Journal of Transport & Health xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Transport & Health

journal homepage: www.elsevier.com/locate/jth

Particulate air pollution and noise: Assessing commuter exposure in africa's most populous city

Enembe O. Okokon[a,*], Pekka Taimisto[a], Anu W. Turunen[a], Olanrewaju A. Amoda[b], Abolaji E. Fasasi[b], Lewis Gregory Adeyemi[b], Jukka Juutilainen[c], Timo Lanki[a]

[a] *Department of Health Protection, THL - National Institute for Health and Welfare, P.O.Box 95, FI-70701 Kuopio, Finland*
[b] *Laboratory Services Department, Lagos State Environmental Protection Agency, Lasepa Building, Governor's Road, Lagos State Government Secretariat, Alausa, Lagos State, Nigeria*
[c] *Department of Environmental Sciences, University of Eastern Finland, Yliopistonranta 1, FI-70210 Kuopio, Finland*

ARTICLE INFO

Keywords:
Road traffic
exposure
particulates
black carbon
noise
transport mode

ABSTRACT

Africa is rapidly urbanising, consequently, there is the growing relevance of daily air pollution and noise exposure during urban commuting. Yet, little is known about commuter exposures in Africa. Lagos has a population in excess of nine million people, and approximately 788,000 registered motor vehicles. We monitored exposures of commuters within the Lagos metropolis to various size fractions of particulate air pollution, black carbon, and noise while traveling by car (taxi), microbus and larger bus with an aim to determine exposure levels and compare between modes. We conducted, altogether, 139 trips on nine designated commuting routes. The highest exposures were recorded when vehicle windows were open and air-conditioners turned off. For example, mean gravimetric PM_{10} levels of 364, 489 and 280 µg/m^3, and mean particle number count (PNC) levels of 92, 52 and 27 (x 10^3 pc /cm^3) were recorded in the car, microbus and larger bus, respectively. With the closed window setting, considerable reduction in particulate matter (PM) concentration was recorded on larger buses compared with cars. The highest mean (85 dB (A)) and highest mean 99th percentile (92 dB(A)) noise levels were obtained during trips on microbuses when windows were left open. This study observed remarkably high particulate air pollution and noise exposures during commuting in the major African city. A major shift to modern mass transportation systems would limit commuter exposure.

1. Background

Particulates are abundantly present in urban air and constitute a serious health risk. Road traffic is a major source of these particles due to combustion emissions from vehicle engines, mechanical shearing of vehicle parts and the friction between vehicle tyres and road surfaces (Kinney et al., 2011). Attrition (mechanical break-up of larger, solid particles) produces thoracic particles (aerodynamic diameter ≤10 µm; PM_{10}) and coarse particles (2.5 < aerodynamic diameter < 10 µm; $PM_{10-2.5}$), while fine particles

Abbreviations: AC, Air-conditioning; BC, Black carbon; CBD, Central business district; CV, Coefficient of variation; dB (A), A-weighted Decibels; PM, Particulate Matter; $PM_{2.5}$, Particulate matter 2.5 micrometres or less; PM_{10}, Particulate matter 10 micrometres or less; $PM_{10-2.5}$, Particulate Matter with diameter between 2.5 and 10 micrometres (coarse particles); PNC, Particle number concentration; pc, Particles; UFP, Ultrafine particles; µm, Micrometre; µg/m^3, Microgram per cubic metre

* Corresponding author. Permanent Address: Department of Community Medicine, Faculty of Medicine, University of Calabar, P.M.B 1115 Calabar, Nigeria.
E-mail addresses: enembe.okokon@thl.fi, enembeoku2001@yahoo.com (E.O. Okokon), pekka.taimisto@thl.fi (P. Taimisto), anu.turunen@thl.fi (A.W. Turunen), lanreamoda@gmail.com (O.A. Amoda), abolajifasasi4@gmail.com (A.E. Fasasi), adeyemilewis@gmail.com (L.G. Adeyemi), jukka.juutilainen@uef.fi (J. Juutilainen), timo.lanki@thl.fi (T. Lanki).

https://doi.org/10.1016/j.jth.2018.04.003
Received 7 September 2017; Received in revised form 6 April 2018; Accepted 8 April 2018
2214-1405/

(particles ≤ 2.5 µm; $PM_{2.5}$) are mainly generated from combustion processes and atmospheric reactions. Particles in these size fractions constitute the mass component of particulate matter (PM), and are commonly used to estimate the health effects of PM.

