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Characteristics of indoor air pollution and estimation of respiratory dosage under varied fuel-type and kitchen-type in the rural areas of Telangana state in India

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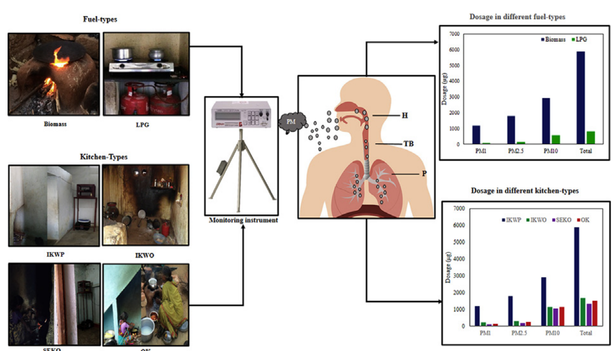
HIGHLIGHTS

- Characteristics of IAP in rural households under varied fuel and kitchen-types.
- Seasonal analysis of PM_{10}, $PM_{2.5}$ and PM_1 with biomass, LPG and biomass-LPG combine in indoor kitchens and outdoor kitchens.
- Estimation of respiratory dosage for different subjects i.e, women, young children and the elderly using MPPD computation model and measured concentrations.
- Comparison of PM dosage for varied fuel-types and kitchen-types.

GRAPHICAL ABSTRACT



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ABSTRACT

Indoor Air Pollution (IAP) is one of the top environmental risks in developing countries including India, with more than a million deaths annually, predominantly through Particulate Matter (PM) exposure. The current study deals with the measurement of PM concentrations in rural households under varied fuel and kitchen-types, evaluation of the indoor air pollution (IAP) characteristics and estimation of respiratory dosage for the different subjects (women, young children and the elderly). Monitoring of particulate matter (PM) was carried out during summer, monsoon and winter season with biomass, LPG and combine of biomass and LPG being used as fuel for cooking. Furthermore, different types of indoor kitchens (with partition and without partition) and outdoor kitchens (separate enclose kitchen and open kitchen) were also considered as kitchen type along with fuel are two crucial factors contributing to IAP. Deposition fractions were calculated using Multiple Particle Path Dosimetry (MPPD) to study the deposition patterns in different parts of the human respiratory tract (HRT) – head, tracheobronchial and pulmonary for women, young children and the elderly people. Dosage of particulate matter was calculated by inputting the recorded PM measurements, a comparison made for biomass-LPG and dosage intensification due to the kitchen-type presented. While the biomass households exhibited high levels of dosage (1181.4 to 5891.7 μg) against the LPG households (89.9 to 811.2 μg), the indoor kitchen types exhibited a maximum intensification of 10.6 times than outdoor kitchens with the same fuel. This study not only establishes the IAP characteristics but also quantifies the role of fuel-type and kitchen-type in IAP. The study also indicates various measures that could be deployed to reduce dosage and thus minimize the health risks.

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1. Introduction

Indoor Air Pollution (IAP) is primarily generated from incomplete and inefficient combustion of solid fuels. It has become a leading health risk across the world (WHO, 2009) with accounting for 3.5 million premature deaths globally every year (Lim et al., 2013). IAP is predominant in rural areas where solid fuels such as agricultural residue, dung cakes and fuel wood are used extensively due to their accessibility and affordability (Menon, 1988; Saksena et al., 1992; Parikh et al., 2001; Balakrishnan et al., 2004; Massey et al., 2013). Prolonged human exposure to IAP especially the fine and ultrafine particles has an increased risk of health: respiratory tract infections, exacerbations of inflammatory lung conditions, cardiac events, stroke, eye disease, tuberculosis (TB) and cancer (Mishra et al., 1999; Smith, 2000; Dutta et al., 2012). The health effects are intensified by the presence of toxic substances such as elemental carbon, poly aromatic hydrocarbons (PAH) in fine and ultrafine particles (Andreae and Merlet, 2001).

IAP is dependent upon multiple determinants such as type of fuel used for cooking, varied types of kitchen set ups, structural characteristics of houses, household ventilation, location of the house, geographical conditions and exposure time (Begum et al., 2009; Balakrishnan et al., 2013). Among these factors, type of fuel and varied kitchen setups affects IAP levels significantly (Balakrishnan et al., 2004; Rohra and Taneja, 2016; Sidhu et al., 2017). Exposure assessment of susceptible people under various IAP determinants is essential in determining the potential health hazard. This assessment can be carried out either by personal monitoring or area monitoring supplemented with questionnaire survey and time activity patterns (Colbeck and Lazaridis, 2010; Sidhu et al., 2017). It can be further developed into dosage of particles in lungs and deciphered to predict the associated health risks (Varghese et al., 2005). The model chosen for this study is the Multiple Particle Path Dosimetry (MPPD) that is extensively used to study deposition fraction of particles in different regions of the lungs as it takes into consideration asymmetric branching pattern of the lungs which is more realistic for studies related to particle dosimetry (Hussain et al., 2011; Menon and S. Nagendra, 2017).

