International Journal of Environmental Science and Technology,
June 2019, Volume 16, Issue 6, pp 2565–2572
DOI:10.1007/s13762-018-1693-z

Spatial and temporal variations in indoor air quality in Lahore, Pakistan

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ABSTRACT

Indoor air pollution is a significant economic burden in Pakistan with an annual cost of 1% of gross domestic product. Moreover, according to the World Health Organization 81% of the population use solid fuels with 70,700 deaths annually attributable to its use. Despite this situation, indoor air pollution remains to be recognized as a hazard at policy level in Pakistan and there are no standards set for permissible levels of indoor pollutants. The current study was designed to monitor the indoor air quality in residential houses (n = 30) in Lahore, Pakistan. $PM_{2.5}$ and bioaerosols were monitored simultaneously in the kitchens and living rooms. Activity diaries were kept during the measurement periods. It was observed that cooking, cleaning and smoking were the principal indoor sources while infiltration from outdoor, particularly in the semi-urban and industrial areas also made significant contributions. Maximum and minimum air change rate per hour was determined for each micro-environment to observe the influence of ventilation on the indoor air quality. Lahore has a low-latitude semi-arid hot climate and a significant impact of season was observed upon bacterial and fungal levels. It was also observed that the $PM_{2.5}$ levels rose during the colder months and decreased significantly during the summer season. Low ventilation rates during the winter season as well as meteorological factors resulted in an elevated PM levels.

Keywords: Bioaerosols, indoor air pollution, particulate matter

INTRODUCTION

In South Asian countries substantial economic growth and urbanization has led to a poor air quality in urban centers. Pakistan, with rising types and number of emission sources and minimal air pollution control strategies, is struggling to arrest the excessive levels of air pollution in urban areas. The World Bank's overview (Sanchez-Triana et al., 2014) concluded that urban air pollution in Pakistan is among the most severe in the world. With over 35% of the population living in urban areas air pollution disproportionately affects the health and productivity of the poor. For example concentrations of $PM_{2.5}$ in Lahore can be up to 14 times higher than the United States Environmental Protection Agency limits (Colbeck at al., 2010) and $PM_{2.5}$-attributable Disability-Adjusted Life Year rates that were 5 to 10 times the lowest rates, which were found in the United States and Japan (Health Effects Institute, 2017). While globally absolute numbers of deaths attributable to $PM_{2.5}$ increased, from 1990 to 2015, by 20% those in Pakistan rose by 64%.

Indoor air pollution is a significant economic burden in Pakistan with an annual cost of 1% of gross domestic product. Moreover, according to the World Health Organization (WHO, 2007) 81% of population use solid fuels with 70,700 deaths annually attributable to solid fuel use. Despite this situation, indoor air pollution remains to be recognized as a hazard at policy level in Pakistan and there are no standards set for permissible levels of indoor pollutants (Sanchez-Triana et al., 2014). Particulate matter is ubiquitous in the indoor environment and bioaerosols are an important component accounting for up to 50% all aerosol particles (Mandal and Brandl, 2011). In this paper we report on measurements of $PM_{2.5}$ and bioaerosols in various households of Lahore, Pakistan.

The city of Lahore (31°15′—31°45′ N and 74°01′—74°39′ E) is the provincial capital of Punjab and the second largest city of Pakistan. The River Ravi flows along the north-western side of the city. This city is spread over an area of 1772 km^2 at an elevation of 217m above sea level. It is one of the most densely populated cities of the world, with around 9,086,000 inhabitants.

