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Health risk assessment due to biomass smoke exposure in Indian indoor environment: An empirical approach using lung deposition model

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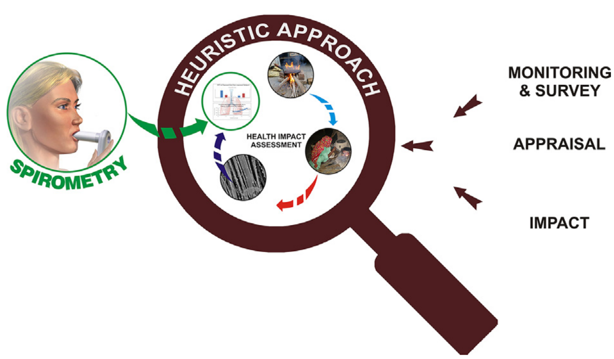
HIGHLIGHTS

- Amalgamation of methodologies to establish health risk.
- Use of scanning electron micrographs to understand particle morphology.
- Evaluation of deposition fraction using the ICRP model.
- Population attributable risk calculated using spirometry.

GRAPHICAL ABSTRACT



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ABSTRACT

The paper subsumes a framework that assesses health risk due to exposure to different fuel combustion through articulation of modern microscopic techniques, empirical equations, lung diagnostic tools and a pre-existing model that has been extrapolated to futuristic aspects (within controlled conditions). The framework was tested on 132 household cooks belonging to different age groups and using different types of fuel. The inhalable fraction released during fuel combustion varied in morphological characteristics and deposition site. Micrographs obtained using Scanning Electron Microscope (SEM) analysis of (biomass smoke) soot indicates aggregate formation attributing to a higher level of health risk. Further, abnormal ventilatory function along with higher risk ($RR > 1$) was more evident within biomass fuel users. The condition further exacerbates while using dung cakes due to high levels of emissions (294.3 particles/liter) that deposit in the upper respiratory tract (0.0899). Further, the population attributable risk percent (79%) calculated on the basis of cooking behavior suggests a 'rural culture' health determinant as clean fuel usage is not practiced as an outcome of low literacy and poor income in the region. These preliminary findings highlight the drudgery of impuissant women who are exposed to high particulate emissions on a regular basis which results in reduced lung function. Nevertheless, further cogitation is required to eliminate the limitations in this study and explore further linkages between exposure and vulnerable group to generate meaningful policy recommendations.

1. Introduction

The World Health Organization (WHO) reports 7 million deaths i.e. one in every eight death of the total global deaths resulted from

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exposure to air pollution (Landrigan et al., 2017; Song et al., 2017). This is now the world's largest environmental health risk, and in particular, regionally affects the developing nations of South-East Asia and Western Pacific regions more (Krzyzanowski & Cohen, 2008). A WHO report (2012) revealed, globally, 3.3 million and 2.6 million deaths were linked to indoor air pollution and ambient air pollution respectively (Barnett, 2014).

Around the world, approximately, 3 billion people rely on traditional cookstoves, out of which 2.7 billion cook using solid biomass fuels such as wood, dungcakes and crop residue (Chakraborty et al., 2014; Po et al., 2011; Bruce et al., 2000). Approximately, 80% of domestic energy in India is derived from biomass burning (Suresh et al., 2016; Holdren et al., 2000). Around 70–90% of rural households rely on such fuels, of which wood is the main component (Parikh, 2011; Malla et al., 2011). Even though biomass combustion releases hazardous pollutants, rural population still rely on it, unaware of the consequences posed by prolonged exposure to the pollutants (Singh & Jamal, 2012). Numerous studies have reported escalation in the levels of indoor air pollution in rural settings. Following this, in 2006, the WHO formulated WHO Guidelines for Indoor Air Quality for selected pollutants to provide a scientific basis for enforcing standards for various pollutants (Bruce et al., 2015).

It has been documented that socio-economic indicators influence exposure level and duration up to a large extent, accounting to the vulnerability of the exposed population (Laxmi et al., 2003). Exposure is highly influenced by the 'user' needs and habits. This includes income and expenditure, cooking pattern, food habits, family size, and time-activity pattern (Ballard-Tremeer & Mathee, 2000). During biomass burning, in addition to particulate matter (PM) and CO, several other hazardous pollutants such as oxides of nitrogen and sulfur, polycyclic aromatic hydrocarbons (PAHs) etc. are released concomitantly (Chakraborty et al., 2014; Mitchell et al., 2016). These pollutants result in several respiratory, cardiovascular, and eye-related diseases (Zhang et al., 2018). Most common of these are cataract, asthma, tuberculosis, chronic bronchitis, chronic obstructive pulmonary disease, wheezing, emphysema, vasoconstriction, increased plasma viscosity and systolic blood pressure (Bruce et al., 2000; Smith et al., 2004; Singh et al., 2014; Fullerton et al., 2008). In recent studies, the primary focus has been on respiratory illnesses due to deposition of particulate matter in different regions of the lungs (Kodgule & Salvi, 2012). Recent cookstove based studies have raised concerns about human health from the noxious effects of exposure to the finer fractions of PM which is often associated with hydrocarbon emissions from incomplete combustion of fuel (Arora & Jain, 2016).

