International Journal of Sustainable Built Environment (2014) 3, 262–271

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International Journal of Sustainable Built Environment

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Original Article/Research

Indoor pollution from solid biomass fuel and rural health damage: A micro-environmental study in rural area of Burdwan, West Bengal

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Received 28 April 2014; accepted 6 November 2014

Abstract

Emissions from biomass combustion are a major source of indoor and outdoor air pollution, and are estimated to cause millions of premature deaths worldwide annually. In this study, we assessed the effect of exposure to biomass smoke on various health status including blood pressure, gaseous component and ventilation pattern of kitchen and living room. For this investigation, a number of measurements were done to obtain indoor air quality (IAQ) data (indoor humidity, temperature, CO, CO_2 and O_3 concentration). Blood pressure was measured at baseline and one hour post-exposure. Results highlighted that a higher concentration of CO_2 was released during burning of dry leaf, straw, cow dung compared to that from straw and LPG gas. Moreover, correlation study showed a strong negative relationship between CO and humidity ($r = -0.609$, $p < 0.000$). Symptoms like eye irritation, shortness of breath, cough and dizziness were highly prevalent among biomass users. Both systolic and diastolic blood pressure showed a strong positive ($p < 0.05$) relationship with age of biomass users. However, wood users suffer from high systolic pressure ($p < 0.037$). On the other hand, a very poor ventilation pattern was recorded in the studied population.

Keywords: Biomass; Indoor air; Blood pressure; Respiratory symptoms; Ventilation

1. Introduction

Biomass (wood, charcoal, animal dung and agriculture residues) is the primary source of fuels used by poor households in developing countries who can hardly afford other fuel types (kerosene, liquefied petroleum gas, electricity) (Akunne et al., 2006). According to WHO (2006), countries like India, Nepal, Pakistan and Sri lanka used biomass as fuel (72%, 88% and 67% respectively) for daily household cooking. Nearly 3 billion people depend on solid fuels (biomass and coal) for cooking and heating and this number is expected to grow until at least 2030 (International Energy agency, 2002; WHO, 2002).

Incomplete combustion of biomass is the main source of indoor air pollution worldwide (WHO, 2011) and in most developing countries; it is burned in open that produces a lot of smoke (Akunne et al., 2006). Biomass smoke contains a wide spectrum of potentially health damaging pollutants that include coarse, fine, and ultrafine particles, carbon monoxide (CO), oxide of nitrogen and sulfur, transition metals, polycyclic aromatic hydrocarbons, volatile organic compounds and bio-aerosols (Zhang and

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Peer review under responsibility of The Gulf Organisation for Research and Development.

http://dx.doi.org/10.1016/j.ijsbe.2014.11.002
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Morawska, 2002; Smith et al., 2000). Recent studies (Mondal et al., 2013; Dasgupta et al., 2006) in rural households had shown that indoor air pollution is due to combustion of biomass fuels. However, in various developing countries wood stove emission is the main source of kitchen-related indoor air pollution in many poor households (Huboyo et al., 2014). Biomass is the only source which produces a lot of pollutants that are harmful for human health and also have effects on climate change (Arbex et al., 2007). During burning of biomass many gaseous pollutants such as CO, CO_2 and O_3 including humidity and temperature are produced (Andreae and Merlet, 2001). These pollutants may alter the properties of the atmosphere since the particles can absorb and reflect solar radiation (Holben et al., 1991).

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). Due to low burning efficiency, the emission of fine particles from traditional wood stove combustion usually is accompanied by CO, hydrocarbon, fine radicals, oxygenated organic and particulate matter emission (Huboyo et al., 2014; Naeher et al., 2005; Schei et al., 2004). However, Begum et al. (2009) pointed out that the measured concentration depends on where and when the monitoring takes place and the significant temporal and spatial variation that may exist within a house including room-to-room differences.

Indoor air pollution is associated with increased risk of several acute and chronic health conditions, including acute respiratory infections, pneumonia, tuberculosis, chronic lung disease, cardiovascular disease, cataracts and cancers (Smith et al., 2000; Balakrishnan et al., 2004; Bruce et al., 2006; Dherani et al., 2008; Pope et al., 2010; Po et al., 2011; Emmelin and wall, 2007). There are many reports (Gao and Mann, 2009; Lee et al., 2005; Mann et al., 2007) which collectively suggest that chronic inhalation of biomass smoke may lead to inflammation and oxidative stress which, in turn, can rise arterial blood pressure. In India, middle-income and upper-income households in urban area typically use electricity or other greener fuels like liquid petroleum gas or natural gas. However, lower-income households in rural area rely primarily on biomass fuels (Begum et al., 2009). These fuels include wood, twigs and dry leaves, animal dung and agriculture residues such as straw, rice husks, bagasses (fiber derived from sugar production).

