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BAD AIR QUALITY = BAD LIFE QUALITY – THE INFLUENCE OF TRANSPORTATION ON AIR QUALITY IN THE CITY OF NAIROBI

BOMAN, JOHAN, UNIVERSITY OF GOTHENBURG, DEPARTMENT OF CHEMISTRY AND MOLECULAR BIOLOGY, ATMOSPHERIC SCIENCE, SE-412 96 GOTHENBURG, SWEDEN JOHAN.BOMAN@CHEM.GU.SE

THYNELL, MARIE, UNIVERSITY OF GOTHENBURG, SCHOOL OF GLOBAL STUDIES, PEACE AND DEVELOPMENT RESEARCH, P.O. BOX 700, SE-405 30 GOTHENBURG, SWEDEN MARIE.THYNELL@GLOBALSTUDIES.GU.SE

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BOMAN, Johan, University of Gothenburg, Department of chemistry and molecular biology, Atmospheric science, SE-412 96 Gothenburg, Sweden.
Johan.boman@chem.gu.se

THYNELL, Marie, University of Gothenburg, School of Global Studies, Peace and development research, P.O. Box 700, SE-405 30 Gothenburg, Sweden.
marie.thynell@globalstudies.gu.se

ABSTRACT

The rapid urbanization in the sub-Saharan countries is generating critical levels of air pollution, which are impeding healthy and fruitful urban development. Traffic is a major contributor to many of the problems in the growing cities. With a few exceptions, air quality guidelines and knowledge of current emissions are lacking in sub-Saharan Africa (SSA) countries and cities. The Eastern Africa Regional Framework Agreement on Air Pollution describes and enacts criteria and actionable targets for addressing air pollution problems. This study will focus on Nairobi, Kenya, to derive relationships between air pollution, building density and road networks to make informed decisions regarding planning and policies to be used in cities in SSA. Information about socio-economic realities will add to the understanding of what steps can be taken to improve conditions from being vicious to become virtuous in cities for the various socio-economic groups.

Keywords: Urban air pollution, $PM_{2.5}$, Nairobi, Urban Africa, Policy, Socio-economics, Informal growth, Transportation, Land use.

INTRODUCTION

In 1943 severe smog episodes were recognized for the first time in Los Angeles. In 1952 more than 4000 deaths were attributed to the “killer fog” of London. Thanks to legislation, monitoring, city planning, technical and social development the air quality is now considerably better in Western cities. Sub-Saharan countries are undergoing rapid urbanization but the lack of air pollution mitigation is one obstacle that impedes healthy and fruitful urban development in the region (Nweke, Sanders, 2009). Current development in the Nairobi urban area illustrates the side-effects that transportation activities have on a growing number of citizens. The degrading air quality is the result of increased anthropogenic activities, including traffic, industry and power production. For the urban population, polluted emissions have become a major health risk factor and contribute globally to over 800 000 premature deaths each year (Kinney et al., 2011). A majority of these deaths occur in developing countries, where emission regulations and air quality guidelines as well as knowledge about current emissions are lacking. The SSA countries and the city of Nairobi are no exception, where there are several policies aimed at regulating the deteriorating conditions. The Eastern Africa Regional Framework Agreement on Air Pollution was enacted to detail and manage criteria and actionable targets regarding air pollution problems. The African Development Bank, AfDB, and the Nairobi Metropolitan Area have also issued guidelines aiming at improving air quality.

This study aims at estimating relationships between air pollution, road networks, land use planning, and economic activities, in order to assist informed planning and policy decision making in Nairobi. Particular attention is paid to the need for improving the scientific basis of assessing the risks associated with polluting emissions, partly due to the lack of air quality measurements and surveys about social and economic activities on, as well as, close to congested roads.

BACKGROUND

Problem

Air pollution in the form of ambient aerosol particles is still considered to be one of the major air quality problems in most urban areas of the world. However, studies focusing on road users and residential areas nearby congested roads are lacking. The particulate air pollution in the centre of Nairobi is 550% higher than the US 24hours standards for particles smaller than 2.5 micrometers ($PM_{2,5}$) (Sclar, Touber, 2007). To find an association between health effects and particles is a challenge since particles vary in both size and composition. This is still the case despite centuries of studies focusing on links between air quality and mortality (Pope et al, 2002; Pope, Dockery, 2006; Krewski, 2009; Heal et al., 2012).

