Atmospheric Environment 89 (2014) 230–234

Contents lists available at ScienceDirect

Atmospheric Environment

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

Indoor air pollution in slum neighbourhoods of Addis Ababa, Ethiopia

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HIGHLIGHTS

- Average $PM_{2.5}$ concentration measured in homes using fuels exceed WHO guidelines.
- We examine differences in the $PM_{2.5}$ concentration from fuel types in urban homes.
- We compare the emission concentration between different stove types.
- The efficiency of traditional stoves is only about 15%.
- The use of clean fuels and efficient cooking stoves will improve indoor air quality.

ARTICLE INFO

Article history:
Received 21 June 2013
Received in revised form
1 January 2014
Accepted 3 January 2014
Available online 23 January 2014

Keywords:
Indoor air pollution
$PM_{2.5}$
Solid fuel
Stove type
Addis Ababa

ABSTRACT

An estimated 95% of the population of Ethiopia uses traditional biomass fuels, such as wood, dung, charcoal, or crop residues, to meet household energy needs. As a result of the harmful smoke emitted from the combustion of biomass fuels, indoor air pollution is responsible for more than 50,000 deaths annually and causes nearly 5% of the burden of disease in Ethiopia. Very limited research on indoor air pollution and its health impacts exists in Ethiopia. This study was, therefore, undertaken to assess the magnitude of indoor air pollution from household fuel use in Addis Ababa, the capital city of Ethiopia. During January and February, 2012, the concentration of fine particulate matter ($PM_{2.5}$) in 59 households was measured using the University of California at Berkeley Particle Monitor (UCB PM). The raw data was analysed using Statistical Package of Social Science (SPSS version 20.0) software to determine variance between groups and descriptive statistics. The geometric mean of 24-h indoor $PM_{2.5}$ concentration is approximately 818 μg m^{-3} (Standard deviation (SD = 3.61)). The highest 24-h geometric mean of $PM_{2.5}$ concentration observed were 1134 μg m^{-3} (SD = 3.36), 637 μg m^{-3} (SD = 4.44), and 335 μg m^{-3} (SD = 2.51), respectively, in households using predominantly solid fuel, kerosene, and clean fuel. Although 24-h mean $PM_{2.5}$ concentration between fuel types differed statistically ($P < 0.05$), post hoc pairwise comparison indicated no significant difference in mean concentration of $PM_{2.5}$ between improved biomass stoves and traditional stoves ($P > 0.05$). The study revealed indoor air pollution is a major environmental and health hazard from home using biomass fuel in Addis Ababa. The use of clean fuels and efficient cooking stoves is recommended.

1. Introduction

More than 3 billion people worldwide depend on solid fuels, including biomass (wood, dung and crop residues) and coal, for cooking and heating (Ezzati and Kammen, 2001). Biomass fuels are at the low end of the energy ladder in terms of combustion efficiency and cleanliness (Smith et al., 1983). Indoor air pollution was responsible for almost 2 million annual deaths and accounts for 2.7% of the global burden of disease (WHO, 2004).

Complex mixtures of gases and particles produced by combustion contaminate indoor and outdoor environments (Smith et al., 2000). Particulate matter in smoke has significant health impacts, particularly for women and children (Ezzati et al., 2002; Sood, 2012; WHO, 2011). Generally, particles classification is based on the aerodynamic properties of particles, which influence their movement and removal processes in air, as well as deposition and removal in the human respiratory tract. The concentration of particles with a diameter less than 10 μm, known as PM_{10}, is the most widely used indicator of indoor air pollution in developing countries. But $PM_{2.5}$ (fine particles

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http://dx.doi.org/10.1016/j.atmosenv.2014.01.003

with a diameter of 2.5 μm or less) has the greatest impact on respiratory health because these particles penetrate the bronchial and alveolar regions of the human body and the body is unable to remove them completely (Bruce et al., 2011).

Traditional fuels (mainly fuel wood and charcoal) supply over 70% of the household energy needs of Sub-Saharan African countries. Since most households use inefficient stoves, a significant proportion of the energy is lost due to poor combustion, causing emissions of pollutants responsible for high concentrations of particulate matter (Wood and Baldwin, 1985). The World Health Organization (WHO) reported 3.7% of the burden of disease in developing countries is associated with indoor smoke (WHO, 2007).

24-h average PM_{10} concentration, referring to the average of 24 hourly PM_{10} concentration measurements over the course of one day, in homes using traditional fuels, such as fuel wood and charcoal, range from 300 to 3000 μg m^{-3}, much higher than the US Environmental Protection Authority (US EPA) standard which is 150 μg m^{-3} (WHO, 2005). In households using an open fire, 24-h average PM_{10} concentration could exceed 20,000 μg m^{-3} (WHO, 2006). Biomass stoves frequently used in the developing world, although slightly more efficient than an open fire, have a low efficiency. Burning solid fuels using basic biomass stoves can produce concentrations of fine particulate matter 100 times higher than concentrations recommended by internationally recognised air quality standards, such as WHO standards set in 2011. In most cases, these stoves are not vented. Therefore residents, especially women and children, will experience greater exposure to indoor air pollutants from smoke. Even when stoves are vented, exposure is 10–30 times higher than levels recommended by health agencies due to emission leakage from the stoves and re-entry of smoke from outside (Smith et al., 2004).