Health danger posed by solid fuel smoke exposure varies with housing and ventilation, energy technology (tripod, oven, stove), pollutant concentration in the immediate breathing environment and the time spent in the environment (Barnes et al., 2005; Ezzati and Kammen, 2001; Ezzati et al., 2000; Qian et al., 2004; Smith et al., 2000). Better ventilation, more efficient vented stoves and cleaner fuels are the most important interventions to reduce impact on health (WHO, 2002). Ventilation represents a possibility but its effects on indoor air pollution are complex. Simple cooking related practices that increase ventilation may represent cost-effective option for poor household in reducing the adverse health impact of exposure to smoke from biomass fuel (Akunne et al., 2006). However, this impact in reduction is not exactly known and it is desirable to better understand it.

The objective of this work is to acquire knowledge about the commonly used biomass at the cooking stoves that causes indoor air pollution especially different gaseous pollutions. This information will give a better scientific understanding to the community of the future predictions and also help to take necessary steps for the safe use of biomass.

2. Methods and materials

2.1. Study area and research design

Present study was conducted in the adjoining rural area of the Burdwan town (23°15′48″N and 87°50′48″E), (Fig. 1) West Bengal, a state in Eastern India. Study area was selected on the basis of the following criteria:(i) The location should be 10 km away from the national high way to minimize the effect of vehicular pollution, (ii) No air-polluting industry like thermal power plant, cement factory, sponge iron factory, rice mill within 10 km radius in order to control the impact of industrial pollution and (iii) Only biomass fuel and LPG gas should be used by the villagers for domestic cooking.

A total of 50 apparently healthy never smoking women were enrolled through village panchayats (local administration). Among the participants 95% women (age 17–70 years) cooked exclusively with solid unprocessed biomass such as cow dung, straw, wood, dry leaf, coal cake, twigs. The remaining 5% women (age 27 years) cooked with cleaner LPG fuel and accordingly they were grouped as references or control. Informed consent of the participants was acquired prior to the study.

2.2. Inclusion and exclusion criteria

The inclusion criteria were

(i) Apparently healthy women, (ii) non-smokers, non-consumption of alcohol and non-chewers of tobacco and (iii) cook regularly with either biomass or LPG at least 2 h/day, 5 days/week for greater than or equal to 10 years.

Exclusion criteria were

(i) Mixed fuel user (biomass + LPG + Kerosene), (ii) pregnant, (iii) currently under medication, (iv) family history of TB or complicated cardiovascular disease and (v) body mass index (BMI <19 and >30 kg/m^2), normal range of BMI 18.5–24.9 kg/m^2 as per World Health Organization classification (Global database on Body Mass Index, 2006).

2.3. Study period

The study was carried out during September–December 2013. Sampling was mainly done at evening time when most of the villagers cooked their food after returning from

