations of BTEX measured.**

BTEX ( $\mu\text{g m}^{-3}$ )	Benzene	Toluene	Ethylbenzol	p-Xylene	m-Xylene	o-Xylene
February (background)	29.7	68.8	11.6	12.1	30.2	09.6
February (peak)	26.2	55.4	11.5	11.5	26.0	10.8

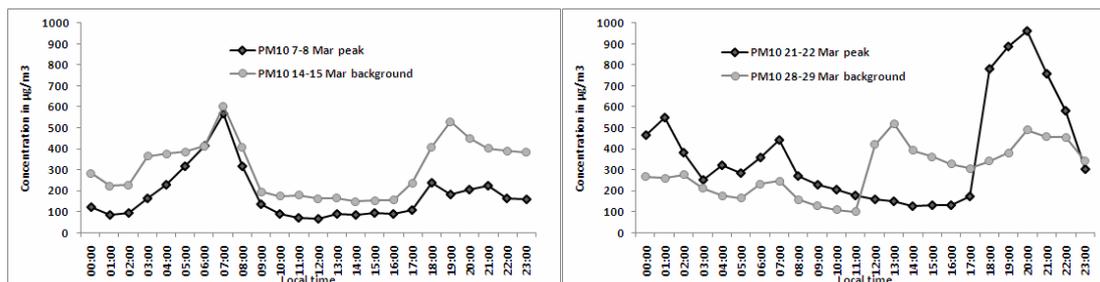
### PM<sub>10</sub> concentrations

Evolution of daily concentrations of PM<sub>10</sub>

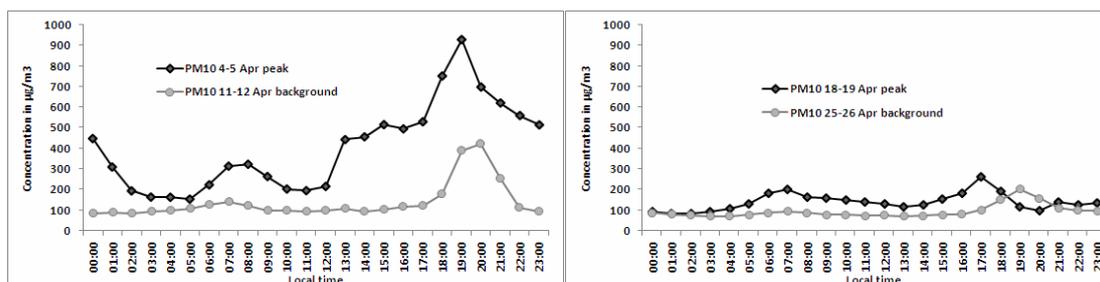
The Fig. 7(a) to 7(e) show the daily variation of PM<sub>10</sub> concentrations at the peak and background sites for the 5-month campaign. We chose to present for each month, the 4 measurements: 2 measurements at the peak site and 2 measurements at the background site. Two curves are placed on the same benchmark, one for the peak site and another for the background site, to compare simultaneously the daily variation of concentrations in both sites. In these different figures, two peaks more visible for most of the curves are observed; the first peak occurs around 7:00, which corresponds to the rush hour of the traffic in the morning. The second peak occurs around 19:00, which corresponds to the rush hour of the traffic in the evening, the flow of vehicles is also very important. However, there is no visible peak at 12:00 and 15:00 as it can be expected.



