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Air-borne concentrations of $Pm_{(10)}$ and $Pm_{(total)}$ in residential micro-environments of Asthmatics

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ABSTRACT

Developing countries are facing major health concerns due to deteriorating air quality. In the ambient air, particulate matter (PM) is attributed as major source of health concerns in children as well as adults but comparatively less information is available about sources and health impacts of indoor PM. The current study was designed to monitor micro-environments of asthmatic residential houses (n=50) in Lahore, Pakistan. PM_{10} and $PM_{(Total)}$ was monitored in the living rooms and immediate outdoor of residential household of each selected site using DustTrak aerosol monitor (model 8533, TSI Inc.). Results of this study indicated poor air quality in the residential indoor environments of asthmatics. The 24-h average values of PM_{10} exceeded 13 times the WHO limits (50 $\mu g/m^3$ 24-hours mean value for PM_{10}). It was noticed that many anthropogenic activities like cleaning, cooking, movement of people and smoking were the principal indoor sources of particulate pollution and observed to have a significant impact on PM levels. The study is significant for being the first of its kind, as previously no data is available focusing on PM_{10} and $PM_{(Total)}$ levels in the urban houses of asthmatics in Pakistan. Even though there is no practical implication to reduce or remove the load of pollutants present in the air but it is recommended to conduct detailed studies to monitor indoor air quality to understand the relationship of environmental conditions and household activities leading to health problems.

Keywords: Asthma, Particulate matter, PM_{10} and $PM_{(Total)}$, Particulate

INTRODUCTION

Environmental pollution is a trouble in many developed and developing countries commonly for those on the way of prompt urbanization and industrialization (Al-Moamary, 2016). Urbanization coupled with industrialization results in poor air quality (Asthma UK, 2018). Many epidemiologic studies have proved the contribution of urban air pollution to mortality and morbidity rate (Brunekreef & Holgate, 2002; Pope & Dockery, 2006). Over the last few decades adverse health effects due to urban air pollution have almost doubled up (Brunekreef & Holgate, 2002; Katsouyanni, 2003). Some of the major indoor air pollution sources are solid fuel combustion, tobacco smoking, pollutants in the outdoor, emissions from construction materials and improper ventilation (Asthma UK, 2018). Air pollution and tobacco smoke may predispose people to lower respiratory tract infection (Loeb, 2003). Indoor air pollution is linked with hospital admissions due to reduced lung function (Timonen *et al*., 2002), severe lower respiratory illness (Atkinson *et al*., 2001), bronchitis, chronic cough (Chauhan & Johnston, 2003) and asthma (Dominci *et al*., 2006). People spend most of time indoors so exposure to numerous air pollutants is presumably to be 63% greater in contrast to outdoors. Pollutants from outdoor origin enter into the indoor (Asthma UK, 2018) as a consequence indoor air quality has dragged sizeable attention in current years.

Particulate matter (PM) is out of 6 potentially damaging air pollutants recognized by clean air act of 1970, managed for the aim of good human fitness. Outdoor PM has well established harmful effects (Rabinovitch *et al*., 2006). Carbonaceous PM is also a major contributor to PM

Author's Contribution: S.S.I.B., Executed the Whole experimental study; **R.A.,** Statistical Data analysis and provided technical help; **Z.A.,** Designed and supervised the project.

accumulation and show important capacity in indoor air quality IAQ (Berry *et al.,* 2005). Consequence of atmospheric PM on human health is fully determined (Gordon *et al*., 2007). PM of aerodynamic diameters between 10-2.5 µm is known as coarse particulate matter having short term and long term risks (Brook *et al*., 2010). PM_{Total} (Particulate matter total) is the total mass concentration of overall particulate matter (PM_{01}, $PM_{2.5}$ & PM_{10}), it has capacity to generate respiratory outcomes in normal persons and with preexisting asthma (Riediker *et al*., 2004). Exposure to aerosol through inhalation route is crucial exhibiting a big source of danger depending on its concentrations and duration so of utmost significance to measure particle concentrations and size fractions (Abdel-Salam, 2006). PM is recently categorized as potential indicator for inspecting health effects due to ambient air pollution (Yao *et al*., 2015).

