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Impact of neighborhood biomass cooking patterns on episodic high indoor particulate matter concentrations in clean fuel homes in Dhaka, Bangladesh

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Abstract

Exposure to particulate matter ($PM_{2.5}$) from the burning of biomass is associated with increased risk of respiratory disease. In Dhaka, Bangladesh, households that do not burn biomass often still experience high concentrations of $PM_{2.5}$ but the sources remain unexplained. We characterized the diurnal variation in the concentrations of $PM_{2.5}$ in 257 households and compared the risk of experiencing high $PM_{2.5}$ concentrations in biomass and non-biomass users. Indoor $PM_{2.5}$ concentrations were estimated every minute over 24 hours once a month from April 2009 through April 2010. We found that households that used gas or electricity experienced $PM_{2.5}$ concentrations exceeding 1000 μg/m^3 for a mean of 35 minutes within a 24-hour period compared to 66 minutes in biomass burning households. In both households that used biomass and those that had no obvious source of particulate matter, the probability of $PM_{2.5}$ exceeding 1000 μg/m^3 were highest during distinct morning, afternoon and evening periods. In such densely populated settings, indoor pollution in clean fuel households may be determined by biomass used by neighbors, with the highest risk of exposure occurring during cooking periods. Community interventions to reduce biomass use may reduce exposure to high concentrations of $PM_{2.5}$ in both biomass and non-biomass using households.

Keywords

Air Pollution; Bangladesh; Cookstove; Particulate Matter; Biomass

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1. Introduction

Exposure to indoor air pollution is significantly associated with an increased risk of respiratory diseases, including acute respiratory infections (Bruce et al. 2000). These infections are responsible for 18% of all deaths among children under the age of five worldwide (Liu et al. 2012). Indoor air pollution exposure is especially high in many low-income settings, including Bangladesh, where the daily mean concentration of fine particles less than 2.5 µm in diameter ($PM_{2.5}$) is as high as 200 µg/m^3 at certain times of the year; eight times the World Health Organization (WHO) air quality guideline of 25 µg/m^3 (Dasgupta et al. 2006a; World Health Organization 2006).

A key source of indoor air pollution is the burning of biomass fuels for cooking or heating. The burning of biomass is typically inefficient and releases over 200 volatile and particulate substances, many of which can induce acute and chronic respiratory diseases (Naeher et al. 2007; Tesfaigzi et al. 2005; 2002; US Environmental Protection Agency 1997). In Bangladesh, biomass fuels include wood, bamboo, jute, paper and dung (Dasgupta et al. 2006a).

In addition to high levels of air pollution in homes burning biomass, households in Dhaka that did not use biomass were also found to be polluted, with mean daily concentrations of $PM_{2.5}$ estimated at over six times the WHO standard (Gurley et al. 2013). The causes of the high pollution levels in these households are unclear. A potential explanation is that in densely populated settings, households that do not burn biomass themselves experience elevated concentrations of $PM_{2.5}$ due to the ambient dispersal of particulates from surrounding homes that do use biomass stoves. Previous controlled experiments have estimated that biomass burning for cooking produces short-term $PM_{2.5}$ concentrations of 1,000 µg/m^3 (Siddiqui et al. 2009). By characterizing the time periods in the day when households that do not burn biomass themselves, experience $PM_{2.5}$ concentrations that exceed 1,000 µg/m^3, we can assess whether biomass burning in the surrounding neighborhood is a likely source of particulate matter in these homes. In this study, we used monitors that allowed us to estimate minute-by-minute $PM_{2.5}$ concentrations over 24-hour periods. We measured $PM_{2.5}$ in households from an urban population in Dhaka over the course of a year, and investigated the diurnal variability in the risk of households experiencing levels of particulates that exceeded 1,000 µg/m^3 in households that did and did not burn biomass fuels.

2. Material and Methods

2. 1. Study households

The study was conducted in Mirpur, a low income area in Dhaka. The study site has been described elsewhere (Haque et al. 2001). The population density in Mirpur is 38,700 persons per square kilometer (Bangladesh Bureau of Statistics 2001). Homes often consist of a single room in single-story buildings with neighboring households tightly packed in narrow alleys (Baker 2007; Begum 2007). The average residential floor space per person in Dhaka is 3.7 m^2 (Begum 2007).

