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Indoor air quality of low and middle income urban households in Durban, South Africa

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ABSTRACT

Introduction: Elevated levels of indoor air pollutants may cause cardiopulmonary disease such as lower respiratory infection, chronic obstructive lung disease and lung cancer, but the association with tuberculosis (TB) is unclear. So far the risk estimates of TB infection or/and disease due to indoor air pollution (IAP) exposure are based on self-reported exposures rather than direct measurements of IAP, and these exposures have not been validated.

Objective: The aim of this paper was to characterize and develop predictive models for concentrations of three air pollutants (PM_{10}, NO_2 and SO_2) in homes of children participating in a childhood TB study.

Methods: Children younger than 15 years living within the eThekwini Municipality in South Africa were recruited for a childhood TB case control study. The homes of these children (n=246) were assessed using a walkthrough checklist, and in 114 of them monitoring of three indoor pollutants was also performed (sampling period: 24 h for PM_{10}, and 2–3 weeks for NO_2 and SO_2). Linear regression models were used to predict PM_{10} and NO_2 concentrations from household characteristics, and these models were validated using leave out one cross validation (LOOCV). SO_2 concentrations were not modeled as concentrations were very low.

Results: Mean indoor concentrations of PM_{10} (n=105), NO_2 (n=82) and SO_2 (n=82) were 64 μg/m^3 (range 6.6–241); 19 μg/m^3 (range 4.5–55) and 0.6 μg/m^3 (range 0.005–3.4) respectively with the distributions for all three pollutants being skewed to the right. Spearman correlations showed weak positive correlations between the three pollutants. The largest contributors to the PM_{10} predictive model were type of housing structure (formal or informal), number of smokers in the household, and type of primary fuel used in the household. The NO_2 predictive model was influenced mostly by the primary fuel type and by distance from the major roadway. The coefficients of determination (R^2) for the models were 0.41 for PM_{10} and 0.31 for NO_2. Spearman correlations were significant between measured vs. predicted PM_{10} and NO_2 with coefficients of 0.66 and 0.55 respectively.

Conclusion: Indoor PM_{10} levels were relatively high in these households. Both PM_{10} and NO_2 can be modeled with a reasonable validity and these predictive models can decrease the necessary number of direct measurements that are expensive and time consuming.

1. Introduction

Indoor air pollution exposure (IAP) is implicated in a range of acute and chronic cardiopulmonary health effects (Chafe et al., 2014; Fullerton et al., 2011; Gordon et al., 2014; Kodgule and Salvi, 2012). The main sources of indoor air pollution in low and middle income countries are the use of solid fuels for cooking and heating, and tobacco smoking. These exposure sources have been estimated to cause 2.9 million (solid fuels) and 0.3 million (second hand smoke) premature deaths per year globally (GDB Risk Factors Collaborators, 2015). Combustion of tobacco, solid fuels, or paraffin emits a large number of chemical compounds in the particulate or gaseous phase (Cao et al., 2015; Chafe et al., 2014; Choi et al., 2015), which may cause various health outcomes. The major part of the disease burden is due to increased risk of ischemic heart disease, chronic obstructive pulmonary disease (COPD) and lung cancer in adults and acute lower respiratory infections in children (Gordon et al., 2014; Smith et al., 2014).

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Estimating personal exposure of individuals to indoor air pollutants has been challenging because of variations both between and within individuals, and because personal exposure measurements are time-consuming. Measuring pollutant concentrations in the households have, however, been shown to provide a good proxy for personal exposure, especially for small children, and for women who work indoors. For example Baumgartner et al. (2011) and Ni et al. (2016) showed a moderate correlation between household $PM_{2.5}$ concentrations and personal exposure $PM_{2.5}$ in women (r=0.58).

Adverse effects, particularly respiratory health outcomes, are generally more strongly associated with particulate phase air pollutants such as particulate matter < 2.5 µm or < 10 µm, ($PM_{2.5}$ and PM_{10},) and black carbon (BC) than the gaseous components (Lam et al., 2012; WHO, 2013). The concentration and composition of PM indoors is influenced by many factors including ventilation, indoor combustion such as secondhand smoke (SHS) or smoke from cooking fuel, ambient air pollution entering the home, and crowding (Vanker et al., 2015; WHO, 2013).

A limited number of studies have specifically examined the association between exposure to IAP and tuberculosis (TB). These studies have found a varying association, with most of them showing a significant relationship (Jafta et al., 2015 and Lin et al., 2014). Statistics of TB incidence in the Durban metropolitan area, high burden of TB in South Africa, ranked 8th out of 52 regions, and accounting for 2.6% and 9.1% of deaths in the age groups < 5 years and 5–14 years in 2013 respectively (Health Systems Trust, 2015).

