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Occupational exposure to roadway emissions and inside informal settlements in sub-Saharan Africa: A pilot study in Nairobi, Kenya

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HIGHLIGHTS

- Few studies examine urban air pollution in sub-Saharan Africa.
- We measure occupational exposure levels along roadsides and in informal settlements.
- We measure $PM_{2.5}$, black carbon (BC) and 15 trace elements in Nairobi, Kenya.
- Black carbon and dust are important contributors to $PM_{2.5}$.
- Results suggest major health benefits from air quality regulations in Kenya.

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ABSTRACT

Few studies examine urban air pollution in sub-Saharan Africa (SSA), yet urbanization rates there are among the highest in the world. In this study, we measured 8-hr average occupational exposure levels of fine particulate matter ($PM_{2.5}$), black carbon (BC), ultra violet active-particulate matter (UV-PM), and trace elements for individuals who worked along roadways in Nairobi, specifically bus drivers, garage workers, street vendors, and women who worked inside informal settlements. We found BC and re-suspended dust were important contributors to $PM_{2.5}$ levels for all study populations, particularly among bus drivers, while $PM_{2.5}$ exposure levels for garage workers, street vendors, and informal settlement residents were not statistically different from each other. We also found a strong signal for biomass emissions and trash burning, which is common in Nairobi's low-income areas and open-air garages. These results suggest that the large portion of urban residents in SSA who walk along roadways would benefit from air quality regulations targeting roadway emissions from diesel vehicles, dust, and trash burning. This is the first study to measure occupational exposure to urban air pollution in SSA and results imply that roadway emissions are a serious public health concern.

1. Introduction

Urbanization rates in Africa are among the highest in the world, where more than half the population is expected to reside in urban areas by 2035 (United Nations (UN) 2010). Recently, studies have addressed the public health issues associated with this rapid urban growth, including poor sanitation and an under-provision of medical goods or services. However, an understudied topic in this field is urban air pollution. The UN estimates roadways are responsible for up to 90% of urban air pollution in developing countries (UN Environment Programme (UNEP) 2011). Reasons for this include the importation of older vehicles, poor maintenance of vehicles, use of dirtier fuels, poor enforcement of air quality regulations (if any are in place), and neglected infrastructure unable to

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support the rapid increase in the vehicle fleet. Roadway emissions may adversely affect the health of residents in sub-Saharan Africa (SSA) who walk along the roadside, use public transportation, or drive a vehicle, and the small literature that exists suggests it is an urgent, growing issue (Gaita et al., 2014; Jonsson et al., 2004; Boman et al. 2009; Eliasson et al., 2009; Gatari et al., 2008; Gatari and Boman, 2003; Van Vliet and Kinney, 2007; Kinney et al., 2011; Odhiambo et al., 2010; Jackson, 2005; Dionisio et al., 2010).

Of particular concern are individuals who spend their workdays outside by the roadway since previous work has found these populations to be more susceptible to respiratory disease or lung cancer (Lewne et al., 2007). Air pollution in informal settlements in SSA is also a major concern, where acute respiratory tract infections and bronchitis are among the most frequent diagnoses (Gulis et al., 2004). Given the lack of data on this topic, in this pilot study, we measured occupational exposure levels for individuals who work by roadways in Nairobi, the capital and most populated city in Kenya, with a population of 3.1 million people and growing at annual rate of 4% (Kenya National Bureau of Statistics (KNBS) 2008). Currently, no air quality regulations are implemented in Kenya, nor is any long-term air quality monitoring occurring, making it difficult to ascertain how serious a problem urban air pollution is.

We measured occupational exposure levels to particulate matter with an aerodynamic diameter <2.5 μm ($PM_{2.5}$), black carbon (BC), ultra violet active-particulate matter (UV-PM), and trace elements in Nairobi for individuals who worked by roadways or inside informal settlements. UV-PM is component of $PM_{2.5}$ that captures yellow-brown colored components of PM sources such as biomass emissions or second-hand smoke (SHS) (Andreae and Gelencser, 2006; Yan et al., 2011). Additionally, few studies have examined air pollution in informal settlements, where 1/3 of residents in Nairobi live and work, yet residents in these areas experience high exposure levels from the open burning of waste, traffic, cook stoves, and dust (Gulis et al., 2004; Dionisio et al., 2010; Arku et al., 2008; Salon and Gulyani, 2010; Muindi et al., 2014). While measuring occupational exposure is not unusual, to the authors' knowledge, this is the first study to measure occupational exposure levels in SSA.

