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Measuring exposure levels of inhalable airborne particles ($PM_{2.5}$) in two socially deprived areas of Nairobi, Kenya

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ABSTRACT

Introduction: Ambient air pollution is a growing global health concern tightly connected to the rapid global urbanization. Health impacts from outdoor air pollution exposure amounts to high burdens of deaths and disease worldwide. However, the lack of systematic collection of air pollution and health data in many low-and middle-income countries remains a challenge for epidemiological studies in the local environment. This study aimed to provide a description of the particulate matter ($PM_{2.5}$) concentration in the poorest urban residential areas of Nairobi, Kenya.
Methods: Real-time measurements of ($PM_{2.5}$) were conducted in two urban informal settlements of Nairobi City, Kenya"s Capital, from February 2013 to October 2013. The measurements were conducted using *DustTrak II 8532* hand-held samplers at a height of about 1.5 m above ground level with a resolution of 1-min logging. Sampling took place from early morning to evenings according to a fixed route of measurement within areas including fixed geographical checkpoints.
Results: The study period average concentration of $PM_{2.5}$ was 166 $\mu g/m^3$ in the Korogocho area and 67 $\mu g/m^3$ in the Viwandani area. The $PM_{2.5}$ levels in both areas reached bimodal daily peaks in the morning and evening. The average peak value of morning concentration in Korogocho was 214 $\mu g/m^3$, and 164 $\mu g/m^3$ in the evening and in Viwandani was 76 $\mu g/m^3$ and 82 $\mu g/m^3$ respectively. The daily mid-day average low observed during was 146 $\mu g/m^3$ in Korogocho and 59 $\mu g/m^3$ in Viwandani.
Conclusion: The results show that residents in both slums are continuously exposed to $PM_{2.5}$ levels exceeding hazardous levels according to World Health Organization guidelines. The study showed a marked disparity between the two slum areas situated only 7 km apart indicating the local situation and sources to be very important for exposure to $PM_{2.5}$.

1. Introduction

The proportion of urban habituating population has grown rapidly in sub-Saharan Africa (SSA) compared to other regions of the world (United Nations Department of Economic and Social Affairs, 2007). This growth has been largely characterized by the development of informal settlements (slums) which are home to more than half of the urban population (UN-HABITAT, 2006; UN-DESA, 2010) in the region. Consequently, the urban environment becomes a public health concern as more people live in urban centers and as these centers increasingly become hubs of poverty, deprivation and exclusion. Many African cities face severe environmental challenges following from: poor solid waste disposal and management; air pollution from burning of waste and emissions from transportation; and inability to provide safe water and sanitation services. World Health Organization, 2002; Ludlow and Roux, 2012. These are likely to be a growing issue of concern as the growth of the urban populations is expected to remain high in SSA countries (Khillare and Sarkar, 2012). In addition to population growth, industrial activities are expected to increase as the region becomes more industrialized (Petkova et al., 2013).

Outdoor and indoor air pollution remains the largest environmental health risk today. It was estimated to cause 7 million deaths globally in 2012 (World Health Organization, 2014). The largest health burden is borne by people living in cities of low- and middle-income countries (LMICs) facing double exposure burden from indoor and outdoor exposure, and where effective environmental policies are not yet in place to protect the public health.

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In these areas the levels of air pollutants are thought to significantly exceed guideline values set by the World Health Organization (2014). However, the reported health burden in LMICs attributable to air pollution is likely to be underestimated due to lack of data on both exposure and health outcomes (Petkova et al., 2013). Local studies are needed on the exposures to ambient air pollution to increase understanding of exposures and risks, and to support local policy processes.

A large body of literature from epidemiological studies has established a link between airborne particles and adverse health outcomes (Pope and Dockery, 2006; Boldo et al., 2006; Brauer et al., 2012; Dadvand et al., 2013; Fann et al., 2012). Further evidence indicates that fine particulate matter ($PM_{2.5}$) has the most profound effects on human health and would therefore serve as the best indicator for hazardous air quality (McNamara et al., 2011; Naeher et al., 2007). With a dearth of monitoring data on air pollution in the SSA region, estimates of burden of disease from air pollution for the region are based mainly on modeled estimates of population-weighted annual average concentrations (Petkova et al., 2013; Cohen et al., 2004). However, these levels may underestimate the concentrations in urban residential areas where there are a larger diversity of processes potentially leading to health effects in relation to air pollution compared non-LMICs, including domestic biomass fuel burning and proximity of high density of unprotected populations to industrial zones and busy roads. Current estimates do not well take into account the localized nature of activities that contribute to poor air quality and may mask socioeconomic differences in the exposure to air pollution (Khillare and Sarkar, 2012).