US Environmental Protection Agency (EPA) established a National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$ and retained the $PM_{\mathbf{10}}$ criterion to meet $PM_{10\text{-}2.5}$ in 1997. The EPA accepted the proof based on the health effects of $PM_{\mathbf{10\text{-}2.5}}$ is still insufficient and more exploration is needed (US EPA, 2004). US EPA has communicated air quality standards for both $PM_{2.5}$ and PM_{10}. In the European Union, the 1st instruction to the Air Quality Framework commenced air quality boundary levels for PM_{10}, but Clean Air for Europe (CAFE) procedure is recently featuring a change to $PM_{2.5}$ levels (Harrison *et al*., 2003). The Clean Air Initiative for Asian Cities (CAI-Asia, 2008) has recorded that in 64 cities ambient PM_{10} remain above WHO guidelines.

In Asian big cities like Lahore, Pakistan, PM is greater than air quality standards adopted in developed countries (Hopke *et al*., 2008). Government of Pakistan has initiated a National Environment Action Plan in 2001 with United Nations Environment Programme. The Pakistan Clean Air Programme has described vehicles exudations, industrial emissions, solid waste burning and cosmic dust as major origin of metropolitan air pollutants (Qadir, 2002). Until 2007 there was no continuous monitoring station, then in 5 major cities of Pakistan: Karachi, Lahore, Quetta, Peshawar and Islamabad monitoring stations were established (Colbeck *et al.,* 2010). In Lahore increased rates of asthma and mental disorders have been correlated with worsening of ambient air during last few decades (Kristan & Pan, 2004; Wang *et al*., 2003).

PM has a severe environmental and health regret in metropolitan Pakistani areas (Colbeck *et al*., 2010; Pak-EPA, 2005) but inadequate for conclusion and policy making (Canova *et al*., 2012). Studies have been conducted to assess roadside exposure to particulate matter (PM_{01} and $PM_{2.5}$) of Lahore, Pakistan during 2007. More recently PM_{10} PM_{Total} has a serious environmental and health concern in urban areas of Pakistan (Colbeck *et al*., 2010; Pak-EPA, 2005) but inadequate for decision and policy making (Canova *et al*., 2012) because it has powerful proof of association with morbidity and mortality (Dominci *et al*., 2006; Pope *et al*., 2006) but research on coarse thoracic particles ($PM_{2.5}$ & PM_{Total}) is limited (Brunekreef & Forsberg, 2005). Previously consequence of air pollution on pulmonary diseases is not conclusive due to difficulty of following subjects through a long enough period of time (To *et al*., 2016). PM_{10} enters our respiratory tract and reaches bronchi region hence can be a better exposure indicator for pulmonary impact assessment (Asthma UK, 2018).

MATERIALS AND METHODS

Study area

The historical city Lahore (31°15'-31°45' N and 74°01'-74°39' E) is provincial capital of Punjab and 2nd biggest city of Pakistan. Ravi River drifts alongside the north-western border of the city. This city covers 1772 km^2 at an altitude of 217m above sea level. Lahore consists of 9 administrative towns and a cantonment area (under military administration). Population of Lahore is about 12,188,000 till June, 2019 (UN, 2019). The city undergoes a hot, semi-arid climate with an average temperature of 24.3°C (Wesolowski *et al.,* 2015). During extremely hot summers average temperature ranges between 33-39°C. The winters go through normally average temperature of 17-22°C (Alam**,** 2012). Lahore city experiences annual rainfall 600-800mm, mostly during monsoon from Mid-July till September (Pakistan Meteorology Department).

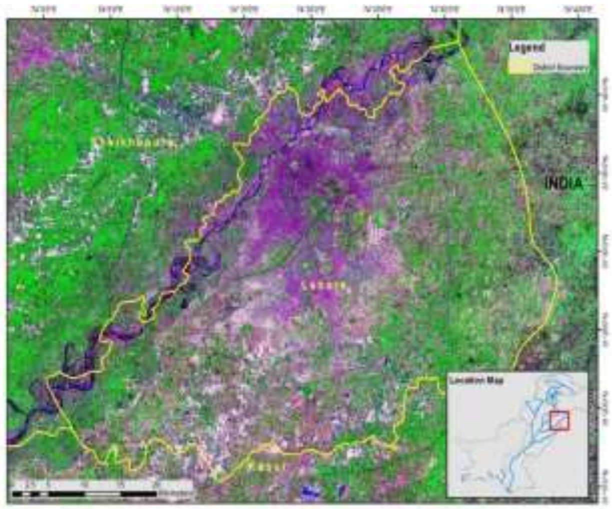

Fig. 1: Map of Lahore city showing areas of indoor sampling

Asthmatic group

This study was conducted from May 2018 to June 2019 at Jinnah Hospital Lahore, Pakistan. Hundred subjects were selected divided into two groups normal (N) and asthmatic (A) group. Fifty patients presenting to hospital with acute asthma were enrolled after informed consent Annexure-II. Asthmatic group includes subjects diagnosed by physicians (pulmonologists) prior study. Asthmatic group thought to have symptoms like wheezing, nocturnal cough, episodes of breath shortness (Global Initiative for Asthma (Waibel *et al.,* 2012).