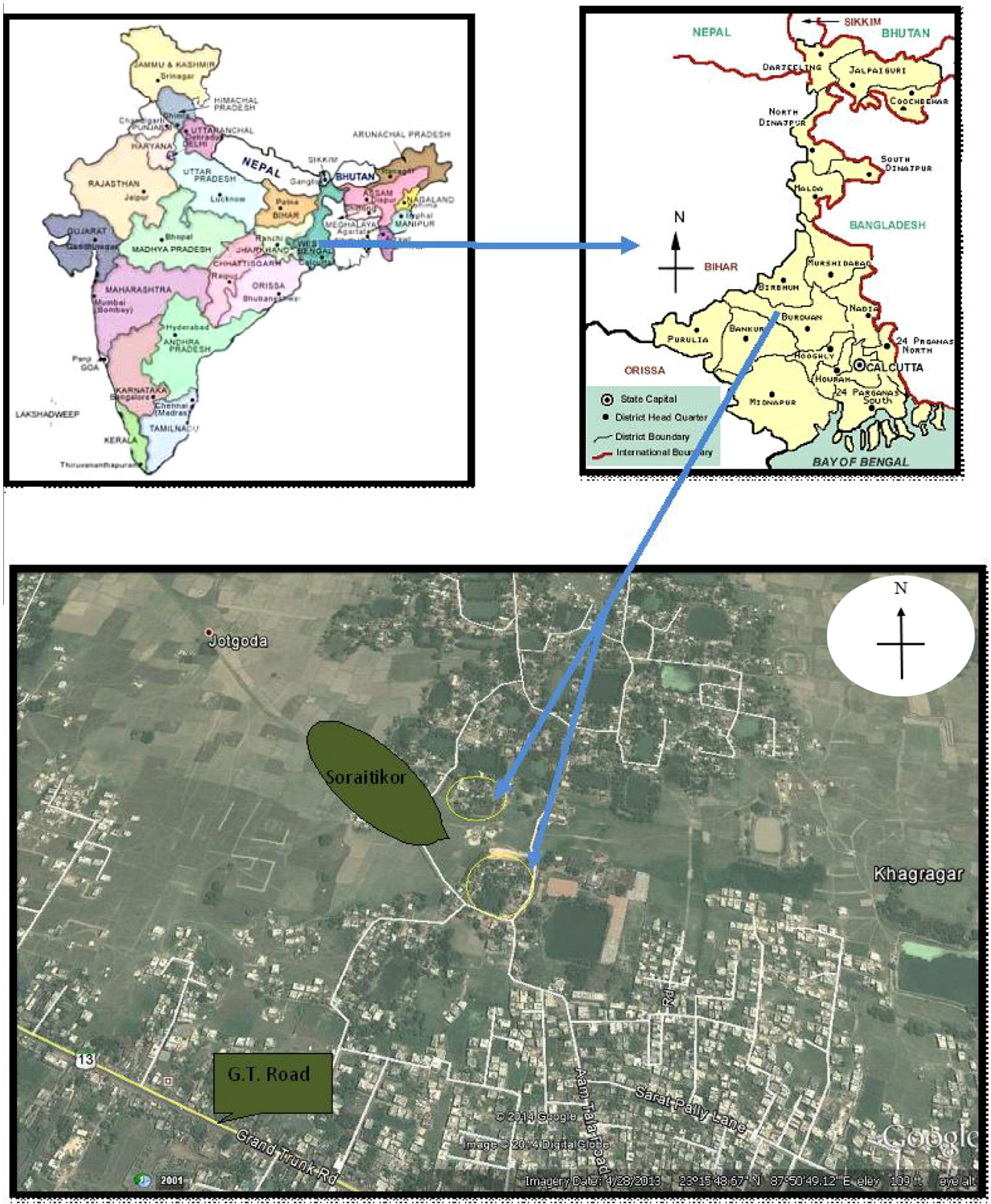

Fig. 1. Study area of interest of rural village of Burdwan, West Bengal, India.

their work place, but day time sampling was also done for those who used to cook their food two times per day.

2.4. Personal interview

Information on demography (age, education, smoking, habits, and occupation of the participants, average family income, cooking hours per day, cooking years, kitchen and fuel type, family structure), occupation of spouse and habit of chewing tobacco was collected through personal interview using structured questionnaire with prior permission of the family. The study protocol was approved by the Ethics committee of the University of Burdwan, Burdwan.

Table 1
Correlation between gaseous component, temperature and humidity in living and kitchen rooms.

Room	Component	Pearson correlation (r)	Significant
L	CO and CO_2	0.049	$p < 0.775$
I	CO and O_3	−0.001	$p < 0.995$
V	CO and humidity	−0.238	$p < 0.162$
I	CO and temperature	0.037	$p < 0.832$
N	CO_2 and O_3	−0.040	$p < 0.818$
G	CO_2 and humidity	0.071	$p < 0.679$
	CO_2 and temperature	0.176	$p < 0.305$
	O_3 and humidity	0.168	$p < 0.326$
	O_3 and temperature	0.438	$p < 0.008$
	Humidity and temperature	0.450	$p < 0.006$
K	CO and CO_2	0.255	$p < 0.134$
I	CO and O_3	0.435	$p < 0.008$
T	CO and humidity	−0.609	$p < 0.000$
C	CO and temperature	−0.178	$p < 0.299$
H	CO_2 and O_3	−0.139	$p < 0.420$
E	CO_2 and humidity	−0.297	$p < 0.078$
N	CO_2 and temperature	−0.442	$p < 0.007$
	O_3 and humidity	0.036	$p < 0.834$
	O_3 and temperature	0.250	$p < 0.142$
	Humidity and temperature	0.395	$p < 0.017$

2.5. Blood pressure measurement

Systolic and diastolic blood pressure levels (SBP and DBP respectively) were measured while the participants were at rest in a sitting position by sphygmomanometer (Aneroid Sphygmomanometer – EHL-ANNER1). Guideline of the British Hypertension society was followed for blood pressure measurement (O'Brien et al., 1997). The hypertension condition was judged by following the recommendation of World Health Organization (2003). The hypertensive condition was confirmed when SBP rose to 140 mmHg or more, or DBP elevated to 90 mmHg or more. For consistent measurement of each participant, we made three blood pressure measurements with an interval of 12 h.

