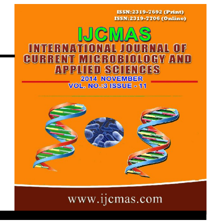

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Original Research Article

Indoor Air Quality in Rural Residential Area - Pune Case Study

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A B S T R A C T

Keywords

Indoor Air Quality, MiniVol (Airmetrics) sampler, Rural, Residential area

Several studies have shown that indoor air pollution can trigger asthma attacks and can be detrimental to respiratory health status. Also indoor air pollution contains a variety of health damaging air pollutants. Cooking fuels are the major sources of indoor air pollution. This study aims to compare particulate matter (PM2.5 and PM10) levels from rural kitchens using diverse cooking fuels. Particulate matter levels were measured in 33 rural representative homes. Amongst which 13 use chullah, 10 houses use kerosene stove, 5 houses use LPG stove and 5 houses use combination of cooking media. Indoor air was passed through 47mm quartz filter paper using MiniVol (Airmetrics) sampler at steady flow rate of 5 l/min for 24 hours. The mass of the PM2.5 and PM10 particles were analyzed gravimetrically using an ultra-sensitive weighing balance with least count 1µg. Higher particulate concentrations were observed in houses using chullah (PM2.5–1218µg/$m^3$and PM10–2993µg/m^3),compared to kerosene stove (PM2.5 - 416µg/$m^3$and PM10 - 491µg/m^3) and LPG stoves (PM2.5–122µg/m^3 and PM10–341µg/m^3) respectively. Comparing with National Ambient Air Quality Standards, observed levels found to be 81.8% and 97% of times above for PM2.5 and PM10 respectively. People living in houses using chullah and kerosene stoves are subjected to significantly increased risk of adverse respiratory health effects.

Introduction

While most media attention has focused on outdoor air pollution in the last few years, indoor air pollution is typically under-reported and less regulated than its counterpart (Ott and Roberts, 1998; Smith 1996a, 1993). A cursory glance at news reports and government reports in recent years on buildings with poor Indoor Air Quality (IAQ) suggests that the number of IAQ-related health complaints, and therefore, the costs of insurance and litigation to redress these problems, is significant, and perhaps rising (Federal Register, 1994; GAO, 1999).

Environmental Protection Agency studies of human exposure to air pollutants indicates that indoor levels of pollutants may be 2–5 times, and occasionally more than 100 times, higher than outdoor levels. These levels of indoor air pollutants may be of particular concern because most people spend about 90% of their times indoor. Research has shown greater exposure to indoor air pollutants in economically developing countries based on income (Smith *et al.,* 1986, 1996b, 2000), and in some cases greater occupational exposure to air pollutants for those in lower income brackets (e.g., Rotko *et al.,* 2000). In addition to exposure, baseline health status and health-related behaviors differ by SES; for example, smoking (CDC, 2005; Watson *et al.,* 2003; Smith, 1993) and physical activity (Giles-Corti and Donovan, 2002). A research discussed in line with SES and health, as well as a summary of studies of socioeconomic factors and particulate matter is given in O'Neill *et al.* (2003).

Figure 1 gives graphical status of worldwide household fuel usage Where China being largest in solid fuel consumption includes biomass and coal. Western countries use fairly large amount of non-solid fuels as compared to the Asian countries wherein India contributes about 25% of households use non-solid fuels (Reddy *et al.,* 1997).The health risk from exposure to particulate air pollution by applying the mean risk per unit ambient concentrations based on the results of some urban epidemiological studies (Smith 1994; WHO 1992, 1997; Hong, *et al.,* 1997; Mishra *et al.,* 1999). The range of risk was found to be 1.2–4.4% increased mortality per 10 μg/m^{3}incremental increase in concentration of respirable suspended particles (PM10).

Children may be more susceptible to environmental exposures than adults, and, due to their developing systems, particularly vulnerable to their effects. About 8.9 million children in the United States, and more than 12.4 million people total, are affected by asthma each year. The largest Black Carbon emissions were from fuel wood (75%), with lower contributions from dung cake (16%) and crop waste (9%). (Venkataraman *et al.,* 2004; Gupta *et al.,* 1997).

