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Trans-generational changes and rural-urban inequality in household fuel use and cookstove ventilation in China: A multi-region study of 0.5 million adults

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A R T I C L E I N F O

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A B S T R A C T

Background: Disease burden estimates related to household air pollution (HAP) relied on cross-sectional data on cooking fuel, overlooking other important sources (e.g. heating) and temporal-regional variations of exposure in geographically diverse settings. We aimed to examine the trends and variations of for cooking and heating fuel use and ventilation in 500,000 adults recruited from 10 diverse localities of China.
Methods: At baseline (2004–08) and two subsequent resurveys (2008–14), participants of China Kadoorie Biobank, aged 30–79, reported their past and current fuel use for cooking and heating and the availability of cookstove ventilation. These were compared across regions, time periods, birth cohorts, and socio-demographic factors.
Results: During 1968–2014, the proportion of self-reported solid fuel use for cooking or heating decreased by two-thirds (from 84% to 27%), whereas those having complete kitchen ventilation tripled (from 19% to 66%). By 2014, despite a continuing downward trend, many in rural areas still used solid fuels for cooking (48%) and heating (72%), often without adequate ventilation (51%), in contrast to urban residents (all < 5%). The large urban-rural inequalities in solid fuel use persisted across multiple generations and also varied by socioeconomic status, especially in rural areas.
Conclusions: Despite marked progress in fuel modernization in the last 50 years, substantial rural-urban inequalities remain in the study population, especially those who were older or of lower socioeconomic status. Uptake of cleaner heating fuel and ventilation has been slow. More proactive and targeted strategies are needed to expedite universal access to clean energy for both cooking and heating.

1. Introduction

Globally about 2.7 billion individuals are currently exposed to high levels of household air pollution (HAP) due to their reliance on polluting and energy inefficient solid fuels (e.g. coal and biomass) for cooking (Kurmi et al., 2008; Zhang and Smith, 2007; Pokhrel et al., 2015; IEA, 2015), In 2015, HAP accounted for an estimated 2.9 million premature deaths, most of which occurred in low- and middle-income countries (LMICs), including 0.6 million in China (GBD 2015 Risk Factors Collaborators, 2016GBD, 2015GBD 2015 Risk Factors Collaborators, 2016), where 450 million individuals are still relying on solid fuels for cooking (IEA, 2016). These estimates were, however, largely based on national modelling data with inadequate empirical evidence to capture the large regional variation in HAP exposure and changes over time (Bonjour et al., 2013).

Fuel use pattern has changed substantially in many fast-growing economies, including China. However, there is inadequate detailed inter-regional evidence on long-term trend and pattern of fuel use, particularly among population subgroups (e.g. by age and other socio-demographic characteristics). Several studies had attempted to examine the patterns of fuel use in China (Duan et al., 2014; Chen et al., 2016; Liao et al., 2016), but were based on short-term observations and

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mostly examined cooking fuel use after 1990's, with little information on heating fuel use and ownership of ventilated cookstoves, both of which contribute importantly to HAP exposure. Comprehensive assessment of contemporary and historical exposure to multiple sources of HAP is crucial to inform appropriate assessment of long-term health effects associated with HAP exposure and development of public health and environmental policies.

Using data from the China Kadoorie Biobank (CKB), an ongoing prospective cohort of 512,891 adults across ten diverse localities of China (Chen et al., 2005; Chen et al., 2011), we examined the patterns of cooking and heating fuel use and ventilated cookstove ownership over time and compared them by region, birth cohort, and selected socio-demographic factors.

2. Materials and methods

2.1. Study participants

The design and methods of CKB have been described in detail elsewhere (Chen et al., 2011; Chen et al., 2005). Briefly, 512,891 adults aged 30–79 years (mean 52 years; 59% female) were recruited in 2004–08 from ten localities (five rural counties [known by the name of the provinces]: Gansu, Henan, Hunan, Sichuan, Zhejiang, and five urban cities: Haikou, Harbin, Liuzhou, Qingdao, Suzhou [semi-urban]) across China, chosen from China's nationally representative Disease Surveillance Points system (Yang et al., 1997) to represent a diverse range of socioeconomic levels, risk exposures and disease patterns (Chen et al., 2011). At baseline, an interviewer-administered questionnaire collected information on demographic and socioeconomic status, lifestyle behaviors and medical history. Subsequently, two resurveys were undertaken in 2008 and 2013–14, involving 19,760 and 24,996 randomly selected surviving participants, respectively (see supplementary method 1 or visit http://www.ckbiobank.org for further details) (Chen et al., 2011). Ethical approval was obtained from relevant authorities in China and in the UK and all participants provided written informed consent.