2.6. Measurement of CO, CO_2 and O_3, temperature, humidity

The gaseous components (CO, CO_2 and O_3) were measured by portable toxic gas indicator (model gaZguard Tx, Mumbai). Instruments were placed 1.5 m away from the stove and height of breathing (in sitting condition). The digital instruments were fully charged before the measurement (Padhi et al., 2010).

2.7. Kitchen and living room pattern with measurement of ventilation

Room temperature and humidity was measured during cooking time by using temperature and humidity meter (model HTC-1). The standard measuring tape was used to measure the kitchen room to living room distance. Ventilation pattern was checked by considering the total number of windows in kitchen and living room. Cross ventilation was noted for parallel placement of window and door in both kitchen and living room.

2.8. Statistical analysis

Study results were statistically analyzed using SPSS statistical software (Statistical software for Social Science for windows, release 20.0 SPSS Inc., Chicago, IL, USA) and Minitab 16. The Principle components analysis, Pearson's correlation and regression analysis were performed to interpret the results. Statistical significance was assigned at $p < 0.05$.

3. Results and discussion

3.1. Material of fire work

Study result revealed that fuel used by the villagers was mostly wood followed by twigs, coal cake, dung, straw, and dry leaf. However, use of gas stove was quite low (data not supplied). The use of greener fuel basically depends on their economic condition. About 30% of the inhabitant/population cooked their food one time per day and 20% population cooked two times per day. However, this cooking frequency also depends on their family strength and nature of job. There is one type of family where all members including child go to work place early in the morning (6–6.30 AM) after preparing their dinner and when they return from their work place they used food prepared in the morning. Similarly another type of family who cooked its food as before used the same in morning hours, but after returning from their work place they cooked for their dinner. Study results also demonstrated that about 70.58% population cooked inside a room. That means they have no specific kitchen and 26.47% population cooked outside their room. However, 2.90% population used to cook in both inside and outside the room. Majority of the population (65%) spends 2–3 h/day for cooking and only 10%, 20% and 5% population cooked their food 4–5 h/day, 2 h/day and ⩾5 h/day, respectively (data not supplied). The correlation study revealed that carbon monoxide is positively correlated with ozone ($r = 0.435$, $p < 0.008$) and negatively with humidity ($r = -0.609$, $p < 0.000$) inside the kitchen. On the other hand CO_2 was negatively related to temperature ($r = -0.442$, $p < 0.007$) and humidity positively related to temperature ($r = 0.395$, $p < 0.017$). In living room only O_3 was significantly related to temperature ($r = 0.438$, $p < 0.008$) and humidity positively related to temperature ($r = 0.450$, $p < 0.006$) (Table 1).

3.2. Kitchen and living room pattern

Total four types of kitchen room were observed in the study area (Fig. 2). Fig. 2(a) demonstrates that there is