The city district experiences a hot, semi-arid climate with an average temperature of 24.3°C (Rasheed et al., 2015). During the extremely hot summers, the maximum average temperature ranges between 33 and 39°C and the minimum averages between 22 to 28°C. The winters experience an average maximum temperature of 17 to 22°C with the minimum ranging between 7 to 12°C (Alam et al., 2012). The city receives an annual rainfall of between 600 to 800 mm, most of it occurring during the monsoon period. Lahore has a five-season semi-arid climate:

- Winter (mid-November to mid-February)
- Spring (mid-February to mid-April)
- Summer (mid-April to June)
- Rainy/Monsoon (July to mid-September)
- Autumn (mid-September to mid-November)

METHODS

Lahore is divided into nine administrative zones and a cantonment area. Thirty houses were selected from all over Lahore to serve as sampling sites for monitoring of indoor air quality in terms of fine particulate matter and bioaerosols. Three categories were defined according to the size of the houses with following details: Category A: small: ≤ 126.5 m^2, Category B: medium: > 126.5 m^2 to 253 m^2, Category C: Large: > 253 m^2. Accordingly three houses; one from each category, were selected from each administrative zone and the cantonment area (Figures 1 and 2). The sampling sites were selected on the basis of their availability and after obtaining consent from the owners. Since the selection of the houses was random, therefore the surroundings of the houses varied considerably with some houses located in industrial areas, some in semi-urban areas while some were located in urban areas. This variation was also useful to provide an insight into the impact of surroundings on the indoor air quality of the sampling sites. All the selected houses were located within 1 km radius from main roads with variable traffic throughout the day. A questionnaire was filled for each sampling site to gain information about the number of occupants, their daily activities, occupations, time spent indoors and outdoors by each member of the household, smoking habits, type of cooking fuel, their health status, and other related factors.

Sampling was undertaken between January 2012 and March 2013. Two real time aerosol monitors (TSI DustTrak 8520) were run in parallel to determine $PM_{2.5}$ concentrations; one in the kitchen and another in the living room. The gravitational (sedimentation) method was applied to collect bioaerosol samples. Agar coated petri plates were exposed face upwards for twenty minutes at each location. The medium used for bacterial sampling was Trypticase Soy Agar (TSA) while Malt Extrose Agar (MEA) was used for fungal sampling. The exposed petri plates were incubated at 37°C for three days. The number of colonies was then counted and the species were identified. The number of colony forming units per cubic meter (CFU/m^3) was determined by Omelyansky's formula:

$$N = 5a*10^4(b.t)^{-1}$$

Where N is the microbial CFU/m^3, a is the number of colonies per petri dish, b is the dish surface (cm^2) and t the exposure time (minutes). Temperature and relative humidity of the sampling site was also noted.. All the selected study sites were naturally ventilated and used natural gas as the cooking fuel.

