Seasonal variations in indoor air quality of urban and rural Asian households

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Burning of fuel for cooking and heating purposes causes smoke and other pollutants within households, resulting in direct human exposure. The present study focuses on assessment of seasonal variations in indoor air quality, including temperature, humidity, light, CO, SO_2, PM_{10} and airborne bacteria. Gaseous emissions were analysed using digital metres and bacterial analysis was done by Gram staining method. Health data were gathered through questionnaires. Humidity, light intensity and concentration of CO, SO_2 and PM_{10} were observed to be comparatively higher ($P < 0.05$) during winter and bacterial colonies were found to be comparatively higher ($P < 0.05$) in rural areas. About 80% of airborne bacteria in both urban and rural areas were Gram-positive. The indoor air quality of rural households was more polluted than urban households, and pollution was more in winter compared to summer due to inefficient cooking techniques and burning of biomass fuel.

Keywords: Health assessment, indoor air, particulate matter, seasonal variations, urban and rural households.

AIR pollution is often considered as an urban issue, but it now extends to rural areas as well. Indoor air pollution causes greater health impacts than outdoor air pollution[1]. The most important factor that describes indoor air quality is the exposure to air pollutants released during the solid fuel combustion, containing biomass or coal used typically for cooking and heating purposes, indoor tobacco smoke, poor ventilation system, construction materials, furnishings and polishing[2]. Biomass fuel refers to the burned plant or animal excretes like dung, and wood, charcoal or crop residue that is used by more than half of the households as energy resource in most of the developing countries and more than 95% of low-income-generating countries[3]. The burning of these fuels is the major source of smoke and other pollutants in the vicinity of a household, resulting in direct human exposure; this is several times more polluted than unprocessed solid or gaseous fuel[4]. Inefficient earthen or small metal stoves, or open pits are typically used for the burning of biomass in inadequately ventilated kitchens by a majority of the rural community, which results in an elevated level of indoor air pollution. Open fires from biomass fuel produce high levels of gaseous and particulate matter (PM), which is 10–20 times higher than the health guidelines available for typical urban outdoor concentrations[5]. Thus, indoor air pollution has a detrimental impact on human health and the environment. The combustion of biomass fuel produces a large amount of toxic pollutants, e.g. carbon monoxide (CO), sulphur dioxide (SO_2), PM, viz. (PM_{10}), nitrogen oxide (NO_2) and many other harmful pollutants[3]. Due to the confined nature of indoor spaces with minimum turnover rates of air, pollutants released inside will not disperse quickly, thus resulting in poor indoor air quality[6].

Carbon monoxide is an asphyxiate which binds with haemoglobin and hinders the transport of oxygen throughout the blood. While old aged people foetuses, and asthmatic patients are vulnerable to high CO levels, women and children are at the risk of direct exposure due to uncleaned fuel combustion for heating and cooking activities[7]. SO_2 is produced due to the oxidation of sulphur during the biomass combustion process, which can be detected at 0.5 ppm (0.9 mg/m³) due to its strong pungent smell. SO_2 can also absorbs in the mucous membrane of upper respiratory tract, however, its absorbency depends upon the level of humidity[8]. Thus, there is a strong association between the risk of diseases and burning of biomass fuel[6]. Although SO_2 concentration is generally lower indoors than outdoors, it can cause detrimental health impacts, i.e. reduced lung functioning and other respiratory problems[8]. PM_{10} has significant health impacts and indoor smoking can add up to 300 μg/m³ PM even after smoking a cigarette. Cooking, i.e. frying can further increase its concentration indoors[9]. Many biological contaminants (bacteria, fungi, dust mites, moulds and pests) have also been found in indoor air and induce infections, direct toxicity or atopic mechanism.