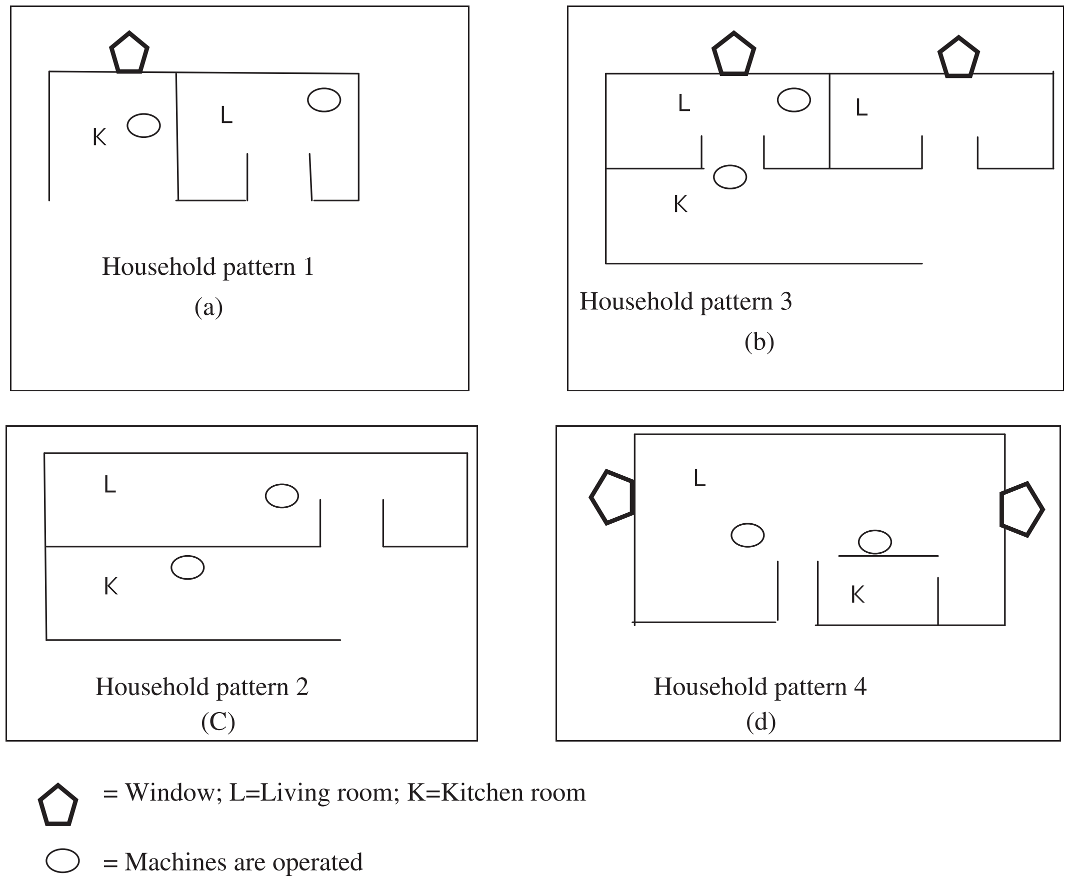

Fig. 2. Pattern of living and kitchen room, location of living and kitchen room, window position and location of instrument for collection of air pollution data.

no direct link between kitchen room and living room, but there is an open corridor through which fuel generated smoke from kitchen passed and directly entered the living room. In Fig. 2(b) and (c), it is clearly demonstrated that smokes from kitchen directly enters the living room. However, in Fig. 2(d), kitchen room is inside the living room. Therefore, from the above kitchen room pattern it is clear that family members of the above mentioned kitchen room are intensely exposed to toxic indoor pollutants generated from solid biomass fuel.

3.3. Status of bio-fuel user

The percentage of biomass fuel user data indicate that nearly 14% respondent used coal cake, 36% respondent wood, 22% twigs, 11% dung and 8% straw and 3% both dry leaf and gas (data not supplied). The variation of gaseous component from fuel to fuel demonstrated that all varieties of fuel do not contribute the same degree of gaseous product. The highest carbon dioxide (CO_2) contributor follows the following sequence Dry leaf > Straw > Cow dung > Gas Stove > Coal Cake > Wood > Twigs. The carbon monoxide (CO) concentration follows the sequence: Coal Cake > Dry leaf > Cow dung > Twigs > Wood > Straw > Gas Stove, whereas ozone concentration follows the sequence Coal Cake > Twigs > Wood > Leaf > Straw > Dung > Gas Stove. Therefore, biomass study clearly revealed that LPG gas is the least contributor of CO_2, CO and O_3 than biomass fuel. Almost a similar observation was reported by Balakrishnan et al. (2011). They reported that the kerosene, coal or biomass produced higher levels of gaseous pollutant than LPG gas or electricity in homes. It is well documented that the concentration of gaseous constituents in living room varies remarkably from fuel to fuel (Balakrishnan et al., 2011; Mondal et al., 2013). However, the variation of concentration of gaseous compounds in living room not only depends on the kitchen room structure but also ventilation pattern of the kitchen room. The higher concentration of gaseous compound inside the living room is very common in rural households. Biomass burning in either open burning or poorly ventilated stoves emits hundreds of health damaging pollutants causing acute respiratory infections, chronic obstructive pulmonary disease, asthma, nasopharyngeal and laryngeal cancers, tuberculosis and diseases of the eye (Andreae and Merlet, 2001). So far as toxicity of gaseous component is concerned CO and O_3 are most dangerous than CO_2. The affinity of CO towards hemoglobin (Hb) is 240–270 times greater than oxygen. Exposure to carbon monoxide is particularly dangerous to urban babies, infants and people with anemia or a history of heart disease. Breathing low levels of the indoor pollutants can

Table 2
Living–kitchen room ratio of different gaseous pollutants.

Fuel type	CO	CO_2	O_3
Dung	0.252 ± 0.17	0.491 ± 0.43	0.447 ± 0.59
Straw	0.234 ± 0.11	0.249 ± 0.08	0.223 ± 0.19
Wood	0.203 ± 0.34	0.338 ± 0.20	0.904 ± 1 .38
Leaf	0.103 ± 0	0.45 ± 0	0.2 ± 0
Coal cake	0.086 ± 0.05	0.396 ± 0.29	0.276 ± 0.26
Twigs	0.074 ± 0.05	0.483 ± 0.33	0.467 ± 0.77
Gas stove	0.001 ± 0	0.142 ± 0	0.106 ± 0.02

Fig. 3. Rural women cooking along with children aged less than five years. (Photograph taken during sampling).

cause fatigue and increase chest pain in people with chronic heart disease. Moreover, breathing higher levels of carbon monoxide causes symptoms such as headaches, dizziness and weakness in healthy people (WHO, 2008).

