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Intra-urban air pollution in a rapidly growing Sahelian city

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ABSTRACT

In this paper we analyze spatial and temporal variations of air pollution (PM_1, $PM_{2.5}$, PM_{10}, CO, NO_x, O_3, Toluene and Benzene) and climate in areas of different development typology in Ouagadougou, Burkina Faso. Analyses are based on measurements from fixed sites and car traverse measurements during field studies in 2007 and 2010. Large spatial and temporal variations were found, showing a generally poor air quality situation, with extreme levels of PM_{10}, commonly exceeding air quality guidelines of WHO. Pollution levels increase considerably with increased atmospheric stability. Important sources were transported dust and re-suspension of dust from unpaved roads, but also traffic emissions and biomass burning. The spatial variations are examined with focus on effects for variations in potential exposure depending on for example area of residence and daily activity pattern, showing that great differences are likely to exist. Ouagadougou, like most developing countries worldwide, currently experiences an extremely rapid population growth in combination with limited financial means. This is likely to create increasingly harmful air pollution situations for the rapidly growing populations of these areas, and shows an urgent need for increased understanding of the pollution situation as well as development of mitigation strategies.

1. Introduction

One of the major problems that generally follow rapid urbanization, especially in areas with limited financial means, is a deteriorating air quality situation. Air pollution has been connected to multiple adverse long-term as well as short term effects for human wellbeing such as increased hospital admissions and life years lost due to for example asthma, acute respiratory infections, heart disease, and lung cancer. However, the great majority of studies of health effects from air pollution exposure are focused on more developed regions, while the greatest health impacts from air pollution occur among the poorest and most vulnerable populations (Fullerton et al., 2008). 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). Poverty in combination with the extreme urbanization rates has created exceptionally poor air quality in Sub-Saharan Africa. Despite this, systematic measurement and monitoring of urban environmental health risks connected to air pollution in these areas has received very limited attention (Arku et al., 2008).

In this paper we analyze spatial and temporal variations of climate and air pollution in areas of different development typology in Ouagadougou, the capital of Burkina Faso. Empirical data of air pollution parameters (focus on carbon monoxide and particulate matter, but also NO_X, O_3, toluene and benzene) as well as meteorological parameters was collected during two field studies in 2007 and 2010. Detailed measurements of meteorology and air pollution were carried out at street side in the urban center, in a centrally located, paved and irrigated residential neighborhood, and in a suburban unpaved and dry, densely inhabited residential neighborhood, as well as at background sites in urban, suburban and rural locations. The aim of this study is to examine the spatial and temporal variations in air pollution, and to connect this to weather situation, traffic, land cover and land use. Sites were therefore chosen to represent areas with different type of land cover, land use and traffic density. Results are discussed in view of potential exposure situation for the inhabitants in the examined parts of the city. Results are also put in a regional and a global perspective in order to examine possible number of people who may reside in similar conditions. Lastly, effect of the expected rapid urban growth on future exposure situation for the inhabitants is discussed.

1.1. Urban air pollution and health effects

There are an abundance of studies focusing on urban air pollution and its effects on human health. The geographical coverage is however very uneven, lacking studies from cities in the developing world and especially from sub-Saharan Africa where urbanization rate is extreme. Urban air pollution is generally dominated by road-vehicle emissions (Sawyer, 2010) but studies in Sub Saharan Africa have pointed to the importance of other factors besides traffic, in particular biomass burning and mineral dust (Arku et al., 2008; Dionisio et al., 2010;

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Etyemezian et al., 2005). The estimated number of premature deaths caused by outdoor air pollution is 0.8 million per year (Cohen et al., 2005).

Air pollutants that commonly draw intense concerns regarding adverse health effects include for example particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NO_X, consisting of NO and NO_2), volatile organic compounds (VOCs, including for example Benzene and Toluene) and ozone (O_3). PM consist of a mixture of solid particles and liquid droplets from a variety of sources. The coarser fraction of PM, (e.g. TSP, PM_{10}), generally originates from mineral dust while the smaller fractions (e.g. $PM_{2.5}$, PM_1, UFP) have various sources, normally dominated by combustion. CO and NO are gasses formed during the incomplete combustion of carbon-containing fuels such as in traffic and biomass burning, while NO_2 is formed during more complete combustion conditions and VOC generally originates from vehicle exhausts or evaporation of liquid fuels, but also from solvents in paint and adhesives, and from biomass burning. O_3 is a secondary pollutant formed by photochemical reactions involving primarily NO_X but also VOC. Due to the many adverse health effects of these and other air pollutants, the World Health Organization has presented air quality guidelines for maximum exposure to selected air pollutants (WHO, 2006a).

Whereas great improvements in vehicle emission rates are under progress in the more developed world, rapid urban growth in less developed countries tend to generate a highly polluting traffic fleet with a large proportion of old, poorly maintained vehicles and a high numbers of two-stroke vehicles (Assamoi and Liousse, 2010; Baumbach et al., 1995; Gwilliam, 2003). A review by Han and Naeher (2006) shows that traffic related air pollution studies are relatively scarce and continuous monitoring of air pollution infrequent in development countries. They also show that ambient levels of air pollutants were poor predictors of personal exposures and that studies should focus on spatial variations through personal monitoring and source specific methods rather than ambient levels and total population.

