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Characteristics of indoor air pollution in rural mountainous and rural coastal communities in Indonesia

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HIGHLIGHTS

- We monitored the indoor $PM_{2.5}$ and CO concentrations in rural Indonesian households.
- The mountainous area has higher indoor air pollutions than those in the coastal area.
- The wood burnings in coastal area show more flaming than those in mountainous area.

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ABSTRACT

The increased use of biomass fuel use among rural Indonesian households for years despite national program on subsidized LPG fuel distribution pose threat of indoor air pollution for the householders. Indoor air pollution levels of $PM_{2.5}$ and CO in the kitchen of 40 households using the fuelwood as the main cooking fuel were measured in the same season in mountainous and coastal areas in Indonesia. The temporal variations of $PM_{2.5}$ and its size distributions were simultaneously measured using photoelectric UCB monitor and personal cascade impactor, respectively. While carbon monoxide (CO) concentrations were measured using USB-CO monitors. Household indoor air pollution in the mountainous area was generally higher than that in the coastal area. This is because the households in coastal area have higher kitchen volume (about three times), smaller ventilation area (about 1.7 times) and shorter cooking duration with wood fuel (0.6 times) than those in mountainous area. Yet, during cooking with fuelwood, the indoor $PM_{2.5}$ concentrations at the cook site showed almost comparable results for both sites. The wood stove burning in coastal area tended to be in flaming combustion than in mountainous area. This can be indicated by a higher fraction of finest particles in $PM_{2.5}$, a higher fraction of EC in $PM_{2.5}$ and a higher fraction of K^+ and Cl^- ions in $PM_{2.5}$ mass concentrations. The time-averaged CO concentrations for 22-h measurements at the mountainous area were higher than those in coastal area. The mountainous area showed higher positive correlation relationship between the measured concentrations of CO and $PM_{2.5}$ than those in the coastal area. The use of cleaner fuel, e.g., subsidized LPG fuel in rural area should be promoted and managed intensively in mountainous area than in coastal area to avoid people exposure of health damaging indoor air pollutants.

1. Introduction

Biomass solid fuels such as dung, wood and agricultural residues continue to be used as cooking fuel by nearly half of the world's population (Smith et al., 2004). Most of these people live in developing countries in Africa and Asia. Globally, in 2010, nearly three and a half million deaths were attributed to household air pollution from solid fuel use (Lim et al., 2012). Currently, fuelwood users in Indonesia are estimated to be 69% and 15% of total rural and urban people, respectively. Meanwhile, the percentage of poor Indonesian people to total population residing in rural areas was approximately 17% compared to 9% in the urban area (BPS, 2011a). These figures imply that not all fuelwood users are categorized as poor people.

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In Indonesia in mid-2007, the government launched a National kerosene conversion program, wherein each household requiring kerosene would receive a free LPG stove. This program was planned to be completed across Indonesia by the end of 2011 (Budya and Arofat, 2011). However, fuelwood users in rural areas also received free LPG stoves because of their low income. Irrespective of the provision of subsidized LPG fuel, some rural households continue to use fuelwood as their primary cooking fuel. As a consequence, these rural populations face potentially dangerous health impacts from fuelwood use.

Wood stove emission is the main source of kitchen-related indoor air pollution in many poor households in developing countries. The mass size distribution of indoor $PM_{2.5}$ from traditional wood stoves is dominated by the submicron particle range, i.e., aerodynamic diameter <0.25 μm (Armendariz et al., 2010). These particle sizes may pose toxic effects and efficiently evade the mucociliary defense system (Naeher et al., 2007). Therefore information on the size distribution of fine particles and their compositions related to wood stove burning emission is important to assess further health impacts. The mass size fraction of $PM_{2.5}$ emitted from wood stove combustion, in fact, depends on many parameters. The significant factors that may affect the emission include the type of wood stove, burning rate, type of wood, stove configuration, and moisture content (McDonald et al., 2000).

Generally, the burning condition (i.e., smoldering or flaming) of the biomass fuel is indicated by modified combustion efficiency, i.e., the molar ratio of emitted CO_2 to the sum of CO and CO_2 (Chen et al., 2007). However, several studies have also characterized the burning condition by analyzing the chemical compositions of particulate emissions.

For example Li et al. (2009) found that combustion efficiency can be improved by increasing air flow in cook stoves to promote the flaming phase, ultimately emitting high levels of black carbon. In contrast, during the smoldering phase of biomass burning, the organic carbon emission was relatively higher than that at the flaming phase (Reid et al., 2005). The relatively high content of potassium in the emissions also indicates flaming predominance in biomass burning (Echalar et al., 1995). Due to low burning efficiency, the emission of fine particles from traditional wood stove combustion usually is accompanied by CO emission. Jetter et al. (2012) tested 22 types of stoves through WBT testing and found that many stoves that had low CO emissions also had low levels of fine particles ($PM_{2.5}$).