3.4. Living room to kitchen room $(l - k)$ ratio of CO, CO_2 and O_3

L–K ratio value clearly indicates that dung user followed by straw, wood, dry leaf, coal cake, twigs users experienced huge indoor toxicity from carbon monoxide than LPG gas user (Table 2). However L–K ratio of CO_2 showed different picture where dung, twigs, dry leaf, wood and straw user were more vulnerable than LPG user. Almost similar results were recorded from our previous study (Mondal et al., 2013) where we have measured other gaseous components like SO_2, NO_2 and particulate matter from a similar type of biomass. Recent studies have successfully demonstrated that CO can be a major pollutant from wood smoke in indoor environment (Commodore et al., 2013; Chowdhury et al., 2013; McCracken et al., 2013; Mukhopadhay et al., 2012; Fitzgerald et al., 2012; Armendariz-Arnez et al., 2010; Northcross et al., 2010). On the other hand L–K ratio of O_3 was the highest recorded in wood user followed by twigs, dung, coal cake, straw, leaf user. However LPG user experienced a very low level of ozone.

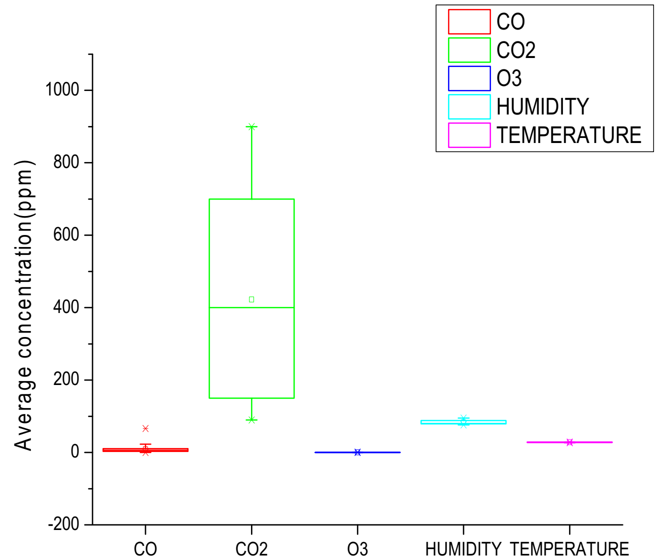

Fig. 4. Box plot showing average concentration of CO, CO_2 and O_3, humidity and temperature in living room.

3.5. Disease pattern in studied population

The studied population experienced various disease/symptoms (data not supplied).

From this study it is clear that eye irritation is common for all types of fuel users followed by shortness of breath (30%), cough (26%) and dizziness (24%). Almost similar results were reported by Sinha et al. (2006) and Saha et al. (2005). This is quite possible, because in India, 90% rural households use biomass solid fuels (wood, dung and

Table 3
Age versus SBP and DBP and significant value.

Fuel type	Systolic blood pressure	Regression co-efficient	$p < 0.05$ In case of SBP	Diastolic Blood Pressure	Regression co-efficient	$p < 0.05$ In case of DBP
Dung	$Y = 0.9853X + 75.342$	0.917	0.186	$Y = 0.7248X + 44.756$	0.922	0.181
Wood	$Y = 2.191X + 40.363$	0.702	0.037	$Y = 0.4479X + 55$	0.121	0.499
Coal cake	$Y = 0.7442X + 84.419$	0.372	0.582	$Y = -0.093X + 70.698$	0.372	0.582
Twigs	$Y = 0.3571X + 87.143$	0.893	0.212	$Y = -0.838X + 112$	0.928	0.173

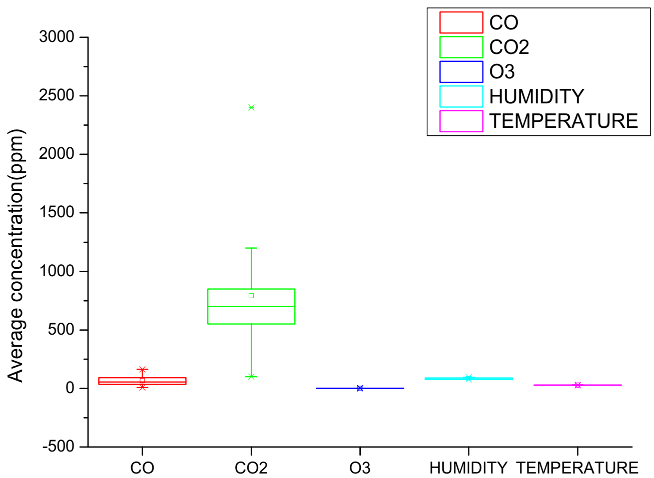

Fig. 5. Box plot showing average concentration of CO, CO_2 and O_3, humidity and temperature in kitchen room.