The study was conducted among households with a child enrolled from January 2008 through April 2009 into a birth cohort investigating the relationship between enteric infections and children's cognitive development. Community health workers, employed by the study, identified all pregnant women in the study area and asked them to participate. Families who planned to emigrate from the study area, newborns with jaundice or severe congenital anomalies (such as paralysis), families who refused to provide blood samples for immune or genetic analyses, and mothers who refused to enroll their child were excluded from the study. Type of cooking fuel used by the household did not determine eligibility into the study.

2.2. Data collection and preparation

Trained study staff visited the homes of participants during March and April 2009 and used a structured questionnaire to collect data from mothers on possible sources and determinants of indoor particulate matter concentrations. Research staff recorded the primary type of cooking fuel; whether the household used kerosene for any purpose; whether the cooking stove was located inside or outside the household; the floor area of the home; the presence of household smokers; and the number of windows and doors that could be opened and were on the exterior of the building as a proxy for ventilation. Increased ventilation in homes that burn biomass is thought to reduce indoor air pollution, as it allows for particulate matter generated by cooking to better escape the home (Dasgupta et al. 2006a). Increased ventilation in homes that do not burn biomass may conversely allow particulate matter into the home.

The Berkeley Air monitor was designed specifically to estimate particle pollution from the use of biomass fuels for household cooking and heating in resource poor settings (Edwards et al. 2006). In our study, Berkeley Air monitors were used to obtain air pollution estimates once a month, from April 2009 through April 2010. At each study visit, the monitor was calibrated according to the manufacturer's instructions. The monitor was then hung in the child's sleeping space, approximately two feet above the bed. The monitor used light scattering sensors to record the concentration of $PM_{2.5}$ every minute for a 24-hour period, 1440 readings in all. The monitor was then retrieved and readings downloaded to a study computer. We used a total of 38 monitors. The monitors could not capture concentrations of $PM_{2.5}$ below 50 μg/m^3.

2.3. Diurnal patterns of risk of high $PM_{2.5}$ concentrations

We explored if and when households experienced $PM_{2.5}$ concentrations that could have originated from the burning of biomass. Previous controlled experiments estimated indoor $PM_{2.5}$ generated by burning biomass during cooking periods. A study in Pakistan found burning biomass resulted in a mean short-term $PM_{2.5}$ concentration of 962 μg/m^3 (Siddiqui et al. 2009). In addition a study in Mozambique found burning biomass resulted in mean concentrations of 1200 μg/m^3 of the slightly larger $PM_{7.5}$ (Ellegård 1996). In our study, measurements greater than 1000 μg/m^3 were considered consistent with particulates caused by the burning of biomass. This value represents concentrations 40 times higher than the WHO recommended daily mean exposure. As there are likely to be substantial heterogeneities in the concentration of particulate matter generated by burning biomass and there will be dispersal of particulates as they move away from the source, sensitivity analyses with different cut points (500 μg/m^3 and 2000 μg/m^3) were also conducted.

We used a regression approach to examine the effect of individual household covariates (ventilation, cooking fuel, cook stove location, kerosene use, smoking, and size of the home) on the probability that particulate matter concentrations exceeded 1000 μg/m^3 at each 'time of day' – 'day of year' combination. We used a generalized additive model (Hastie and Tibshirani 1995). Generalized additive models are a flexible and widely used approach that can capture variability in predictor coefficients over time (Guisan et al. 2002). Rather than a single estimate of the effect of a household covariate on household particulate matter concentrations, generalized additive models allow examination of when during the day the effect of the covariate is higher and when it is not important in determining the odds of high $PM_{2.5}$ concentration.