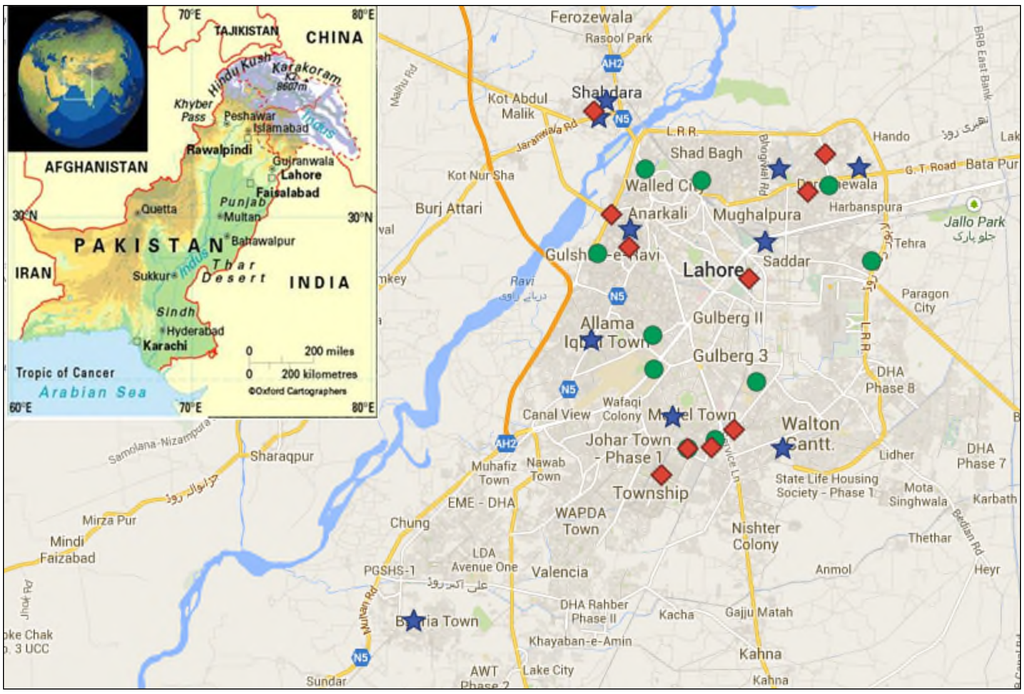
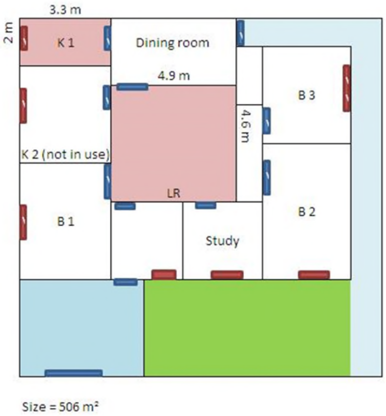
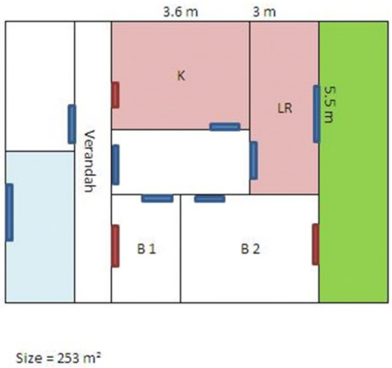


Figure 1: Location of study sites within Lahore city marked according to size (◆= category 1; ● = category 2; ★ = category 3)



Room	Doors (ft)	Doors (m)	Windows (ft)	Windows (m)
K	6.7 X 3	2.01 X 0.9	2 X 1.5	0.6 X 0.45
B1	6.7 X 3	2.01 X 0.9	4 x 3	1.2 X 0.9
B2	6.7 X 3	2.01 X 0.9	4 x 3	1.2 X 0.9
B3	6.7 X 3	2.01 X 0.9	4 x 3	1.2 X 0.9

KITCHEN			
LENGTH (m)	WIDTH (m)	HEIGHT (m)	VOLUME (m³)
3.35	2.13	3.05	21.80
LIVING ROOM			
LENGTH (m)	WIDTH (m)	HEIGHT (m)	VOLUME (m³)
4.88	4.57	3.05	67.96



Room	Doors (ft)	Doors (m)	Windows (ft)	Windows (m)
K	6.8 x 3.5	2.04 x 1.05	2.5 x 4	0.75 x 1.2
LR	6.8 x 3.5	2.04 x 1.05	No window	No window
	6.8 x 4	2.04 x 1.2		
B1	6.8 x 3.5	2.04 x 1.05	3 x 4	0.9 x 1.2
B2	6.8 x 3.5	2.04 x 1.05	3 x 4	0.9 x 1.2

KITCHEN			
LENGTH (m)	WIDTH (m)	HEIGHT (m)	VOLUME (m³)
3.66	2.13	3.05	23.79
LIVING ROOM			
LENGTH (m)	WIDTH (m)	HEIGHT (m)	VOLUME (m³)
5.49	3.05	3.05	50.97

Figure 2: Example floor plans

RESULTS & DISCUSSION

The time spent by each member in the house varied from less than eight hours to a full day. Mostly females and elderly people stayed at home with males and students spending more time outdoors. Of the males, 73% spent less than 8 hours at home while only 7% spent more than 16 hours at home. Of the females, only 38% spent less than 8 hours at home and 62% more than 16 hours. The time spent in kitchens was quite variable and among females, 57% spent 4 hours or less in the kitchen while 37% were in the kitchen for 5 to 8 hours daily.

