Science of the Total Environment 512–513 (2015) 194–200

Contents lists available at ScienceDirect

Science of the Total Environment

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

Levels of $PM_{2.5}/PM_{10}$ and associated metal(loid)s in rural households of Henan Province, China

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HIGHLIGHTS

- PM and associated metal(loid)s exhibited seasonal variability.
- Using coal could result in more severe indoor air pollutants.
- Using electricity would effectively improve indoor air quality in rural China.

ARTICLE INFO

Article history:
Received 13 October 2014
Received in revised form 14 January 2015
Accepted 16 January 2015
Available online 23 January 2015

Editor: P. Kassomenos

Keywords:
Indoor air pollution
Solid biomass fuel
PM
Trace element
Rural area

ABSTRACT

Although a majority of China's rural residents use solid fuels (biomass and coal) for household cooking and heating, clean energy such as electricity and liquid petroleum gas is becoming more popular in the rural area. Unfortunately, both solid fuels and clean energy could result in indoor air pollution. Daily respirable particulate matter (PM ≤ 10 μm) and inhalable particulate matter (PM ≤ 2.5 μm) were investigated in kitchens, sitting rooms and outdoor area in rural Henan during autumn (Sep to Oct 2012) and winter (Jan 2013). The results showed that PM ($PM_{2.5}$ and PM_{10}) and associated metal(loid)s varied among the two seasons and the four types of domestic energy used. Mean concentrations of $PM_{2.5}$ and PM_{10} in kitchens during winter were 59.2–140.4% and 30.5–145.1% higher than those during autumn, respectively. Similar with the trends of $PM_{2.5}$ and PM_{10}, concentrations of As, Pb, Zn, Cd, Cu, Ni and Mn in household $PM_{2.5}$ and PM_{10} were apparently higher in winter than those in autumn. The highest mean concentrations of $PM_{2.5}$ and PM_{10} (368.5 and 588.7 μg m^{-3}) were recorded in sitting rooms in Baofeng during winter, which were 5.7 and 3.9 times of corresponding health based guidelines for $PM_{2.5}$ and PM_{10}, respectively. Using coal can result in severe indoor air pollutants including PM and associated metal(loid)s compared with using crop residues, electricity and gas in rural Henan Province. Rural residents' exposure to $PM_{2.5}$ and PM_{10} would be roughly reduced by 13.5–22.2% and 8.9–37.7% via replacing coal or crop residues with electricity. The present study suggested that increased use of electricity as domestic energy would effectively improve indoor air quality in rural China.

1. Introduction

Over the past decades, much attention has been placed on investigating, monitoring and regulating air pollution in the outdoor environment. There seems to be a general misconception that air pollution is only an outdoor phenomenon. A number of studies noted that indoor air can be many times more contaminated than outdoor air (Jiang and Bell, 2008; Wong et al., 2004). Indoor air pollution derived from solid fuels is the single largest environmental risk factor in China (Smith et al., 2004). Approximately 420,000 premature deaths occur annually due to use of solid fuels in Chinese households, which is 40% more than premature deaths (300,000) attributed to outdoor air pollution in Chinese cities (Cohen et al., 2004). It has been estimated that 4–5% of deaths in developing countries and approximately 3.5 million deaths per year in China

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http://dx.doi.org/10.1016/j.scitotenv.2015.01.041
0048-9697/

result from indoor air pollution (Mestl et al., 2007; Smith and Mehta, 2003). Moreover, people (especially women and children) spend majority of their time indoors and thus the potential health risks posed by indoor air pollutants are of great concern. Therefore, it is critical to characterize profiles and concentrations of health-damaging pollutants in rural households.

An overwhelming majority of China's rural residents use solid fuels (mainly including biomass and coal) for household cooking and heating (Smith et al., 2004). The pollutants produced from combustion of solid fuels include suspended particulates (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur dioxide (SO_2) and heavy metals (Clark et al., 2013). Combustion of biomass and coal is the dominant source of indoor air pollution in China (Ding et al., 2012; Zhang and Smith, 2007). The rural residents generally experienced a higher exposure to particular matter (PM) in indoor air than the urban residents, even though the outdoor air particulate levels in rural areas are much lower than in urban areas (Mestl et al., 2007). Adverse health effects resulted from household air pollution due to combustion of biomass and coal included respiratory illnesses, lung cancer, chronic obstructive pulmonary disease, weakening of the immune system, and reduction in lung function in China (Zhang and Smith, 2007).

With the rapid development of the economy and society, commercial energies such as electricity and liquid petroleum gas (gas) are becoming more popular in Chinese rural households. In 2010, 23% of rural households were reported to use clean fuels (gas or electricity) as their main cooking fuel (NBS, 2012). The use of multi-fuels is a common feature of domestic energy in rural China mainly due to fuel availability. There may be day-to-day or seasonal changes in emissions of indoor air pollutants because of changes in energy use patterns or housing conditions in rural China. It is recognized that understanding the patterns of exposure to PM and associated metal(loid)s is required to evaluate and design environmental health interventions, but only limited studies have been conducted to investigate the levels and temporal patterns of indoor air pollutants using different types of domestic energy in rural China.