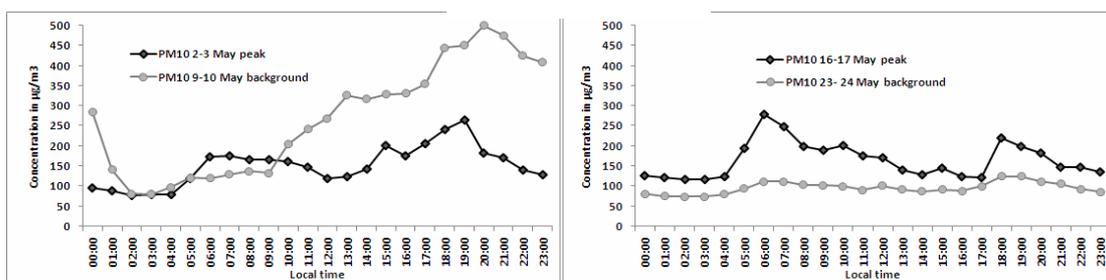
(a) February



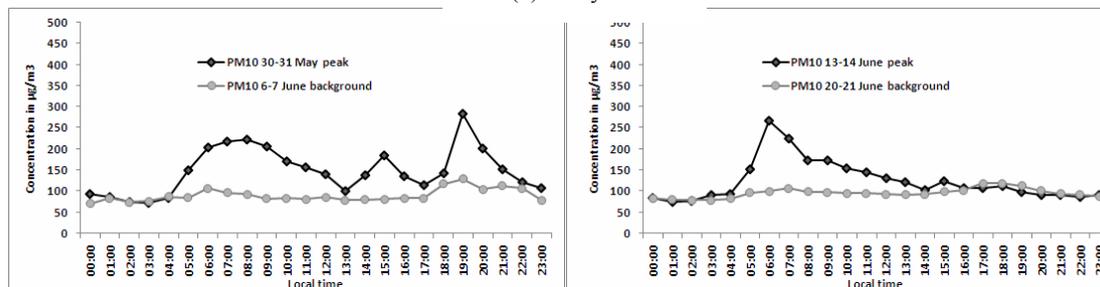
(b) March



(c) April



(d) May



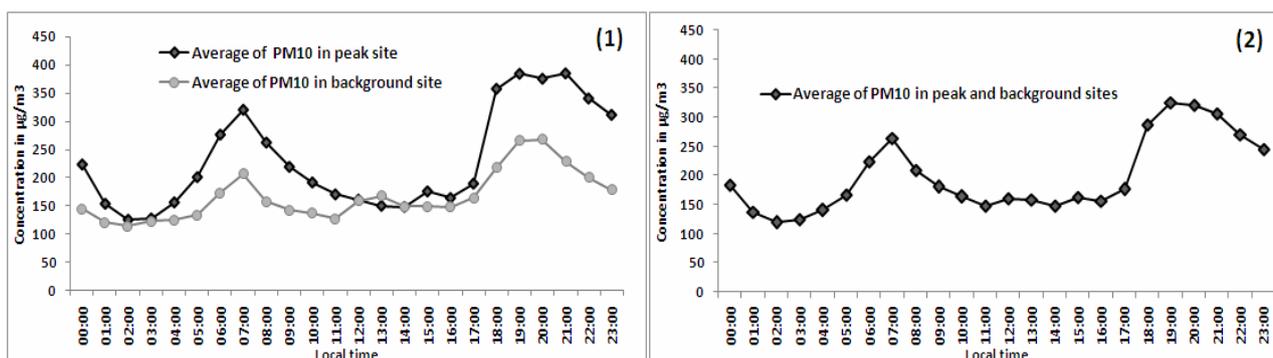
(e) June

**Fig. 7.** Evolution of daily concentrations of PM<sub>10</sub> (µg m<sup>-3</sup>) in the two measurement sites: (a) February, (b) March, (c) April, (d) May, (e) June.

Indeed, these are rushing periods in the traffic, but these rushes of the traffic are less important than those of 7:00 and 19:00. Fig. 8(1) shows the daily variation in average for the five months at the peak and background sites. The Fig. 8(2) presents the daily variation in average for the two sites. In these two figures, the two daily peaks appear clearly, the first around 7:00 and the second around 19:00. The analysis of these different figures allows us to deduce that the human activity, particularly the traffic of vehicles has an impact on the total concentration of PM<sub>10</sub> in the city of Ouagadougou. Indeed, vehicles contribute to the rising of dust particles on the paved and unpaved roads, and also contribute to emissions from exhaust systems (soot, organic particles). The same observation of the influence of human activity on daily concentrations of PM<sub>10</sub> was noticed by Latha and Badarinath (2005) in a city in India.