The model was constructed as follows:

$$\begin{aligned}
&\text{logit}\left(Pr\left[y_{i,t,d}\right]\right)\\
&\quad=\beta_0+\beta_1 \quad hhid_i\\
&\quad+\beta_2 \quad vent_i * fuel_i\\
&\quad+\beta_3 \quad vent_i * (1-fuel_i)\\
&\quad+\beta_4 \quad fuel_i\\
&\quad+\beta_5 \quad stove_i\\
&\quad+\beta_6 \quad kerosene_i\\
&\quad+\beta_7 \quad smoke_i\\
&\quad+\beta_8 \quad size_i\\
&\quad+s_1\left(t,d\right)+s_2\left(t\right)\cdot vent_i * fuel_i\\
&\quad+s_3\left(t\right)\cdot vent_i * (1-fuel_i)\\
&\quad+s_4\left(t\right)\cdot fuel_i\\
&\quad+s_5\left(t\right)\cdot stove_i\\
&\quad+s_6\left(t\right)\cdot kerosene_i\\
&\quad+s_7\left(t\right)\cdot smoke_i\\
&\quad+s_8\left(t\right)\cdot size_i
\end{aligned}$$

where $Pr(y_{i,t,d})$ is the probability that the $PM_{2.5}$ estimate exceeded 1000 μg/ m^3 at household *i* at time of the day *t* and consecutive day since the start of the study *d* (April 1 2009 was day 1), is the model intercept and the beta coefficients represent the mean effect across a 24-hour time period for the associated covariate. The variable *vent* is a binary ventilation proxy, as indicated by whether the household had more than the median number of external windows and doors, *fuel* is whether the primary cooking fuel type was biomass, *stove* is whether the household stove was outside, *kerosene* is whether the household reported any kerosene use (such as for heat, lighting or cooking), *smoke* indicated the presence of household smokers, *size* is the estimated floor area of the household, $s_{2\text{-}8}$ are the smoothing splines for the changing effect of household covariates throughout the day. We included a random intercept for each household (*hhid*). s_1 is the smoothing splines for time of day and time of year for the reference group, defined as households that used clean fuel, used an outside stove, had no household smokers and did not use kerosene for any purpose. These represented homes that had no obvious household sources of $PM_{2.5}$ based on measured household covariates.

We used cyclic cubic regression splines that resulted in the fitted $PM_{2.5}$ concentration at the end of the day matching the value at the start of the day. Confidence intervals for all parameters were estimated using a Bayesian posterior covariance matrix (Wood 2006). We selected the best model by first fitting the full model and removing model terms one by one if the 95% confidence region for the term included zero throughout the day and the associated beta coefficient was not statistically different from zero. The fuel type and ventilation terms were retained in the model, irrespective of their significance as their association with high $PM_{2.5}$ concentrations were of particular interest to the study. To calculate the odds ratio of each covariate in the final model, we took the exponential of the model coefficient estimates. In addition, we transformed the odds of $PM_{2.5}$ exceeding 1000 μg/m^3 into estimated probabilities using: .

$$Pr\left(y_{i,t,d}\right)=exp \quad \left\{logit\left(Pr\left[y_{i,t,d}\right]\right)\right\}/\left\{1+exp \quad \left\{logit\left(Pr\left[y_{i,t,d}\right]\right)\right\}\right\}$$

2.4. Approvals

Prior to enrollment in the study, all mothers provided informed consent for participation. Institutional Review Boards at the icddr,b, Dhaka, Bangladesh (formerly known as the International Centre for Diarrheal Diseases Research, Bangladesh); Johns Hopkins Bloomberg School of Public Health, Baltimore, MD; the University of Virginia, Charlottesville, VA and the Centers for Disease Control and Prevention, Atlanta, GA reviewed and approved the protocol.

3. Results

Two hundred and fifty-seven households were recruited into the study. Study households had a mean floor area of 9.9 m^2 and 2.1 external windows and doors (median of 2) (Table 1). One hundred and eighty-four (71%) of the mothers and 167 (65%) of fathers had no education beyond elementary level. Eighty-five (33%) of the households had their stoves located inside the home. Biomass was used as the cooking fuel in 16% of households. The major types of fuel used in these households were wood (97%), bamboo (79%) and paper (68%), with some households reporting use of more than one type of biomass. Sixty four percent of households used gas and 19% used electricity. Particulate matter concentration data were collected on an average of 11.2 separate 24-hour measurements per household over the course of the year. We collected over four million readings of $PM_{2.5}$, all of which was included in the analysis. The mean $PM_{2.5}$ concentration from a 24-hour measurement was previously reported to be 190 μg/m^3 (95% confidence interval of 170 – 210); 308 μg/m^3 (237 – 378) in households that used biomass (16% of households) and 165 μg/m^3 (130 – 200) in households that only used clean fuels (84% of households) (Gurley et al. 2013). As the $PM_{2.5}$ concentrations appear to log-normally distributed (Figure S1), we also provide geometric mean values: 101 μg/m^3 in households that used biomass (95% confidence interval of 92 – 109) and 79 μg/m^3 (67 – 91) in clean fuel households.