Table 1 shows the 24 hour average PM2.5 concentrations for the kitchens and living rooms in all the houses. On average the smallest houses (category A) had the lowest concentrations in both kitchens and living rooms while the medium sized houses (category B) had the highest 24 hour concentrations, again in both kitchens and living rooms.

Numerous studies have reported on the impact of solid fuel use for cooking and heating in developing countries (WHO, 2007; Nasir et al., 2013; Rohra and Taneja, 2016; World Bank, 2016) but few have considered indoor air quality in major cities (Colbeck et al, 2010). The concentrations in the current study are towards the higher end of those in Indian urban areas (Rohra and Taneja, 2016). For example Taneja (2014) measured PM2.5 in 5 homes in Taj, India and reported levels of 168.2±43.2 μg m^{-3}. In low income houses, using clean fuels, in

Dhaka, Bangladesh the average PM2.5 concentration was 165 µg m^{-3} (Gurley et al., 2013a). According to WHO guidelines, the permissible levels of PM2.5 should not exceed 25µg m^{-3} in a 24-hour period. The average PM2.5 levels documented in this study were 13 times higher than the WHO limits in both the kitchens and living rooms of the selected sites. Long term exposure to such high levels of fine particulate matter can be detrimental for human health and thus need to be controlled.

	Average (µg m^{-3})			Average (µg m^{-3})			Average (µg m^{-3})	
	kitchen	**living room**		**kitchen**	**living room**		**kitchen**	**living room**
A1	224	140	B1	983	463	C1	343	194
A2	189	149	B2	237	203	C2	80	68
A3	185	168	B3	446	227	C3	137	138
A4	70	120	B4	185	166	C4	321	388
A5*	133	177	B5	250	115	C5*	852	974
A6	202	123	B6	200	214	C6	505	730
A7	343	336	B7	440	476	C7	389	285
A8	192	180	B8*	736	895	C8	286	387
A9	423	509	B9	383	657	C9	255	449
A10	457	383	B10*	743	417	C10	138	149

Table 1: 24 hour averages of PM2.5 in the kitchens and living

* smoking carried out indoors

Many Asian countries have high smoking prevalence and in Pakistan 41% of the male population smoke (World Bank, 2017). It has been reported that Southeast Asian countries have globally the highest levels of exposure to tobacco smoke (Singh and Lal, 2011). Lee et al. (2010) measured PM2.5 in indoor public places in Asian countries and concluded that PM2.5 was clearly associated with the presence of indoor smoking. In Pakistan the maximum concentration during smoking was 390 µg m^{-3}. For houses in Bangladesh Gurley et al. (2013b) concluded that smoking indoors was associated with an increase in the number of hours that the PM2.5 concentrations exceeded 100 µg $m-^{3}$. Although smokers were present in eight houses, cigarettes were smoked in the indoor environment in four of them. As is evident from Table 1 the living rooms in houses B8 and C5 experienced PM2.5 concentrations 200 µg m^{-3} greater than others in the same category. Although smoking took place in A5 it was for less than one hour and so hasn't had a significant effect on the 24 hour concentration.

The density of traffic on roads can have an impact on indoor air quality of nearby homes by infiltration. In the current study 7 houses were between 1 km and 500 m of a heavily trafficked road and of these 3 were occupied by smokers. Of the remaining four homes (A2, A7, A8 and C2) only C2 exhibits lower PM2.5 concentrations which suggests that indoor sources dominated those outdoors in the vast majority of the houses.