However, the diurnal cycle of PM<sub>10</sub> concentrations is different to that observed by Rajot et al. (2008), in a fallow of Banizoumbou at Niger (a country site). They show that the daily cycle of PM<sub>10</sub> is similar to the cycle of air temperature. This was linked to the development of an atmospheric boundary layer turbulence, which becomes thicker when the temperature is high. This turbulence causes convection for which wind speed reach a maximum around 10:00. The wind speed is then greater than or equal to 6 m s<sup>-1</sup> generating the maximum concentration of PM<sub>10</sub> at this time. Fig. 9, which represents the daily wind profile in Ouagadougou shows that the wind speeds fall below this threshold of 6 m s<sup>-1</sup>. Winds are therefore low in Ouagadougou compared to those of Banizoumbou. In addition, conditions of Banizoumbou are not those of Ouagadougou which is more exposed to human activity. These reasons may justify the difference between the observations of Banizoumbou and Ouagadougou. However, it should be better to do detailed studies to better explain the variation of the daily concentration of PM<sub>10</sub> in Ouagadougou.

Fig. 7 and Fig. 8 also show that the concentrations at the peak site are higher than those of the background site and, a downward trend from February to June can be observed. This will be discussed in the next paragraph.



**Fig. 8.** Daily evolution of PM<sub>10</sub> concentration (µg m<sup>-3</sup>) at the two measurement sites: (1) black curve: average of the peak site, gray curve: average of the background and peak sites, (2) average of the two combined sites.

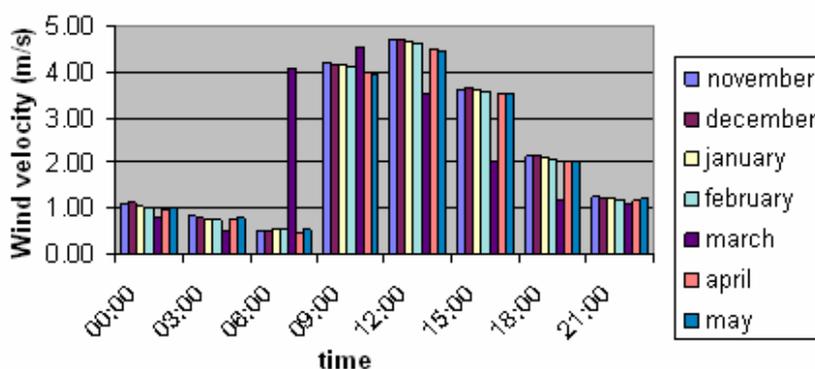


Fig. 9. Daily wind speed in Ouagadougou, November 2006 to May 2007.