Nairobi, the capital city of Kenya has been selected for this study because Kenya remains one of the least urbanized countries in the world (lowest 10%). In Nairobi, a number of interrelated problems are challenging future city development, including slum expansion, ethnic segregation, decaying infrastructure services, public health hazards, bad air quality and environmental degradation (Ministry of Nairobi Metropolitan Development, 2008; McCormack and Schüz, 2012). Most of the African countries lack legal air quality regulations to abate the pollution problem (van Vliet, Kinney, 2007; NEMA, 2008). To set proper guidelines more research in situ is required. The vision of the Ministry of Nairobi Metropolitan Development (2008) is "*To be a World Class African metropolis".* And the mission is to manage the Nairobi Metropolis by "*providing sustainable infrastructural services and high quality of life to all its residents, visitors and investors".* Kenya is one of the top-thirty countries experiencing a high urbanization rate without having developed capacities to follow and handle such rapid growth. The population of Nairobi is already exposed to high air pollution levels, and the rapidly increasing population, unstable supply and demand of transportation, and increasing economic activities, may give rise to catastrophic consequences on the quality of life in the city, Figure 1. According to UNEP (2013) 90 % of urban air pollution in rapidly growing developing cities comes from motor vehicles, but also the production of goods, ways of heating houses, and dusty roads. Nairobi as well as other cities suffers from lack of suitable interventions and regulations. For instance, the average travel time to work in Nairobi is 57 minutes, versus 25.5 minutes in the US and 46% of accident fatalities are pedestrians, whereas in the US the equivalent number is 12% (Sclar, Touber, 2007). In Nairobi walking is the main mean of mobility of low-income families and the socio-economic and environmental challenges in the city are related to the degradation of the physical and living environment.

Air pollution can be attributed to not only particulate matter, but also to gaseous pollutants. In countries where air quality has been monitored for long times, a set of criteria pollutants are monitored on a regular basis, Table I. These pollutants have a long record of influencing health and some also effect vegetation and built structures.


Figure 1. A road side market in Nairobi, where both the traders and their customers are exposed to air pollution from the traffic.

Table I – Set of criteria pollutants, exemplified by EU legislation.

Pollutant	Averaging period	EQS* (µg/m^3)
Nitrogen dioxide	Year	40
Oxides of nitrogen	Year	40
Sulphur dioxide	24 hours	125
Carbon monoxide	8 hour mean	10 000
Ozone	8 hour mean	120
Benzene	Year	5
Particulate matter (PM_{10})	Year	40
Particulate matter ($PM_{2.5}$)	Year	25
Lead (in particles)	Year	0.5

- EQS: Environmental Quality Standard limit concentration

Criteria pollutants have complex relationships with each other; ozone for example is a secondary pollutant that is formed through photochemical reactions of other gaseous precursors. Over the past decades there has also been a shift in focus related to the particulate pollution, from Total Suspended Particulate matter (TSP) over inhalable particles (PM_{10}) to respirable ($PM_{2.5}$) and ultra-fine particles (UFP). The shift comes from development of measurement techniques in combination with epidemiological and toxicity studies where the smaller (UFP) particles have been seen as causing more harm than the larger particle fractions (Heal et al., 2012). With the exception of ozone the other pollutants in Table I can be directly related to transportation, primarily from road based vehicles.

The risk for morbidity and mortality has been shown to increase with exposure to respirable particles and is predominantly linked to respiratory and cardiovascular issues (WHO, 2006). Despite little evidence suggesting a threshold below which there are no anticipated adverse health effects, WHO issued air quality guidelines for $PM_{2.5}$ in 2005. In US and Western Europe 3-5 µg/m^3 for $PM_{2.5}$ is estimated to be the background concentration, just lower than values for which adverse health effects have been demonstrated (WHO, 2006). Only a few estimates have been made in the SSA countries. Kinney et al. (2011) reported a rural background $PM_{2.5}$ mass concentration of 10.7 µg/m^3 at Kenyatta University, outside Nairobi. At a roof level urban background site at the University of Nairobi an average $PM_{2.5}$ mass concentration of 34.9 µg/m^3 was reported. In the dry climate region of Burkina Faso, Boman et al. (2009) found $PM_{2.5}$ mass concentrations of 27 – 164 µg/m^3. Particulate matter is a serious problem in Nairobi and in many other African cities considering that an increase of $PM_{2.5}$ by 10 µg/m^3 increases the mortality by 2.8 – 4.8 % (Krewski, 2009) and the knowledge required for regulating specific sources is still insufficient (Grahame, Schlesinger, 2007). These higher concentrations indicate a higher exposure and consequently a higher risk of health effects.