Industrial emissions from both large-scale facilities (cement, fertilizer, and power plants) and a wide range of small-to-medium-scale industries (brick kilns – mainly in the outskirts, plastic molding, etc.) make a major contribution to air pollution (Alam et al. 2014). However their effect is reported to be widespread rather than localized (Gurjar et al., 2008) Diesel generators are often used as a back-up power supply in the industrial areas. Ten houses were within 1 km of an industrial point source but without chemical characterization of the particulate matter or measurements of gases air pollutants it is difficult to ascertain to the importance of such sources on indoor air quality in the houses. The PM2.5 levels are similar to those in other houses. Since ambient sampling was not conducted in the current research, it is difficult to say for sure if outdoor sources played any significant part in defining the obtained results for PM2.5.

Since monitoring of fine particulate matter was conducted in all months of the year, the obtained results were segregated according to seasons to observe if there was any impact of seasons upon PM levels or not. As seen in Figure 3, highest mean $PM_{2.5}$ levels were obtained during the winter season while the summer season exhibited lowest concentrations.

A one–way ANOVA indicated a significant variation in PM2.5 levels with season in both kitchens ($p = 0.022$) and living rooms ($p = 0.005$). The seasonal variation for bacterial and fungal levels in indoor environments is shown in Figure 4. A significant impact of season was observed upon bacterial and fungal levels in the kitchens ($p = 0.035$ and $p = 0.045$ respectively) while in the living rooms, seasonal variations were not so pronounced ($p = 0.53$ and $p = 0.60$ respectively)

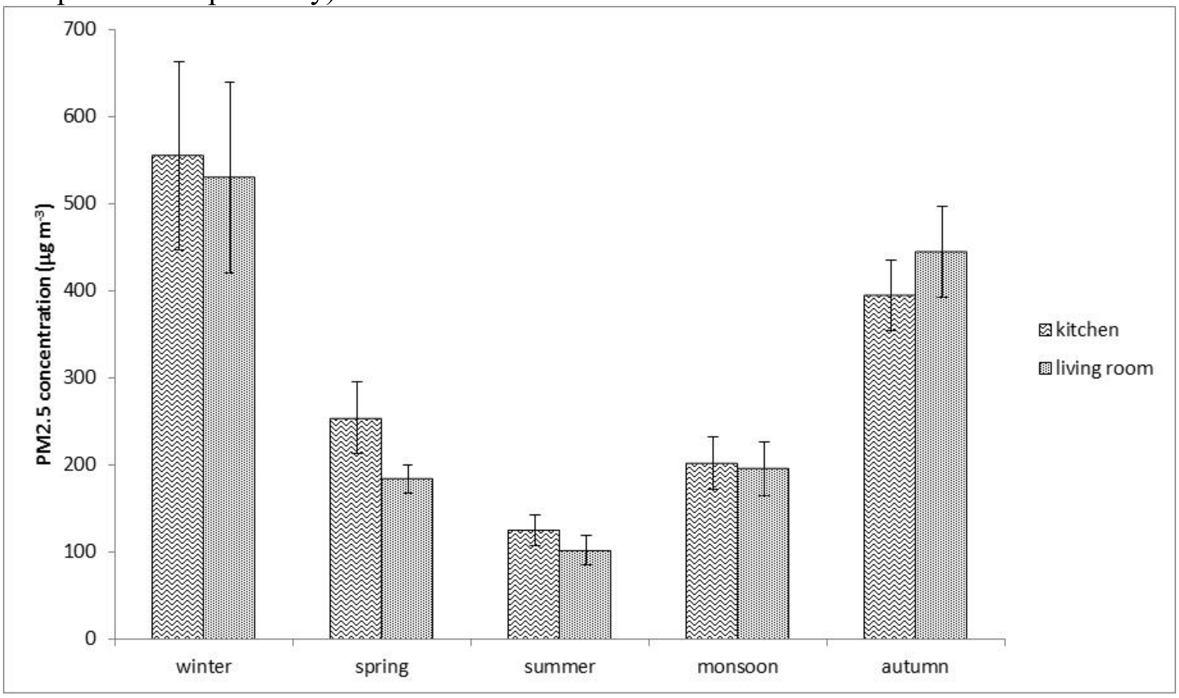


Figure 3: Seasonal variation in $PM_{2.5}$ in kitchens and living rooms. Error bars show standard error.

