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ASSESSMENT OF FINE PARTICULATE MATTER AND GASEOUS EMISSIONS IN URBAN AND RURAL KITCHENS USING DIFFERENT FUELS

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ABSTRACT

Cooking is a major source of $PM_{2.5}$ in kitchens and concentrations can vary with the types of fuel in use. Moreover location of stove, ventilation, and cooking styles also contribute to the varying levels $PM_{2.5}$. In this study, an urban and a rural kitchen were selected for monitoring mass concentrations of $PM_{2.5}$ over a period of 24 hours using a real-time aerosol monitor. The urban kitchen used natural gas as the cooking fuel while LPG was used in the rural kitchen due to unavailability of natural gas. The average concentration of $PM_{2.5}$ in the urban kitchen was recorded to be 119 µg/m³ and 160 µg/m³ in the rural kitchen. The activities of the occupants were also noted to record which activity generated the highest levels of particulate matter. Cooking was identified as the major source with cleaning activities on second number. Gaseous emissions from different types of bio fuels were also measured using a gas analyzer. CO, NO_2 and SO_2 were measured in three urban and three rural kitchens. NO_2 was found only during wood combustion and SO_2 was not found in any fuel. CO was measured to be 19.5 ppm and 54 ppm in the first two urban houses using natural gas respectively while it was only 6 ppm in third urban kitchen using LPG. In the rural area, CO was recorded to be 43 ppm in the kitchen using wood, 167 ppm in the kitchen using animal dung and 693 ppm in the kitchen burning both wood and animal dung. NO_2 was 7 ppm in the kitchen burning wood and 10 ppm in kitchen where wood and animal dung was used as a fuel. Natural gas and LPG were identified as cleaner fuels with lower emissions. However none of the pollutant level was in compliance with the WHO standards.

Keywords: $PM_{2.5}$, Real-time monitoring, Biomass fuels, Natural gas, Liquefied Petroleum Gas.

INTRODUCTION

Biomass is the first fuel to be used by man and thus has a certain place in the human life. Around the globe, 2.5 billion people consume biomass fuels such as wood, charcoal, animal wastes and agricultural remaining. It is estimated that 2.7 billion people will be using biomass for cooking purposes in 2030 (Isler and Karaosmanoglu, 2009). In developing countries like Pakistan, people continue to use biomass even if they have cleaner fuels available since poverty is the main obstacle to the acceptance and use of cleaner fuels (Nasir *et al*. 2015; Jan *et al*. 2012).

In Pakistan, majority of the people (almost 70%) live in rural areas and biomass is used as a cooking fuel in 94% houses of rural areas and 58% in urban areas. These solid fuels create indoor air pollution that can pose a serious threat to human life (Colbeck *et al*., 2010a). 70% of the domestic sector energy of Pakistan comes from biomass and 53% of that is from wood (Siddiqui *et al*., 2009). But unfortunately people do not consider indoor air pollution as an environmental or health hazard in Pakistan.

Incomplete combustion of biomass fuels produces large amounts of noxious pollutants such as respirable particulate matter, nitrogen oxides, sulfur dioxide and carbon monoxide. This problem is aggravated when cooking areas are inadequately ventilated and the houses lack a separate kitchen (Mishra *et al*., 2004). Indoor air pollution depends on some factors, which are; the nature of fuel used, the time used up during cooking, structural properties of houses, and the ventilation inside the houses (Begum *et al.*, 2009). Among these, burning of cooking fuels and improper air exchange severely affects the indoor air quality (Singh and Jamal, 2012).

Household's choice of fuel type most commonly depends upon four factors: (a) price of fuel, kind of stove and fuel accessibility; (b) stove characteristics and cooking practices; (c) cultural preferences; and lastly (d) the possible health effects. Last one is the most important but it is often ignored (Fullerton *et al*. 2008).

There is a link between household use of energy and income known as the energy ladder which shows the transition from the use of biomass fuels to use of modern fuels with increase in income. People with low income use mostly crop waste, dung, and wood for household fuel combustion. LPG, electricity, or natural gas is used as fuel by high income group mostly (WHO, 2006).

