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Seasonal concentrations and determinants of indoor particulate matter in a low-income community in Dhaka, Bangladesh

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ABSTRACT

Indoor exposure to particulate matter (PM) increases the risk of acute lower respiratory tract infections, which are the leading cause of death in young children in Bangladesh. Few studies, however, have measured children's exposures to indoor PM over time. The World Health Organization recommends that daily indoor concentrations of PM less than 2.5 μm in diameter ($PM_{2.5}$) not exceed 25 μg/m^3. This study aimed to describe the seasonal variation and determinants of concentrations of indoor $PM_{2.5}$ in a low-income community in urban Dhaka, Bangladesh. $PM_{2.5}$ was measured in homes monthly during May 2009 to April 2010. We calculated the time-weighted average, 90th percentile $PM_{2.5}$ concentrations and the daily hours $PM_{2.5}$ exceeded 100 μg/m^3. Linear regression models were used to estimate the associations between fuel use, ventilation, indoor smoking, and season to each metric describing indoor $PM_{2.5}$ concentrations. Time-weighted average $PM_{2.5}$ concentrations were 190 μg/m^3 (95% CI 170–210). Sixteen percent of 258 households primarily used biomass fuels for cooking and $PM_{2.5}$ concentrations in these homes had average concentrations 75 μg/m^3 (95% CI 56–124) greater than other homes. $PM_{2.5}$ concentrations were also associated with burning both biomass and kerosene, indoor smoking, and ventilation, and were more than twice as high during winter than during other seasons. Young children in this community are exposed to indoor $PM_{2.5}$ concentrations 7 times greater than those recommended by World Health Organization guidelines. Interventions to reduce biomass burning could result in a daily reduction of 75 μg/m^3 (40%) in time-weighted average $PM_{2.5}$ concentrations.

1. Introduction

Acute lower respiratory tract infections, including pneumonia, are the leading cause of death in children aged <5 years in Bangladesh (Baqui et al., 2001; Black et al., 2003). An estimated 25,000 Bangladeshi children died from acute lower respiratory infections in 2008 (Black et al., 2010). A recent meta-analysis of epidemiologic studies found that children <5 years of age with exposure to smoke from biomass fires in and around the household were 1.8 (95% confidence interval [95% CI] 1.3–2.2) times more likely to experience acute lower respiratory infections than children without this exposure (Dherani et al., 2008). The World Health Organization estimated that 32,000 childhood deaths from pneumonia were attributable to indoor exposures to biomass smoke in Bangladesh in 2001 (WHO, 2007).

Biomass fuels burn inefficiently and smoke from biomass combustion releases fine particles into the air which can be breathed into the lower lung (Naeher et al., 2007). Although households in low-income countries frequently burn biomass for cooking or heating (WHO, 2007), little is known about

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particulate matter (PM) concentrations in these homes. Until recently, most standard air quality monitors capable of measuring PM concentrations were large, expensive machines that required technical expertise to deploy (Smith, 2002). Therefore, most epidemiologic studies used proxy PM exposure measurements, such as the type of cooking fuel or estimates of the amount of time the child spends near the cooking fire (Dherani et al., 2008; Ezzati and Kammen, 2002). These proxy exposures were consistently associated with an increased risk of acute lower respiratory infections in children, suggesting that they are useful for discriminating between levels of exposure (Dherani et al., 2008). However, these proxy measures of exposure had major limitations (Ezzati and Kammen, 2002). First, proxy exposures do not allow for comparison of exposure to PM between countries or study sites. For example, if burning wood for cooking is associated with an increased risk of acute lower respiratory infections in two studies, this provides no information about how exposures to PM may differ between those study populations. Second, these proxy measurements provide little information about how PM exposures differ between participants within the study, only whether or not the difference resulted in significant increases in risk. Third, there may be seasonal variations in fuel use or other household determinants of PM concentrations which may not be accurately captured by interviews, making it difficult to capture seasonal variations in exposure.

The few published studies describing measured indoor PM in low-income countries are limited by small sample sizes, cross-sectional design, and/or absence of detailed analyses that limit interpretations of seasonal variation and determinants of indoor PM concentrations (Ezzati and Kammen, 2002; Dasgupta et al., 2006a and b; Ezzati and Kammen, 2001; Bautista et al., 2009). However, information about seasonal variation and determinants of indoor PM concentrations could improve the design of interventions to decrease exposure by quantifying how PM would decrease with interventions aimed at changing fuel type or increasing ventilation (Ezzati and Kammen, 2002).

For one year we measured PM concentrations each month in children's homes in a low-income community in urban Dhaka, Bangladesh monthly as part of an epidemiologic study to estimate the incidence and timing of acute lower respiratory infections in children <2 years of age. The objectives of this study were to describe seasonal patterns of indoor particulate matter concentrations and to estimate the association between these concentrations and potential sources of particulates in the home.

2. Materials and methods

2.1. Study population

Mirpur is a densely populated, low-income, urban community in Dhaka, Bangladesh (Haque et al., 2001). In January 2008, researchers at the International Center for Diarrheal Diseases Research, Bangladesh (icddr,b) and the University of Virginia began enrolling a cohort of children in this community at birth to study the incidence and etiology of childhood gastrointestinal and respiratory infections and their associations with cognitive development. All pregnant women residing in the Mirpur study area between January 2008 and April 2009 were identified by community health workers employed by the study and asked to participate in the cohort. All children enrolled in this cohort between January 2008 and April 2009 were eligible to enroll in our sub-study to examine the relationship between indoor air pollution and respiratory disease. This paper presents findings on about the $PM_{2.5}$ concentrations in these children's homes.