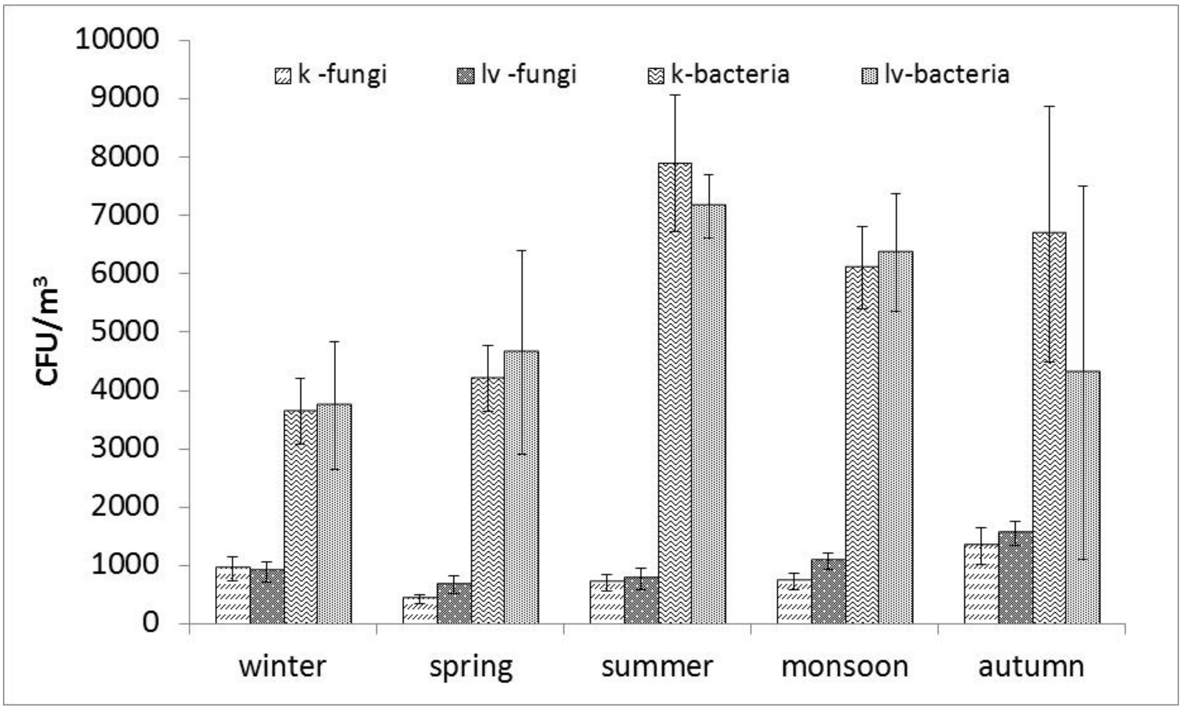


Figure 4: Seasonal variation in fungi and bacteria in kitchens and living rooms. Error bars show standard error.

The concentrations of fungi and bacteria are in the range reported by Nasir et al. (2012) and references therein. Seasons have been documented by many researchers to significantly influence pollutant levels in both the indoor and outdoor environments. Particulate matter and bioaerosol concentrations were found to be affected by changing seasons in this study with highest levels of particulate matter during the winter season and lowest during the summers as also observed by many other researchers (e.g. Massey et al., 2013; Meadow et al., 2014; Nevalainen et al., 2015). Ahmed (2007) reported that seasons had a marked impact upon bioaerosol levels while Nasir et al. (2013) revealed higher concentrations of particulate matter in rural houses during the winter season. Since the climate of Lahore is hot and dry for the most part of the year, windows are kept open for maximum time during the spring, summer and monsoon seasons.