Generally gaseous fuels, including natural gas and LPG, burn more cleanly then liquid fuels i.e.

kerosene and liquid fuels are cleaner then solid fuels i.e. wood, agricultural residues or animal dung. However, as mentioned earlier, the choice of fuel mostly relies on the cost of the fuel or the income effect (Kojima *et al*., 2011).

In a study involving assessment of particulate emissions by different fuels in urban and rural areas of Pakistan, higher levels of particulate matter were observed in rural kitchens using bio fuels as compared to urban kitchens using natural gas and LPG (Colbeck *et al*, 2010b). The indoor levels of particulate matter were higher due to particular activities such a cooking, cleaning and smoking.

The present study was conducted to determine the concentrations of $PM_{2.5}$ in an urban and rural kitchen using almost same fuel type. Same fuel type was selected to observe if difference in locality i.e. an urban and a rural environment contributed to any difference in $PM_{2.5}$ concentrations. Moreover, gaseous emissions were also measured from a variety of fuels in urban and rural kitchens to evaluate which fuel was cleaner and posed fewer health hazards.

MATERIALS AND METHODS

For this study, the urban area was selected to be Lahore city, Pakistan and the rural area was a village in Tehsil Shakargarh (Figure 1). For the assessment of particulate matter, both the urban and rural houses which were selected contained six occupants each and burned natural gas and LPG respectively as cooking fuel. LPG was burned in the rural kitchen due to unavailability of natural gas in that area. Some other characteristics that were observed included ventilation in the kitchens, number of residents in each house and activity patterns including cooking, cleaning, and sweeping.

Fig 1: Location of Study sites (Source: Google Maps)

DustTrak aerosol monitor (model 8520, TSI Inc.) was used to measure mass concentrations of $PM_{2.5}$ in both kitchens. It was placed for 24 hours in both kitchens and major activities like cooking time and duration were also noted.

Similarly, three houses were selected each in rural and urban area on the basis of type of fuel used to determine the gaseous emissions from different fuel types. In urban houses, LPG and Natural Gas were being used and in rural houses, biomass fuel i.e. wood, and animal dung were being used as cooking fuels.Gas Analyzer IMR 2800, USA was used for the analysis of gases. Three samples were collected from each house. Some characteristics, such as, number of residents, cooking duration, ventilation, were also observed. The gases measured were carbon monoxide CO, nitrogen oxides NO_x, and sulfur dioxide SO_2. Temperature of the gas and room temperature were also measured.

RESULTS AND DISCUSSION

The 24-h average concentration of $PM_{2.5}$ was recorded to be 160 µg/m³ in the rural kitchen while it was 119 µg/m³ in the urban kitchen. The number of occupants was the same in both houses i.e. six. However there were some visitors in the rural house during the study period. Both kitchens burned two stoves and an exhaust fan was also present in each kitchen. The urban kitchen lacked a window however and the door remained opened in both kitchens. The urban kitchen was approximately 20% ventilated while the rural kitchen was 30% ventilated approximately.

The maximum and minimum values for $PM_{2.5}$ in the urban kitchen were recorded to be 379.7 µg/m^3 and 45 µg/m^3 respectively. On the other hand the maximum and minimum concentrations of fine particulate were 1060 µg/m^3 and 36.5 µg/m^3 respectively in the rural kitchen. Major activities being carried out in the two kitchens were also noted down (Figure 2 and 3).

