Energy for Sustainable Development 21 (2014) 51–59

Contents lists available at ScienceDirect

Energy for Sustainable Development

Indoor PM and CO concentrations in rural Guizhou, China

Line W.H. Alnes [a,b], Heidi E.S. Mestl [a], Janne Berger [a], Hefeng Zhang [c], Shuxiao Wang [c], Zeqin Dong [d], Liying Ma [d], Yu Hu [d], Wei Zhang [d], Kristin Aunan [a,b,*]

[a] Center for International Climate and Environmental Research — Oslo (CICERO), P.O. Box 1129 Blindern, N-0318 Oslo, Norway
[b] Dept. of Chemistry, University of Oslo, P.O. Box 1033 Blindern, 0315 Oslo, Norway
[c] State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, China
[d] Guizhou Research & Designing Institute of Environmental Science, 1 Tongren Road, Jinyang New District, Guiyang, Guizhou Province, 550081, China

ARTICLE INFO

Article history:
Received 10 September 2013
Revised 5 March 2014
Accepted 21 May 2014
Available online 17 June 2014

Keywords:
Household air pollution
Solid fuels
Particulate matter
Carbon monoxide
China

ABSTRACT

Household air pollution (HAP) from use of solid fuels varies greatly depending on stove technology, fuel, housing characteristics, season, and geographical area. Accurate information about indoor air pollution concentration as well as personal exposure is vital for more precise estimates of the health burden from HAP. We measured indoor fine particles ≤2.5 μm in aerodynamic diameter ($PM_{2.5}$) and carbon monoxide (CO) concentrations for 48 h in 179 homes in winter and 122 homes in summer in rural Guizhou, China. Furthermore, we measured personal CO exposure among 1796 women. The highest median [25th–75th percentiles] $PM_{2.5}$ kitchen concentrations were found in winter in biomass homes with an open fire (557 [303–882] μg/m^3) or a stove without chimney (533 [210–770] μg/m^3), while homes with a chimney stove had lower median kitchen concentrations (337 [212–1114] μg/m^3 and 371 [192–1208] μg/m^3 for biomass and coal, respectively). There was large seasonal variability with lower concentrations in summer for both $PM_{2.5}$ and CO. Indoor CO concentrations were more correlated with type of fuel than stove technology, with higher median winter concentrations in kitchens using biomass (2.4 [0.9–4.6] ppm) than coal (0.7 [0.6–1.5] ppm). Personal CO exposure was relatively low, with median 1.3 [0.9–2.1] ppm. Stove and fuel type, ventilation, kitchen configuration, occupation, secondhand tobacco smoke, time spent outdoors, and ambient temperature were all associated with personal CO exposure. We found that CO could not be used as a suitable proxy for $PM_{2.5}$ in this setting due to large heterogeneity in stove and fuel use within homes. We also found only a weak correlation between personal and indoor measurements, highlighting the importance of doing personal measurements in epidemiological research. Most households exceeded the PM_{10} Chinese indoor air pollution standard of 150 μg/m^3. Hence, continued efforts are needed to mitigate health damaging levels of HAP.

Introduction

Exposure to household air pollution (HAP) from use of solid fuels represents a major health risk on a global scale. According to recent estimates, 4 million people die prematurely each year due to exposure to air pollution from use of solid fuels for cooking, and HAP is the leading environmental risk factor for global disease burden (Lim et al., 2012). Several studies have made detailed measurements of household air pollution in rural China (Baumgartner et al., 2011; Edwards et al., 2007; Fischer and Koshland, 2007; He et al., 2005; Jin et al., 2005; Zhang et al., 2012) and other developing countries (Armendáriz-Arnez et al., 2008; Balakrishnan et al., 2004; Chengappa et al., 2007; Clark et al., 2010; Dionisio et al., 2012; Dutta et al., 2007; Ezzati et al., 2000b; Smith et al., 2010). Large cultural and climatic differences between populations lead to large differences in HAP, and measurements from one area are not necessarily representative for other areas. Due to the lack of reliable exposure information, previous global burden of disease estimates for HAP have used a simplified dichotomous exposure variable (using solid fuels for cooking or not). The most recent comparative risk assessment used an improved exposure metric (Lim et al., 2012), but relied on a single study in India to estimate concentration levels for the rest of the world (Balakrishnan et al., 2013). It is important to have reliable exposure estimates to be able to assess the health burden from HAP. Therefore, more field measurements are needed to add to the body of evidence of levels and drivers of HAP concentration and exposure.