Previous air pollution studies in Nairobi have focused on quantifying levels in areas along major roads, and industrial and commercial areas (Gatari et al., 2009; Kinney et al., 2011; Odhiambo et al., 2010). However, sources of pollution, such as factories or dumpsites, might require grass roots approach in identification and quantification (Hunter, 2011). Therefore, few studies have measured air quality in residential areas (Dionisio et al., 2010a, 2010b), let alone in poor urban neighborhoods in SSA. Hence, this study sought to bridge this gap by providing information on the concentration levels of fine particulate matter ($PM_{2.5}$) in poor urban residential areas of Nairobi city, Kenya.

2. Methods

2.1. Study area

The study area covered two slum areas, Korogocho and Viwandani, located 12 and 7 km from Nairobi City center respectively. The size of each of the areas is approximately 0.5 square kilometres. Korogocho area lies west of the main dumping ground, Dandora, accumulating waste from the whole city. Viwandani area has industries situated to the North, and a dumpsite located in the southern area. The accumulated waste in Viwandani is smaller compared to Dandora. The majority of the Viwandani residents earn their living by working in the industries, mainly as casual labourers or informal workers, and are highly mobile, while Korogocho has a more stable population. Most houses in Korogocho are made of mud or timber with roofing composed of tin assembled from waste, while in Viwandani most housing structures are made of iron sheets. Characteristics of open spaces in the two informal settlements are large amounts of litter and waste, as proper garbage disposal remains a huge challenge. The majority of households either dispose garbage in public open spaces, in the river, or burn the waste at dumpsites or in open places (Ludlow and Roux, 2012; Gulis et al., 2004). The road networks within the two areas are mainly unpaved roads.

2.2. Instrumentation

An air sampler, *DustTrak, II Model 8532* (TSI Inc., Shoreview, MN, USA), was used for sampling fine particulate mass ($PM_{2.5}$). It is a handheld sampler, which uses a laser photometer to estimate aerosol mass concentration in real-time and is designed for fitting selectable sampling heads, or different particle size fractions of respirable particle mass. The air sampler is factory calibrated to the respirable fraction of standard ISO 12,103-1, A1 test dust (formerly Arizona Test Dust). The two available samplers were fitted with $PM_{2.5}$ sampling heads and their impaction plates were oiled and zeroed prior to each sampling event (TSI, 2011). The photometers are considered precision instruments and their accuracy on the measurements is dependent on the type of calibration aerosol compared to the aerosol being sampled. Therefore, for accurate measurement data we developed a custom calibration factor for the aerosols in the study area, which involved comparing gravimetric and photometric sample measurements taken side-by-side. This was achieved by sampling $PM_{2.5}$ particles on 37 mm diameter Teflon filters of 2 µm pore size using two personal samplers (*BGI model 400*) next to each *DustTrak* sampler. The filters were weighed before and after sampling for fixed time periods of 8 h for 3 days, at same time of the day and at the same location. It resulted in collecting a total of 24 h of day time samples. The ratio of the averages of the 24 h measurements between the *BGI* and *DustTrak* was then used as the calibration factor for the real-time measurements in the two informal settlements.

The filters were manually weighed using an analogue semi-micro analytical balance (Ainsworth) at Institute of Nuclear Science and Technology (INST), University of Nairobi. Triplicate weight measurements were taken for each weighing and the average weight were calculated as the weight of the empty or loaded filter. Gravimetric concentration mass in micrograms of the collected particles was calculated as the difference in weights between the loaded filter and the empty filter. The obtained mass was adjusted by a factor of 0.82, which was developed by comparing weighed empty and loaded mass of filters in the INST laboratory, and their equivalent weight observed at Lamont-Doherty Earth Observatory, Columbia University, USA. The latter laboratory had a more advanced low mass weighing and calibrated facilities, which INST took the opportunity of collaboration to calibrate the local micro-balance. The particle mass (gravimetric mass) was calculated using the formula;

$$\text{Particle Mass} = (W_2 - W_1)x0.82$$

Where W_1=empty filter weight (mg) and W_2=loaded filter weight (mg). These weights (W_1 and W_2) were the average of the three weight readings of the filter during each weighing session. The gravimetric concentration was then calculated by dividing the collected time and adjusted particle mass by the volume of sampled air, which was calculated from the pump flow rate and the time of particle collection. The custom calibration factor was then calculated using the formula:

$$Calibration\ Factor = \frac{Gravimetric\ Concentration}{DustTrak\ Concentration}$$

The calibration results are summarized in Table 1 below and the obtained calibration factor of 0.31 was used to adjust the measurements taken using the *DustTrak*. The calibration factor obtained indicates that *DustTrak* overestimated the $PM_{2.5}$ measurements as reported in other studies (McNamara et al., 2011).

2.3. Particulate matter ($PM_{2.5}$) measurement scheme

Continuous real-time sampling of particulate matter of aerodynamic diameter of 2.5 m or less ($PM_{2.5}$) was conducted in the