The seasonal variability in the current study could be due to reduced ventilation during the colder months as windows and doors are generally kept closed throughout the day. Moreover, use of gas heaters for space heating also generates considerable amounts of particulate matter. People prefer to spend maximum time indoors and their activities may also influence indoor air quality. Therefore the accumulation of particulate matter in the indoor environment is possible during winters. On the other hand, during the summer season, doors and windows are kept open with ceiling fans also being used to maximize the circulation of air.

The main source for indoor air fungi is predominantly outdoor air. Hence meteorological, geographical and seasonal factors are important. Typically winter concentrations are lowest and summer concentrations are the highest. This pattern has been reported from many different climatic regions (Meadow et al., 2014). Previous work has found that relative humidity of indoor is positively correlated with concentrations of culturable fungi (Nevalainen et al., 2015). Our results show that although temperature had a direct but weak relation with bacteria, relative humidity exhibited no significant association with bacterial and fungal levels. This discrepancy may be the result of limitations with the sedimentation sampling methodology.

Ventilation practices contribute significantly in defining the air quality of any indoor environment as the infiltration and exfiltration rates are dependent upon it. Climate also plays an influential role in the form of a limiting factor when designing and constructing buildings which are naturally ventilated. Since Lahore is located in the tropical zone and characterized by a semi-arid hot climate, winters are relatively short with long, hot summers. Therefore it is natural for people to keep the windows open for most part of the day. Natural ventilation is more suitable in areas with a mild climate and all the selected houses for this study were naturally ventilated as is the common practice in Lahore.

There are few standards for indoor bioaerosols. The National Institute of Occupational Safety and Health (NIOSH) have a maxium limit of 1000 CFU m^3 for the total number of bioaerosols while the total culturable count for bacteria should be no higher than 500 CFU m^3 (NIOSH, 1998; AIHA, 1996). Referring to these standard values, it is apparent that the detected microbial levels in this study exceeded these concentrations.

CONCLUSIONS

Monitoring of indoor air quality of thirty residences of Lahore revealed mean PM2.5 levels to be 13 times higher than the WHO recommended limits while even background levels were 4-5 times higher. There were a number of factors that influenced the indoor air quality and, in particular, ventilation. Seasonal weather patterns effects the ventilation strategy which then influences indoor air quality. PM concentrations were highest levels during winter when the air exchange rate was a minimum due to closed windows and doors. Moreover gas heaters were also being used for space heating thereby contributing significantly in increasing indoor PM2.5 concentrations. The mean PM2.5 levels dropped during the spring season as ventilation practices improved and attained minimum concentrations in the summer as use of ceiling fans and open windows allowed maximum dilution of air. The bacterial and fungal species identified in the sampling sites were recognized to be a common constituent of the indoor air and opportunistic pathogens as well. The PM2.5 concentrations exhibited significant variability over time and it is important that future long term studies are carried out which should include simultaneous ambient sampling.

With rapid urbanisation Pakistan is struggling to provide adequate housing to meet the demand. Currently there is no formal housing policy, nor a land use policy. There is a distinct lack of low-cost urban housing. As such there is a chronic housing shortage and much of what does exist is of poor quality (Jabeen et al., 2017). It is important that more research is undertaken to evaluate the level of indoor air pollution and its health impacts. The outcome of this research may facilitate policy makers to incorporate indoor air quality regulations in future housing decisions. For example ventilation plays an important role in defining the air quality and there is a dire need for the builders and construction authorities to consider minimum air exchange rates in building designs.

ACKNOWLEDGEMENTS

This work forms part of the PhD thesis of Sidra Safdar entitled "Assessment of air-borne particulate matter (PM2.5) and bioaerosols in different residential built micro-environments of Lahore, Pakistan" University of the Punjab, 2015

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https://doi.org/10.1007/s13762-018-1693-z