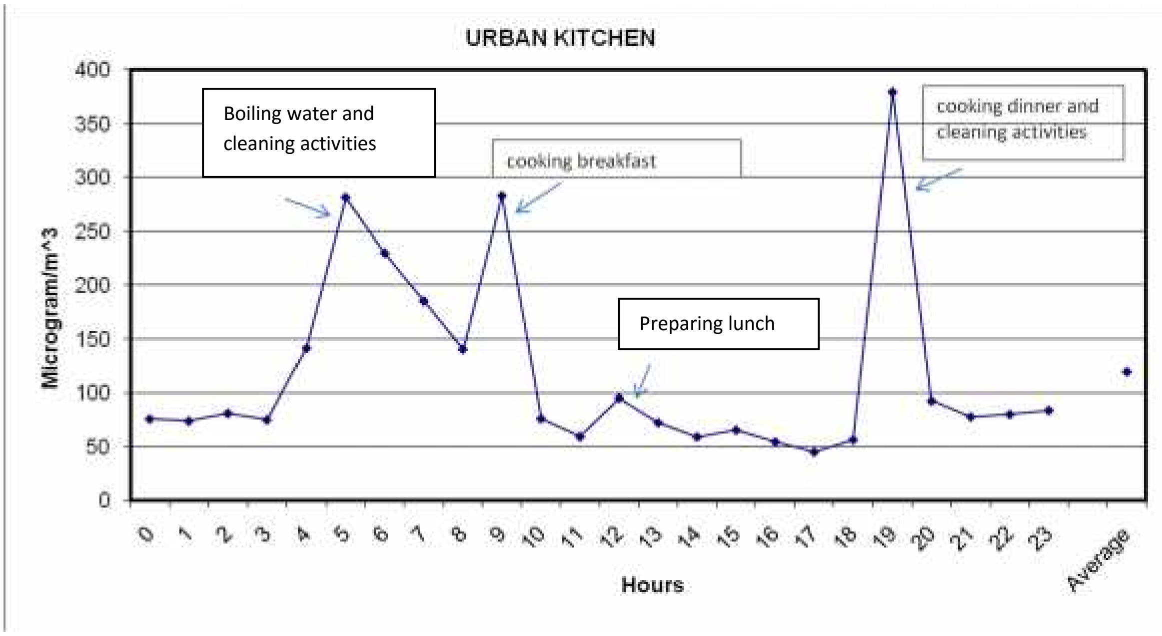

Fig 2: 24 hour concentration of $PM_{2.5}$ in urban kitchen

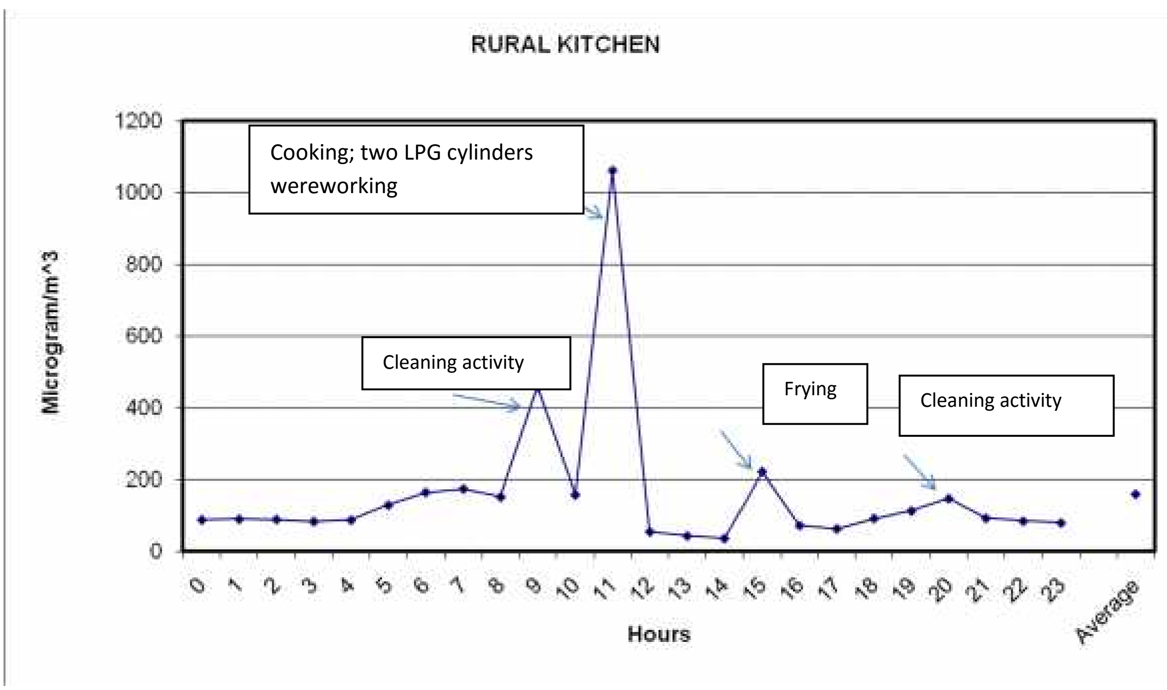

Fig 3: 24-hour concentration of $PM_{2.5}$ in rural kitchen

With reference to the gaseous emissions from kitchens during cooking in three urban houses and three rural houses, SO_2 was not found to be emitted from any fuel type while NO_2 was observed only when wood was burned as a fuel. The mean value of CO was 19.5 ppm in the first urban house and 54 ppm in the second urban house. Both houses used natural gas as cooking fuel. The value of CO in the third urban house where LPG was used was found to be 6 ppm. On the other hand the mean value of CO was found to be 43 ppm in the first rural house and that of NO_2 was 7 ppm. Type of fuel was wood. In second rural house where animal dung was being burned, the mean value of CO was found to be 167 ppm and NO_2 was not found. Third urban house burned both wood and animal dung and highest concentrations of CO and NO_2 were observed there i.e. 693 ppm and 10 ppm respectively.

The comparison of CO concentration found from all fuels i.e. natural gas, LPG, wood, animal dung and a combination of wood and animal dung shows that highest concentration was found in the combination of wood and animal dung and LPG showed the minimum concentration. Similarly a comparison of NO_2 concentration found from all fuels shows that combination of wood and animal dung showed the highest concentration. It was not found in natural gas, LPG and animal dung (Figure 4).

