Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Household air pollution following replacement of traditional open fire with an improved rocket type cookstove

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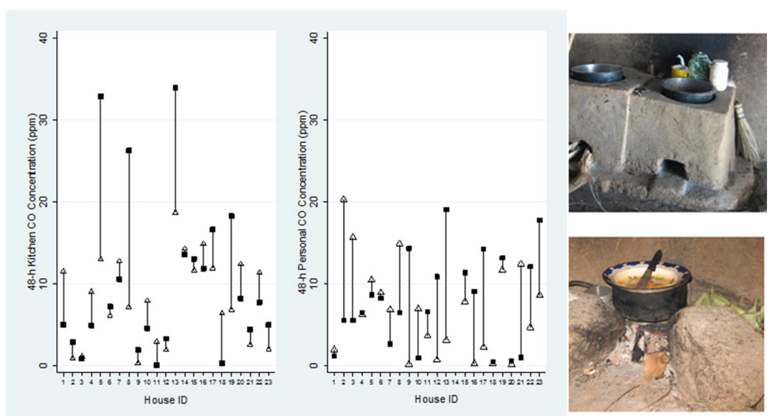
HIGHLIGHTS

- Non-significant reductions in 48-hour kitchen and personal CO concentrations observed after introduction of improved rocket mud stove.
- Larger, statistically significant, reductions in peak pollutant concentrations during cooking phase.
- Kitchen CO and $PM_{2.5}$ correlated well over averaging times approximating 1 day but was highly dependent on cooking phase.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 7 June 2016
Received in revised form 11 October 2016
Accepted 12 October 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Biomass fuel use
Household air pollution
Particulate matter
Carbon monoxide
Improved cookstoves
Kenya

ABSTRACT

Cooking with biomass fuel is an important source of household air pollution (HAP) in developing countries, and a leading risk factor for ill-health. Although various designs of "improved cookstoves" (ICS) have been promoted as HAP interventions in these settings, few of them have undergone in-field evaluation, partly due to the challenge of conducting field measurements in remote settings. In this study we assessed the change in carbon monoxide (CO) exposure following the replacement of the traditional three-stone stove with a popular ICS in 49 homes in Western Kenya. We also assessed the suitability of using kitchen CO as a proxy for kitchen $PM_{2.5}$. Reduction in 48 h mean kitchen CO was 3.1 ppm (95% CI: −8.1, 1.8) and in personal CO was 0.9 ppm (95% CI: −4.3, 2.6) following stove replacements. Overall, 48-h kitchen and personal CO exposures were lower after stove replacement (28% and 12%, respectively) but with wide confidence intervals that also suggested possible increases in exposure. There were statistically significant reductions in peak kitchen and personal CO concentrations represented by the 8-h 95th percentile: reductions of 26.1 ppm (95% CI: −44.6, −7.6) and 8.0 ppm (95% CI: −12.2, −3.8), respectively. This is equivalent to 53% reduction in kitchen CO and 39% reduction in personal CO.
We found good correlation between kitchen CO and $PM_{2.5}$ concentrations overall ($r = 0.73$, n = 33 over averaging periods approximating 1 day), which varied by time of day and exposure setting. These variations limit the applicability of CO as a proxy measure for $PM_{2.5}$ concentrations. A combination of interventions, including better

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http://dx.doi.org/10.1016/j.scitotenv.2016.10.233

designed stoves, improved ventilation and cleaner fuels, may be needed to reduce HAP to levels that are likely to improve health.

1. Introduction

Biomass fuel is the predominant form of cooking energy in sub-Saharan Africa and many other developing countries (IEA, 2015). Harvesting and use of biomass fuel has several implications for health, the environment, and human welfare (Bailis et al., 2003; UNEP and WMO, 2011; Parikh, 2011). According to the Global Burden of Disease report, the health burden associated with household air pollution from solid fuel use is 3.5 million (2.7–4.4 million) deaths and 4.5% (3.5–5.3) of global Disability Adjusted Life Years (DALYs) (Lim et al., 2012). It is now considered the leading risk factor for ill health in South Asia and number two in sub-Saharan Africa. Use of biomass fuels is estimated to increase with the rising population in sub-Saharan Africa (SSA) and South East Asia (IEA, 2011) Studies have also shown that households do not make a complete fuel switch even when income is not a constraint; instead they stack fuels and stoves (i.e. use both traditional and clean fuels and stoves) (Masera et al., 2000). Because biomass is likely to remain an important energy source in developing countries in the near term, promotion of clean cookstoves is warranted and in line with energy access targets under the UN Sustainable Energy for All initiative, Sustainable Development Goals, UN Foundation's Global Alliance for Clean Cookstoves (GACC) and the WHO (WHO, 2014; Griggs et al., 2013).