A Housing Development Agency report on informal settlements in South Africa shows that Durban has 25% of its households classified as informal dwellings. This is the biggest proportion in the large urban cities in the country (Housing Development Agency, 2013). The dwelling structures in informal households are made of makeshift material such as corrugated iron sheets, wood and cardboard and tarpaulin without a solid foundation.

The primary objective of the present study was to quantify indoor air pollution by measuring pollutant concentrations in low- and middle-income households in Durban, South Africa and extrapolate these data through modeling to homes selected for a study looking at the relationship between IAP and childhood PTB.

2. Methods and materials

2.1. Study setting

The Durban metropolitan area has a population of over 3 million subjects that live in low, middle and high income housing. The city has a tropical climate with hot months (September – May) averaging a minimum of 22 °C and a mild colder season (June - August) with temperatures averaging a minimum of 16 °C (Statistics South Africa, 2005).

Previous studies in Durban that accessed ambient pollutant concentrations found annual PM_{10}, NO_2 and SO_2 ranges to be around 50, 15 and 10 µg/m^3 respectively (Naidoo et al., 2013). A study conducted in Durban metropolitan homes between 2003 and 2005 showed indoor PM_{10} concentrations ranging from 18 to177 µg/m^3 with a mean (SD) of 65 (32) µg/m^3 and NO_2 concentrations ranging from 9 to 29 µg/m^3 with a mean (SD) of 18 (4) µg/m^3 (Naidoo et al., 2007).

2.2. Identification and recruitment of participants

The present study involved households participating in the “Childhood TB study” where we are looking at the association between TB and exposure to IAP. Caregivers of children identified as cases or controls were recruited. The cases were children of age ≤15 years, newly diagnosed as having pulmonary tuberculosis (PTB). The controls were age- and sex-matched children without PTB identified from the same communities as cases with PTB.

2.3. Environmental exposure assessments

The homes (n=246) of the participants were visited, and a home walkthrough checklist (HWTC) and environmental air sampling of indoor air pollutants associated with combustion of cooking fuels and second hand smoke (SHS) were conducted in 114 of them. The monitoring of indoor pollutants was done as newly diagnosed cases and controls were identified. Monitoring of all households was not always possible on the day walkthrough information was collected because of logistics such as availability of monitoring equipment at the time and access to the households. Thus, household selection for sampling was on a convenience basis. The pollutants measured were particulate matter (PM_{10}), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2).

2.3.1. Home walkthrough assessment

The walkthrough checklist instrument used in assessment of the homes is a modified version of the instrument used in the South Durban Health Study to include energy uses, cooking and heating activities (Jafta et al., 2012). The instrument collects information on housing conditions and activities of the occupants; the type of energy for cooking and heating, presence or frequent visits of smokers, visible mold and moisture in the homes, ventilation practices and crowding. This information was collected across different rooms or areas of interest in the home.

2.3.2. Particulate matter (PM_{10})

2.3.2.1. Sampling. Because of the differences in housing size and structures, PM monitors were placed in one of the following areas or rooms, in order of preference: (1) a family/living room, (2) a child's sleep area, or (3) a room used as both a sleep and cooking area.

Airborne particulate matter (PM_{10}) was collected for a 24 h period in the participating households using battery operated MiniVol air samplers which were equipped with an impactor (Airmetrics, Springfield, OR) and 47 mm PTFE (Teflon/Polytetrafluoroethylene) filters with 2.0 µm pore size (Pall Corporation, Ann Arbor, MI, USA). The performance of a miniVol sampler has been validated against the USEPA recommended reference methods for determination of particulate matter concentration and was found to be comparable (Baldauf et al., 2001; Chen et al., 2011). The flow rate of the samplers was set at 5 L/min as recommended by the manufacturer. During deployment, the flow rate of the sampler was calibrated, and at the end of the sampling period the flow rate was measured again using a rotameter. A field blank filter was included for each batch of filters used to sample PM_{10} and analysed gravimetrically as part of quality control. At the end of each PM sampling period a post sampling questionnaire was administered to investigate activities and possible sources of PM in the house during sampling. A repeated 24 h sampling of PM_{10} was collected in 16% (n=17) of the homes.

2.3.2.2. Weighing of filters. All PTFE filters received a visual quality inspection for defects and damages. The filters were also conditioned in a room with controlled temperature and humidity for at least 24 h before weighing. Filters were weighed before and after sampling on a microbalance scale (Radwag, Radom, Poland), which is accurate to one microgram. On both pre and post sampling weighing sessions, each filter was weighed five times and its average mass and the standard deviation (SD) were noted. The weighing session for each batch of filters was repeated twice with an interval of at least four hours between the sessions, resulting in three weighing sessions for all filters.

Loading and unloading of filters from sampler filter holders was done in a clean room and filter holders were kept in air tight zip lock