The 1991 National Census for the first time inquired about the fuel used for cooking. It revealed that about 90% of the rural population relied upon the biomass fuels like animal dung, crop residues and wood. A small portion used coal. Nation-wide about 78% of the population relied upon the biomass fuels and 3% on coal (IIPS, Mumbai 1995). The latest census shows that 90% of rural households and 72.3% of total households in India still rely on biomass (wood, crop residues, dung) for household cooking (Census, 2001). In one of the first studies on domestic pollution conducted in four villages of Gujarat in 1981, average levels of total suspended particulate in indoor air were estimated to be 7000 μg/m^3, about 100 times higher than the WHO standard of 60–90 μg/m^3. The World Bank has designated indoor air pollution in developing countries as one of the four most critical global environmental problems (Anon, 1998–99).

Indoor pollution sources that release gases or particles into the air are the primary cause of indoor air quality problems in homes. Inadequate ventilation can increase indoor pollutant levels by not bringing in enough outdoor air to dilute emissions from indoor sources and by not carrying indoor air pollutants out of the home. High temperature and humidity levels can also increase concentrations of some pollutants.

In 2000, cooking energy and biofuel consumption in India was estimated separately for rural and urban regions. The total cooking energy consumption for India was 6325 PJ with rural population using about 84%. This reflects both the large rural population and the use of low-efficiency biofuel cooking devices. Biofuel consumption for cooking in major states in regions in India showed high fuel wood consumption in all regions large dung cake and crop waste consumption in northern and eastern states. Error bars with 95% CI were estimated in national central value and uncertainty range of fuel wood consumption was 281 (192–409) Tg yr^{-1}, with predominance in all regions (GazalaHabib, *et al.*, 2004).

Study Area

The study area - Manjari village (18°31'19.83"N, 73°58'36.85"E, and 560m ASL) is typical rural setting situated on Deccan Plateau. It lays on the leeward side of the Sahyadrimountain ranges also known as Western Ghats. It is 100km east from the Konkan- the west Coast. The height above the sea level and the leeward location relating to Western Ghats have made city climate moderate and salubrious (Fig. 2). Total population of village is about 24,509 and total area is about 1180.40 hectors (Census, 2001). Village area is typically agricultural and about 90% people are farmers by occupation. Most of families in this area come under low income group. About 548 families come under the poverty line.

Materials and Methods

Exclusive review of the earlier studies, the literature and the protocol helped in revealing that rural households depend upon various fuel sources. A micro level reconnaissance survey for understanding the fuel types and usage patterns in the study area was undertaken. Most of the families of that area are used unprocessed biomass as fuel like Dung cakes, wood, agricultural residue etc. Some people also use kerosene stoves and gas burners. About 70% of families use chullah for cooking. Enlightening three types of cooking media i.e. chullah, stove, and gas burner. These cooking media mainly uses wood, cow dunk, kerosene, and liquefied petroleum gas (LPG) as fuel. Some families use mechanical ventilation system likes ceiling fans or exhaust fans for ventilation in their homes; it also affects the indoor air quality during sampling period.

Here in a cross-sectional, time-waited pollution monitored and interviewer administered survey; the sample size was selected considering logistics, random variation in the analytical procedure, feasibility, cost effectiveness and the occurrence of a constituent at a point of sampling.

The study area is atypical Indian village with an average of 5 members. There seemed to be significant variation in type and quantity of cooking fuel usage in each of the house. Therefore no particular fuel pattern or trend for quality and quantity could be identified. In order to represent the typical condition, a simple random sampling was carried out.

Indoor air quality as Particulate matter levels were measured for 24hrs in 33 randomly selected households out of which 17 use chullah, 10 houses use kerosene and 6 houses use LPG for cooking. Required fundamental parameters covering household status in terms of ventilation, usage of fuel i.e. quantification and hours of usage, etc. were documented in questionnaire on receiving formal consent.