Jiang and Bell (2008) indicated that levels of PM_{10} in rural kitchens are three times higher than those in urban kitchens during cooking in Liaoning Province. Compared with Guizhou and Shaanxi Provinces using coal as the primary domestic energy, both Inner Mongolia and Gansu Provinces using biomass as the primary fuel had the highest PM_4 concentrations (Jin et al., 2005). As the 3rd largest provincial population (94.06 million), Henan Province is also the 5th highest producer and consumer (283.7 million tons) of coal and produces the largest yield of winter wheat (31.77 million tons) in China (China Energy Statistical Yearbook, 2012; China Statistical Yearbook, 2013). For many years, both coal and crop residues have been, and still are the primary domestic energy in rural Henan Province. Unfortunately, the status of indoor air pollution in rural households in this province is still not clear. It is hypothesized that the levels of household $PM_{2.5}/PM_{10}$ and associated metal(loid)s (As, Pb, Zn, Cd, Cu, Ni and Mn) in rural households of Henan Province exceed China's indoor air quality standards and that there are seasonal variations of PM and the associated metal(loid)s in rural households using different types of domestic energy in the province.

The main objectives of the present work were to: (1) characterize $PM_{2.5}/PM_{10}$ and associated metal(loid)s (As, Pb, Zn, Cd, Cu, Ni and Mn) in rural households of Henan Province; and (2) investigate differences in $PM_{2.5}/PM_{10}$ and associated metal(loid)s among four types of domestic energy (crop residues, coal, liquid petroleum gas and electricity).

2. Materials and methods

2.1. Characteristics of the sampling houses

The present investigations were conducted in nine households in a village of Baofeng County (BF) and in three households in another village of Fangcheng County (FC), both from Henan Province (Fig. 1). The two villages are around 110 km apart. The selection of households was based on the following criteria: (i) Houses possess similar structures (number and layout of rooms) that are typical in the selected village; (ii) the stoves in the selected households are representative in the village. Coal is a primary fuel used by nearly all households for heating and by a majority of households for cooking in Baofeng County, which is mainly dependent on coal-mine exploitation and agricultural production. Crop residues are commonly used for cooking and heating in Fangcheng County, mainly dependent on agricultural production. Two kinds of clean fuels including liquid petroleum gas (gas) and electricity are also used in few rural households of Baofeng County for cooking recently. Representative households using the four types of domestic energy: crop residues, coal, electricity and gas were selected for sampling.

The structure of selected households in the two villages is similar, which is one-story consisting of a kitchen and living areas (with a sitting room, two bed rooms and a storage room), and a yard with area of about 40–50 m^2. Kitchens and living areas are usually separated and around 3–5 m apart. The sitting room has a door open to outside and is also connected with the two bed rooms by entrance. The average area of kitchen and sitting room is about 10–15 m^2 and 15–20 m^2, respectively. Cooking activities are usually limited in the kitchen. The cooking stoves using coal have no chimneys, while the cooking stoves using crop residues have chimneys. Ventilation in the kitchens is generally based on natural draft. There is also a heating stove with a chimney in the sitting room, which only operates in winter.

2.2. Collection of household $PM_{2.5}$ and PM_{10}

To ensure that the samples are representative of the rural households in Henan Province, three households were selected for each type of domestic energy used. At each of the households, four stationary active samplers (7388MAS aerosol sampler, Zhongshan SLC Environmental Technology Corp., China) were deployed, with two ($PM_{2.5}$ and PM_{10}) each in the kitchen and sitting room. In addition, two stationary active samplers were also deployed in outdoor in one of the three households which used the same domestic energy. A low volume air sampler was used, with a flow rate of 5.0 L min^{-1} (±5%). The sampler was placed at least 1.0 m away from the wall or windows and approximately 1.0 m from the stove in the kitchen and sitting room. Levels of outdoor $PM_{2.5}$ and PM_{10} were measured in the yard of rural households, approximately 1.0 m from the main house. Other criteria for selecting the sampling positions included the accessibility to electricity, the safety and stabilization of the samplers and avoidance of interference with household activities. All stationary monitors were placed on a flat surface at a height of approximately 1.2 m. During autumn (Sep to Oct 2012), the stationary sampling was conducted for nine consecutive days and the filters ($PM_{2.5}$ and PM_{10}) were changed and collected every three days, while during winter (Jan 2013), the sampling was done for six consecutive days and the filters ($PM_{2.5}$ and PM_{10}) were changed and collected every two days (Table 1). One sample of field blank was taken for each sampling day. During sampling period, people lived as usual except that they were asked not to smoke in the sampling room. The flow rate of the sampler was checked and recalibrated by adjusting the flow meter before and after sampling. All samplings were conducted during days with no precipitation and wind speed was less than 3 m s^{-1}.

The filters ($PM_{2.5}$ PTFE membrane, 46.2 mm in diameter, Whatman; PM_{10} QM-A quartz fiber filter, 47 mm in diameter, Whatman) were desiccated at 25 °C and relative humidity (40–50%) for at least 24 h and then weighed (0.001 mg precision, Sartious Micro, Japan) before and after sampling, respectively. The 24-h PM concentrations were calculated by dividing the blank-corrected increase in filter mass by the total air volume sampled. All of the sampled filters were sealed in a petri dish with parafilm and stored at −25 °C in dark until chemical analyses.