A developing country like Pakistan is fighting to deal with such environmental problems which are directly related to poverty and health[10]. About 62% of Pakistan's population lives in rural areas, where the use of biomass fuel is widespread for cooking and heating purposes[11]. About 94% of the rural population use biomass fuel for heating and cooking thus, contributing to indoor air

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pollution with high levels of smoke, PM and CO (ref. 12). Inefficient cooking practices and incompletely burnt fuel inside poorly ventilated houses cause many health problems[13], including lung cancer, acute lower respiratory tract infection, chronic pulmonary diseases, low birth weight, nutritional deficiency, cataract and cardiovascular diseases[14]. About 28,000 deaths per year and around 40 million cases of acute respiratory illness have been reported in Pakistan due to deteriorated indoor air quality[15]. The health effects, including eye and respiratory diseases, have been reported largely among Pakistan women[16]. The present study focuses on the assessment of seasonal variations in indoor air quality of urban and rural residential areas and evaluates the health status of people affected by poor indoor air quality.

Methodology

Selection of study sites

Two study sites (urban and rural) were selected for the measurement and comparison of indoor air quality. Two additional sites were also selected as control group (one urban and one rural). Selection of these study sites was done on the basis of the structure of houses and availability of essential resources. Residents living in study sites (rural and urban) had limited access to resources, whereas residents in the control group had a good lifestyle. Twenty-four random houses were selected for sampling and health survey from urban and rural study areas, and comparisons were made between them alongside the control group. Sampling was done in winter (January and February) and summer (June and July) in order to check the significant differences between the two areas in different seasons.

Indoor air quality parameters

Digital metres (metric method) were used to determine the temperature and humidity (digital thermometer and hygrometer P320 respectively); light intensity (lux meter LX-9621), carbon monoxide (CEM, CO-180) and sulphur dioxide (ToxiRAE Pro, PGM-1860) levels were also measured. A high-volume air sampler (Sibata Model HV-1000F) was used to measure PM_{10} (μm) with a suction flow rate of 800 l/min. Indoor air microbial sampling was done using lsogeny broth (LB) agar medium, because it is nutritionally rich and potential for petri plate bacteria. The petri plates were then exposed to air for 1–2 min to accumulate sufficient amount of airborne bacteria upon them, and incubated for 48 h at 37°C. The colonies that appeared on the plates were counted in colony forming units (CFU) for each of the urban and rural sites. Colony morphology was determined as its shape and colour. For microbial cell identification, Gram staining method was used to determine whether the bacteria were Gram-positive or mixed.

Health status

The questionnaire survey was conducted on the same 24 households of both areas, focusing on house construction, energy source for burning, cooking time and frequency, cost of fuel and its availability, and health conditions associated with fuel burning and other pollution sources. For statistical analysis, independent *t*-test was applied to humidity, CO, SO_2, PM_{10} and microbial colonies to determine the significant difference between both areas and for various seasons. Correlation between all the parameters was used to find their relationship. Descriptive statistics was applied to the questionnaire in order to compare both areas to evaluate the health status of the sites.

Results and discussion

The temperature in urban areas ranged from 8.8°C to 26°C in winter and 32.8°C to 39.2°C in summer, whereas in rural areas it ranged from 7°C to 21°C in winter and 31.8°C to 38°C in summer. The humidity level in urban areas ranged from 52% to 73% in winter and 34% to 60% in summer while in rural areas it was 40% to 60% in winter and 39% to 55% in summer. According to the ASHRAE standards[17], humidity for indoor households is 85% maximum. The lower limit is not defined by the standards, rather it should be maintained at 65% to reduce the condition suitable for microbial growth[17]. The level of humidity was up to 73%; this was due to increased cooking activity and the impact of seasonal temperature. The intensity of light varied in both areas; it ranged from 5 to 45 lx in urban house and 20 to 310 lx in rural houses. The light level depends on the time of monitoring. During daytime it was 310 lx in the rural houses. Open kitchen and windows were factors that increased light intensity. CO level in urban households ranged from 3 ppm to 9 ppm during winter and 2 ppm to 7 ppm during summer, whereas in rural houses, it varied from 4 to 11 ppm during winter and 2 to 11 ppm during summer. According to the USEPA national ambient air quality standards[18], the level of CO should not exceed 9 ppm, but it was up to 11 ppm during cooking time in rural households. The study on CO during cooking time in urban and rural areas using biomass fuel in Bangladesh exceeding high also revealed levels of CO up to 19.6 ppm (ref. 19). The level of SO_2 was found to be within limits in urban houses, ranging from 0.04 to 0.06 ppm in winter and 0.02 to 0.04 ppm in summers. However, in rural houses, it was slightly high ranging from 0.04 to 0.12 ppm in winter and 0.02 to 0.08 in summer. SO_2 levels were not considerably high indoors because of low contents of sulphur in fuels. Also, SO_2 is not as reactive like ozone or NO_2, which can be absorbed or can react with other materials[20]. The levels of PM_{10} in urban houses varied from 2.0 mg/m^3 in winter to 1.0 mg/m^3 in summer, while in rural houses, it varied from 2.8 mg/m^3 in winters to 2.9 mg/m^3 in summer. According to the USEPA standards[18], its allowable limit is 0.15 mg/m^3. Overall, most rural kitchens were muddy with thatched roofs and less ventilated. This results in capture considerable amount of PM deposits on ceilings, which can get mixed in indoor air when agitated or scrubbed by the resident[21].