Sampling and Analysis

Representative samples were collected for respirable particulate matter (PM10 and PM2.5) over a period 24 hours in each of identified household. A portable low volume sampler (LVS – AirMetricsMiniVol®) was used keeping standard flow rate of 5 liters per minute (LPM). Pure quartz filter paper having Ø47mm and 1–2 µm pore size was used. These have key features mainly; tissue quartz, fiber mats, better particle collection efficiency, moderate flow resistance and less hygroscopic (US-EPA document, 1997). Filter papers were baked in oven at 105°C to remove excess impurities. Then were weighed on microbalance (M5 – Sartorious) with least count of 1µg. Weighed filter papers (both pre and post) were placed in desiccator to remove moisture content if any. All gravimetric analysis as well as filter paper handling was done in an Environmental Controlled Room maintaining 20°C temperature and 40% humidity.

In coordination with the home owner/tenant, indoor air sampling locations were selected. The sampler was placed in kitchen. The indoor air samples were collected 3–5 feet above finished floor i.e. breathing zone and 3–4 feet away from cooking source.

Statistics

Descriptive analysis of household area, cooking fuel usage, smoking status, particulate concentrations and other covariates were performed initially. Also probability distribution of particulate concentration was estimated using descriptive with 95% confidence interval for mean and histogram. Subsequently, our main goal was to determine whether improvements in air quality were associated with cooking fuel usage. Empirical relationship between risk factors and particulate matter was determined.

Analyses were conducted with the use of SPSS software. P values less than 0.05 and P values less than 0.01 were interpreted as statistically significant.

Results and Discussion

Amongst all the air pollutants emitted from cooking fuel and predominantly from biomass, the one that has shown the maximum amount of adverse health effects is particulate matter. Cooking indoors has higher exposure levels to biomass smoke than outdoor. Whereas separate kitchen do not make any significant difference to the overall exposure of the cook, it significantly reduces exposure to other members in house.

Of the participants, 39% were using chullah as cooking media and firewood, cow dung as cooking fuel. Over 30% of the study households used clean fuels such as kerosene and liquefied petroleum gas. Rest of 15% households use more than two fuels for cooking, and were grouped as mix fuel users. Frequency of biomass-fuel use in households with access to clean fuels varied depending upon availability of clean fuels, the economic situation of the household, and occasional social considerations. But for the most part these households used biomass fuels, as there was no direct cost involved in procuring the fuels locally.

Rural areas here are largely dependent on biomass fuel as primary source for bulk of population. This dominance is highly dictated by the sub type and quantity of fuel. Distribution of study household characteristics is shown in Table 1. On an average 4.4 people live in study household and area varies from 64 ft^2 to 138 ft^2. Average per capita biomass consumption was reported to be 39.4kgs of fire wood and that of cow dung was slightly higher i.e. 45.3kgs; whereas cleaner fuels account for just 3.6kg of LPG and 2.3 kg of kerosene. Five households have smokers, smoking hand rolled bidi. According to primary data collection on an average 22.7 bidies were being smoked over a month. It is observed rural and urban households often consume a mix of both traditional and conventional energy types depending on household income. Poorer households use greater quantities of traditional fuels while higher income families tend to rely more on modern energy resources.

The per capita consumption for slums is based on interviews with the Slum Development Department of the Pune city Municipal Corporation (PMC); however, the same has been also referred to through literature survey from various studies in India (MSPI, 1999–2000). The distribution of population using various fuel types is assumed to be in the ratio of 60:20:20; Kerosene: fuel wood: LPG from the discussion with the Department of Health, PMC. Figure 3 represents the detailed comparative account of household cooking fuel usage in urban slum and study village around Pune city. Rural areas are characterized by limited access that people have to adequate, affordable and convenient energy sources. Biomass particularly wood consumption in rural area is 2.5 times more than urban slum. Whereas there's hardly any use of cow dung as cooking fuel, fraction is at higher level in rural setting. Cleaner fuel is widely used in city and even after limited supply per capita consumption was fund to be almost equal.

Overall levels of particulate concentrations in study area were found to be more compared to urban slums. There was hardly any urban household which uses cow dung for cooking. According to available data clean fuel usage show opposite trend in both the settings. Rural households consume half the kerosene quantity per capita per year; inadequate and delayed supply compared to urban setting might be the reason. Understanding the family size, meteorology, socioeconomic status and literacy were found to be major impact factors in overall fuel contribution.