Of the 257 households, 229 (89%) had at least one 24-hour measurement where $PM_{2.5}$ levels exceeded 1000 μg/m^3 for at least 15 minutes, a period of time that is unlikely to be caused by sporadic spikes in particulates that are not representative of true $PM_{2.5}$ concentrations. In biomass burning households, concentrations of $PM_{2.5}$ exceeded 1000 μg/m^3 for at least 15 minutes for 52% of 24-hour measurements, with a mean of 66 minutes per 24-hour measurement. In clean fuel households, concentrations of $PM_{2.5}$ exceeded 1000 μg/m^3 for at least 15 minutes in 27% of 24-hour measurements, with a mean of 35 minutes per 24-hour measurement (Table 2).

3. 1. Generalized Additive Model

The final model included all terms except for the presence of household smokers, size of home and the location of the stove. There was a mean probability of 0.013 (95% confidence intervals: 0.010 – 0.019) that an individual reading of household $PM_{2.5}$ was over 1000 μg/m^3 in homes that had no obvious source of particulate matter (clean fuel users that did not use kerosene for any purpose). However, there were significant differences by time of day and time of year (Figure 1). Diurnally, there was a trimodal pattern in the probability of $PM_{2.5}$ exceeding 1000 μg/m^3 with the highest risk occurring at morning (peak around 8.30am), early afternoon (1.45pm) and evening periods (8pm) (Figure 1A). In addition, the probability of $PM_{2.5}$ exceeding 1000 μg/m^3 was substantially elevated during winter months, where it reached up to 0.13 (0.11 – 0.14) during evening periods for these households (Figure 1B). This represents a 10 fold increase compared to the mean probability of $PM_{2.5}$ exceeding 1000 μg/m^3 at any time.

The mean effect of burning biomass across a 24-hour period was to increase the odds of $PM_{2.5}$ concentrations exceeding 1000 μg/m^3 by 2.0 times compared to clean fuel households (1.4 – 2.8) (Table 3). The model shows that households that used biomass had the greatest risk in $PM_{2.5}$ concentrations exceeding 1000 μg/m^3 at morning, early afternoon and evening periods. The maximum odds ratio of high $PM_{2.5}$ for the use of biomass compared to clean fuel users was 3.0 (2.2 – 4.0) (Figure 2A). The correlation in the diurnal patterns of the probability of high $PM_{2.5}$ between biomass and clean fuel households was 0.89.

In households that used biomass, having more than the two external windows or doors reduced the odds of $PM_{2.5}$ concentrations exceeding 1,000 μg/m^3 by an average of 0.8 times (0.6 – 1.1) whereas in households that used clean fuels, the effect was to increase the odds of high $PM_{2.5}$ by 1.1 times (0.5 – 2.6). While we did not observe a significant effect of increased windows at any time of day, the diurnal patterns in the effects of additional windows were negatively correlated between biomass and clean fuel users (Figure 2B), indicating that when they are beneficial in biomass users in reducing risk of high PM concentrations, they may be detrimental to clean fuel users. Furthermore, after adjusting for the primary cooking fuel type, households that reported any use of kerosene were independently associated with the odds of $PM_{2.5}$ exceeding 1000 μg/m^3 by 1.4 times (1.1 – 1.7).

We also conducted sensitivity analyses with different cut points (500 μg/m^3 and 2000 μg/m^3). In each case we found a consistent tri-modal pattern in the diurnal distribution of risk of experiencing particulate matter concentrations above the cut point, with morning, early afternoon and evening peaks (Figures S2 - S5).

