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Traffic impacts on $PM_{2.5}$ air quality in Nairobi, Kenya

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ABSTRACT

Motor vehicle traffic is an important source of particulate pollution in cities of the developing world, where rapid growth, coupled with a lack of effective transport and land use planning, may result in harmful levels of fine particles ($PM_{2.5}$) in the air. However, a lack of air monitoring data hinders health impact assessments and the development of transportation and land use policies that could reduce health burdens due to outdoor air pollution. To address this important need, a study of traffic-related $PM_{2.5}$ was carried out in the city of Nairobi, Kenya, a model city for sub-Saharan Africa, in July 2009. Sampling was carried out using portable filter-based air samplers carried in backpacks by technicians on weekdays over two weeks at several sites in and around Nairobi ranging from high-traffic roadways to rural background. Mean daytime concentrations of $PM_{2.5}$ ranged from 10.7 at the rural background site to 98.1 $\mu g/m^3$ on a sidewalk in the central business district. Horizontal dispersion measurements demonstrated a decrease in $PM_{2.5}$ concentration from 128.7 to 18.7 $\mu g/m^3$ over 100 m downwind of a major intersection in Nairobi. A vertical dispersion experiment revealed a decrease from 119.5 $\mu g/m^3$ at street level to 42.8 $\mu g/m^3$ on a third-floor rooftop in the central business district. Though not directly comparable to air quality guidelines, which are based on 24-h or annual averages, the urban concentrations we observed raise concern with regard to public health and related policy. Taken together with survey data on commuting patterns within Nairobi, these results suggest that many Nairobi residents are exposed on a regular basis to elevated concentrations of fine particle air pollution, with potentially serious long-term implications for health.

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1. Introduction

Motor vehicle traffic is an important source of harmful emissions of particulate pollution in cities of the developing world, where economic growth, coupled with a lack of effective transport and land use planning is resulting in increasing vehicle ownership and traffic congestion. These factors combine to create air pollution hotspots near roads. Urban growth is expected to continue at a rapid pace in the developing world, particularly in sub-Saharan Africa (UN, 2010) as rural populations continue to migrate to cities in search of employment and expectations of better living conditions. If nothing is done to reduce emissions and to better plan for urbanization, this trend can be expected to further exacerbate already serious air quality problems in sub-Saharan African cities as well as the health impacts that accompany them. Fine particulate matter ($PM_{2.5}$), generated by fuel combustion (e.g., in motor vehicles) has been linked to a wide range of health effects, including more than 800,000 deaths in cities around the world (Cohen et al., 2004; Pope and Dockery, 2006). However, little information exists on levels of particulate air pollutants currently experienced by urban residents in Africa (Gatari et al., 2005; Maina et al., 2006; van Vliet and Kinney, 2007). This data gap hinders health impact assessments, the development of cost-effective strategies to reduce the health burden due to outdoor air pollution and the ability to influence urban transportation and planning policies in relation to air quality and health.

Nairobi, Kenya is in many ways typical of the fast growing cities of sub-Saharan Africa. Central Nairobi had a resident population of 3.2 million in 2009 with a daytime population of 4.2 million (Kenya National Bureau of Statistics (KNBS) 2008, in Ministry of Transport, 2010). The resident population is up from about 1.3 million in 1989 (East African Statistical Department, in Obudho, 1997) representing a 3.9% annual growth. Similarly, the overall proportion of urban dwellers in Kenya has increased from 8% in the 1980s to over 34% in 2003 and is expected to reach 50% by 2020 (KNBS, 2008 in Ministry of Transport, 2010). The larger Nairobi metropolitan area had a population of 6.1 million in 2007, which is projected to rise to over 12 million by 2030 (Ministry of Nairobi Metropolitan Development, 2008). Much of this growth is occurring in the peri-urban regions, which are absorbing spillovers from the central city where scarce rental housing is increasingly unaffordable to average citizens. This growth, combined with a lack of investment in public transport and urban road infrastructure has resulted in increasing road deterioration, numbers of motor vehicles and congestion (Ministry of Transport and Communications, 2004). Spatially, the growth is taking the shape of urban sprawl which, along with growing urban air pollution exacerbates a number of other health risks, such as diabetes (see for example, Frumkin et al., 2004). Commercial and industrial activities remain concentrated in a central area where traffic congestion has become the norm. In an attempt to alleviate congestion, large-scale road infrastructure projects are currently underway in and around Nairobi and others are being planned. Considerations for long-term improvements in air quality and health must be taken into account as these projects are planned and implemented. Thus, the results of this study come at a crucial time.

It has been estimated that 90% of urban air pollution in rapidly growing cities in developing countries is attributable to motor vehicle emissions (UNEP, 2010) so while there are many sources of air pollution in Nairobi, including open air burning of refuse and biomass (Gatari, 2006), industrial operations and domestic cooking fires, motor vehicles play a critical role in the problem. Increasing road congestion, along with a high prevalence of old, poorly-maintained vehicles and low quality fuels, contribute to this problem. One projection estimates that in a "do nothing" (or business as usual) scenario, the number of vehicle trips between 2004 and 2025 in the Nairobi Metropolitan Area will increase by 148% and that the average speed of trips will decrease from 35 km/h to 11 km/h as congestion increases (Japanese International Cooperation Agency, 2006) which makes it reasonable to assume that if nothing is done, urban air quality will worsen. The mixture of vehicles in 2004 was 29% passenger cars, 35% light-duty trucks, 7% heavy-duty trucks, 7% minibuses (Matatus), and 22% others (KNBS, 2007). Between 2002 and 2006, the number of trucks increased by about 60% (KNBS, 2007), reflecting increased activities in the agricultural and industrial sectors. Most trucks and buses rely on high sulfur diesel fuel ($\leq$5000 ppm S) which leads to high particulate emissions. A large proportion of newly-registered vehicles in Nairobi are imported as used vehicles from East Asia.

There are important health implications of roadway emissions, particularly for highly exposed individuals near roadways and/or for population subgroups that are particularly sensitive to health effects, such as children and the elderly (Pope et al., 2002; Jansen et al., 2005; Ibald-Mulli et al., 2004). Of great concern are the large concentrations of pedestrians who walk along busy Nairobi roads. Aligula et al. (2005) reported that 49% of daily trips in Nairobi were either on foot or bicycle. However, bicycle use was limited by safety concerns (especially over lack of bicycle lanes) (Khayesi et al., 2010). Another 42% of trips used minibuses or other forms of public transport, while 9% were made in private vehicles. Another significant concern involves populations such as street vendors and traffic police, who spend their days along and on congested roadsides and roads.

Motor vehicle emissions include a range of pollutants, including particulate matter (PM), carbon monoxide, sulfur oxides, nitrogen oxides and a wide range of volatile organic compounds, which react with sunlight to form ozone. Many of these pollutants have well-known health effects which may be exhibited with short term exposure, including wheezing, coughing, shortness of breath, phlegm and sore throats as well as irritation of existing respiratory conditions such as asthma (Hedley et al., 2003; Frumkin et al., 2004; Schwela et al., 2006). However, $PM_{2.5}$ is of particular significance because research on health effects in urban areas has demonstrated associations between both short-term and long-term average ambient $PM_{2.5}$ concentrations and a variety of adverse health outcomes. These include increased post neonatal infant mortality (Woodruff et al., 2006) and premature deaths related to heart and lung diseases (e.g., Dockery et al., 1993; Schwartz, 1994; Samet et al., 2000; Pope et al., 2002). $PM_{2.5}$ is a complex mixture of solid or liquid organic and inorganic particles that