crop residue) as a primary source of domestic energy, and pollutants released from burning of biomass in indoor air are directly related to different diseases (Sinha et al., 2006; Balakrishnan et al., 2002). The combustion of biomass fuels produced a large number of air pollutants including CO, CO, O_3, NO_x and SO_2, respirable particulate matters, formaldehyde and benzene (Mondal et al., 2011, 2013; Albalak et al., 2001). Study results also indicate that about 55.50% children below five years always remain with their mothers during cooking time (Fig. 3) (data not supplied). This picture is not healthy so far as children health is concerned. Recent studies among children showed a strong association between biomass fuel exposure and their health.

Systolic and diastolic blood pressure data indicate that wood, coal cake and twigs fuel users experienced high systolic pressure than other users. Again diastolic pressure is high for wood users only, but other fuel users do not indicate any significant variation in diastolic blood pressure. Regression analysis showed that wood user have a highly significant relation between age of fuel user and systolic blood pressure. From the blood pressure study it is revealed that 20% respondent are hypertensive . However, 15% respondent are pre-hypertensive. Biomass users experienced higher prevalence of systolic and diastolic pressure (Table 3). Similar higher levels of both systolic and diastolic pressure were recorded from the biomass users of Hooghly, Howrah, Burdwan and Birbhum districts of West Bengal (Dutta et al., 2012). However, systolic hypertension is more common than diastolic hypertension in the general population in India (Jonas et al., 2010). The present finding is in agreement with an earlier study. Thrift et al. (2010) reported that this known risk factor for hypertension in India is probably due to excessive intake of salt and maternal malnutrition. Similar observation is reported by Emiroglu et al. (2010). They suggested that long-term exposure to smoke from solid fuel can be linked with impaired systolic and diastolic function of the heart. Another study conducted by Miller et al. (2007) has shown higher diastolic blood pressure among Guatemalan women exposed to wood smoke.

The average concentration (ppm) of different gaseous components such as CO, CO_2 and O_3, humidity and

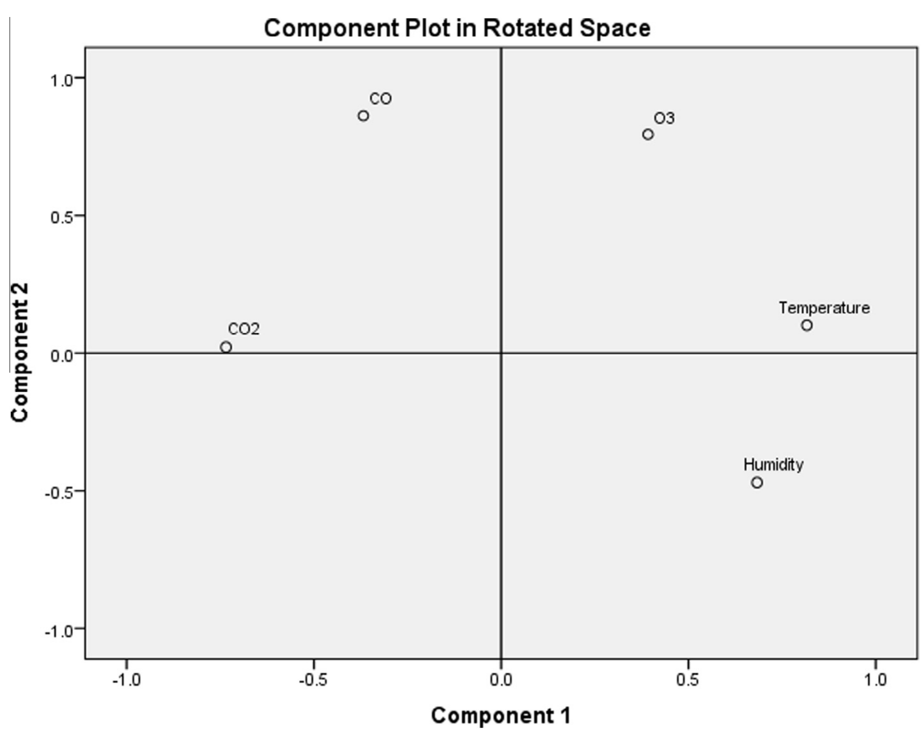

Fig. 6. Factor analysis loading plot at kitchen room.