The *t*-test results of the parameters showed that indoor air pollution were higher in rural areas than urban areas, and was more in winter because of increase in indoor heating activities. The levels of light, CO and PM_{10} were found significantly ($P < 0.05$) higher in rural houses than urban houses during winter and summer seasons (Table 1). The reason was poor ventilation, dust and low wind flow in confined and small kitchens of the village houses, as 76% of the respondents reported closed kitchen[9]. In urban residences, 92% respondents had a closed kitchen, but had at least one window and exhaust fan, which helped in the rapid dispersion of pollutants. The type of fuel used also affects the indoor pollution level. In this study 56% of urban community reported using heaters and 78% of rural community used coal and dung in winter. A study done Bangladesh compared the urban and rural indoor air pollution levels and also found increased level of CO up to 19.6 ppm during cooking time and PM_{10} up to 1.051 mg/m³, which were higher than the standard levels[19]. The results of correlation (Table 2) between different parameters showed a negative correlation between CO and humidity level, CO and temperature, SO_2 and temperature, as well as PM_{10} and temperature in both type of houses (Table 2). A positive significant relation was found between CO and SO_2, humidity and SO_2, humidity and PM_{10}, as well as SO_2 and PM_{10} ($P < 0.01$). This may be due to the same origin of all pollutants or because of meteorological factors. A survey in Nepal showed that the concentration of PM in kitchens varied with the style of cooking. The modern cooking system with electric stoves and chimneys resulted in PM concentration of 0.4 mg/m^3 whereas traditional cooking stoves with no chimneys or any other ventilation system resulted in PM concentration of 10 mg/m^3 (ref. 22). A study on eight primary schools of Portugal with poor exhaust systems in the canteen's kitchen showed that there was a significant ($P < 0.01$) association between cooking and high levels of PM[23]. It has also been noted that despite the recent switch to alternative cleaner energy source from the polluting solid fuels, long-term exposure in the past might have an adverse effect an elderly people[24].

Table 1. Comparison of indoor air quality parameters between urban and rural houses

Parameters	Mean ± SD	
	Urban	Rural
Winter		
Temperature (°C)	17.04 ± 1.2^a	14 ± 1.1^b
Humidity (%)	62.3 ± 6.0^a	52.7 ± 6.6^b
Light (lx)	21.3 ± 13.9^a	88.3 ± 40.6^b
CO (ppm)	5.8 ± 1.8^a	7.6 ± 2.1^b
SO_2 (ppm)	0.05 ± 0.007	0.07 ± 0.02
PM_{10} (mg/m³)	2.0 ± 0.3^a	2.8 ± 0.5^b
Summer		
Temperature (°C)	35.7 ± 1.9	34.3 ± 1.6
Humidity (%)	50.1 ± 7.6^a	43.6 ± 4.8^b
Light (lx)	19.0 ± 12.0^a	105 ± 95.6^b
CO (ppm)	4.3 ± 1.7^a	6.5 ± 2.9^b
SO_2 (ppm)	0.02 ± 0.07	0.04 ± 0.01
PM_{10} (mg/m³)	1.0 ± 0.28^a	2.9 ± 0.4^b

Different alphabets in different columns significantly differ at $P < 0.05$.

