Atmospheric Environment 135 (2016) 31–40

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Measurements of NO_2, SO_2, NH_3, HNO_3 and O_3 in West African urban environments

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HIGHLIGHTS

- An original database of gaseous pollution measured in two West African capitals.
- Analysis of diurnal, seasonal and annual patterns of gases concentrations.
- Traffic is the major source of primary pollutants (NO_2) in Dakar.
- Domestic fires are an important source contributing to NH_3 concentrations in Bamako.
- NO_2, SO_2 and NH_3 levels are of the same order of those from Asian mega cities.

ARTICLE INFO

Article history:
Received 9 July 2015
Received in revised form
25 March 2016
Accepted 28 March 2016
Available online 30 March 2016

Keywords:
Urban emissions
Passive samplers
Nitrogen dioxide
Sulphur dioxide
Ammonia
Nitric acid
Ozone
West Africa

ABSTRACT

In this paper, we present the measurements of atmospheric gas concentrations of NO_2, SO_2, NH_3, HNO_3, and O_3 performed at two traffic sites in the context of the POLCA (Pollution of African Capitals) program. These gases were measured using a passive sampling technique from Jan. 2008 to Dec. 2009 at Dakar and from Jun. 2008 to Dec. 2009 at Bamako. In addition, during these periods there were two intensive measurement campaigns (from 19 Jan. to 2 Feb. 2009 at Bamako and from 30 Nov. to 13 Dec. 2009 at Dakar) where real-time active analysers were used to measure NO_2 and SO_2. Results show that Dakar has a pollution level for NO_2 and SO_2 higher than that of Bamako, whereas it is lower for NH_3 concentrations. Monthly values of NO_2 range between 21.1 and 43.5 ppb in Dakar with an annual mean concentration of 31.7 ppb (59.6 μg/m3). NO_2 values in Bamako are 9.4–22.6 ppb with a mean of 16.2 ppb. At Dakar, the mean annual NO_2 limit value (21.3 ppb or 40 μg/m3) recommended by the World Health Organization (WHO) is widely exceeded. The mean annual concentration of SO_2 is 15.9 ppb in Dakar and 3.6 ppb in Bamako. These differences may be explained by different sources of traffic between Bamako (with mainly gasoline vehicles) and Dakar (with mainly diesel vehicles). The annual mean NH_3 concentration is about two times higher in Bamako (46.7 ppb) than in Dakar (21.1 ppb). In addition to other possible sources, we assume that the ammonia from domestic fires and uncontrolled garbage incineration may have more influence at Bamako than at Dakar. The mean annual concentrations of HNO_3 and O_3 are 1.3 ppb and 7.7 ppb in Dakar and 0.6 ppb and 5.1 ppb in Bamako, respectively. Seasonal variation in measured gas concentrations are low in Bamako and more pronounced in Dakar, except for HNO_3 and NH_3. At Dakar, NO_2 and SO_2 daily mean concentrations are higher during the weekdays than on weekends, when urban activities are reduced, whereas at Bamako, no significant difference was observed between weekdays and weekends. At Dakar, the daily average concentrations of SO_2 in the dry season (11.6–39.6 ppb) widely exceed the WHO air quality guideline (7.6 ppb or 20 μg/m3 as 24-h average). Finally, the spatial

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http://dx.doi.org/10.1016/j.atmosenv.2016.03.050
1352-2310/

distribution of gases at different sites in these two capitals have been investigated and showed higher pollution levels at the traffic sites, especially for NO_2, NH_3 and SO_2, and lower levels in the suburban area, with the exception of ozone.

1. Introduction

The deterioration of air quality is one of the major problems that generally follows rapid urbanization, especially in developing countries. According to the World Bank 2012 report, urban outdoor air pollution in Africa is responsible for an estimated 49,000 premature deaths annually, the main burden borne by sub-Saharan African countries (Schwela, 2012). In addition, the urban areas in Sub-Saharan Africa are among the fastest growing in the world with an expected urbanization rate of over 3% per year over the next twenty years (UN Population Division, 2008). African urban air pollution is aggravated by a highly polluting traffic fleet with a large proportion of old and poorly maintained vehicles, poor fuel quality and large numbers of two-stroke vehicles (Assamoi and Liousse, 2010). A review by Han and Naeher (2006) indicated that traffic-related air pollution studies are relatively scarce, and continuous monitoring of air pollution is infrequent in developing countries. Domestic fires using wood, charcoal or animal waste also contribute significantly to pollution levels in West African cities (Liousse et al., 2014). Therefore, during the next decade, West and Central Africa will be confronted with the emergence of megacities with poor air quality and severe health problems. A considerable increase in pollutant emissions from Africa is then expected by 2030 if no regulations are applied (Liousse et al., 2014).