Particulate matter mass has shown consistent links with cardiopulmonary diseases (Bauer et al., 2010), increased hospital admissions and mortality (Thurston et al., 2016; Pope et al., 2010) in both short- and long-term exposures scenarios. Fine particles ($PM_{2.5}$) are considered to be an important indicator of PM-related health risk (World Health Organization, 2006). There is strong statistical correlation between these fractions ($PM_{2.5}$ and PM_{10}). $PM_{10\text{-}2.5}$ also exerts short-term effects on morbidity and mortality (Brunekreef and Forsberg, 2005; Adar et al., 2014). Fewer studies have evaluated associations between long-term exposure and health. More recently, increasing attention has been given to evidence which implicates ultra-fine particles as determinants of environmentally-related health risk (Devlin et al., 2014; Knibbs et al., 2011; Pekkanen et al., 1997; Pietropaoli et al., 2004). Ultra-fine particles (UFP) (aerodynamic diameter < 0.1 µm) dominate particle count but account for a small proportion of mass concentrations. Black carbon (BC) contributes substantially to the fine and ultrafine particulate fractions. Black carbon concentrations are higher closer to combustion sources such as diesel engine exhausts and has been proposed as a more reliable tracer of traffic-related air pollution than $PM_{2.5}$ (Karanasiou et al., 2014; Reche et al., 2011). Black carbon exhibits significant association with cardiovascular and all-cause mortality, asthma in children, and cardiovascular diseases in all ages (Knibbs et al., 2011; World Health Organization, 2012).

Commuters are also exposed to road traffic noise which dominates community noise (Paunović et al., 2009). Independently, noise increases risk of annoyance, cardiovascular disorders, cognitive impairments, and is a suspected risk factor for other mental health conditions such as anxiety and depression (Basner et al., 2013; World Health Organization, 2011). Short-term noise exposure has been observed to show association with reduced heart rate variability (Huang 2004). Long term noise exposure has repeatedly shown an association with increasing systolic (Sørensen et al., 2011) and diastolic (Bilenko et al., 2015) blood pressure, self-reported hypertension (Fuks et al., 2016), and an increasing trend of ischaemic heart diseases, although, often without statistical significance (de Kluizenaar et al., 2013). The common identified pathway for cardiovascular effects is the induction of stress reaction involving the sympathetic nervous system and the endocrine (pituitary-adreno cortical) system (Ising and Kruppa, 2004; Basner et al., 2013). Of note, however, is the paucity of research evidence on health effects of road-traffic noise exposure when compared with particulates.

City commuters are substantially exposed to PM and BC during routine transit to destinations (Karanasiou et al., 2014; Weichenthal et al., 2015). Pollutant concentrations on roadways often exceed background levels (Zuurbier et al., 2010; Kinney et al., 2011). Kerbside pollution levels also exceed ambient levels because of nearby traffic sources (Kinney et al., 2011; Moreno et al., 2015).

Commuter exposure to traffic-sourced pollutants may vary depending on the mode of transportation. The determinants of intermodal differences have been examined in previous studies (Karanasiou et al., 2014; McNabola et al., 2009; Okokon et al., 2017). The magnitude of traffic-related PM exposure is influenced by immediate locale-specific factors such as traffic volume, traffic mix, types of fuel, route etc. (de Nazelle et al., 2012; Wu et al., 2013), but is also subject to remote and far-ranging factors such as transportation policy, clean air regulation, city planning and technology (Karanasiou et al., 2014).

Over the years, affluent nations have designed policies which limit emission and atmospheric concentration of particulates. Trends show that while many industrialised countries experience decreasing air pollution, a clear contrast exists in many lower and middle-income countries, where pollutant levels are persistently high (World Health Organization, 2006). The most recent World Health Organization estimates indicate that populations exceeding 80% of urban dwellers are exposed to pollutant concentrations above stipulated limits (World Health Organization, 2016). The most polluted cities were found in lower- and middle-income countries. Onitsha, a city in south-eastern Nigeria, had the highest annual mean PM_{10} concentration of 594 µg/m^3 (World Health Organization, 2016). Intermodal exposure patterns in African countries have poor representation in literature: there is glaring absence of data on personal exposure compared with data on ambient levels (Baumbach et al., 1995; Olajire et al., 2011; Owoade et al., 2013). Our study, therefore, aims to measure exposure to thoracic, coarse, fine and ultrafine particulate air pollution, BC and noise when commuting by car, microbus, and larger bus in Lagos, Nigeria, the most populous African city. A further aim is to compare car mode exposure with the larger bus and the microbus.

2. Materials and methods

2.1. Study city and schedule

The study was conducted in Lagos, a West African city that is located in the south-western part of Nigeria. Lagos is the commercial hub of Nigeria. Metropolitan Lagos comprises four islands and a mainland area. Official figures from the 2006 decennial census placed the population at approximately 9,100,000 inhabitants (National Population Commission, 2006), and as of December, 2009, there were about 833,957 registered motor vehicles and 25,958 motorcycles in Lagos (Lagos Bureau of Statistics, 2016). Lagos has two central business districts (CBDs), namely, Lagos Island and Ikeja. Most Government institutions, ministries and secretariats, and private-sector head offices are located in these CBDs. There is marked unidirectional flow of traffic into the CBDs in the morning hours of any workday and a reverse flow at the close of work.

The study was conducted in the latter months of 2015 and early in 2016. The monitoring period spanned two seasons, the pre-Harmattan season, and the Harmattan season. The Harmattan season is a yearly period when dusty dry north-easterly winds from the Sahara desert blow southward across West Africa (Breuning-Madsen and Awadzi, 2005). The period is marked by a characteristic dustiness of the atmosphere, lower ambient temperatures and reduced visibility. Expectedly, there were no rains during the monitoring period (Table S1).