As a part of a larger epidemiological study that examined the relationship between HAP exposure and health outcomes, we performed a series of air pollution measurements. Personal carbon monoxide (CO) exposure was measured for all participants, while kitchen and living room concentrations of particulate matter ≤2.5 μm ($PM_{2.5}$) and CO was measured in a 10% subsample of homes. By using these air pollution

* Corresponding author at: CICERO Center for International Climate and Environmental Research — Oslo, P.O. Box 1129 Blindern, N-0318 Oslo, Norway. Tel.: +47 22 85 87 50.
E-mail address: kristin.aunan@cicero.uio.no (K. Aunan).

http://dx.doi.org/10.1016/j.esd.2014.05.004
0973-0826/

measurements, we have assessed: (i) indoor $PM_{2.5}$ concentrations and main predictors; (ii) indoor CO concentrations and main predictors; (iii) personal CO exposures and main predictors; (iv) the correlation between indoor CO and $PM_{2.5}$ concentrations; and (v) the correlation between personal and indoor measurements.

Materials and methods

Study area

The study was conducted in Guizhou Province, in southwest China. This is the poorest province in China measured by GDP per capita, and is home to 35 million people (Guizhou Provincial Bureau of Statistics, 2011). Guizhou is a mountainous region ranging in altitude between 150 and 1700 m with a humid sub-tropical climate. The annual average temperature is 15 °C, ranging from 22–25 °C in July to 4–6 °C in January, usually necessitating heating in wintertime. 66% of the population lives in rural areas (Guizhou Provincial Bureau of Statistics, 2011). 90% of households used solid fuels in 2000 (ACMR, 2004), but, in the last decade, coal has been replaced with electricity or gas, and increasing numbers of rural households have installed biogas digesters to produce biogas from pig manure. According to survey data from 2010, 62% of households in the province used solid fuels for cooking, with 30% and 32%, respectively, using coal or biomass as their main fuel (ACMR, 2012).

Study population

A clustered household survey was conducted among 1796 women ≥30 years in 3 counties in Guizhou Province: Xiuwen, Congjiang, and Danzhai. The clusters were selected based on main cooking fuel: raw coal, biomass, or a mix of biomass and biogas, respectively. This was hypothesized to represent a gradient in household air pollution levels. A village functionary assisted with recruiting eligible participants. All women ≥30 years living in the study villages were invited to participate in the main study, while a 10% random subsample was selected for indoor air pollution monitoring. Informed consent was obtained from all women taking part in the study, and study approval was given by the Bureau of Health of Guizhou Province, Bureau of Environment Protection of Guizhou Province, and the Regional Committee for medical and health research ethics in South-East Norway. All villages were located in rural areas, and the women who participated in the study are among the more marginalized groups in Guizhou. Illiteracy rate among the participants was 73%. For comparison, 20% of the adult female population in Guizhou is illiterate (National Bureau of Statistics of China, 2010). 36% of the participants were Han Chinese, and the remaining 64% belonged to different ethnic minority groups (50% Miao, 13% Dong, 1% other minorities). Guizhou as a whole has an ethnic minority population of 36% (Guizhou Provincial Bureau of Statistics, 2011). The average number of residents per household was 4.7 (s.d. 1.6). The houses were usually made of brick or wood, and were relatively large (4.3 rooms per house on average, s.d. 1.6). About a third of the households had an open kitchen and living room configuration, whereas the remaining two-thirds had separate rooms for kitchen and living space. Both living room and kitchen had at least one stove, but stoves in the living room (often combined heating/cooking) were not always in use, especially during summer. The average number of stoves per household was 2.9 (s.d. 1.2). Though homes in Guizhou are heterogeneous in regard to configuration and stove/fuel use, we have attempted some generalizations. "Biomass" homes used a combination of wood logs, twigs and branches, and charcoal. They also used clean fuels like biogas and electricity, but they rarely used coal. "Coal" homes used only raw coal, supplemented by some electricity. More detailed information about stove and fuel combinations can be found in the Supplementary Information.