Several improved cookstove (ICS) projects have been initiated worldwide (Ruiz-Mercado et al., 2011); however, few have been evaluated on pollutant exposure reduction under actual use conditions. Although some field evaluations have been performed for clean cookstoves in Africa (see review in Ochieng et al., 2013a; de la Sota et al., 2014; Pennise et al., 2009), the data is still minimal compared to settings like China and Asia. Yet this is a region in which ICS are seen as the most feasible near term intervention to reduce health risks related to household air pollution (WHO, 2014). Poverty precludes clean fuel access for the majority of the population in the near term. Factors that have hindered air quality measurements in developing countries include high cost of monitoring instruments, limited infrastructure e.g. power supply for operating instruments, laboratory facilities, and expertise for processing and analyzing collected samples. Consequently indirect indicators of exposure such as fuel type, housing characteristics, time spent near fire or even presence of tears while cooking are common in the literature (Ezzati and Kammen, 2002; Ellegard, 1997).

Carbon monoxide (CO) has often been used as a surrogate for exposure to particulate matter with diameter < 2.5 μm ($PM_{2.5}$), the pollutant typically of interest due to the extensive evidence of associated health effects (Rückerl et al., 2011). CO, a single gaseous molecule, is relatively easy to measure compared to particles, a complex mixture. CO has been used as an indicator of biomass smoke exposure in various studies including the Randomized Exposure Study of Pollution Indoors and Respiratory Effects (RESPIRE) in Guatemala (Smith-Sivertsen et al., 2009). Although the two pollutants have generally had good correlation (Dionisio et al., 2008; Dionisio et al., 2012; Naeher et al., 2001; Smith et al., 2010), correlation coefficients have varied widely across studies, implying a possible influence of household and individual factors. These factors have not been adequately characterised however, as all previous evaluations have utilised time-integrated concentrations. Better understanding of factors influencing the correlation between CO and $PM_{2.5}$ can help identify conditions under which CO is an appropriate surrogate for $PM_{2.5}$ and predictor of health benefits of ICS interventions.

CO is also of interest in its own right as an exposure related to health effects. WHO has set guidelines for short-term exposure to ensure that the carboxyhaemoglobin level of 2.5% is not exceeded: 100 mg/m^3 (87.1 ppm) for 15 min, 35 mg/m^3 (30 ppm) for 1 h and 10 mg/m^3 (8.7 ppm) for 8 h (WHO, 2010). There is also increasing concern over health effects of chronic exposure to low CO concentrations, which may be associated with exacerbation of existing health conditions such as heart disease, neurological and psychological problems, and low birth weight (WHO, 2010). Indoor combustion of biomass leads to both high short-term and chronic exposures to CO.

The aims of this study were to assess (1) whether an improved cookstove, the rocket mud stove, is associated with lower kitchen concentrations and personal exposure to CO compared to traditional three-stone stoves; and (2) the correlation between kitchen $PM_{2.5}$ and CO over different averaging times and cooking conditions. We also explored the determinants of this correlation.

2. Materials and methods

2.1. Study site and population

The study was approved by the Research Ethics Committee of the London School of Hygiene and Tropical Medicine in the UK and by the Ministry of Higher Education, Science and Technology in Kenya. The study was conducted in Siaya County, located in south western Kenya. The County has an area of 1520 km^2, with a population of 493,326 (Kenya National Bureau of Statistic [KNBS], 2010). Biomass is the primary cooking fuel in the setting, with just 0.3% of the households having access to modern energy (KNBS, 2010). Fuel wood is mainly sourced from farms, bush lands and non-gazetted forests which cover an area of 463 ha and are rapidly declining. Because of high poverty rates, a switch to relatively expensive clean energy alternatives (e.g. liquefied petroleum gas) is unlikely to occur in the near term, making ICS attractive as a potential means to reduce exposure to air pollution in this region. Cooking is typically done indoors either in a kitchen attached to the rest of the house or in a separate kitchen. Most separate kitchens are poorly ventilated, with small round holes rather than windows that are designed to let in light rather than serve as ventilation.

The traditional stove is the three-stone fire, which is typically lit 3 times a day: for preparation of breakfast (between 6 and 8 am), lunch (12–1 pm) and dinner (7–9 pm). Outside these periods the stoves are generally not in use. The common meal in the region is vegetable or stew and *ugali*, a type of bread that is prepared by first boiling the water then gradually pouring in maize flour and stirring until it becomes a thick paste. The meal takes about 15 min to prepare and entails alternating between burning and smouldering fire, which can result in very smoky episodes. Ugali is prepared twice a day, both for lunch and evening meal. Although children are not carried on mothers' back during cooking as done in other settings, they tend to stay close to their mothers while they cook.

2.2. Improved stove programme

The rocket mud stove was promoted by Deutsche Gesellschaft für Internationale (GIZ) under the joint Dutch-German programme “Energizing Development” (EnDev), which aims to increase the number of people having access to modern energy. Among other measures, this is to be achieved through the promotion of modern cooking technologies in >20 project sites in Africa. The anticipated long term impacts of the programme include better health, reduction of wood cutting and climate protection. Prior to the stove programme evaluated in this study, the three-stone fire was the exclusive stove used in the region. The rocket stove project in Kenya was first piloted in 2005, and its