2.2. Assessment of fuel use and cookstove ventilation

Throughout this study, fuels used for cooking and heating and cookstove ventilation were used as proxies for HAP exposure. At baseline, participants were asked to provide information relating to HAP exposures in each of their three most recent residences ('baseline residence'—the residence at baseline, 'penultimate residence'—the previous residence, 'antepenultimate residence'—the residence before the penultimate) (see Fig. A1 in Supplementary file), including duration of residence, cooking frequency (daily, weekly, monthly, never/rarely cook, no kitchen), primary cooking fuel (gas, electricity, coal, wood, other) for those who reported cooking at least monthly, winter heating use (yes, no), primary heating fuel if appropriate (district heating, gas, electricity, coal, wood, other), and cookstove ventilation availability (whether there is/was a chimney or extractor attached to cookstove(s) owned: 'complete' for all stoves, 'partial' for some stoves, and 'none') for those with a kitchen. The same questions were repeated in subsequent resurveys assessing recent exposure (in the past 12 months) in the participants' current residence. In most analyses, gas, electricity, and district heating (available in northern China only) were aggregated into 'clean fuels', as they are associated with lower emissions in the households (Gordon et al., 2014).

Based on the information from the three most recent residences recalled at baseline (defined as the 'informative recall period', which could date back as far as birth), we estimated the lifelong fuel use and ventilation history (or as long as possible) for five birth cohorts in the study population (1939 or earlier, 1940–49, 1950–59, 1960–69, 1970 or later). We also derived composite indicators on long-term HAP exposure to identify participants who consistently used solid or clean fuels, or had none or complete cookstove ventilation in all three most recent residences.

2.3. Datasets used for specific analyses

Individuals (n = 2303) with a recall period greater than their age were excluded from main analyses, leaving 510,588 participants at baseline. We further excluded those who did not cook regularly (n = 130,581), rather than including them in the unexposed group, for in China domestic cooking is predominantly done by females and such classification would distort the distribution of important gender-related socio-demographic characteristics (e.g. education) across exposure categories. Similarly, in the analyses on heating fuel we excluded all participants who had no heating in corresponding residences (baseline n = 130,992), primarily those from Zhejiang (n = 57,685), a coastal rural region, at baseline and first resurvey (where > 99% participants reported that they did not use heating) and those from Haikou (n = 29,632), situated in the tropical south where heating is not necessary. Lastly, we excluded those who reported using 'other' fuel for cooking (n = 199) or heating (n = 15). The final sample consisted of 377,280 participants for cooking-related, 290,280 for heating-related and 509,839 for ventilation-related analyses at baseline, with the corresponding numbers available for similar analyses on other time periods given in Fig. A2 in Supplimentary file .

2.4. Statistical analysis

Proportions (in percentages) of cooking and heating fuel type and cookstove ventilation availability at various residences were adjusted for age (5-year groups), gender and region structure of the CKB population as appropriate using direct standardization. They were then cross-tabulated by selected socio-demographic characteristics (age, gender, regions, education level and household income), and were plotted in stacked area graphs over five periods of residence (antepenultimate, penultimate, and baseline, first and second resurveys), with the median and inter-quartile range of *year started living* in each residence ($YSL_{median(IQR)}$) or *year of participation* in resurvey to indicate the period during which information on fuel use and ventilation availability in the study population was captured.

An age-at-risk analysis approach was used to examine the lifetime HAP exposure pattern by birth cohorts. First, total duration of exposure to each category of HAP was estimated by summing the reported number of years in each residence with that specific exposure. Then, the age period covering the duration of exposure was stratified into 5-year age bands from 0 to 79 years. The percentages of duration in each age band being exposed to each category of each HAP indicator were calculated adjusting for gender and region by direct standardization (see Supplementary method 2). Finally, we plotted these percentages, stratifying for birth cohorts against age to examine the variation of lifetime exposure patterns across different generations. Estimates in the oldest age band of the participants born in 1939 or earlier (75–79 years) are likely to be unreliable due to small sample size (n = 1305) and were therefore excluded from these analyses.

As a sensitivity analysis, we restricted to participants who provided complete lifetime exposure data and to 14,691 participants who were interviewed at baseline and at the subsequent two resurveys. All analyses were conducted in SAS version 9.3.

3. Results

Of the 510,588 participants with baseline data analyzed, the mean (SD) age was 51.6 (10.7) years, and the total recall period was 39.7 (14.5) years, with 80% of the information provided covering ≥70% of adulthood (≥15 years). By combining the baseline and the subsequent two resurveys (mean [SD] prospective period: 8.0 [0.8] years), the present study captured almost 50 years of fuel use and cookstove