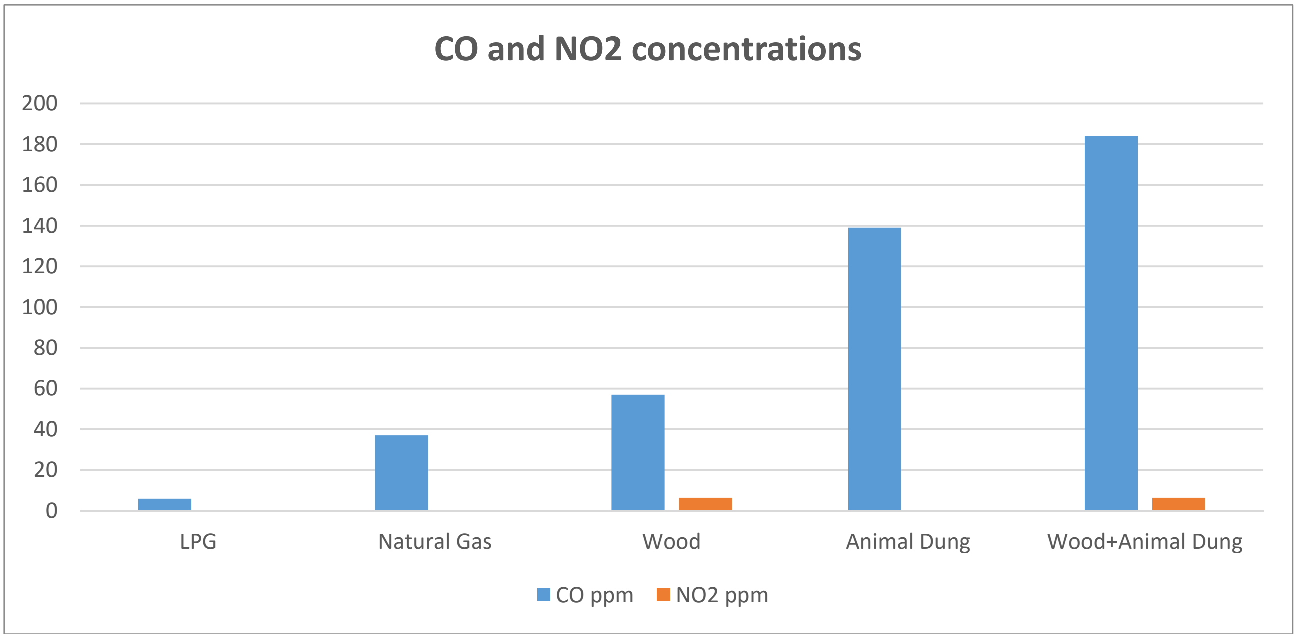

Fig 4: Comparison of CO and NO_2 emissions from different fuel types

Worldwide around 3 billion people use biomass fuels in their households. The most significant reason of indoor air pollution in developing countries is the production of pollutants during combustion of solid fuels, used for cooking and heating (Colbeck *et al*. 2010a).

In the present study, the concentrations of $PM_{2.5}$ in both rural and urban houses were found to be higher than the permissible limits specified by World Health Organization (WHO) for $PM_{2.5}$ i.e. 25 $\mu g/m^3$. A study indicates that a major cause of indoor air pollution is the poor mixing of air in the stove or when it is not properly ventilated. The concentrations of CO and PM often exceed the air quality standards, in such cases (Siddiqui *et al*., 2009).In rural kitchen, there were windows near the cooking area, a door which was mostly left open, an exhaust fan, and a ceiling fan. There were two LPG cylinders. Sometimes both were used for cooking. Outside the kitchen was a courtyard where movement of people was more and cleaning activities were also high. However, in urban kitchen, there was a door which was mostly left open, and one exhaust fan. Exhaust fan was off during most of the study period mostly due to load-shedding of power supply. There were two natural gas stoves and mostly both were used for cooking. Movement of people was low as compared to that in the rural kitchen which also explains lower concentrations of $PM_{2.5}$ in urban kitchen

In the urban kitchen, major sources of particulate matter were identified to be cooking and cleaning activities. The highest concentration was detected at around 7 pm when both cooking and cleaning were being carried out. Similarly in the rural kitchen, the concentration of fine particulate matter increased when two LPG cylinders were being used simultaneously at 11 am and when some frying was done at around 3 pm. Another high peak was observed at 9 am when there were four people working in the kitchen and cleaning of the room took place. It is evident from a study carried out by Colbeck and Nasir (2010) that specific indoor activities, such as cooking, cleaning and smoking lead to high concentrations of indoor air pollutants. Movement of people can also cause variation in the concentration of Particulate Matter. When there are more people in the sampling area, the concentration of PM will be higher as observed in this study.

Moreover, ventilation rates also have an impact on indoor air pollution (Begum *et al*., 2009). In the present study, space available for ventilation was also determined both in rural and urban kitchens. It was found that rural kitchen was approximately 30 % ventilated while urban kitchen was approximately 20 % ventilated. The main purpose of ventilation in buildings is to create a more suitable indoor environment for persons and processes (Sundell, 2004). It is related to the concentrations of pollutants in the indoor environment. It was shown in a study that concentration of pollutants, which was low, increased when the ventilation was reduced (Turiel *et al.*, 1983). However in this study, although the rural kitchen was better ventilated than the urban kitchen, higher concentrations were observed in the former. The major reason behind this increased level can be attributed to the use of two LPG cylinders, movement of people in and around the kitchen and the presence of a bricked courtyard outside the kitchen.

Due to the combustion of fuels, many gases are also released. In the second part of this study, gaseous emissions from the combustion of rural and urban fuels were assessed.The gases analyzed were CO, NO_2 and SO_2. SO_2 was not observed in any of the kitchens under study and NO_2 was found only in two rural kitchens where wood was being burned. The reason for absence of SO_2 can be contributed to the fact that none of the kitchens used coal as a fuel which is a major source of SO_2.