### Evolution of PM<sub>10</sub> concentrations during the 5 months

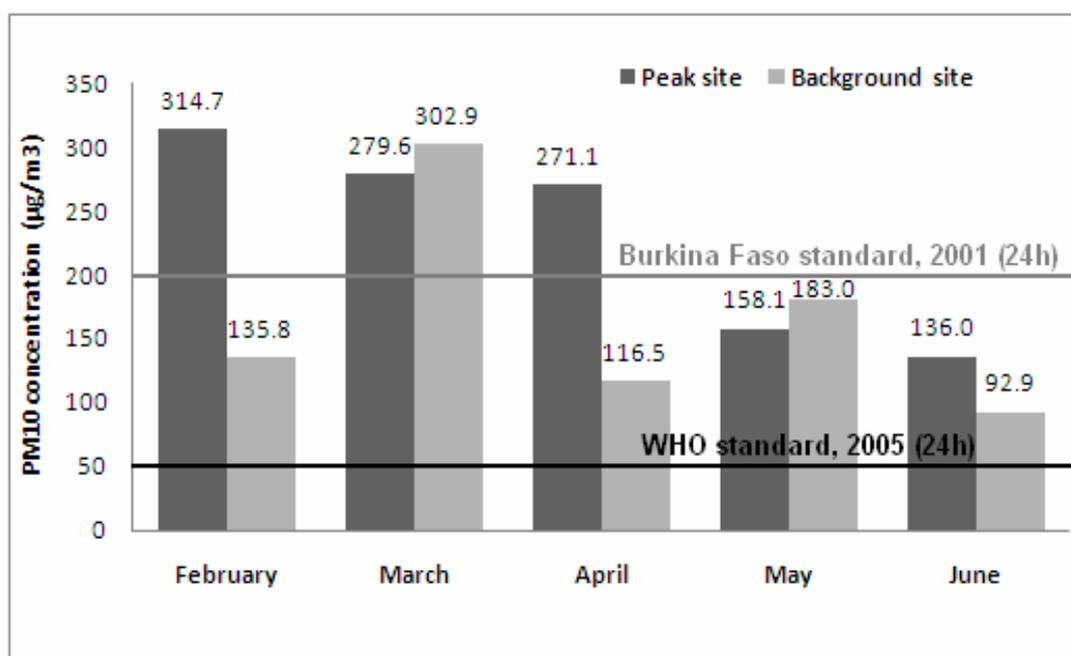
Fig. 10 reports the results of measurements during the 5-month campaign. The concentration obtained for each month is an average of two measurements. The duration of each measurement is 24 hours. The interval between two measurements is two weeks. The results show that PM<sub>10</sub> concentrations are higher in the dry season (February-April) and lower in the beginning of the rainy season (May and June). This seasonal variability was also observed in the investigation of Marticorena *et al.* (2010) in the context of a measurement campaign on desert aerosols in the framework of AMMA<sup>1</sup> program. However there is a difference between variation at the peak site and variation at the background site. At the peak site, there is a downward trend from February to June. At the background site, the concentration in February (135.8  $\mu\text{g m}^{-3}$ ) is lower than in March (302.9  $\mu\text{g m}^{-3}$ ), after that, the concentration decreases again in April (116.5  $\mu\text{g m}^{-3}$ ) and then it increases in May (183  $\mu\text{g m}^{-3}$ ) and finally it down to a low value in June (92.9  $\mu\text{g m}^{-3}$ ). This monthly variability in the background site is similar to the variability observed by Marticorena *et al.* (2010) and Lebel *et al.* (2009). The high concentrations of PM<sub>10</sub> observed during the dry season in the Sahel are due to the transport of dust from the Sahara and not to a local dust emission (Marticorena *et al.*, 2010; Lebel *et al.*, 2009). The high concentrations of PM<sub>10</sub> observed at the beginning of the rainy season (May-July) are due to a local dust emission (Marticorena *et al.*, 2010). Indeed, at the beginning of the rainy season, there are high surface winds produced by the passage of Mesoscale Convective Systems (MCS). These high surface winds are responsible for high emissions of local dust. These MCS are also bringing precipitation in the Sahel. During our measurement campaign, we also found these high surface winds that resulted in high levels of PM<sub>10</sub> recorded in our measurements. This is shown in Fig. 10 for May at the background site.

About the peak site, the highest concentration is observed in February. This is probably related to the contribution of local dust emission, especially, emissions from the traffic of vehicles on unpaved roads. However, we could not overlook the possibility of an emission related to the intrusion of a high surface wind. The relatively low concentrations of particles at the peak site at the beginning of rainy season may be related to the watering of unpaved roads by rainwater which limits dust emissions from

<sup>1</sup> African Monsoon Multidisciplinary Analyses : <http://amma-international.org/index>

unpaved roads. According to Marticorena et al. (2010), the minimum concentration of PM<sub>10</sub> coincides with the maximum in precipitation rates which inhibits dust emission by increasing soil moisture and vegetation cover, but which also suggests an additional influence of wet scavenging of dust concentration.