4. Discussion

In a densely populated urban area of Dhaka, indoor $PM_{2.5}$ concentrations varied widely throughout the day and season. The probability of $PM_{2.5}$ exceeding 1000 μg/m^3 in households that used biomass was highest during morning, midday and evening periods. In Bangladesh most households eat meals three times a day (Food and Agriculture Organization of the United Nations 2008). These peaks in $PM_{2.5}$ likely correspond with morning, early afternoon and evening cooking times. Households that used clean fuels, such as gas or electricity and did not use kerosene for any purpose and therefore had no obvious sources of particulate matter within their own households, had the highest risk of $PM_{2.5}$ concentrations exceeding 1000 μg/m^3 at similar periods in the day to biomass burning households. These findings suggest that households that do not burn biomass fuels nevertheless experienced increased particulate matter exposures consistent with originating from nearby biomass burning during cooking times.

The presence of concentrations of $PM_{2.5}$ consistent with originating from the nearby burning of biomass in households with no obvious source of particulates may be explained by the ambient dispersal of particulates from neighbors that use biomass fuels. Periods of increased traffic may also contribute to indoor household particulate matter as a result of the dispersal of increased ambient PM from vehicles moving into homes. However, the effects of traffic in our study are likely to be minimal. Maximum roadside $PM_{2.5}$ concentrations along major roads have been estimated at 327 μg/m^3 in Lahore, Pakistan (Colbeck et al. 2011), levels substantially below the threshold concentration of 1000 μg/m^3 used here. In addition, as a result of the compact housing and narrow streets the study area has no major roadways and few vehicles, limiting the immediate effects of traffic.

Concentrations of $PM_{2.5}$ exceeded 1000 μg/m^3 for over 30 minutes more in households that used biomass compared to households that did not, in a 24-hour period. If these increased periods of high $PM_{2.5}$ levels are associated with cooking, an intervention to promote the use of clean fuels or improved cook stoves may reduce brief periods of high PM concentrations, which could be particularly important in the increased risk of respiratory disease (Ezzati and Kammen 2001). Nevertheless, the results presented here suggest that in this setting, household residents in individual homes that switch to clean fuels may still experience over half an hour per day of $PM_{2.5}$ concentrations that are consistent with originating from the burning of biomass. Data from this study has previously shown that the presence of household smokers was associated with $PM_{2.5}$ concentrations exceeding 100 μg/m^3 (Gurley et al. 2013). We did not find a similar association at the higher cut-off of 1,000 μg/m^3 indicating that the effects of tobacco smoke occurs only at lower $PM_{2.5}$ concentrations.

It has previously been found that outdoor particulate matter concentrations in Bangladesh were highest during the cooler and drier winter months (Begum et al. 2006). Our finding of a similar pattern in indoor air suggests that ambient air may play a major role in determining indoor particulate matter concentrations. Factors that may contribute to seasonal differences in indoor $PM_{2.5}$ include meteorological effects on ambient air, variation in ambient sources and changes in household behaviors. Regional meteorological patterns result in frequent temperature inversions during Bangladeshi winters. These occur when cool air is trapped below a body of warm air, creating stable atmospheric conditions which can trap particulates near the surface of the earth (Oke 1987). A potential seasonal source of ambient $PM_{2.5}$ is brick kilns that use coal and wood fuel. These are located throughout Dhaka and operate continuously during October through April, but not during other times of the year (Begum 2004; Guttikunda 2009). Finally, homes may use other fuels for heat during this period. Data from the Bangladesh Meteorological Department show that minimum daily temperatures fall to 54–57°F during December and January, which may represent sufficiently cool temperatures for additional heating requirements for houses that are not insulated. However, as the majority of stoves were located outside of the living area, they were unlikely to be used for heating purposes.

Ventilation has previously been found to decrease household $PM_{2.5}$ concentrations (Dasgupta et al. 2006a; 2006b). However, we found that having more than two external windows or doors was not significantly associated with changes in the risk of high $PM_{2.5}$ levels in either biomass or clean fuel homes. The number of external windows and doors may be a poor proxy for ventilation because it did not capture when they were open. Better characterization of the airflow into and out of households would improve estimates of the magnitude of the effect of ventilation on indoor PM concentrations.