Several studies have been carried out to understand IAP levels in rural India. However, most of the studies have been limited to the villages located in the Indo-Gangetic plain (IGP) of North India (Awasthi et al., 2010; Massey et al., 2013; Pachauri et al., 2013; Rajput et al., 2014) and very few studies in south India (Parikh et al., 2001; Balakrishnan et al., 2004; Satsangi et al., 2014; Aung et al., 2016). Since IAP varies significantly with climatology, geography, population and fuel usage, the disparity in terms of the quantum of the studies between south and north India provides an opportunity to make villages in south India as a subject for the current study. Also, very few studies are reported on particulate respiratory dosage on woman especially during cooking in LPG households of an urban setups (Varghese et al., 2005). Thus, the objective of this study is to characterize PM concentrations in varied fuel-kitchen setups followed by estimation of respiratory dosage for the different subjects (women, young children and the elderly) and associated health impacts.

2. Materials and methods

2.1. Setting

The study site was Kishannagar village in Mahbubnagar district of southern Telangana, India (17.3850° N, 78.4867° E). The selection of the village was based on key factors like fuel usage, socioeconomic status, structural characteristics of households and climate as well as the high biomass usage among its households (80.5%) along with LPG (17.7%) (Census, 2011). For this study, data from the last census in 2011 has been used. In addition, questionnaire survey was carried out (Table S1 in Supplementary Information (SI)) to estimate the data for the year 2016. Although the survey showed a decline in the percentage houses using fire wood, it concurred with the census on fire-wood being the primary fuel in these areas. The study site has a tropical climate which is representative of villages in South India. The study was conducted during different seasons namely – winter, summer and south-west monsoon (season classification as per Indian Meteorological Department (IMD)).

2.2. Monitoring and data collection

2.2.1. Instrumentation and data analysis

Air samples were captured using a 16-channel optical particle counter (Model 1.108, Grimm Labortechnik Ltd., Ainring, Germany) that measures both number and mass distribution of particles ranging from 300 nm to 20 μm using light scattering technology (single particle count) where in a semiconductor laser serves as the light source. The instrument was calibrated periodically with reproducibility of $\pm 2\%$ so as to ensure the correctness of data collected. All the necessary background and flow checks were carried out for the instrument prior to each monitoring. The instrument was kept at an obstruction free spot for a period of 24-h in each household and at a height of normal human respiration levels (~1.5 m). The PM data collected at 1-minute resolution was extracted using the instrument software and the data was further analyzed using origin pro (8.5 version) and Microsoft excel (MS office 2013).

2.2.2. Monitoring campaign

Households selected for monitoring were based on aforementioned IAP impacting factors such as type of fuel and type of kitchen. The four common kitchen types (Fig. 1 and Fig. S1 in SI) present in the study site are namely: Indoor kitchen with partition (IKWP); Indoor kitchen without partition (IKWO); Separate enclosed kitchen outside the house (SEKO) and Open kitchen (OK) (means open-air cooking). The monitoring campaign was carried out in 40 households during summer season (18th April–31st May 2016) and winter season (8th December 2016–25th February 2017) and in 20 households in monsoon season (12th June–14th July 2016) with continuous sampling in batches of 4–5 days followed by 1–2 days break for maintenance of equipment. Of the 40 households monitored during summer and winter, 30 operated on biomass (wood 90%, dung cakes 5% and agricultural residue 5%), 6 on LPG and 4 on a combination of biomass and LPG. In the monsoon season, out of the 20 households 12 operated on biomass, 2 on LPG and 4 on a combination of biomass and LPG.

2.3. Particle dosimetry model

The most common metric used to demonstrate deposition in human anatomy mainly head (H) tracheobronchial (TB) and Pulmonary (P) of human respiratory tract (HRT) is Deposition fraction (DF). DF is the fraction of the number of inhaled particles deposited in HRT. It is a function of anatomy of lungs, breathing rate, tidal volume, Mass Median Aerodynamic Diameter (MMAD) and Geometric Standard Deviation (GSD). DF could be calculated by different mathematical models such as International Commission on Radiological Protection model (ICRP), the National Council on Radiation Protection and Measurements (NCRP) and MPPD. The ICRP 66, first developed in 1994 is a semi empirical model consists of algebraic equations derived from fitting experimental and theoretical results. This model considers simple morphometric structure of the lung and it adopted single path for estimating deposition in different lung regions (ICRP, 1994; Jarvis et al., 1996). The model ignores the presence of the branching structure of the lungs and naturally occurring structural elements of lung. Therefore, model estimates are less realistic in nature (Hofmann, 2011; Oldham and Robinson, 2007). On the other hand, MPPD model is single and multi-path model based on actual measurements of single airways and represents the asymmetric branching pattern of the lung. Therefore, the model estimates are more realistic and provides better assessment of dosage and of health