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Estimating household air pollution exposures and health impacts from space heating in rural China

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ABSTRACT

Exposure to and the related burden of diseases caused by pollution from solid fuel cooking, known as household air pollution (HAP), has been incorporated in the assessment of the Global Burden of Diseases (GBD) project. In contrast, HAP from space heating using solid fuels, prevalent in countries at middle or high altitudes, is less studied and missing from the GBD assessment. China is an ideal example to estimate the bias of exposure and burden of diseases assessment when space heating is neglected, considering its remarkably changing demands for heating from the north to the south and a large solid-fuel-dependent rural population. In this study, based on a meta-analysis of 27 field measurement studies in rural China, we derive the indoor $PM_{2.5}$ (fine particulate matter with an aerodynamic diameter smaller than 2.5 μm) concentration for both the heating and non-heating seasons. Combining this dataset with time-activity patterns and percentage of households using solid fuels, we assess the population-weighted annual mean exposure to $PM_{2.5}$ (PWE) and the health impacts associated with HAP in mainland rural China by county for the year 2010. We find that ignoring heating impacts leads to an underestimation in PWE estimates by 38 μg/m^3 for the nationwide rural population (16 to 40 as interquartile range) with substantial negative bias in northern provinces. Correspondingly, premature deaths and disability-adjusted life years will be underestimated by approximately 30×10^3 and 60×10^4 in 2010, respectively. Our study poses the need for incorporating heating effects into HAP risk assessments in China as well as globally.

1. Introduction

Increased evidence suggests that $PM_{2.5}$ (fine particulate matter with an aerodynamic diameter smaller than 2.5 μm) exposure from household solid-fuel use is associated with an increase in the risk of cardiovascular and pulmonary diseases in rural China (Zhang and Smith, 2007). Household air pollution (HAP) from solid cooking fuel use is ranked by the Global Burden of Disease project as the second most important environmental risk factor for premature deaths in China, leading to 605 thousand premature deaths in 2016 (IHME, 2016). Population-weighted annual mean exposure to $PM_{2.5}$ (PWE, μg/m^3) in this risk assessment is estimated on the basis of cooking fuel types (Forouzanfar et al., 2016), whereas impacts of heating are not considered. This means an undifferentiated exposure level during heating and non-heating seasons.

Unlike other major countries relying on solid fuels, including India and sub-Saharan African countries where heating needs are rare, a substantial amount of solid fuels are combusted for heating in rural China, especially the northern parts (Duan et al., 2014). According to a nationwide residential energy consumption survey, space heating accounts for almost 50% of total residential energy use in China (Wei et al., 2016). For rural households without access to district heating, burning solid fuels in heating stoves or “kangs” in winter remains to be the most common home-heating practices, which are known for high emissions of various pollutants and smoke backflow even for the improved types (Chen et al., 2016a; Zhuang et al., 2009). Recent studies

Abbreviations: HAP, household air pollution; GBD, Global Burden of Diseases; $PM_{2.5}$, fine particulate matter with an aerodynamic diameter smaller than 2.5 μm; PWE, population-weighted annual mean exposure to $PM_{2.5}$; DALYs, disability-adjusted life years; HD, number of heating days; ALRI, acute lower respiratory infection; LC, lung cancer; COPD, chronic obstructive pulmonary disease; IHD, ischemic heart disease; PAFs, population attributable fractions; IER models, integrated exposure-response models; RR, relative risk; LPG, Liquefied Petroleum Gas; SNG, synthetic natural gas; WHO, World Health Organization

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have already revealed significant contributions of heating to ambient air pollution in winter, especially in northern China (Archer-Nicholls et al., 2016; Liu et al., 2016).

Evidently, space heating in winter will also contribute to indoor air pollution with more solid fuel combustion and worse ventilation (MEP, 2013). In addition, the amount of time people spend indoors, especially during the heating season, makes exposure to indoor pollutants an even more important concern. While several field measurement studies have reported increased indoor $PM_{2.5}$ concentrations and personal exposure levels in rural China in winter (Alnes et al., 2014; Baumgartner et al., 2011; Wu et al., 2015; Zhong et al., 2012), the heating contribution has not been incorporated, so far, into regional or nationwide assessment of indoor air pollution exposure and health impacts. In this study, we re-assess the PWE to HAP and quantify the bias if heating impacts were neglected, by differentiating indoor $PM_{2.5}$ concentration in heating and non-heating seasons. The exposures were calculated with the inclusion of time-activity patterns and an updated indoor $PM_{2.5}$ database with a close examination of the heating impact. Associated health impacts were also estimated and bias resulting from neglecting space heating was quantified.

2. Method

This study adopted the time-activity pattern method to estimate PWE from space heating in rural China at the provincial level from 1980 to 2012 based on an updated indoor $PM_{2.5}$ database. Premature deaths and disability-adjusted life years (DALYs) were calculated as metrics to assess the burden of diseases from HAP for the years of 1990, 1995, 2000, 2005 and 2010. Detailed methods are described below, and a flowchart of the assessment is attached (Fig. 1). Specifically, county-level PWE and burden of diseases were estimated for the year 2010 to characterize the spatial pattern.