Air quality levels were measured in identified households and statistical particulars of the same were represented in Figure 4. Comparative account of household fuel usage shows houses using chullah have higher particulate concentrations; followed by Kerosene and LPG, respectively. Overall median PM2.5 level across all study households in 24-hrs sampling period was 110 $\mu g/m^3$(IQR–78)and that of PM10 was 204 $\mu g/m^3$ (IQR–287). Households having biomass chullah show highest i.e. 1218 $\mu g/m^3$ and 2993$\mu g/m^3$ for PM2.5 and PM10 concentration respectively. Whereas gas stove using LPG and liquid stoves using kerosene being cleaner fuels reported lowest particulate concentrations.

Amongst these 18.2% households satisfy the World Health Organization (WHO) and National Ambient Air Quality Standard (NAAQS) of PM2.5. Taking in to account PM10 hardly 3% of the households fall below prescribed standard. Indoor particulate concentrations in houses may have greater temporal peaks with contaminant effect on health (Fig. 4). These are predominantly representative of household activities, compared to outdoor particulate concentration. However exposure burden can vary greatly among individuals living in the same indoor environment.

Biomass is popular and equally chief domestic fuel source because of its very easy to access and widely available (Salvi and Barnes, 2009). Biological entities form the major fuel source of almost 90% rural households and 50% total world population dependent as their main domestic fuel (WRI 98–99). Biological sources of fuel such as wood, crop residues, animal dung, dried twigs and wood coal clustered to form biomass fuel (Salvi and Barnes 2010). Particulate matter emission estimates project for Pune city reports about 70 % of families rely on chullah as a cooking medium. Study households using biomass as cooking fuel account 10 fold above the standards prescribed by World Health Organization. PM10 concentrations were reported to be at higher level in households using more than one cooking fuel i.e. 738.4µg/m^3 followed by biomass and then cleaner fuel i.e. 573.8µg/m^3 and 196.1µg/m^3, respectively. Shuffled trend was observed for PM2.5 concentrations with biomass fuel at higher level with 259.1µg/m^3 and lowest for cleaner fuel with 116.3µg/m^3. Dung cake particulate suspensions have capability to deplete physiologically relevant antioxidants, ascorbate (AA), urate (UA) and reduced glutathione (GSH) from a synthetic model of human respiratory tract lining fluid (Mudway and Kelly, 1998; Mudway *et al.,* 2004). On a per unit heat delivered basis, the emissions of CO and TSP from both dung cakes and crop residues are two to three times higher compared to those from fuel wood (Veena *et al.,* 2005, Smith, 1996a).

Concentration ranking places kerosene stove at second place, subsequent to cow dung. The diurnal variation at various kerosene using houses show peak reading for PM2.5 and PM10 are 416.0µg/m^3 and 491.0µg/m^3, respectively (Fig. 5). On similar grounds studies were conducted in Nagpur region. There the sites which kerosene was used as a cooking fuel, the mass concentration observed in range of 82.6µg/m^3 to 152.3µg/m^3 (Monkkonen *et al.,* 2005) which is four times during recent study. For the other cleaner fuel i.e. liquefied petroleum gas (LPG) reported maximum particulate concentration of 150µg/m^3 and 341µg/m^3 was recorded for PM2.5 and PM10, respectively. Particulate pollutants lead to asthma prevalence, studies conducted by the National Institute of Occupational Health (NIOH) (Annual Report, 1983) on the prevalence of respiratory symptoms in women using traditional fuels (biomass) (n=175) and LPG (n=99), matched for economic status and age, indicated that the relative risk (with 95% C.I.) for cough and shortness of breath (dyspnea) was 3.2 (1.6–6.7), and 4.6 (1.2–18.2), respectively.

In comparison to earlier studies the current concentrations were more i.e. PM2.5 about 2.5 times and PM2.5 about 1.5 times. Ex. Nagpur was one of the study areas for fine particle mass concentration and particle number in 2005. The sites where LPG was used the mean mass concentration increased from 55.5µg/m^3 to 144.6µg/m^3. In the measuring sites where kerosene was used as a cooking fuel, the mass concentration increased from 82.6µg/m^3 to 152.3µg/m^3. The highest measured indoor mass concentration was 3000 µg/m^3 (Monkkonen *et al.,* 2005). Lack of ventilation facility, residential area and the cooking in chullah with biomass fuel i.e. average Cow dung cakes and Fire wood per contribute to high PM loads.