Normal group

Normal group contain no symptoms of wheezing or previous asthma history.

Filling of questionnaire

Questionnaire was filled by each subject to get information regarding name, gender, daily activities, health status, smoking habits, type of fuel at home, living conditions, number of occupants, their daily activities, occupations, time spent indoors and outdoors by each member of the household and all relevant factors. The data thus obtained was useful in providing with an insight into the indoor conditions of the occupants and the possible exposures to asthma pollutants at home. The questionnaire is attached as Annexure-I.

Fifty houses of each normal and asthmatics subjects were selected from all nine administrative towns of Lahore which to be served as monitoring sites of IAQ in terms of PM_{10} and $PM_{(Total)}$. In order to ensure a random mix of houses sampling sites of varying floor area were selected from each town. Selected sites were located within a distance of 02km from heavy traffic roads with a variety of urban habitat surroundings. Among the selected houses 20 houses were located in urban, 10 in semi urban areas, 10 in commercial areas and 10 were present near parks. Three categories were specified as per house size with following details.

Small: 62.71 m^2
Medium: 211-104 m^2
Large: 418.06 m^2

Since the number of people and their activities are also an important contributor towards indoor air quality, three levels of occupancy were also defined:

Low: 03-05 occupants
Medium: 06-09 occupants
High: 8-12 occupants

Inclusion criteria

Subjects were included based on previous asthma symptoms.

Sampling for $PM_{(10)}$ and $PM_{(Total)}$

Two most broadly used methods for PM sampling and monitoring are the light scattering and gravimetric method. Gravimetric method is appropriate and used as reference but light scattering method is better for preliminary aerosols measurements (Niu *et al.,* 2002). Amongst many commercially accessible photometers, DustTrak aerosol monitor (model 8533, TSI Inc.) is considered to give comparatively more accurate and precise PM_{10} and $PM_{(Total)}$ readings in comparison to other models of DustTrak e. g., model 8520 (Yanosky *et al.,* 2002).

DustTrak aerosol monitor (model 8533, TSI Inc.) is a direct reading real-time photometer and has a laser diode with 90° light scattering. Its sensitivity lays 0.001-100 mg/m^3 with range of 0.1-10 PM particle size. The aerosol monitors were factory calibrated before to monitor with air flow rate (1.7 L/min). The aerosol monitor has separate inlet nozzles for measurement of indoor and outdoor PM_{10} and PM_{Total}. Since coarse PM is a major constituent of the outdoor air (Geller *et al.,* 2002), therefore this size fraction was selected for monitoring in the indoor and outdoor micro-environments of asthmatics in Lahore. The 24-h average values of PM_{10} & $PM_{(Total)}$ were recorded. Data logging interval (1 min) and the sampling duration (01 hr) was set and recorded after each hour.

Before running the instrument at any sampling site the inlet nozzles were cleaned and lubricated each time according to the prescribed protocol given in the instruction manual of the equipment. The aerosol monitor is powered by electricity and as an alternative power supply Cameleon C-size rechargeable batteries were used. Same time of the day was selected to take the readings of PM at different selected sites. The instruments were placed at a height of approximately one meter from the ground. Care was taken while performing daily routine activities and no major activity was allowed near to the instrument which could otherwise cause a sudden increase in PM levels. Monitoring in the indoor and outdoor micro-environments of asthmatics in Lahore was carried out. The data was later on transferred to a computer using the TrakPro software for further analysis. The monitoring of indoor and outdoor asthmatic patients began in May, 2018 and continued till June, 2019. The monitoring was conducted for 24-hrs once at each selected sampling sites as the instruments were somewhat noisy and many residents were being disturbed by their presence. This factor was a significant limitation in this study. Different household activities were considered to be a cause of variation in concentrations of PM within a house. PM was observed in the living rooms of the subjects in case of indoor and at roof top in case of outdoor.

Data analysis

Correlation between Indoor and outdoor PM concentrations was applied to observe any significant impact of particulate matter concentrations (a=0.05) using SPSS (v.22).

RESULTS

Data collection

Data was collected from the administrative towns of City District Lahore include Iqbal Town, Samanabad Town, Gulberg Town, Nishtar Town, Aziz Bhatti Town, Ravi Town, Data Ganj Buksh Town, Shalimar Town, Wagha Town and Cantonment as shown in the Fig. 2 (Source: GOP, 2019). Sites selected were located in variety of urban, semi urban, industrial and commercial areas (Table I).

