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Using personal exposure measurements of particulate matter to estimate health impacts associated with cooking in peri-urban Accra, Ghana☆

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ABSTRACT

This study assessed personal exposure to $PM_{2.5}$ and the associated potential health outcomes in Accra, Ghana. The Household Air Pollution Tool model was employed to estimate health benefits attributable to various fuel use scenarios using user-derived and publicly available inputs, including the Global Burden of Disease data presented by the Institute for Health Metrics and Evaluation. This study assessed personal exposure for four fuel user groups: LPG-only, LPG and charcoal, charcoal only, and wood use alone or in combination with any other fuel. Ambient $PM_{2.5}$ concentrations were also assessed during the study period. The wood user group demonstrated significantly higher $PM_{2.5}$ exposure than the other three user groups, which all had average $PM_{2.5}$ personal exposure similar to the average ambient $PM_{2.5}$ concentration. The results of the exposure assessment imply that ambient particulate matter may drive the majority of $PM_{2.5}$ exposure in peri-urban LPG and charcoal using households in Accra and therefore for the majority of homes in Accra (~80% are non-wood users in urban Ghana), reductions in $PM_{2.5}$ exposure and associated health gains may require reducing ambient PM. From a study by Zhou et al., in Accra biomass burning accounted for 39–62% of total $PM_{2.5}$ mass in the kitchen in different neighborhoods. Road dust and vehicle emissions comprised 12–33% of $PM_{2.5}$ mass. This means that even if direct PM emissions are low from LPG and charcoal burning homes, homes using wood fuel to meet their household energy needs contribute to ambient PM, which influences the $PM_{2.5}$ exposure of their non-wood using neighbors.

Introduction

Approximately 3 billion people globally rely on dirty solid fuels to cook and heat their homes. Most households use inefficient stoves, such as three-stone fires, which incompletely combust solid fuels, releasing toxic substances (Bonjour et al., 2013). Adverse health effects have been well documented in studies of cookstoves and the associated kitchen and household air pollution (KAP and HAP, respectively). Exposure to HAP is now identified as the most important environmental risk factor for ill health in developing countries, resulting in an estimated 3.8 million premature deaths per year worldwide (WHO). DALYs sum the years of life lost due to premature death in the population and the years of life lived with disability for people living with a disease or resulting condition.

Further studies show that clean cooking interventions can reduce the risk of diseases related to household air pollution by creating access to improved cooking technologies, such as cleaner burning fuels or stoves that increase the completeness of solid fuel combustion. A methodology has been developed to standardize the quantification of health benefits from clean cooking interventions that reduce exposure to HAP (Pillarisetti, Mehta, & Smith, 2016). Under this new method, estimates of avoided premature death and disability are made by inputting personal exposure (PE) measurements before and after an intervention into the Household Air Pollution Intervention Tool (HAPIT) model, developed at the University of California, Berkeley. HAPIT outputs deaths and DALYs averted from an intervention, yielding a potentially tradeable commodity of aDALYs (averted disability-adjusted life years) (Pillarisetti et al., 2016).

In the Greater Accra region, 3.5% of people depend on wood and 45.4% depend on charcoal to meet their daily cooking needs. The introduction of clean and fuel-efficient cooking technologies to regions dependent on solid fuels is necessary to alleviate the associated negative health, environmental, and social impacts. In fact, the Ghanaian government has previously implemented programs to promote LPG use, and in the 2010 census, 41.4% of households in the Greater Accra area reported LPG as their primary fuel (Agbemabiese, Nkomo, & Sokona, 2012;

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Kemausuor, Obeng, Brew-Hammond, & Duker, 2011). Numerous other technologies have been designed and introduced in the region in an effort to provide access to cleaner cooking solutions for those still using solid fuels (Agbemabiese et al., 2012; Kemausuor et al., 2011). Performance of such cooking technologies has largely been determined in controlled testing environments. However, results from such controlled tests are often not indicative of real-world performance because they provide no information on user acceptability, making actual impacts difficult to extrapolate. Assessing cooking technologies in real-world settings is critical for understanding true performance, estimating the related impacts, and gauging adoptability of promising stoves. Here, we assessesed real-world exposure and usage patterns associated with different cooking technologies to better understand their potential health implications.

Methods

Study overview

Personal exposure to particulate matter under 2.5 μm ($PM_{2.5}$) was monitored for modeling health outcomes to produce an estimate of aDALYs under a scaled-up LPG program. $PM_{2.5}$ was selected for monitoring because it serves as a proxy for the complex mixture that makes up air pollution and is associated with a variety of adverse health effects (e.g. (Naeher et al., 2007)). The study also collected information on stove usage.