While we captured the primary fuel types used by households, we did not measure the frequency or timing of temporary changes in fuel use, including those resulting from power outages or gas shortages. Such events would dampen any differences across fuel types, but may explain some of the $PM_{2.5}$ observed in households with clean fuel.

Monitors were placed near the child's sleeping space rather than by cooking locations, however, the homes in the study are very small and often consist of only one room.

Monitor placement is unlikely to have had an impact on $PM_{2.5}$ estimates. In addition we did not capture the cooking times of the households and although the timings of the peaks in particulate matter are likely to be well correlated with cooking times, future studies may benefit from capturing this precisely. Finally, the Berkeley Air monitor provides an affordable way of capturing a large number of sequential measurements of air pollution in polluted settings. It is limited, however, by having a relatively high lower limit of detection of 50 $\mu g/m^3$, which makes them less suited to less polluted environments. As we were using a cut point of 1000 in our analyses we were not affected by this limit of detection.

5. Conclusion and recommendations

Although households burning clean fuels had lower $PM_{2.5}$ concentrations than households burning biomass, these households nevertheless experienced increased risk of high $PM_{2.5}$ concentrations during cooking times, resulting in household exposure levels that exceeded WHO guidelines. Spatiotemporal analyses of individual household $PM_{2.5}$ concentrations as they relate to the cooking fuels and stoves used across a community could provide further insight into this exposure risk. The results presented here could have important implications for interventions to reduce indoor PM exposures, which often focus on promoting improved stoves that either operate on clean fuels or burn biomass more effectively (Romieu et al. 2009; Smith et al. 2006). Intervention projects that promote improved cookstoves in similar environments that target individual households may not observe expected reductions in PM exposures due to the ongoing pollution from neighbors who continue to burn biomass. Conversely, interventions that target all the biomass burning homes in the community can potentially affect both those individual, targeted households, as well as households using clean fuels.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements

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Practical implications

This study demonstrates that household air pollution in Dhaka, Bangladesh may be substantially affected by factors outside of the home. In particular, it highlights the role of neighborhood cooking practices on household pollution levels. The results of this study will help inform cookstove intervention projects. These projects will only partially reduce exposure to extremely high levels of pollution. In contrast, community-wide interventions will have an impact on homes that both do and do not use biomass themselves.