Airborne particles of all sizes have adverse health effects, but the smaller particle size has more important health effects compared to coarser particle sizes (Franck et al., 2011). Effects of coarse particles, such as PM_{10}, are still of interest in a health perspective, as a clear connection is found between increased exposure to coarse particles and an increase in for example daily mortality (Brunekreef and Forsberg, 2005; Faustini et al., 2011; Mallone et al., 2011; Perez et al., 2008). However, Chang et al. (2011) stresses the difficulty of estimating human exposure to coarse particles for example due to an often very large spatial heterogeneity in concentrations.

The Sahara desert is the world's largest source of aeolian dust (Goudie and Middleton, 2001). Adverse health effects connected to increased concentrations of Saharan dust have been found in Spain (Perez et al., 2008) and in Italy (Mallone et al., 2011). However, a study of the long range transportation of dust show that West Africa is the region most affected by dust transported from the Saharan desert but least studied (De Longueville et al., 2010). The additional influence of re-suspension of road dust for levels of PM_{10} is discussed by Etyemezian et al. (2005) who suggest that most of the geological material found in PM_{10} was due to re-suspension of road dust connected to the prevalence of unpaved roads in Addis Ababa, Ethiopia. Unpaved roads were also found to be important for levels of PM in the African cities Ouagadougou, Dar es Salaam and Gaborone by Eliasson et al. (2009) and Accra by Arku et al. (2008) and Dionisio et al. (2010). Boman et al. (2009) found soil as major components also in particles with an aerodynamic diameter <2.5 mm ($PM_{2.5}$) in Ouagadougou, Burkina Faso, where daily concentrations constantly exceeded WHO guidelines for maximum 24 mean value, often between four and six times (WHO, 2006a).

It is well established that meteorological factors have an impact on concentrations of air pollution, causing increased pollutant concentrations during episodes of high atmospheric stability and low wind speeds due to restricted ventilation and dispersion (e.g. Oke, 1987; Pasquill, 1962). An increase in pollution concentrations during stable atmospheric conditions have been noticed in the African cities Dar es Salaam, Tanzania (Jonsson et al., 2004) and Ouagadougou, Burkina Faso (Boman et al., 2009). Due to the restricted ventilation and dispersion, stable atmospheric conditions also increase importance of urban-derived pollutants for urban air pollution levels (Arnfield, 2003; Graham et al., 2004; Papanastasiou and Melas, 2009).

1.2. Study area

The capital of Burkina Faso, Ouagadougou (12° 22′N, 1° 31′W, 300 masl), is located in the Sahel region of West Africa (Fig. 1). In an extensive report by UN habitat (2010), Ouagadougou was pointed out as the world's fastest growing city with an expected population growth of 81% over ten years — from 1.9 million in 2010 to 3.4 million in 2020. Burkina Faso is a poor country, showing the 9th lowest human development index in the world in the 2010 UN Human Development Report (HDR, 2010), thus lacking financial means to deal with this rapid urban growth. As a result the urban spatial change is mainly in the form of unplanned spontaneous settlements rapidly growing at the outskirts of the city. Buildings in these areas are simple, often made of clay with corrugated steel roofs, and prepared roads are basically non-existent. These areas are uncontrolled by the government and generally lack access to electricity, water, sanitation and infrastructure (De Jong et al., 2000). The urban structure in Ouagadougou (Fig. 1) in general is spread out and dominated by low buildings and sparse vegetation, with many dry, open areas spread out over the city. In the urban center, building materials are mainly modern, such as concrete or tiles, and most roads are paved. Near the urban center are modern residential, hotel and business grounds. These are generally surrounded by irrigated gardens, and most roads are paved. Planned residential and small scale commercial areas outside the urban center are generally un-irrigated and most roads unpaved.

One of the adverse health effects closely connected to air pollution is lower respiratory infections, which is the most important cause of death in Burkina Faso, amounting to 20% of all deaths (WHO, 2006b). The rapid urban growth in combination with limited financial means has also resulted in very poor air quality (Boman et al., 2009; Lindén et al., 2008). This is due to several factors. Bultynck (1999) shows that the vehicle fleet in Ouagadougou is old (average vehicle age: 14 years old) with a high percentage of highly polluting 2-stroke vehicles (approximately 75%). In addition, over 80% of the households in Ouagadougou use biomass as the main household fuel (Ouedraogo, 2004). Cleaner fuels, such as gas or electricity, are almost exclusively available to the inhabitants in the highest income bracket. Re-suspension of road dust from the many unpaved roads is suggested as another important source of air pollution (Boman et al., 2009; Eliasson et al., 2009). Though much of the air pollutants in Ouagadougou are urban-derived, more factors are involved. As the city is located in the hot semi-arid steppe climate of the Sahel, climate consists of a dry period from October to April and a wet period from May to September (DMN, 2001). Precipitation is during the wet period on average 700 mm, while the seven months of dry period generally receives less than 100 mm of rain.

During the dry season, the influence of dust transported with the Harmattan winds blowing in from the Sahara desert in the north and north-east affects the whole Sahelian region and creates strong seasonal differences with highest levels of airborne dust generally found in February and lowest levels generally found in August (Prasad, 2011; Shendell and Ana, 2011; Titcombe and Simcik, 2011). According to the meteorological office in Ouagadougou, visibility is generally reduced to nearly half in the dry season compared to the wet period (DMN, 2001).

Stable nocturnal atmospheric conditions are frequent in the early dry season in Ouagadougou (Lindén and Holmer, 2011), and pollution levels are significantly higher during high atmospheric stability