Due to rapid urbanization in Africa and in particular in the metropolitan area of Nairobi the air quality will deteriorate quickly. Nairobi is a dynamic growth engine and accounts for more than 30% of national GDP in Kenya. However, as a result of rapid urbanization coupled with dramatic increases in motorization and the need for transportation of people and goods the road network in Nairobi has become overloaded with long traffic delays that increase the health hazards for all road users. One US study (Zhang, Batterman, 2013) estimated that a 30 minute daily delay in traffic due to congestion results in an increase of $PM_{2.5}$ exposure of 14 ± 8% for a typical working adult on weekdays. Transferred to the conditions in Nairobi the increase in exposure due to congestion on most roads is considerable. The 16 km trip between the city centre and the Kenyatta International airport for example normally takes two to three hours despite a multi-lane high standard road.

This scenario is complicated by the fact that 50 – 70% of the city's inhabitants are estimated to live in informal settlements often close to important transport corridors. A number of inter-related problems, expansion of unstable and informal working conditions, undernourishment, and environmental degradation are general public health hazards and are challenging future city development. Identification of pollution sources, health effects, and long-term implications of the pollutants for different socio-economic groups is required to develop plans to alleviate the problems of bad air quality (McCormack, Schüz, 2012).

A first step is to derive relationships between air pollution, building density, road networks and municipal planning to provide required information for stakeholders. A higher mortality and hospitalization rate due to deterioration of air quality will hamper the socio-economic development of SSA. Currently there are no legal air quality regulations implemented in most African countries to abate the pollution problem (Kinney et al., 2011). To set proper guidelines more on-the-ground research is needed to investigate the consequences of current levels of air pollution that are threatening future development in rapidly growing cities and countries (Bell et al., 2005; Nweke, Sanders, 2009).

Focus

The general lack of knowledge concerning the amount and content of the polluting emissions and its subsequent impact on the road users has generated a need to explore the complexity involved. From the social science point of view information about the economic activities, land use planning (including transport and urban planning) and the growing informal sector forms a framework that makes it possible to study the influence of emissions on selected groups of road users and persons involved in activities close to the roads. The knowledge of chemical and physical behaviour, sources and transport properties of air pollutants is of great importance in understanding and modelling the pollutants' influence on local environment and health. Several studies have recognised the lack of integrated urban planning and the slow capacity building to handle the problems associated with these urban challenges in SSA cities like Nairobi (McCormack, Schüz, 2012; Dimitriou, Gakenheimer, 2011; Gulis et al., 2004; Wothaya, 2012; Gulyani et al., 2010).

One of the main obstacles for policy makers is identified as lack of local measurement data of key air pollutants in the region thus making assessment of air pollution situation inaccurate (Rockström et al., 2009). Much more knowledge of the local conditions and socio-economic activities based on regular proficient measurements is thus crucial in developing further knowledge. The measurements reported in Kenya so far constitute a valuable set of background data although they are mainly short time measurements of a limited number of pollutants (Gatari et al., 2009; Gatari, Boman, 2003; Gatari et al., 2005; Kinney et al., 2011). These measurements have not been related to the health of road users or residential citizens that dwell and work close to the roads. A review article on the particulate pollution variations measured continuously in Nairobi over three years with generalization of the results for SSA urban areas is currently in manuscript by Prof Boman and co-workers, Figure 2. A continuation of previous measurement campaigns is necessary for a better understanding of the impact on road users and persons in the vicinity of heavily trafficked roads in Nairobi and in a longer time span also for other urban areas in the SSA region.

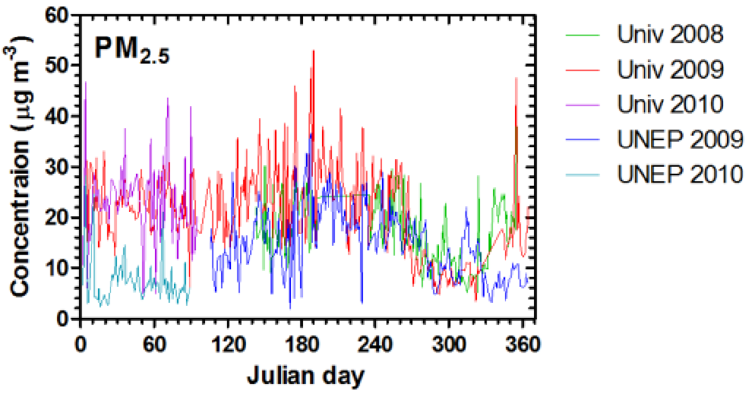

Figure 2. Seasonal variation of $PM_{2.5}$ particle concentrations in Nairobi. Source: Manuscript in preparation.