Contribution of PM2.5 in PM10 is 24.6% from chullah using combination of all three fuels i.e. cow dung, fire wood, kerosene whereas when only firewood is used as fuel in those chullah, the contribution of PM2.5 increases to 45.6% which is similar to that from dung cake and wood (about 41.8%). PM2.5 from LPG and kerosene is about 66% & 64%, respectively. Although the total mass concentrations of PM10 from Kerosene and LPG seems to be comparatively less from those released by chullah, it is very important to note that the PM2.5 contributions from the same are significantly higher making it much more potential hazard from exposure and health point of view (Fig. 6). The evidence of long-term effects on lung health of relatively low levels of exposure to particulate pollution has increased substantially during the past decade. (Laden *et al.*, 2006; Dockery and Brunekreef, 2006) Inhalation of smoke and other particulates has been associated with increased airways and systemic inflammation, (Donaldson *et al.*, 2001; Gan *et al.*, 2004) as well as oxidative stress (Nel, 2005).

Observed association between the indoor particulate matter and few household variables do vary significantly across study area. No significant modification according to baseline exposure was seen for usage of mosquito repellent, overall smoking and usage cleaner fuels. However, a significant association was seen on PM2.5 with presence of windows (p=0.014). Similar effects were observed for PM10 concentration which varied significantly with number of residents (p=0.007), household area per resident (p=0.006). Quantity of fuel used per year, mainly firewood and cow dung show most significant association of 0.003 and 0.000, respectively.

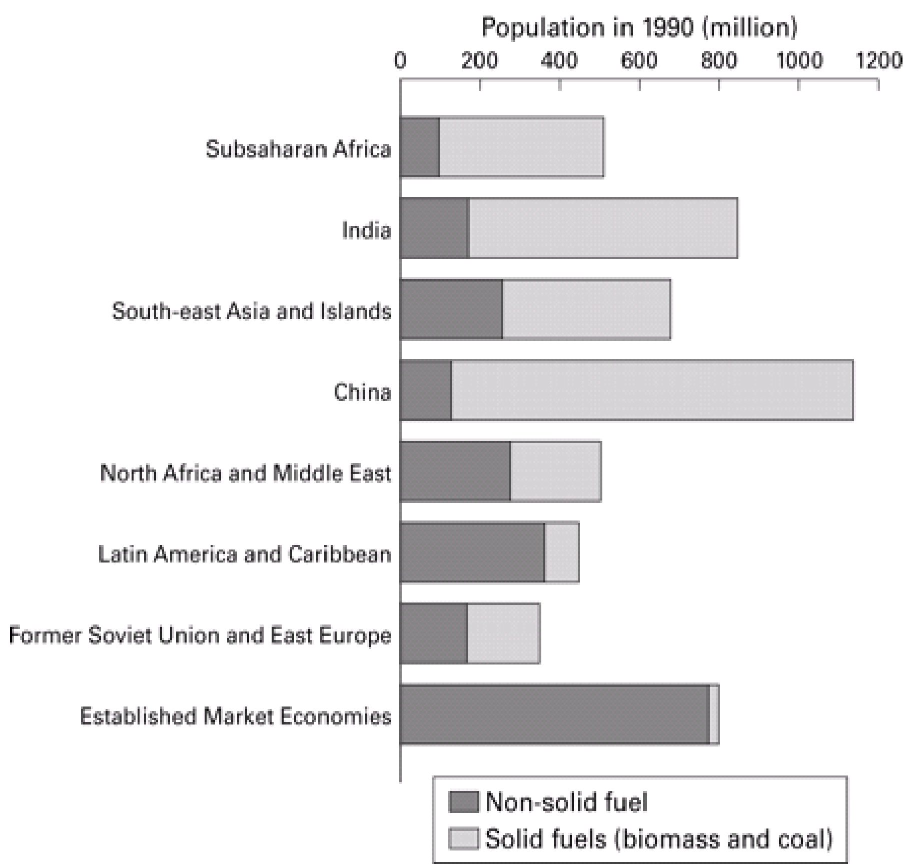


Fig.1 World distribution of household fuel use (From Reddy *et al.*, 1997)