Personal exposure

Personal CO measurements on the 1796 participants took place between February–May 2009 and November–December 2009. The target measurement duration was 48 h. Occasionally the participants were unavailable when the investigator returned to collect the CO tube, in which case, the investigator would return later in the evening or the next day. The mean monitoring time was 52 (s.d. 4.4) hours. Most measurements lasted longer than 48 h, and only 20% was within 1 h of the targeted measurement duration of 48 h. The CO tube was attached to the participants clothing in the chest area during the day and placed near the bed while sleeping. 59 people were excluded because they had forgotten to wear the CO tube for the entire measurement duration, or they had lost the tube. 10 participants were smokers and were excluded from the study. The total number of personal CO measurements available for analysis was 1727. An interviewer administered questionnaire was used to collect information on pollution related variables such as participation in cooking activities, fuel used for cooking and heating, stoves used while monitoring, and smoking in the household during monitoring, housing characteristics, and socioeconomic variables.

Indoor air pollution measurements

A 10% subsample of the households in the main study was randomly selected for indoor monitoring. The monitoring took place in three phases, February–May 2009, September 2009 and November 2009–January 2010. November–March is defined as winter and April–October as summer based on measured night-time minimum kitchen temperature, which was usually well below 16 ºC in winter. The houses measured during the summer are a subsample of the houses measured in winter. Both kitchen and living room concentrations were measured, with the exception of September 2009 when only the kitchen was included. Coal using households were not measured during summertime. Seven villages in Danzhai, four villages in Congjiang, and two villages in Xiuwen county were selected for indoor monitoring to represent, respectively, biogas, biomass and coal using households. In all, 179 (33 biogas, 82 biomass, 64 coal) household measurements were done in winter and 122 (31 biogas, 91 biomass) in summer. $PM_{2.5}$ and CO was monitored for an average of 48 (s.d. 1.2) hours. Monitors were placed 1 m from the stove, 145 cm above ground, and at least 1 m away from any doors or windows.

Particle measurements

Indoor particulate pollution was monitored using the UCB-PATS photoelectric real time particle and temperature monitors developed at UC Berkeley (Berkeley Air, CA, USA). The UCB-PATS is a small, portable, battery-operated (9 V) data logging monitor for use in indoor environments in developing countries (Chowdhury et al., 2007). It uses a photoelectric (light scattering) detector and is capable of measuring $PM_{2.5}$ concentrations down to 50 μg/m^3. The photoelectric sensor is sensitive primarily to particles smaller than 2.5 μm. Light scattering devices require calibration for each pollutant source because different particles have different light scattering behavior. The UCB-PATS were factory-calibrated for wood smoke, but not for coal. The monitors were calibrated for coal smoke using co-location chamber tests as described in the Supplementary Information. UCB-PATS monitors have been used in several studies of HAP as they log minute-by-minute data, are relatively inexpensive, and are not intrusive for the participants. We did not compare the UCB-PATS to gravimetric measurements in the field, but performed calibration checks against gravimetric measurements in lab. Co-location tests showed good inter-correlation between the UCB-PATS both for biomass and coal with standard deviation 39 μg/m^3 for biomass. Due to lower sensitivity to coal smoke, the standard deviation for coal was 105 μg/m^3. The lower signal-to-noise ratio for coal implies that the coal measurements must be interpreted with care. No systematic errors were found.