Microbiological results

The number of colonies was found higher in rural (4–48 CFU) as compared to urban (1–24 CFU) houses, and was found more during summer than in winter (Table 3). The morphology of most of the colonies was irregular in shape, merged and located at the periphery of the petri plate. A few round colonies were also observed. The colour of the colonies varied from white, creamy white to mild yellow. All the colonies were opaque. Results of the *t*-test showed a statistical significant difference ($P < 0.05$) between urban and rural houses with seasonal variation. The number of colonies was higher in rural houses compared to urban houses in both seasons. Moreover, the highest number of colonies was observed during summer in rural houses (293 CFU/m^3) and the least during winter in urban houses (69 CFU/m^3). High temperature in summer with greater humidity provides more nutrients (due to increase in the rate of decomposition of waste and food leftovers) for bacterial growth. Rural houses have poor hygienic conditions and more number of residents in a confined house, triggering the growth of bacteria[25]. The

Table 2. Correlations between indoor air quality parameters in urban and rural houses

Parameters	Pearson correlation (*r*)	
	Urban	Rural
CO and humidity	–0.347	–0.229
CO and SO_2	0.401*	0.232*
CO and PM_{10}	0.288	0.185
CO and temperature	–0.399	–0.243
Humidity and SO_2	0.536**	0.222**
Humidity and PM_{10}	0.643**	0.152**
Humidity and temperature	0.718	0.667
SO_2 and PM_{10}	0.676**	0.112**
SO_2 and temperature	–0.822	–0.532
PM_{10} and temperature	–0.809	–0.046

Correlation is significant at *$P < 0.05$ and **$P < 0.01$.

Table 3. Comparison of bacterial analysis between urban and rural houses

	Winter		Summer	
Parameters	Urban	Rural	Urban	Rural
Mean ± SD	5.5 ± 4.8[a]	10.7 ± 6.6[b]	10.6 ± 8.8[a]	24.4 ± 12.4[b]
Total CFU/m^3	69	130	128	293
% Gram-positive	91.6	50	83.3	66.6
% Mixed	8.4	50	16.7	33.4

Different alphabets in different columns significantly differ at $P < 0.05$.

level of humidity, number of persons per room, type of activities and rate of air circulations affect the level and species of indoor bacteria. Furthermore, it was found that in conventional indoor environments, human presence was the most significant source of airborne bacteria[26].

Gram staining results

The Gram staining test indicated that about 80% of total colonies were Gram-positive, whereas the rest 20% were mixed (Gram-positive and Gram-negative). In urban houses during winter season, 91.6% of bacteria were Gram-positive, while in rural houses 50% were Gram-positive and 50% were mixed cultures. During summer, 83.3% of bacteria in urban houses were Gram-positive while 16.7% were mixed and in rural houses only 66.6% were Gram-positive and the rest 33.4% were mixed type. The difference in the type of bacteria between urban and rural areas was because of excess of contaminated fuel sources, i.e. cow dung, coal, wood burning, etc. in rural areas, and indoor radiators and invertor air conditioning units in urban areas (Table 3). The bacteria varied from circular to rod-shaped in all houses of both urban and rural areas. Gram-positive bacteria have a thick layer of peptidoglycan in their cell membrane which protects them from desiccation, thus they can better survive in dry and warm conditions compared to the Gram-negative bacteria[27]. Their number is significantly lower indoors compared to outdoors, but excessive moisture level, humidity, temperature, food availability and even intensity of light can trigger the growth of different species. The excessive growth of bacteria, results in adverse health impacts on the residents, illness, allergies, etc. It is estimated that about 30% of health issues related to indoor environment are mainly caused by the indoor airborne bacteria[28]. They also play a role in the reduction of beneficial bacteria that aid in digestion and other important biological process, thus further worsening the situation[29].