Study area with monitoring locations marked

Table.1 Characteristics of Study Households

Features	Median (IQR)	Features	Median (IQR)
Area of house	85.50 (33.25)	Wood (kg/month)	150 (97.5)
Number of residents	5 (3.50)	Cow Dung (kg/month)	210 (120)
LPG – 14.2kg users, (n)	6	Kerosene (kg/month)	6.02 (2.15)
Smokers, (n)	5	Bidi, (n/month)	150 (90)

Figure.3 Comparative account of fuel usage in urban slums and rural area

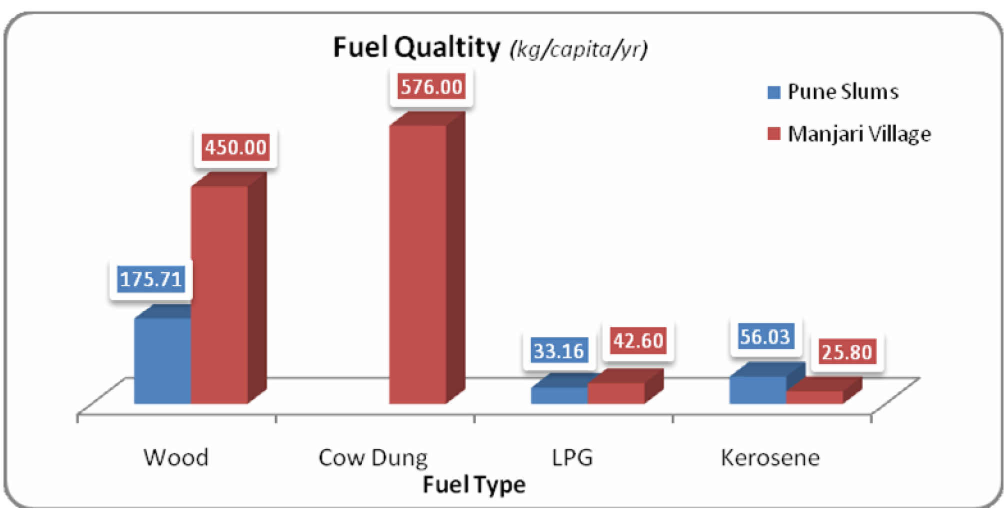


Fig.4 Indoor particulate levels in rural houses

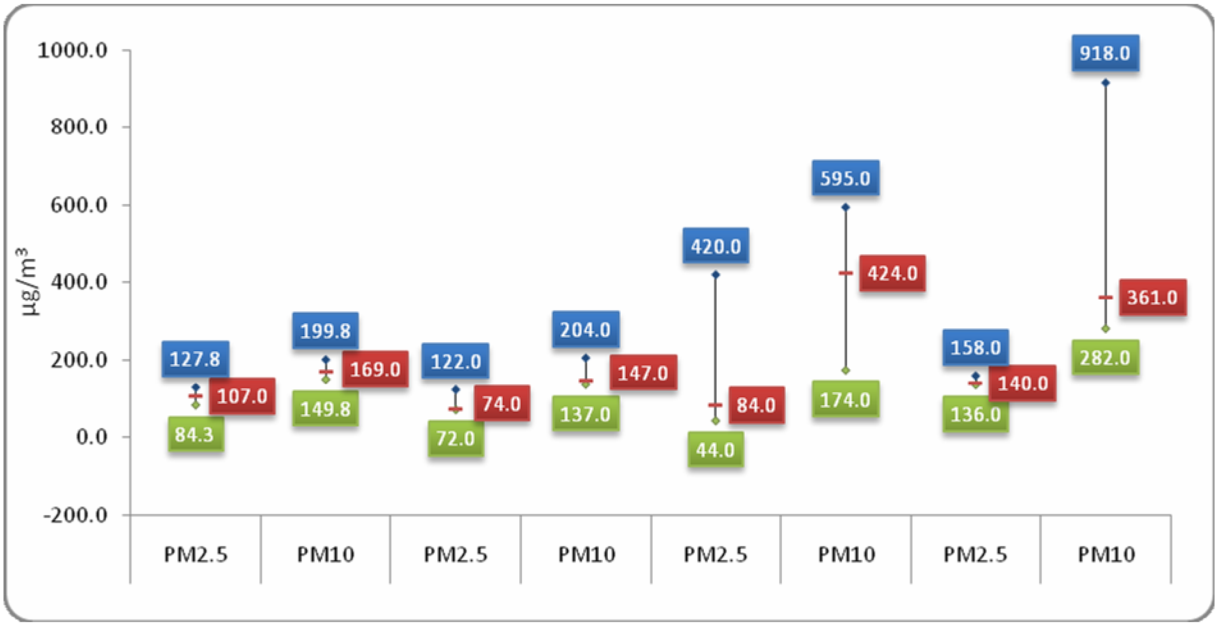
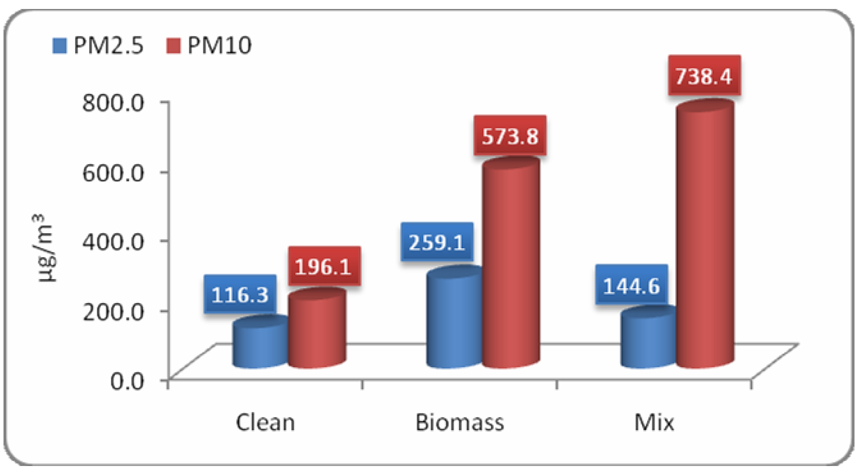


Fig.5 Variation in particulate emissions with change in fuel type



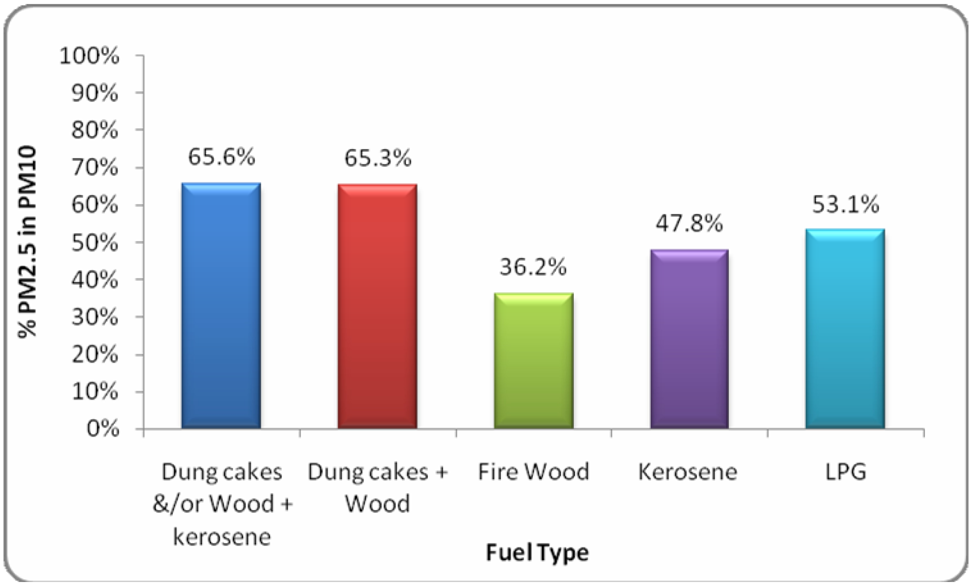


Fig.6 Contribution of PM2.5 in PM10 in each fuel type

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