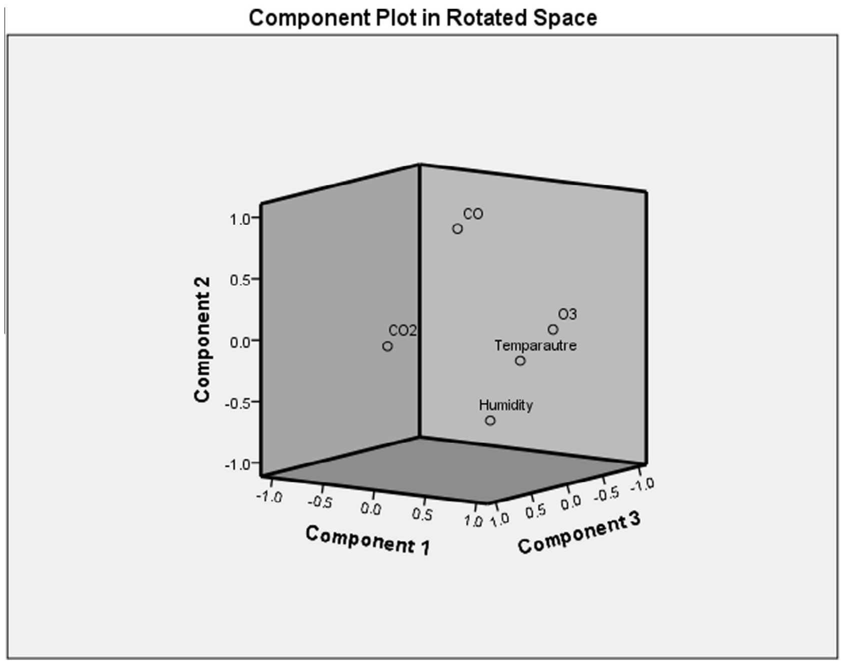

Fig. 7. Factor analysis loading plot at living room.

temperature at kitchen room and living room is depicted in Fig. 4 and 5. From Fig. 5 it is clear that in kitchen CO_2 is very high compared to the other two gaseous components and a similar picture was recorded in living room also, but a slightly higher level of CO_2 was recorded in living room. This is probably due to ill ventilation of living room. However, Mondal et al. (2013) reported that a high concentration of gaseous pollutants inside the living room may be due to smoking. But such smoking report was absolutely absent in this study. Statistical factor analysis results isolated two important factors (Humidity and ozone) which directly or indirectly are responsible for creating unhygienic and suffocating environment inside the kitchen. However, in the living room, three factors were extracted from factor analysis. Factors were temperature, carbon monoxide and carbon dioxide. Basically both carbon monoxide and dioxide were generated from burning biomass during cooking at kitchen and the temperature is the result of synergistic effect of both CO and CO_2. The principle components (PC) 1 and 2 accounted for 39.229% and 71.375% variability in the data set of the pollutant respectively at kitchen (Fig. 6). However, components PC1, PC2 and PC3 accounted for 32.539%, 56.524% and 78.118% variability respectively at living room (Supplementary Tables 1 and 2), (Fig. 7.)

4. Conclusions

In order to determine indoor air pollution levels in households in rural areas, different gaseous components (CO_2, CO and O_3) were measured along with health status of rural inhabitant especially respiratory problems and systolic and diastolic blood pressure during cooking period. Collection of sample is designed to explore the variation in fuel type, kitchen type, position of kitchen and ventilation pattern of kitchen. It was observed that a higher level of CO_2 was released from dry leaf, straw, cow dung, followed by coal cake and wood and least in twigs and CO from coal cake, dry leaf and cow dung followed by wood and straw and least LPG gas. However, O_3 level was the highest in coal cake and the lowest in LPG gas. Systolic and diastolic pressure levels of rural inhabitants showed a significantly positive relationship with type of fuel used and age. Symptoms like eye irritation, shortness of breath, cough and dizziness are highly predominant among fuel users. Renewed and more intensive efforts to improve indoor air quality could result in large exposure reductions and health benefits for the population. Thorough intervention studies, including monitoring of indoor air pollution levels, health impact and cost–benefit analysis, constitute future research needs. This study also should guide decision-maker in the assessment of environmental health-policy strategies linked with exposure to biomass burning in this sub-tropical region, taking into account the exposure distribution in the population. Moreover, the use of alternative fuels to biomass fuel and use of improved ventilated stove is highly desired to be promoted by concerned organizations.

Acknowledgements

The authors express their sincere thanks to the funding agency, University Grant Commission [F. No. 42-434/2013(SR), Dated 12 March 2013] for financial support to conduct the entire research work. The authors are also thankful to all the faculties and non-teaching staff of the

Department of Environmental Science, The University of Burdwan, Burdwan, West Bengal, India for their unconditional help and moral support.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ijsbe.2014.11.002.

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Funding for preparation of this report provided by the Air Health Effects Division, Health Canada, Ottawa, ON, Canada.

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