2.2. Measurement of household characteristics and indoor $PM_{2.5}$

Every household with a child participating in the sub-study was visited in April–May 2009 and characteristics of the household were recorded using a structured questionnaire and observation form. Our study aimed to describe the determinants of indoor concentrations of particulate matter, so we attempted to measure all known sources of particulates for each household. Trained research assistants collected information from the child's mother about the number of people who lived in the house; the area of the dwelling's floor space; the number of windows and doors that opened to the outside; whether the cooking stove was inside or outside the living space; the kind of fuels burned in the home for cooking or other purposes; and whether or not any household members smoked tobacco in the house. During this survey in April–May 2009, many household respondents told us that they had specialized stoves for cooking with natural gas or electricity, but these cleaner fuel sources were sometimes unavailable due to regular power outages or limited natural gas supply. If cleaner fuels were unavailable, some households burned biomass in traditional stoves as an alternative strategy. Therefore, we conducted a survey during March 2011 to collect data on all fuel types used by the household since May 2009 to capture this heterogeneity. Households that were not available to participate in the survey at the end of the study were categorized based on their baseline fuel use information.

From May 2009 through April 2010, concentrations of particulate matter of approximately 2.5 μm in diameter ($PM_{2.5}$) were measured in the child's sleeping space for a 24 h period once per month using PM monitors manufactured by the Berkeley Air Monitoring Group (Smith et al., 2007; Chowdhury et al., 2007; Edwards et al., 2006). The monitors were converted smoke detectors that used light scattering sensors to measure $PM_{2.5}$ approximate concentrations and these measurements were shown to correlate with gravimetric-based $PM_{2.5}$ samples (Chowdhury et al., 2007). The monitors were designed for use in highly polluted indoor environments and had a lower limit of detection of 50 $\mu g/m^3$ (Edwards et al., 2006).

Trained research assistants zeroed the monitors, placed them on the wall approximately two feet above the bed where the child enrolled in the birth cohort slept, and then retrieved the monitors from the home at least 24 h later. The monitors logged the measured concentrations of $PM_{2.5}$ once per minute and these data were downloaded to a study computer. Twenty-four hours of measurements were retained for each day of sampling for the analysis, with 1 min resolution (data collected at one minute intervals) for a total of 1440 measurements per each 24 h period. 24 h observations with fewer than 1300 min measurements recorded due to monitor or human error were excluded from the analysis. Readings at or below the limit of detection (50 $\mu g/m^3$) were replaced using the beta substitution method for censored data arising from limits of detection (Ganser and Hewett, 2010).

2.3. Statistical analyses

We described study households in terms of whether their cooking stove was inside or outside, the type of fuel used for cooking at baseline, tobacco smoking inside the home, and the number of doors and windows that opened to the outside. We created fuel use categories to capture heterogeneity in fuel use based on the survey at the end of the study and classified households as either using clean fuels only during the study period, which included both natural gas and electricity, using biomass fuels only, or using primarily clean, but occasionally biomass fuels. Households with missing data on fuel use from the survey at the end of the study were classified as burning biomass only if they reported at baseline that their primary fuel source was biomass. All others with missing data were classified as using primarily clean fuels with some biomass.

The $PM_{2.5}$ concentrations were summarized for each 24-h observation period using three exposure metrics. Time-weighted average (arithmetic mean) $PM_{2.5}$ concentrations were calculated to represent daily exposures and the 90th percentile $PM_{2.5}$ concentration was used as an indicator of peak daily exposures in the home. In addition, we calculated the number of hours that the $PM_{2.5}$ concentrations exceeded 100 $\mu g/m^3$ for each 24 h observation period (daily hours $>100\ \mu g/m^3$). The threshold of 100 $\mu g/m^3$ does not represent a concentration associated with poorer health outcomes but was chosen for exploratory analyses because it represented twice the limit of detection of the monitors and four times the World Health Organization guidelines for indoor air quality (25 $\mu g/m^3$ daily mean) (WHO, 2005).

The number of hours that the $PM_{2.5}$ concentrations exceeded 100 $\mu g/m^3$ were plotted by measurement date and locally weighted scatterplot smoothing (LOWESS) curves (Cleveland and Devlin, 1988) were estimated to compare seasonal variation in $PM_{2.5}$ concentrations by fuel type. We defined four seasons: winter (December–February), spring (March–May), monsoon (June–September), and post-monsoon (October–November) (Salam et al., 2003). To account for the clustered nature of observations within each household, generalized estimating equations were fitted to estimate the population-averaged associations between fuel use, stove location, the number of windows and doors, indoor tobacco smoking, and season with time-weighted average $PM_{2.5}$ concentrations, 90th percentile $PM_{2.5}$ concentrations, and daily hours $>100\ \mu g/m^3$ (Liang and Zeger, 1986). We defined binary variables for each season and the season with the lowest values defined the baseline. An additional analysis objective was to estimate the subject-specific associations with covariates as well as the proportion of the variation in $PM_{2.5}$ concentrations that was explained by differences between households. To accomplish this, a random effects model, including a random intercept for each household, was fitted for each of the exposure metrics in Stata