Air pollutants that commonly draw intense concerns regarding adverse health include particulate matter (PM), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and ozone (O_3) (WHO, 2005). The environmental effects of SO_2 and NO_2 pollutants are associated with the acidification of precipitation, visibility reduction, and have deleterious effects on human health and plants (Yuan et al., 2006; Bytnerowicz et al., 2007; Brimblecombe et al., 2007). NO_2 is one of the main traffic-related air pollutants and long-term exposures to this irritant gas may reduce immunity and lead to respiratory infections (Chauhan et al., 1998; Kampa and Castanas, 2008). Anthropogenic SO_2 is emitted during the combustion of sulphur-containing fossil fuels, principally coal and heavy oils. Exposure to SO_2 can affect the respiratory system, causing bronchoconstriction, especially in asthmatic subjects (Balmes et al., 1987; Bernstein et al., 2004). Tropospheric ozone (O_3), formed by the reaction of NO_x and volatile organic compounds (VOCs), is also a major environmental concern because of its adverse impact on human health, crops and forest ecosystems and its greenhouse gas effect responsible for climate change (Tager et al., 2005; Mauzerall and Wang, 2001; Hansen et al., 2002). Other pollutants also have direct and indirect effects with a wide range of impacts on human health, ecosystems, agriculture and materials. For example, nitric acid (HNO_3) is an important transformation product of NO_x and has the potential to cause adverse respiratory effects through both acidification and oxidation reactions (Aris et al., 1993; Koenig et al., 1994; Gauderman et al., 2002). Ammonia (NH_3) is the most abundant alkaline gas in the atmosphere and plays an important role in the nitrogen cycle in ecosystems, the neutralization of acids in the air, and the formation of fine particulate matter ($PM_{2.5}$) (Bouwman et al., 2002; Schiferl et al., 2014).

Although air pollution is recognized as an emerging public health problem, most developing nations do not have sufficient data to evaluate its impacts. However, gases and particles are widely measured, and their effects on health have been thoroughly studied in developed countries (EEA, 2012). Only a few studies have been conducted in developing countries, such as in West and Central Africa or South Africa over short periods (Arku et al., 2008; Linden et al., 2012; Lourens et al., 2012; Kirenga et al., 2015). Within the framework of the POLCA program ("POLlution des Capitales Africaines", pollution of African capitals), a preliminary study on urban air pollution in West and Central Africa was conducted from 23 February to 8 March 2004 during the dry season in eight African capitals. The preliminary results clearly indicate the high pollution levels in African capitals, with higher concentrations of NH_3 and NO_2 found in Sahelian capitals (e.g., Bamako, Ouagadougou, and Dakar) (Liousse and Galy-Lacaux, 2010).

To improve the characterization of African urban pollution, including gas and aerosol studies and their potential impacts on health, a program dedicated to urban pollution was required. Supported by the CORUS 2 program (Cooperation for Academic and Scientific Research), a second POLCA program for 3-yr was launched in 2007. The objectives were to characterize atmospheric pollution, including both gases and particles, in two West African capitals (Dakar, Senegal and Bamako, Mali) and to assess the impact of such pollution on human health, especially in terms of respiratory diseases. Results of particulate pollution and health related impacts in African urban capitals have been published in Liousse and Galy-Lacaux (2010), Doumbia et al. (2012) and Val et al. (2013).

The present paper focuses on gas measurements in the POLCA 2 program. It aims at quantifying ambient levels of gaseous pollution at traffic sites in Dakar and Bamako for 5 pollutants (NO_2, SO_2, NH_3, HNO_3 and O_3) from January 2008 to December 2009 and from June 2008 to December 2009, respectively. Daily, monthly, seasonal and annual concentration estimations as well as tentative spatial variability within each town are presented. Finally, gas concentration measurements performed in Dakar and Bamako are compared to other urban sites around the world.

2. Experimental design

2.1. Sampling sites

Two traffic sampling sites (for long-term measurement) were selected in African cities: Dakar (Senegal) and Bamako (Mali). These sites are under the influence of two major atmospheric airflows: hot and dry continental air from the Saharan desert (Harmattan) and cooler humid maritime air masses (Monsoon) originating from the equatorial Atlantic Ocean. The West African climate (and its variability) is largely a function of the position of the Intertropical Convergence Zone (ITCZ) at the confluence of these two airflows. Extreme latitudinal positions of the ITCZ are ~5°N in January against ~22°N in August. This pattern results in two contrasted climatic regimes (wet and dry seasons), with a marked year-to-year variability and modulation in durations and intensities of these seasons.

Dakar (14°40′20″ N, 17°25′22″ W, sea level), is a coastal city in West Senegal with a population of 3 million people (25% of the national total), and covers approximately 550 km^2. Dakar has a hot