Peri-urban households were selected to represent Ghana's large, urbanizing population. Although these households have certain distinguishing characteristics, such as being located on the perimeter of the city and engaging in some agricultural practices, they do not have a distinct census classification. Rather they fall within the urban category in the Ghanaian national census, making their numbers difficult to estimate. Nationally, 50.9% of the population (24.7 million people) is classified as urban, while 90.5% of Greater Accra (3.6 million people) is listed as urban (Ghana Statistical Service (2010 Ghanaian Census, Citation: Ghana Statistical Service, 2012)). Households were selected to represent a cross-section of the expected fuel mixtures used for cooking in the region, based on surveys conducted before the start of measurements and from previous census results. Groups were identified as: 1. Exclusive LPG users; 2. LPG and charcoal users; 3. Exclusive charcoal users; 4. Any wood use

Due to budget constraints, a total sample size of 60 was selected with 15 households targeted for each of the four study groups.

Participant availability, geographic and seasonal considerations, and equipment failures resulted in 45 households/individuals being successfully sampled. Seven households were sampled from the LPG-only group, 18 from the LPG and charcoal group, 11 from the charcoal only group, and nine from any wood use group. Due to differences in fuel use reported during initial participant selection, and measured and reported fuel during the same period, some households were recatagorized during analysis.

During the monitoring period, three consecutive daily household visits allowed the following:

- Continuous 48-hour measurements of PE to $PM_{2.5}$ collected using gravimetric equipment in all households.
- 48-hour real-time measurements of PE to $PM_{2.5}$ collected using light scattering monitors in 50% of households.
- 48-hour stove usage of up to two of the most commonly used stoves in each home.
- Daily surveys of participant time-activity.

Over the entire study period, outdoor ambient $PM_{2.5}$ was measured by the Ghana Environmental Protection Agency (Ghana EPA) near study households to determine the influence of ambient air pollution on PE.

Inclusion and exclusion criteria

During household selection, the following inclusion criteria were used: the participant (1) was over 18 years of age, (2) was not pregnant, and (3) did not smoke cigarettes. Additional survey data was collected to understand the socioeconomic make-up of the selection pool. None of this information was used to screen participants from the overall potential pool.

Recruitment, consent, and stove types

Participant selection was challenging due to the difficulty of finding LPG-exclusive homes. A few homes declined to particpate due to scepticism about the study. A participant selection survey was administered in order to find a cross-section of socio-economically comparable homes in the same areas with the desired fuel(s) used. Representatives from Berkeley Air Monitoring Group (Berkeley Air) conducted an intensive in-country training for a field team of 6 and stayed through the first week of sampling to ensure a smooth study start up and to provide supervision and expert troubleshooting. The fieldwork occurred over a four-week span, which commenced on July 23rd and finished on August 18th, 2017. Stove types varied across the households in the study catchment area and included: three-stone fires; built-in, u-shaped mud stoves without chimneys; charcoal pot stoves (both cast aluminum and ceramic-lined sheet metal models); 1–4 burner LPG stoves; and in two homes, drum stoves (typically installed outdoors, for smoking fish) (Table 1).

Data collection device descriptions and protocols

Stove use monitoring

Stove Use Monitoring Sensors (SUMs) were deployed to assess usage of various cooking appliances throughout this study. The device used as a Stove Use Monitor was the commercially available iButton (model DS1922T, Maxim Integrated, CA), with a maximum temperature of 125 °C. iButtons were synced to local time and set to log an instantaneous temperature every ten minutes.

SUMs placement was guided by best practices described by Ruiz-Mercado, Canuz, and Smith (2012) and Mukhopadhyay et al. (2012). On traditional wood stoves, the SUMs were bundled in metal tape with insulating silicone pads and placed on the side of one of the stones in the three-stone fires, or next to a wall on the U-shaped mud stoves. For LPG stoves, the iButton was placed in between burners on the surface of the stove with a piece of silicone insulation and metal tape. For charcoal pot stoves, SUMs were placed on a handle or ear of the stove, again with insulation and metal tape.

Personal exposure monitoring

$PM_{2.5}$ was measured using both the gold standard gravimetric method (Ultrasonic Portable Air Sampler (UPAS), Access Sensor Technologies, Fort Collins, CO) and a real-time light scattering method, using a particle and temperature sensor (PATS+, Berkeley Air Monitoring Group, Berkeley, CA). The UPAS is a small, time-integrated monitor with a $PM_{2.5}$ cyclone, which secures over a cassette holding a standard 37-mm air sampling filter. All study participants' personal exposure was measured gravimetrically, and a subset (50%) were collocated with PATS+. $PM_{2.5}$ mass deposition of the UPAS filters was determined gravimetrically by weighing the PTFE filters before and after sampling in a constant humidity and temperature room on an electronic microbalance with 1 μg resolution (Mettler Toledo, OH).

Participants were outfitted with an apron designed to hold the UPAS and PATS+ on the center of the chest, with inlets exposed to the outside air near the breathing zone. The aprons were designed and