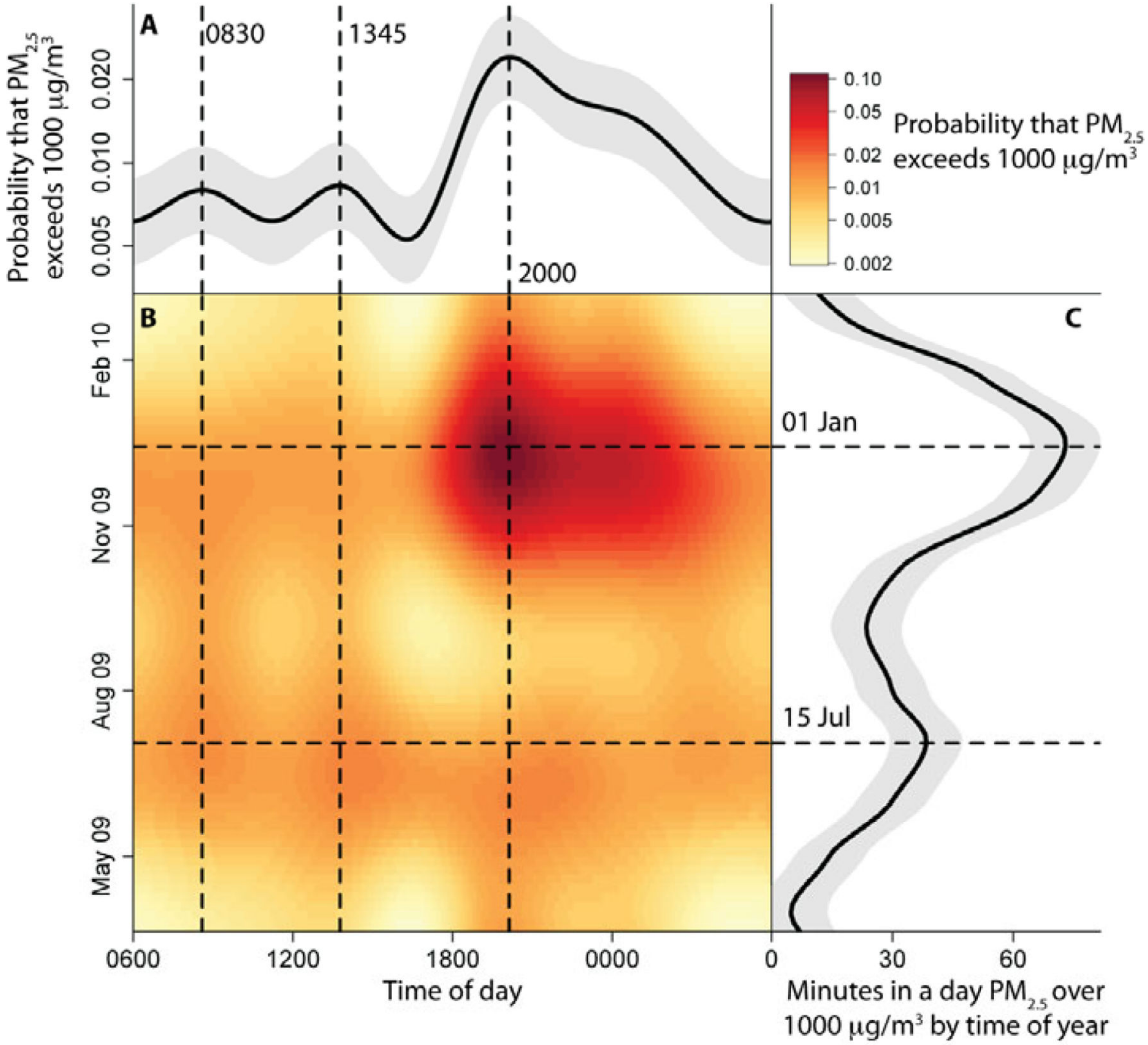

Figure 1. Risk of $PM_{2.5}$ concentrations exceeding 1000 μg/m^3 by time of day and time of year in households with no obvious source of particulate matter

(A) Model estimates of the probability that $PM_{2.5}$ exceeds 1000 μg/m^3 by time of day. Axes are on a logarithmic scale for visualization purposes. **(B)** Model estimates of the probability that $PM_{2.5}$ exceeds 1000 μg/m^3 by time of day and time of year. **(C)** Mean number of minutes over 24-hours that $PM_{2.5}$ exceeds 1000 μg/m^3 by time of year in these households using a loess curve.