In our work not only the $PM_{2.5}$ mass is determined, but also their trace element and black carbon content. Previous studies show that the concentrations of these pollutants in Nairobi are high (Gatari, Boman, 2003), especially on street level (Kinney et al., 2011). The many poorly maintained vehicles and a city infrastructure unable to cope with the increased vehicle load is a major source of air pollutants, both particulate and gaseous (Kumar, Barrett, 2008). Regional climatic conditions also play an important role and their influence can only be understood if measurements are carried out for a longer period of time, combined with a local dispersion model.

Emerging issues

This paper mainly gives the background to a study being the first one in a forthcoming series of studies on determining the relationships between the urban air pollution situation, supply of transportation, land use and road network to make informed decisions on planning and policies within cities in the sub-Saharan Africa region. The questions we want to answer are as follows:

1. What are the relative contributions of different sources (natural and anthropogenic) to air pollution levels on busy transport corridors in Nairobi? And in particular the Outer Ring Road where 480-600 motorized vehicles passes at peak hour (AfDB, 2012) and the Juja Road.

2. Which are the likely effects of the polluting concentrations and the on-going economic activities (mainly informal) along some of the heavily trafficked roads on the health of low-income persons?

3. Based on previous and current measurements and high spatial resolution modelling, what recommendations can be given to improve the conditions of the effected persons?

DATA AND METHODOLOGY

For this study $PM_{2.5}$ samples were collected at two sites in Nairobi from January to April 2010. A central site was located at the main campus of University of Nairobi close to the city centre while a second site was located five kilometres north of the University, in the compounds of UNEP. Six samples per week were collected (one per weekdays and one per weekend). The elemental composition of the particles was determined by energy dispersive x-ray fluorescence (EDXRF). EDXRF is a non-destructive analysis technique well suited for analysis of aerosol samples since no sample preparation is needed and all elements in the sample with concentrations above the detection limit are quantified without any prior knowledge of sample composition (Gatari et al., 2009). To investigate the potential air pollution sources of Nairobi city, source apportionment and back trajectory analysis are used to determine the source type and indicate the air parcel pathway and transport.

The social science methods to be applied include making interviews with road users and persons working nearby the roads in two different socio-economic groups. Interviews will also be conducted with stakeholders such as officials at the Ministry of Transport, Kenya, the city council of Nairobi, owners of Matatu businesses, Kenya Bus Services and other relevant international organisations. Earlier policies and ways to mitigate the problems will also be scrutinized. Questionnaires will be distributed to 300 exposed persons and handled by means of statistical programs prior to the final analysis.

RESULTS AND DISCUSSION

The results of measurements of particulate pollution show a significant difference between street level concentrations and urban background concentrations. The concentrations of $PM_{2.5}$ are in most cases lower in sub-urban areas, showing the influence of the slowly moving traffic in city centres such as Nairobi. In this study the average 24 hour $PM_{2.5}$ background concentration in the city centre site was 22 µg/m^3 while it was 7.3 µg/m^3 at the UNEP, sub-urban, site. These concentrations are relatively low compared to the guideline value of 25 µg/m^3 set by the World Health Organisation (WHO, 2006) as a 24 hour average. Some differences are attributed to air mass movements, while local conditions like weekly traffic patterns also influence the results. Figure 3 shows the weekly pattern of particulate air pollution, $PM_{2.5}$, in the city center of Nairobi during the measurement weeks in 2010.