1.1. Background

Respiratory disease, an illness associated with poor air quality, is the second leading cause of morbidity in Kenya and though issues of indoor air pollution in rural areas of SSA have been explored, there is less work examining the effects of urban air pollution on the burden of disease (World Health Organization (WHO) 2009; Dherani et al., 2008). Kenya provides an interesting setting for this study because it is a country experiencing rapid urban growth. In 2009, 8.9 million or 20% of Kenya's population resided in urban areas (KNBS, 2009) and by 2020 it is estimated that 50% of the population will live in urban areas (KNBS, 2008). This rapid growth is being met with increased demand for vehicles. Between 1992 and 2001, the number of vehicles in Kenya increased by 46%, wherein 2004 about 18% of vehicles used diesel fuel, and it is expected 30,000 vehicles will be added each year (UNEP, 2006).

Currently, Kenya has draft air quality regulations that were last updated in 2008, but it is unclear when these regulations will be implemented. Although, in the past couple decades, the Kenyan government has made some progress in placing more restrictions on fuel emission standards. For example, in 2006, Kenya started to phase out the use of leaded gasoline, and in 2010, required that imports and exports of diesel fuel be low sulfur diesel (National Environmental Management Authority (NEMA) and Motor Vehicle Inspection Unit (MVIU) 2009). However, many challenges remain. Currently, the inspection of vehicles for safety and performance is conducted through the Motor Vehicle Inspection Unit (MVIU) and the Ministry of Transport (NEMA, 2011). But there are only 17 MVIU centers, making it impossible to inspect exhaust emissions for the 1.4 million vehicles in Kenya. Consequently, understanding the potential health impacts of roadway emissions is critical to informing future urban and transportation policies and air quality regulations.

2. Materials and methods

2.1. Research location and participants

Despite Nairobi's proximity to the equator (1.32° S and 36.9° E), it experiences mild seasonal variation due to its high altitude (approximately 1.6 km) (Gatari and Boman, 2003). Nairobi has two rainy seasons from March to May and October to December, so to avoid the rainy season, this pilot study took place for 3 weeks between August 2 and 18, 2011. We obtained ethical approval to conduct this study through Columbia University's Institutional Review Board and approval of research from Kenya's Ministry of Education, Science, and Technology.

To observe variation in exposure levels of $PM_{2.5}$ across and within occupations, we recruited 3 individuals from 4 occupations (i.e., 12 participants). These occupational groups were street vendors, bus drivers, mechanics, and women who lived and worked in or near Mathare, one of the oldest informal settlements in Nairobi. Each participant carried the pump for 3 days throughout the week for 8 h each day ($N = 12$ participants * 3 days = 36), and each week, another set of participants from each study population would carry the pump. Four of the participants were women and the rest were male. In week 1, participants carried pumps from 8:30am to 5:30pm, then in weeks 2 and 3 between 7:30am and 4:30pm on Tuesday, Wednesday, and Thursday. The reason for moving the sampling an hour earlier during weeks 2 and 3 was due to heavy traffic, making it difficult to access some of the participants after 8:00 am. The morning rush hour starts at 6:30am and ends at 9:30am, and evening rush hour is from 4pm to 6pm. We recruited individuals who worked in the eastern (week 1), southern (week 2), and western (week 3) parts of Nairobi (Figure S1). The western part of Nairobi is characterized as suburban and affluent, while the eastern part of Nairobi is characterized as working class and is where most of the informal settlements are located, so pollution emissions may differ by site (Odhubo 1997). We did not take measurements in the Central Business District (CBD), except for bus drivers who started their route there, due to heavy construction in the area.

Next, we briefly describe the study populations. Mechanics in Nairobi mostly work in garages near roadways, but it is not unusual for mechanics to be called to the street to fix vehicles. During week 3, the mechanic was on strike at his shop the first day, so he worked on the street for that day only. Street vendors sell goods while walking along the roads or between street lanes in different areas of Nairobi, typically by busy roadways or roundabouts. Bus drivers operate two types of diesel vehicles in Nairobi, 40-passenger buses or 14-passenger minibuses, and both are inexpensive forms of public transportation relative to taxis or motorbikes. Private bus companies own and operate the larger buses, while individuals own the 14-passenger vehicles. We measured exposure levels for 40-passenger bus drivers only since they were more consistent in routes and hours. We also recruited three women from Kosovo, a village in Mathare, who worked in or near Mathare.

2.2. Sample collection

Fine particle concentrations were collected on pre-weighed