PM<sub>10</sub> concentrations exceed Burkina Faso standard for PM<sub>10</sub> in dry season except in February at the background site. The concentrations are closer to this standard limit in wet season especially at the peak site. The air concentrations of PM<sub>10</sub> in the city of Ouagadougou are largely above the WHO standard (which is 20 µg m<sup>-3</sup>, (WHO, 2005)) with a factor of 2 to 6 (Fig. 10).



**Fig. 10.** Monthly mean concentrations of PM<sub>10</sub> at the measurements sites.

Table 6 compares the annual average concentrations obtained in 2007 (Marticorena et al., 2010) with the results established in 2007 during our campaign of measurement (5 months). The sites of the AMMA campaign are the background sites located between latitudes 13°N to 14°N. Banizoumbou and Cinzana stations are located in the countryside and the devices are placed at the height of 6.5 meters. M'bour in Senegal is also a background site but it's located near Atlantic Ocean at the height of 9.5 meters. Our sites of Ouagadougou are around the latitude 12°N and the device is placed at the height between 1.5 and 2 meters.

On this table 6, the concentrations of PM<sub>10</sub> decrease, from Banizoumbou (227 µg m<sup>-3</sup>) to M'bour (199 µg m<sup>-3</sup>), i.e., from East to West. The concentrations at the background site (166 µg m<sup>-3</sup>) and at the peak site (224 µg m<sup>-3</sup>) of Ouagadougou are in the same order of magnitude of those obtained in the AMMA stations. It should be expected that concentrations of PM<sub>10</sub> in Ouagadougou are lower than those observed in the AMMA stations, because Ouagadougou is located at a lower level in latitude, thus, far from the Sahara which is the main source of dust. But this observation can be explained by the fact that we have an average of 5 months where the dust emissions are

the most important (dry season). The second explanation can be related to a local emission from vehicles on unpaved roads. In addition, the height, at which our device is placed (about 2 meters), is lower than the height of AMMA devices (6.5 to 9.5 meters). We can conclude that concentrations of PM<sub>10</sub> in the air obtained during our measurement campaign are in the same order of magnitude as the concentrations obtained in general at the Sahel. In the table 6, PM<sub>10</sub> concentrations are very high in the Sahel compared to the limit of WHO standard.

**Table 6: Comparison of annual PM<sub>10</sub> concentrations obtained in 2007 in the AMMA stations with the average concentrations obtained from the 5-month campaign.**

Observation stations	Concentration in $\mu\text{g m}^{-3}$
Banizoumbou : Niger (Marticorena et al., 2010)	227
Cinzana : Mali (Marticorena et al., 2010)	147
Mbour : Sénégal (Marticorena et al., 2010)	119
Background site in Ouagadougou ( <b>this study</b> )	166
Peak site in Ouagadougou ( <b>this study</b> )	224

### Conclusion

As a result of this investigation on air quality in the city of Ouagadougou, the following conclusions can be drawn:

- Concentrations of NO<sub>2</sub> are below the limit set by the WHO standard in the city in general, except in some downtown areas where the car traffic is important; this threshold value is exceeded. The SO<sub>2</sub> concentrations remain low throughout the city;
- BTEX concentrations are a concern in the city;
- The daily concentrations of PM<sub>10</sub> in the city of Ouagadougou have two peaks: the first peak occurs around 7 a.m. and the second peak occurs at around 19 p.m.;
- PM<sub>10</sub> concentrations are high during the dry season and low during the rainy season;
- PM<sub>10</sub> concentrations are very high in the city, they largely exceed the threshold value set by the WHO standard;
- PM<sub>10</sub> concentrations in Ouagadougou are in the same order of magnitude than the concentrations obtained in the Sahel in general;
- The traffic of vehicles on unpaved roads and the dust from Sahara significantly contribute to the concentrations of PM<sub>10</sub> observed in the city of Ouagadougou.

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