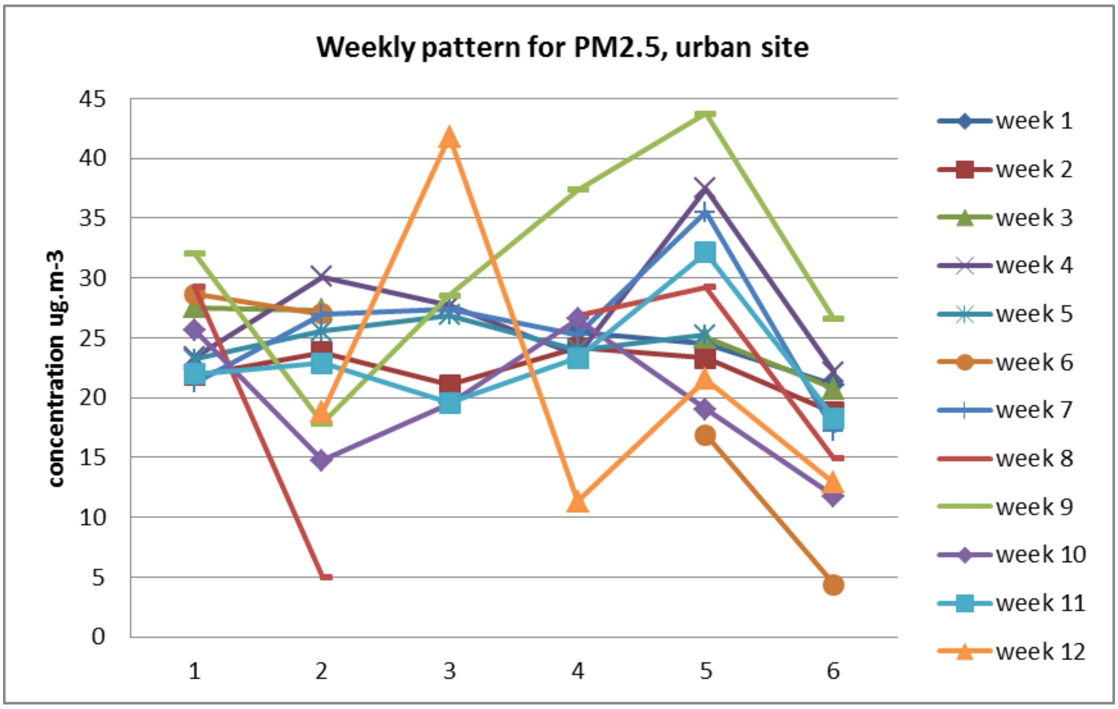

Figure 3 – Weekly pattern of particulate air pollution, $PM_{2.5}$, in the centre of Nairobi, Kenya. 1-6 are the weekday with Monday as 1. During weekends only one sample was collected, enumerated 6.

Not all weeks contains a complete set of data. The figure clearly shows the traffic increase, and associated congestion and slow traffic, on Fridays when many of the city dwellers leave the city for the weekend. During the weekend the particulate concentration is lower than the workdays, indicating a lower city activity. This is a pattern that can be subjectively appreciated when living in Nairobi and can probably be similar in many other cities in the region. A similar pattern is seen for the concentrations of the 13 elements quantified in the particles although there are differences that can be ascribed to different sources.

Therefore information about conditions of two different socio-economic groups will add to the understanding of what steps can be taken to improve air quality for people involved in informal activities in cities.

CONCLUSIONS/IMPLICATIONS

The research illustrates how air pollution measurement data can be used as a framework to link several international policy agendas that focus on air pollution such as the UN Commission on Sustainable Development (UNCSD14/15) and the Millennium Development Goals (MDG's). This project aims at developing recommendations for local administrations and a teaching agenda to assist African cities. Based on the research findings further data conceptualisation, monitoring, capacity building and more studies will be developed to assist the various kinds of stakeholder involved in the complex development in emerging urban Africa. To abate the harmful air pollution problems in the SSA region several international policy agendas in support of green growth, low carbon transport, social equity, poverty reduction and an inclusive city planning. Slowly some capacity to handle the difficulties is emerging at the AfDB, JICA and in international consultancy companies. Due to lack of measurement data from African cities and Nairobi in particular attention should be paid to increase the scientific basis for addressing the risks both in social sciences and science. This work financed by Swedish funding also fits well into the environmental and climate policy of the Swedish government for the period 2011-2014 (UF2010/39205/UP). Furthermore, the research findings will be discussed with the various actors and stakeholders in Nairobi and recommendations will be elaborated in collaboration with The University of Nairobi (Institute of Development Studies, Department of Urban and Regional Planning), The Kenya Institute for Public Policy Research and Analysis, KIPPRA, The African Development Bank Department of Infrastructure, Japan International Cooperation Agency Kenya Office (JICA) and The Ministry of Higher Education, Science and Technology because all of them have shown a huge interest in progressing in this highly important area of research.

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