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Biomass fuel use and the exposure of children to particulate air pollution in southern Nepal

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ABSTRACT

The exposure of children to air pollution in low resource settings is believed to be high because of the common use of biomass fuels for cooking. We used microenvironment sampling to estimate the respirable fraction of air pollution (particles with median diameter less than 4 μm) to which 7–9 year old children in southern Nepal were exposed. Sampling was conducted for a total 2649 h in 55 households, 8 schools and 8 outdoor locations of rural Dhanusha. We conducted gravimetric and photometric sampling in a subsample of the children in our study in the locations in which they usually resided (bedroom/living room, kitchen, veranda, in school and outdoors), repeated three times over one year. Using time activity information, a 24-hour time weighted average was modeled for all the children in the study. Approximately two-thirds of homes used biomass fuels, with the remainder mostly using gas. The exposure of children to air pollution was very high. The 24-hour time weighted average over the whole year was 168 μg/m^3. The non-kitchen related samples tended to show approximately double the concentration in winter than spring/autumn, and four times that of the monsoon season. There was no difference between the exposure of boys and girls. Air pollution in rural households was much higher than the World Health Organization and the National Ambient Air Quality Standards for Nepal recommendations for particulate exposure.

1. Introduction

Indoor air pollution is a major cause of ill-health in low-income countries. It is mostly due to the burning of biomass fuels (also referred to as "solid fuels"), a group of organic materials – particularly wood, dung, straw, and charcoal – used as a source of heat and light (Rehfuess, 2006). It is estimated that between one-third and half of the world's population use biomass as a source of energy because it is readily available and usually cheap (Torres-Duque et al., 2008). Globally, solid fuel use is estimated to cause 3.5 million premature deaths per year, around one million of which are attributed to acute respiratory infections in young children (Lim et al., 2012; Murray et al., 2012). The deaths occur predominantly in poorly resourced settings where an increased susceptibility to illness coexists with high levels of pathogens in the environment and reduced access to healthcare. As well as increased mortality, household cooking with solid fuels accounts for 4.3% (95% CI: 3.4 to 5.3) of Disability Adjusted Life Years lost worldwide (6% for children under 5 years old), while ambient air pollution accounts for a further 3.1% (95% CI: 2.7 to 3.4). These figures make indoor air pollution the third leading contributor to global disease burden, and the highest in South Asia (Lim et al., 2012). There is strong evidence linking solid fuel use to chronic obstructive pulmonary disease (Kurmi et al., 2010), pneumonia in children under 5 (Dherani et al., 2008), lung cancer (Kurmi et al., 2012), and tuberculosis (Sumpter and Chandramohan, 2013). There is also weaker evidence for a link with low birthweight (Pope et al., 2010) (Shah and Balkhair, 2011), anemia and stunting (Fullerton et al., 2008; Kyu et al., 2009; Rehfuess, 2006).

Incomplete combustion of biomass fuels in poorly ventilated houses produces domestic levels of airborne particles hundreds of times higher than commonly encountered outdoors (Fullerton et al., 2008). Indoor air concentrations of PM_{10} (particles with median diameter less than 10 μm) can be up to 10000 μg/m^3 during cooking (Rehfuess, 2006).

Biomass fuel usage is very common in Nepal, with estimates of use in 75% of households (Statistics, 2012), particularly in poorer areas outside

Abbreviations: GPS, Global Positioning System; LOD, limit of detection; PM, particle mass; TWA, time-weighted average.

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the major cities. The burning of biomass in Nepal has been shown to adversely affect lung function in young adults (Kurmi et al., 2013) and exacerbate respiratory disease in children (Bates et al., 2013). Despite its high prevalence and adverse health effects, most research takes fuel usage as a proxy for true exposure. In this study, we sampled the respirable fraction of particle mass (PM_4) for children aged 7 to 9 years in the microenvironments in which they spent time. We also collected data on fuel usage, household characteristics and children's time–activity patterns, to produce a time-weighted average (TWA) exposure.

2. Materials and methods

The study was part of a larger follow-up of children born after a randomized controlled trial in which pregnant women were allocated to multiple micronutrient or iron and folic acid supplements (Osrin et al., 2005). We attempted to find all the children from the trial at seven to nine years of age. Particulate matter concentrations were measured in a subsample and the data were used to model the likely exposure for all children based on household fuel usage and time–activity information. A 24-hour TWA exposure estimate was created for each child in relation to respirable particulate (<4 μm median aerodynamic diameter — PM_4). Sampling was carried out from December 2011 to December 2012. Questionnaire data were collected for all children in the cohort whom we were able to find.