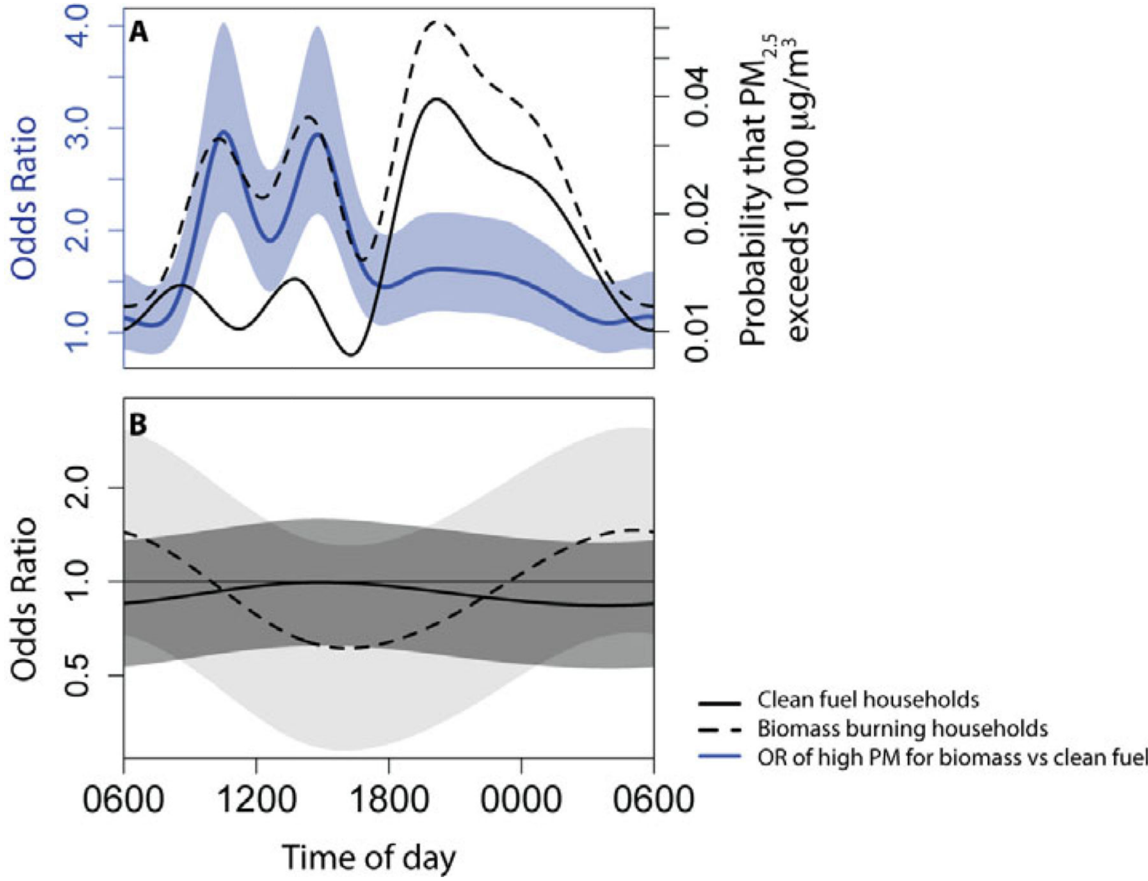

Figure 2. Variation in the effects of (A) biomass use and (B) having more than two external windows and doors throughout a 24-hour period on the odds of $PM_{2.5}$ concentrations exceeding 1000 μg/m^3 for biomass and clean fuel households

(A) Model estimates of the probability that $PM_{2.5}$ exceeds 1000 μg/m^3 in clean fuel households (solid line) and biomass households (dashed line). The blue line is the odds ratio of $PM_{2.5}$ exceeding 1000 μg/m^3 between the two household types. **(B)** Odds ratio of $PM_{2.5}$ exceeding 1000 μg/m^3 in households with more than two external windows and doors versus households with fewer external windows and doors for clean fuel households (solid line) and biomass households (dashed line). The shaded areas are 95% confidence intervals.

Table 1

Baseline characteristics of study households (N=257).

Household characteristics	**N (%)**
Primary cooking fuel type	
Biomass	40 (16)
Gas	164 (64)
Electricity	50 (19)
Kerosene	3 (1)
Cook stove characteristics	
Located inside the home	85 (33)
- of which are biomass users	16 (6)
Other potential sources of indoor $PM_{2.5}$	
Burn kerosene for any purpose (e.g. for heat, light or cooking)	119 (46)
Any cigarette smokers in household	73 (28)
Ventilation	
Mean number of external windows and doors	2.1
Mean floor area of dwelling	9.9 m^2

Table 2

Overview of PM measurements by fuel type and time of day.

	Mean minutes in a day over 1000 μg/m^3
By fuel type:	
- Principally use biomass	66
- Clean fuel users	35
By ventilation:	
- Two or more windows	34
- Fewer than two windows	53
By time:	
- 6am – 12am	7
- 12am – 6pm	7
- 6pm – 12pm	18
- 12pm – 6am	9
By use of kerosene:	
- No reported use	31
- Any reported use	51

Table 3
Model fit characteristics of the generalized additive model

The intercept for the model represents the odds of $PM_{2.5}$ concentrations exceeding 1000 μg/m^3 in households with two or fewer external windows or doors that do not burn biomass and do not use kerosene and therefore have no household source of particulates. The coefficient values are the exponentiated estimates from the final model and represent the mean odds ratio that $PM_{2.5}$ concentrations exceed 1000 μg/m^3.

Covariate	Estimate	p-value
Intercept	0.01	<0.001
Principally use biomass	2.0	<0.001
More than two windows – biomass users	0.8	0.23
More than two windows – clean fuel users	1.1	0.85
Any use of kerosene	1.4	0.01