2.1. Indoor $PM_{2.5}$ concentration

An indoor particulate matter level dataset was compiled using air pollution databases published by United Nations Environment Programme and World Health Organization (WHO), as well as updated data from field measurements published between 2009 and 2017. There were 501 publications from 2009 to 2017 that were identified from the Web of Science database relevant to indoor air pollution in China. Nine out of the 501 publications contain field measurements in rural areas and report indoor PM concentrations for households with a dominant fuel type. Measurements taken for dung cake, peat, and biomass pellet were excluded because these fuel types were not recorded in published energy databases (IEA, 2010; Wang et al., 2013), and their total consumption was assumed to be < 5% of rural residential energy consumption in China. In total, 27 studies were included in this updated dataset, covering 18 out of 33 provinces and municipalities in mainland China from both high and low space heating demanding regions. All the 27 studies were reviewed in depth and sampling details including sampled province, season, household fuel type (coal, crop residue, coal and clean energy), and indoor microenvironment (kitchen, living room, bedroom or not specified) were collected from the literature and statistically analyzed. For studies only reporting sampling periods without indicating if space heating was adopted, periods with monthly averaged

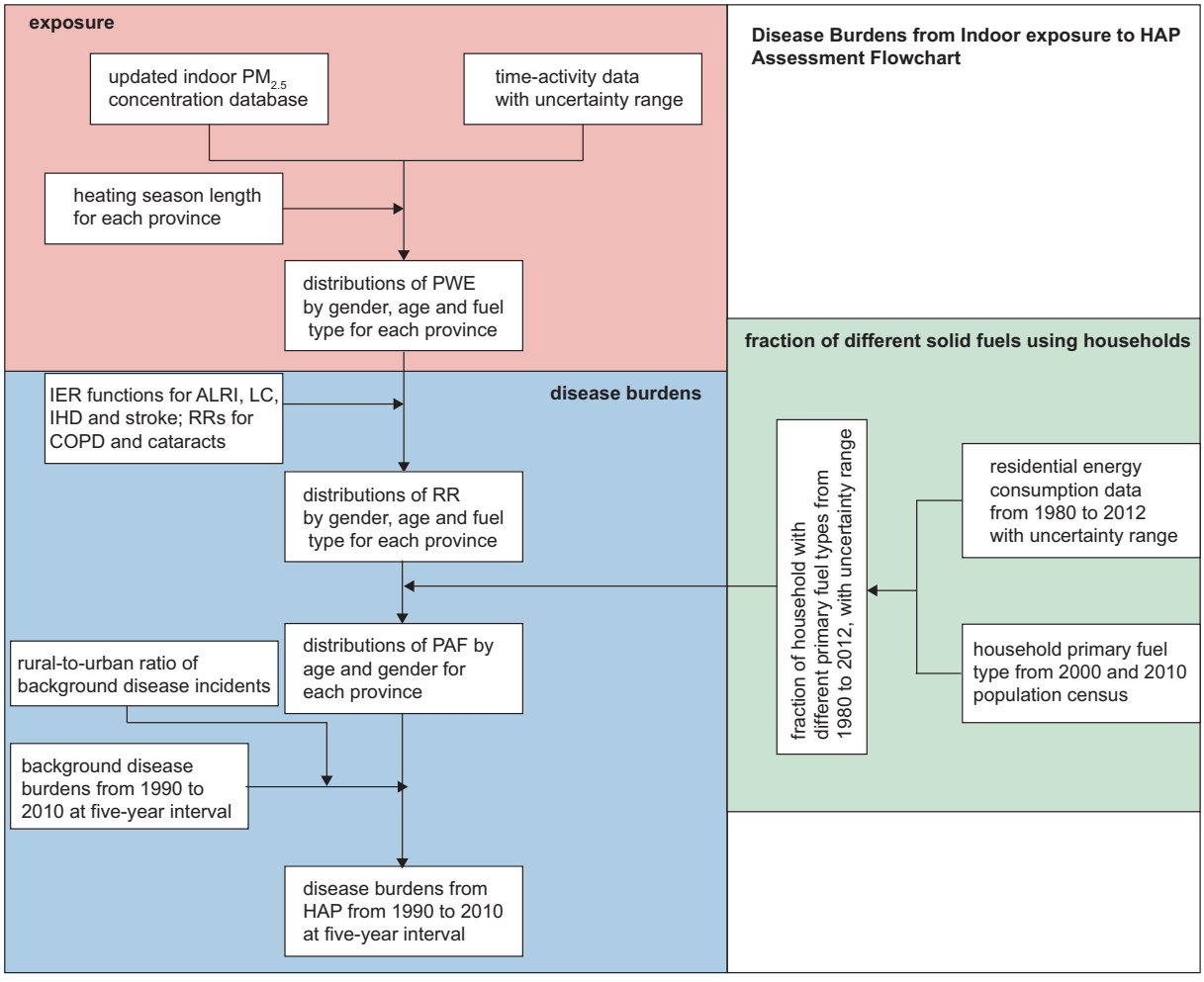

Fig. 1. Flowchart of health burdens from indoor exposure to HAP assessment.