2.1. Setting

The study was predominantly carried out in Dhanusha district in the Terai region that makes up the southern half of Nepal, bordering India. Nepal ranks 157th out of 186 countries in the Human Development Index and average life expectancy is 69 years (UNDP, 2013). A plain district with a population of 760 000, Dhanusha's economy centers on agriculture. The urban samples were taken in the district capital, Janakpur, which houses about one-eighth of the district population (Central Bureau of Statisics, 2012a). There are few asphalted roads, even in the city. Mechanized traffic consists mostly of motorbikes and small numbers of cars, tractors, trucks and buses.

2.2. Sampling strategy

Samples were taken at the following locations:

- Bedroom. A Casella Apex gravimetric sampler was placed in the room where the child slept, set to sample from late afternoon and collected first thing the following morning. For the first season we chose to sample in 40 houses, corresponding to 5% of the total expected sample number.
- Veranda. A TSI DustTrak monitor was placed in the veranda, approximately equidistant from the inside of the building and the outside. Sampling was done in the evening to coincide with the time that the child was normally on the veranda.
- Kitchen. An Apex sampler was placed in the kitchen about 1 m away from the stove for the period of cooking, and also when there was no cooking for a three-hour period (at least 1 h after cooking had ceased). The DustTrak was also used to collect seven 12-hour samples to look at changes in air pollution concentration over time.
- School. Four urban and four rural schools were chosen according to their accessibility and willingness to participate. Consent was taken from school principals prior to sampling. An Apex sampler was placed in a classroom chosen by the principal, during school hours, which varied from school to school and by season. Care was taken not to place it close to the door, windows, or blackboard. All classrooms were on the ground floor.
- Outdoors. Outdoor samples were taken by members of staff, close to their homes in eight rural and urban areas. An Apex sampler was kept in the garden or compound, as far away as possible from the house or adjacent houses.

To take account of seasonal variation in air pollution levels, we repeated the measurements three times over a year. Samples were taken during the winter season (December to March), the monsoon season (June to September), and the hotter spring and autumn seasons (April, May, October and November). We stratified our sample by urban or rural location as we thought the dust and traffic and the close proximity of air pollution from neighbors would make these locations different. We also stratified bedroom samples by ceiling type as different roof types were believed to allow different degrees of ventilation. We stratified the kitchen samples by the type of fuel used: biomass and non-biomass. We attempted to make the sample representative of all the children in our study. We chose houses to sample in by randomly ordering the first 100 children seen in the larger follow-up study, and proceeding down the list until the required number in each stratum was found. After assessing the results from the first season, the sampling schedule was adapted. Due to the lack of variation by roof type, the number of bedroom samples was reduced and the number of outdoor and kitchen samples increased. Sampling times and duration are shown in Table 1.

2.3. Time activity

During a pilot phase, field team members visited 40 families with children aged seven to nine years to establish the main locations that children spent their time in. The questionnaire was then administered to all 851 children in the cohort. A parent or guardian was taken through an "average" school day and asked to say where the child would be for most of the time in half-hour blocks over a 24-hour period. Children divided their time between five locations: bedroom/living room, kitchen, veranda, in school and outdoors. Periods in the kitchen were subdivided into time when cooking was taking place and time when it was not. A table was created for each child, summarizing the amount of time in each pre-determined location.

2.4. Gravimetric sampling

Gravimetric sampling was conducted in accordance with the "Methods for Determination of Hazardous Substances (MDHS) no. 14/3 (Health and Safety Executive, 2000) guidelines" (Health and Safety Executive, 2000), using the Casella Apex gravimetric sampler (Casella, Bedford, UK). New glass fiber 37 mm filters (Casella, Bedford, UK)

Table 1
Sampling times and duration.

Location	Number of samples	Average start time (range)	Average end time (range)	Average duration (minutes)	Total sampling time (hours)
Bedroom	96	15:49 (14:30 to 17:38)	09:35 (07:52 to 15:25)	1064 (854 to 1397)	1720
Veranda	31	16:53 (15:43 to 17:05)	19:53 (18:42 to 20:05)	180 (179 to 180)	96
Kitchen cooking	31	07:48 (07:00 to 08:50)	10:38 (09:20 to 11:59)	163 (60 to 202)	85
Kitchen no cooking	29	11:43 (09:41 to 15:04)	14:18 (13:17 to 18:04)	184 (180 to 229)	92
Kitchen 12 hour samples	7	07:24 (07:00 to 08:00)	19:24 (19:00 to 20:00)	720 (720 to 720)	96
School	22	09:26 (06:55 to 11:57)	13:55 (11:15 to 16:30)	275 (120 to 330)	101
Outdoors	38	07:11 (05:07 to 10:30)	19:02 (17:07 to 20:24)	725 (678 to 796)	459