In the first urban house, there were 6 residents and the mean concentration of CO was 19 ppm. Exhaust chimney system was good so there was less concentration of gases. In the second urban house, the mean concentration of CO was 54 ppm despite the fact that the number of residents was only 5 and cooking activity was also low. The high concentration of CO was due to the improper chimney exhaust system. It was very low due to which there was more concentration of smoke. In the third urban house LPG cylinders were used and there was only 6 ppm emission of CO with no traces of NO_2.

In the first rural house, wood was being used as fuel. Cooking was done in traditional three stone stoves. More than two women were engaged in cooking. It was done in open air. There were rooms in the adjacent area which were exposed to the smoke. The mean value of CO was found to be 43 ppm and that of NO_2 was 7 ppm.

In the second rural house, animal dung was being used as fuel. The mean concentration of CO was 167 ppm and NO_2 was not found. It was observed that animal dung combustion emitted a lot of smoke, even more as compared to wood combustion. Cooking was done in open air. The people in the courtyard were exposed to this smoke. But according to the women, who were doing the cooking, they were used to this smoke and it did not irritate them. However, the young people or the new generation did not like to cook on these traditional stoves.

The third rural house used a combination of wood and animal dung. In that house there were many children. They were also moving around the stoves. Many women and young girls were engaged in cooking. The highest concentration of CO was found in this house i.e. 693 ppm. The concentration of NO_2 was found to be 10 ppm.

A study carried out by Singh and Jamal (2012) showed that the pollutants produced during burning of solid fuels depend on type of fuel, mode of burning, temperature, air flow and some other factors. Burning of biomass releases hundreds of chemicals in the form of gases or particulates. According to USEPA (1997) smoke emitted from wood burning stoves contains17 pollutants, including carbon monoxide, small amounts of nitrogen dioxide, respirable particulates. The use of biomass fuels produces higher pollutant levels, much higher than the standards or guidelines. PM and CO is considered major sources of many types of health effects from the mixture of pollutants emitted from biomass combustion smoke (Rehfuess *et al.*, 2011).

These results support the previous studies (Colbeck *et al*., 2008; Kojima *et al*., 2011) that LPG and natural gas are cleaner fuels as compared to wood and animal dung. It was also noted that the concentration of indoor air pollution is largely based on activities and life style of the residents. There can be changes in the concentration of PM within the same house if the people change their life style. The concentration of CO was very less in urban kitchen as compared to that in the rural kitchens while NO_2 was not present in any of the urban kitchens. According to another study, stoves burning wood are known to emit the highest concentrations of CO and particulate matter while LPG stoves showed better results in terms of air quality (Naeher *et al*, 2000).

However, it is noteworthy that none of the pollutant levels were in compliance with the WHO standards. $PM_{2.5}$ concentrations are much higher than the WHO standard of 25 µg/m³ even in the urban kitchen. Cooking style can be a contributor to this increased emission of particulate matter since frying emits higher concentrations of $PM_{2.5}$ than boiling (Huboyo*et al*, 2011) and the typical cooking style in Pakistan includes frying and extensive cooking of the food.

Conclusions: Since $PM_{2.5}$ concentrations are higher in the rural kitchen as compared to the urban kitchen despite the similarity of fuel, it is evident that only fuel type is not responsible for higher pollutant levels. Many other factors must also be considered i.e. the cooking style, number of people present, ventilation and even the surroundings. In this instance the rural kitchen was surrounded by a bricked courtyard which caused dust from outside to infiltrate the kitchen. Moreover, extensive cooking which also included frying is another factor responsible for increased PM levels. The courtyard outside the urban kitchen was tiled so lesser amount of dust was generated. In case of gaseous emissions, CO levels were the highest when both wood and animal dung were used as a fuel. All of the pollutant levels were observed to be much above the WHO standards.

REFERENCES

Begum, B. A., S. K. Paul, M. D. Hossain, S. K. Biswas and P. K. Hopke (2009).Indoor air pollution from particulate matter emissions in different households in rural areas of Bangladesh. Building and Environment.44: 898-903.