A study conducted in households in a Guatemalan village using open fire indoors revealed $PM_{2.5}$ concentrations exceeded 5000 μg m^{-3} (Neaher and Smith, 2000). In Nepal, much higher concentrations, over 8000 μg m^{-3}, were measured in households with open fires. In households using kerosene, concentrations were more than 3000 μg m^{-3} (Lohani, 2011). In Zimbabwe concentrations of approximately 2000 μg m^{-3} were recorded (Mishra, 2003), while in Kenya, concentrations ranged from 300 to 15,000 μg m^{-3}, much lower than the values reported in other countries (Ezzati and Kammen, 2001).

Per capita energy consumption in Ethiopia is approximately 16 gigajoules (GJ) (World Bank, 2011). An estimated 95% of the energy supply in Ethiopia comes from biomass sources and, in 2007, indoor air pollution was responsible for more than 50,000 deaths and nearly 5% of the national burden of disease was due to solid fuel use (WHO, 2007). 85% of the population lives in rural areas in sub-standard housing with poor sanitation conditions (Kumie and Berhan, 2003).

The estimated energy consumption per household in Addis Ababa is approximately 7 GJ, slightly less than half the per capita consumption. Traditional fuels (fuel wood, charcoal and dung) meet about 75% of household energy needs. Kerosene, LPG and electricity provide the remaining 25%. In the last decade, kerosene use in Addis Ababa has declined considerably as a result of a doubling in the cost of kerosene, largely because of the removal of subsidies. At the same time, the price of electricity has declined by more than 50% and it is currently sold at approximately 75% less than the price of kerosene. Traditional fuel still accounts for more than half of household energy use, though consumption has declined by more than 20% (Asfaw and Demissie, 2012).

This study therefore presents the results from measurements of indoor pollution in Addis Ababa, focussing on concentrations of particulate matter in homes using fuel wood, charcoal and kerosene as fuel. Emphasis is given to $PM_{2.5}$ concentrations since the health impacts associated with fine particulate matter is a major concern.

2. Methods and materials

2.1. Description of the study area

The study was conducted in Addis Ababa, the capital city of Ethiopia, which has over 500,000 households with an average family size of 5. Addis Ababa is situated at the centre of the country at an altitude varying between 2200 and 2800 masl, between latitude 9.0300° N and longitude 38.7400° E. Average annual temperatures range from 8.2 °C to 25.1 °C (CSA and ICF-International, 2012). The study was conducted in households in poor and overcrowded districts. An estimated 80% of the population in Addis Ababa lives in poor districts which were selected to form the study area in this study (UN-HABITAT, 2007).

2.2. Data collection method

Measurements of fine particulate concentrations were conducted in selected households representative of residential conditions in inner city Addis Ababa that involved largely slum residences. Prior to measurements of particulate matter being taken, a questionnaire was completed to collect basic household data such as fuel used, stove type and kitchen conditions. WHO considers the health impacts associated with fine particulate air pollution as much more severe than larger particulate air pollution (WHO, 2006), therefore the study focused on $PM_{2.5}$ concentrations. 60 households in 4 sub-cities in Addis Ababa were selected for sampling.

Sampling was done with consideration of the basic household characteristics, such as fuel type, stove type and kitchen type. Households were selected using a cluster sampling method to ensure these basic characteristics were included. Clustering was essential to efficiently utilise the limited material and human resources available. It involved a 3 stage sampling scheme aimed at selecting 15 households in each sub-city. The first stage involved selecting sub-cities and 15 households per sub-city were targeted. In the second stage, districts within the sub-cities were selected targeting 5 to 8 households per district. In the third and final stage, a possible 60 households from 4 sub-cities in the selected districts were identified as sample households for indoor emission measurements. $PM_{2.5}$ monitors, as shown in Fig. 1, were placed in each household for 24 h to measure the concentration of $PM_{2.5}$ particles from cook stoves using biomass or kerosene as fuel.

The University of California at Berkeley Particle Monitor (UCB PM) uses a photoelectric detector which is sensitive to particle sizes corresponding to $PM_{2.5}$ (Litton et al., 2004). Particles of size less than 2.5 μm are thought to be most important for health (Edwards et al., 2006). The UCB PM has 2 independent sensors, ionisation and photoelectric light scattering chambers for measurement of particulate matters. All combustion-derived particles are nearly in the lower size range, and the photoelectric sensor is capable of detecting most of the emissions. The data is reported as mass concentrations in milligram per cubic metre (mg m^{-3}).

Data from the UCB PM was obtained at minute intervals over a 24 h period. Measurements were taken in each household near where cooking took place, or in the nearest room to the cooking location if cooking took place outside. Samplers were placed at approximately 1.5 m away from the stove and 1 m above the ground to measure $PM_{2.5}$ concentration and avoid damage to the sampler as shown in Fig. 1.