Exposed individuals and their lifestyle

In urban houses, only a few families (36% of the total urban population) were living in the same house as a joint family, whereas in rural houses, more families (64% of the total rural population) were living in a same house or in compact houses, thus increasing the overall chances of exposed individuals. The mean values for the number of households versus number of the rooms for accommodation was also considerably different in both sites. In urban houses, six persons on an average were living in four rooms, whereas in rural houses nine people were living in only two rooms. The construction material for an urban kitchen was concrete, whereas rural houses had muddy walls with thatched roof 68%, corrugated iron 28% and the other cemented roof 4%. In urban houses, 92% of the kitchens had either window, exhaust fans or a proper ventilation system, whereas in rural houses, 76% kitchens were either confined or merged into the living area where most of the residents spent their time. All the urban households used gas stoves, whereas the rural households used different types of biomass fuel, including cow dung (12%), wood, gas cylinders (8%) and mixed fuel (68%) (Table 4). The majority of urban residents had not witnessed any visible adverse effects from fuel burning and smoke (89%), because they were aware to minimize the effects, i.e. using face masks, installing central heating systems instead of coal burning, etc. However, most of the rural residents experienced witnessed biomass burning effects (68%), i.e. headache, sore eyes, dizziness, breathing difficulties, etc. Although their awareness about adverse health effects was minimal (48%), their willingness to change was encouraging (96%). The cooking frequency also varied in both type of houses, where 88% of rural people cooked twice a day, 74% of urban people cooked thrice a day. A study deduced that concentration of PM was higher in the kitchen than other rooms due to the use of biomass fuel for cooking purposes. As women spend most of their time in the kitchen, they are exposured more to PM and thus have a high risk of disease.

Besides, 84% of urban respondents were found to report shortage of purposes cooking gas for during winters. About 76% did not use any alternative, while 16% use gas cylinders and 8% electric stoves. During winter 56% of urban households used gas heaters, while 78% of rural households used coal and dung for heating purposes. Comparison of obtained results with control group revealed that due to the use of heaters and coal burning, 52% respondents reported shortness of breath while the other issues were headache, dizziness, eye irritation, eye

Table 4. Comparison of fuel as well as concern regarding indoor air pollution (IAP) in urban and rural houses

	Urban		Rural	
Fuel/biomass burning effect	Yes (28%)	No (72%)	Yes (68%)	No (32%)
Smoking	Yes (24%)	No (76%)	Yes (72%)	No (28%)
Paint/polish respiratory ailment	Yes (48%)	No (52%)	–	–
Awareness to minimize IAP	Yes (89%)	No (11%)	Yes (48%)	No (52%)
Willing to change fuel use	–	–	Yes (96%)	No (4%)

watering, nausea, restlessness, high blood pressure and even skin irritation. Due to the burning of biomass fuel, several issues have been identified in rural people, i.e. sneezing, dry throat, eye irritation, headache, shortness of breath and dizziness. Several studies have shown that the burning of biomass, indoor smoking, paint polish cause respiratory ailments. Fullerton *et al.*[14], reported the impact of indoor air pollution caused by the burning of biomass fuel, including dung, wood and charcoal used for cooking and heating purposes. Some of the respondents did not consider these burning-related ailments as serious, but as a part of their normal routine. Also, 89% urban respondents and 48% rural respondents were aware of how to minimize indoor air pollution. Health problems caused by air pollution were typically chronic because their impacts often took longer time periods to showup[4]. Respiratory ailments had become relatively frequent among most of the respondents and they might have acquired themselves to live with it[1].

The most common and abundant use of biomass fuel in the rural community was due to its free or cheap availability, because most people owned cows for dung production. Women played a major role in collecting wood from vacant plots and open spaces. Also, 8% of people preferred LPG cylinder over biomass fuel due to smoke issues. However, for most of the community, type of fuel, easy access and cheap cost are top priority[13]. Lung cancer, weakness, unstable pregnancy, respiratory infections in children and tuberculosis were reported, particularly in rural areas where biomass was used for burning purposes indoors in Pakistan. Children are more prone to harmful impacts. Yoon *et al.*[30] reported that younger children are more prone to polluted air than older children. A study in Korea of indoor air quality of urban and rural preschools was conducted and compared with outdoor air quality. The results showed that indoor urban air was more polluted than outdoor rural air. Another study revealed that 50.3% people had severe pulmonary diseases, 22.7% had infectious related to respiration, 19.6% had asthma and 7.4% were affected by lung cancer. The reason for this was primarily poverty, lack of information, less access to natural gas and easy availability of biomass fuel for burning and cooking purpose[2]. Although 96% of the rural respondents were willing to change their mode of cooking and heating to avoid indoor pollution, they could not do so due to unavailability of gas source and poor socio-economic status. Thus, the government should help improve the health and socio-economic status[10].

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