Currently, few studies on indoor air pollution in the developing world have been done concurrently in mountainous and coastal rural areas. The characteristics of indoor air pollution in these two distinct areas are believed to be quite different because of the differing living environments, i.e., different meteorological conditions (e.g., ambient temperature and wind), land use, and topography. The purpose of this study is to identify the different characteristics of indoor air pollution level in distinctive locations through measurements of the indoor pollution levels ($PM_{2.5}$ and CO) of the household kitchens in mountainous and coastal areas of rural Indonesia. In addition, the size-segregated $PM_{2.5}$ concentrations at the cook site are evaluated to characterize the fine particle distributions from fuelwood burning. We will quantify the size-segregated carbonaceous components, i.e., organic carbon (OC) and elemental carbon (EC, i.e., black carbon), as well as inorganic water-soluble ions of indoor $PM_{2.5}$ related to fuelwood combustion. The time-averaged levels of $PM_{2.5}$ and CO are important in comparing the results with other studies dealing with biomass fuel use. The chemical characteristics (OC, EC, ions) will help to determine differences in burning conditions at locations with different characteristics (mountainous and coastal). Differences in the two regions can have an impact on burning conditions, emission characteristics, and also health exposure. By revealing these characteristics, it is expected that appropriate measures can be identified to reduce indoor air pollution in rural areas with different characteristics.

2. Methodology

2.1. Study setting

The study was undertaken in the same season (June–July 2011) at two different locations representing rural high-altitude and low-altitude regions in Indonesia. The mountainous rural area was in Lembang (Sunten Jaya village), West Bandung Regency, West Java Province, and the coastal area was in Juwana (Bakaran Wetan village), Pati Regency Central Java Province (Fig. 1). The Bakaran Wetan village is a semi-rural area located on the main north highway on Java Island. Based on a national survey in 2010 (BPS, 2011b), approximately 62.4% of respondents from 158,205 households in rural areas of West Bandung Regency still use fuelwood as the primary cooking fuel whereas 36.3% use LPG as the main cooking fuel. In Pati, however, the survey showed that out of 237,388 households, 47.35% cooked using wood for cooking whereas the remaining 51.7% used LPG. In addition, many households used dual fuels (LPG and wood) since the national program on conversion of kerosene to LPG was implemented in this area. We sampled 20 dual-fuel users (fuelwood as the main cooking fuel) randomly in both sites. This means we sampled 20 households in total for each site, for which we expected to obtain 40 data points. Table 1 summarizes the characteristics of the two villages gathered from the village office data and that obtained from measurements.

Indoor air concentrations were mainly measured in the kitchen and the living room (for control) in each household. In addition, we also measured $PM_{2.5}$ concentrations at the cook site, i.e., where the cooks do their cooking in front of the stove (the position approximately 1 m above ground and 60–80 cm from the stove perimeter). During sampling, the people were asked to conduct their usual activities including use (or non-use) of the LPG stove and to refrain from smoking in the kitchen. In addition to the daily cooking activities in the sampled households, data on housing characteristics, as well as cooking characteristics, were gathered. The cooking time was recorded from the ignition of the wood stove to the end of cooking activities. The volume and ventilation spaces were measured using metric tape, however, unspecified ventilation, such as porous spaces at the wall or roof, was neglected.

2.2. Measurements

Daily $PM_{2.5}$ and CO concentrations were measured every minute using a UCB (University of California Berkeley) monitor and USB (Universal Serial Bus)-CO monitor respectively, whereas the mass size distribution of $PM_{2.5}$ was measured using a cascade impactor. UCBs are a type of inexpensive particle monitors that are based on photoelectric principles and are manufactured by Berkeley Air Monitoring Group (the device name is now UCB-PTAS). Temporal variations of the $PM_{2.5}$ concentrations were monitored in the kitchen and the living room (as a control) using the UCBs. In the kitchen, the UCBs were hung in the middle of the wall in front of the stove, and in the living room, the UCBs were hung at the house pillar or at a wall in the middle of the living room. The device placement in the kitchen did not follow standard placement (i.e., at the combustion zone) as in previous studies (Armendariz et al., 2010; Dutta et al., 2007). The rationale for this placement derives from the idea of the room volume effect on the indoor $PM_{2.5}$ concentration because the two sites have different kitchen room volumes. Moreover, we put another device (the cascade impactor) at