Colbeck, I., Z. A. Nasir, S. Hasnain and S. Sultan (2008). Indoor air quality at rural and urban sites in Pakistan. Water, Air, & Soil Pollut: Focus 8:61–69.

Colbeck, I. and Z. A. Nasir (2010). Indoor Air Pollution.In Human Exposure to Pollutants via Dermal Absorption and Inhalation.Ed. Lazaridis, M. and Colbeck, I. Environmental Pollution. 17: 41-42.

Colbeck, I., Z. A. Nasir and Z. Ali (2010a). The state of indoor air quality in Pakistan – a review. Environmental Science and Pollution Research. 17: 1187-1196.

Colbeck, I., Z. A. Nasir and Z. Ali (2010b). Characteristics of indoor/outdoor particulate pollution in urban and rural residential environment of Pakistan. Indoor Air – International J. Environment and Health. 20: 40-51.

Fullerton, D. G., N. Bruce and S. B. Gorden (2008). Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. Transections of the Royal Society of Tropical Medicine and Hygiene. 102: 843-851.

Huboyo, H. S., S. Tohno and R. Cao (2011). Indoor $PM_{2.5}$ Characteristics and CO Concentration Related to Water-Based and Oil-Based Cooking Emissions Using a Gas Stove. Aerosol and Air Quality Research.11: 401–411.

Isler, A., and F. Karaosmanoglu (2009)."Biofuels in Turkey", in Karapınar, B., Adaman, F., Ozertan, G. (Eds), *Rethinking Structural Reform in Turkish Agriculture: Beyond the World Bank's Strategy*, Nova Science, New York, NY, pp.321-44.

Jan, I., H. Khan and S. Hyatt (2012), Determinants of Rural Household Energy Choices: an example from Pakistan. Pol. J. Environ. Stud. 21 (3): 635-641.

Kojima, M., R. Bacon and X. Zhou (2011). The World Bank, Policy Research Working Paper 5731: Who uses Bottled Gas? Evidence from Households in Developing Countries. pp: 2-61

Mishra, V., X. Dai, K. R. Smith and L. Mika (2004).Maternal exposure to biomass smoke and reduced birth weight in Zimbabwe.Annals of Epidemiology. 14: 740-747.

Naeher, L. P., B. P. Leadere and K. R. Smith (2000).Particulate Matter and Carbon Monoxide in Highland Guatemala: Indoor and Outdoor Levels from Traditional and Improved Wood Stoves and Gas Stoves. Indoor Air. 10: 200–205.

Nasir, Z. A., F. Murtaza and I. Colbeck (2015). Role of poverty in fuel choice and exposure to indoor air pollution in Pakistan. J. Integrative Environmental Sciences, (ahead-of-print), 1-11.

Rehfuess, E. A., N. G. Bruce and K. R. Smith, (2011). Solid Fuel Use: Health Effect. Encyclopedia of Environmental Health. 5: 150-161

Siddiqui, A. R., K. Lee, D. Bennett, X. Yang, K. H. Brown, Z. A. Bhutta and E. B. Gold (2009). Indoor carbon monoxide and $PM_{2.5}$ concentrations by cooking fuels in Pakistan. Indoor Air – International J. Environment and Health. 19: 75-82.

Singh, A. L. and S. Jamal, (2012). Indoor Air Quality in Areas of Different Exposure: An experimental study. Global Advanced Research J. Geography and Regional Planning. 1: 1-6.

Sundell, J. (2004). On the history of indoor air quality and health.Indoor Air. 14: 51-58

Turiel, I., C. D. Hollowell, R. R. Miksch, J. V. Rudy, M. J. Coye and R. A. Young, (1983). The effects of reduced ventilation on indoor air quality in an office building.Atmospheric Environment. 17: 51-64.

USEPA (1997). Exposure Factors Handbook (Final Report).U.S. Environmental Protection Agency, Washington, DC, EPA/600/P-95/002F a-c, 1997.

WHO (2006). Household energy, indoor air pollution and health, in: Fuel for Life: household energy and health. http://www.who.int/indoorair/publications/fuelforlife/en/index.html