Numerous studies worldwide have focused on source characterization and physical attributes of PM associated with biomass burning. However, only few studies have detailed account of deposition due to exposure to a varied particle size range. Knowledge of deposition of inhaled particles within the respiratory tract is essential to understand the toxic effect of airborne pollutants and quantify deposition (Yeh et al., 1976). Further, the pragmatic approach to study the influence of deposition requires vast knowledge of the mechanisms involved in deposition. Depending on the size and shape, the particles get deposited in the nasopharyngeal, tracheobronchial and pulmonary regions of the lung by means of four mechanisms: Impaction, Interception, Sedimentation, and Suspension (Tena & Clarà, 2012; Newhouse et al., 1976; Lourenço & Cotromanes, 1982; Heyder, 1982). Among the various factors that influence the deposition of inhaled particles, three major factors are- Aerosol Property (size distribution, concentration, particle hygroscopicity), Air Flow Property (lung capacity, breathing capacity), and Respiratory Tract (lung structure and morphology) (Tena & Clarà, 2012). Various models of inhaled particle deposition make use of generalized morphology and anatomy of respiratory tract to predict modicum of particle deposition caused by fundamental physical processes in the lungs. Several models generate estimates for health assessment and characterization, focusing primarily on dose-response based frameworks (Cao et al., 2017; Rosenbaum et al., 2008).

Following this, the aim of the paper is to ascertain the risk resulting from exposure to biomass smoke. The paper, firstly, draws comparison between the exposure variations among differential cook fuel users through lung deposition model. In the subsequent sections, the deposition results are validated through stochastic risk assessment and pulmonary function tests to establish vulnerability in the population.

2. Materials and methods

Smoke caused due to biomass combustion is a major threat to people involved in cooking on a day-to-day basis (Cincinelli & Martellini, 2017). There is a vast literature on biomass burning and health impacts, but, a majority of these studies follow an epidemiological approach (Piddock et al., 2014). Studying regional deposition in the lungs can help us to better understand the damage caused due to exposure. This study uses a heuristic approach to study deposition resulting from exposure to biomass smoke.

2.1. Research design

The presented work is a cross-sectional study over Kemla village (26°41′ N, 76°53′ E) in Karauli district of Rajasthan, India. As most people (85.04%) in the district reside in rural areas (www.census2011.co.in), the source of income is limited to such an extent that dependence on solid biomass fuel has become a necessity than a choice (Balakrishnan et al., 2004). This along with poor literacy among female (www.census2011.co.in) is a major reason behind the un-awareness of using biomass for cooking purposes (Akintan et al., 2018). Women are unaware of the adverse impact of prolonged exposure to biomass smoke (Parikh, 2011). The Annual Health Survey Report of Rajasthan (2012) showed the highest number of cases registered for Tuberculosis and Acute Respiratory Infection in the Karauli district (www.census2011.co.in). Simultaneously, the Biomass Assessment Report Rajasthan (2011) highlighted the overall high biomass consumption in Karauli (651,745 MT/year) and hence, the biomass consumption per area is also very high for Karauli (129.2 MT/km^2) in comparison to that of Rajasthan (81.91 MT/km^2) (Rajasthan Renewable Energy Corporation Ltd., 2011). High dependence on biomass fuel adds to the susceptibility and, thereby, the vulnerability of the women.

The study draws a comparison between the exposure and deposition among different cook fuel users and alterations in the lung capacity of the examined population (Fig. 1). The particles emitted from combustion of cooking fuel were monitored using aerosol spectrometer and further analyzed for its morphological characteristics using the scanning electron microscope. Further, particle characteristics were fed into the model to obtain the deposition fraction in different regions of the lungs. Lung function measurement was conducted among women belonging to different age groups using biomass and LPG as cook fuels. Women who volunteered to participate in the study were examined using spirometer.

2.2. Air sampling and SEM viewing

The GRIMM Aerosol Spectrometer 1.108 was used to monitor particles released during fuel combustion. It is a portable instrument well-suited for the remote study location (Grimm & Eatough, 2009). The sampling was carried out in May 2017 for four consecutive days, 18-h each day encompassing the cooking cycle; a total of four different fuel types was monitored. The air flow was set to 1.2 Lpm. The sampler was placed at a distance of 1 m from the stove and at an approximate breathing height of 0.76 m to match the exposure of women during cooking (Balakrishnan et al., 2004). The soot deposited on the filter paper during the cooking cycle was analyzed after appropriate pre-processing (Sachdeva & Attri, 2008). Uniform distribution of particles was assumed and small fragments were cut and mounted on the aluminum stub for sputter coating (Agrawal et al., 2011). Sputter coating was