Fig. 2: Map showing GPS prevalence of asthmatic patients. Red dots indicate (asthmatic) & green circle dots (normal).

None of the buildings was air tight, rather all were naturally ventilated. Since the climate of Lahore is warm mostly throughout the year and windows were generally held open except during the winters.

In most of the houses, majority of occupants were students, house wives and job workers. Natural gas was used as the primary cooking fuel in all houses. The kitchen and living room were mostly connected in houses. Direct connection existed between house size, room size and asthma occurrence rate (Table II).

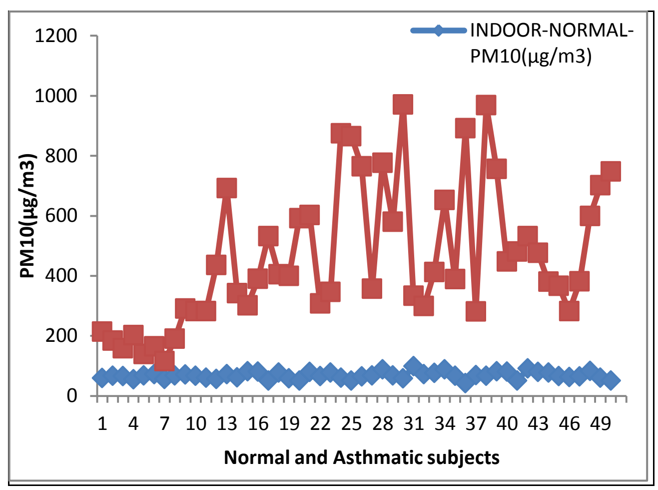

Fig. 3: PM_{10} concentration (indoor) of normal and asthmatic subjects.

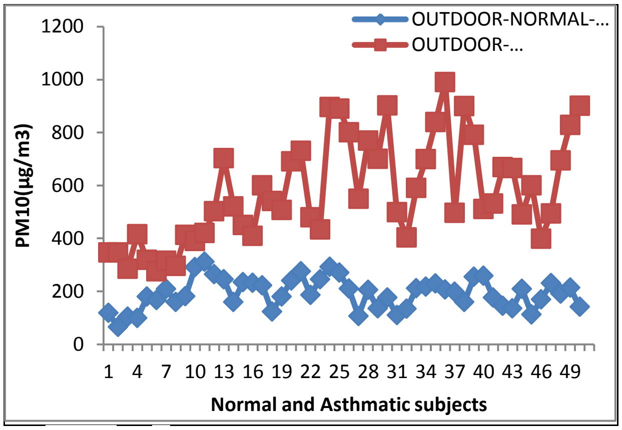

Fig 4: PM_{10} concentration (outdoor) of normal and asthmatic subjects

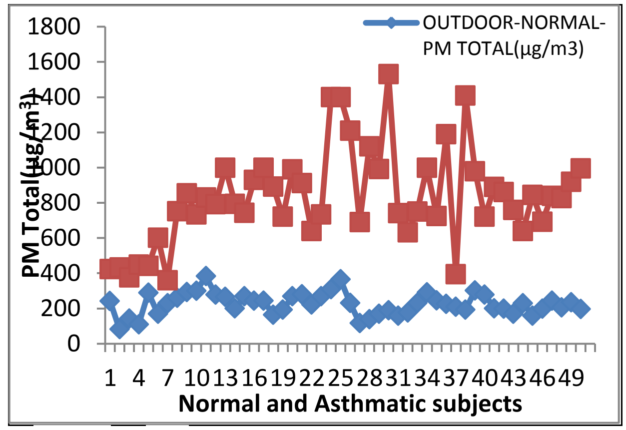

Fig. 6: PM $_{Total}$ concentration (outdoor) of normal and asthmatic subjects.

The 24-h average values of PM_{10} and PM $_{Total}$ were calculated at 100 different sites (Fig 2). These 100 sites include 50 houses of normal subjects (N) and 50 houses of asthmatic patients (A). All the parameters were observed in the living rooms of the subjects in case of indoor and at roof top in case of outdoor.

The difference in minimum and maximum indoor concentration of normal subjects for PM_{10} was (42µg/m^3 & 98µg/m^3) and outdoor concentration (65µg/m^3 & 312µg/m^3). Difference in minimum and maximum indoor concentration of asthmatic subjects for PM_{10} was (116µg/m^3 & 970µg/m^3) and outdoor concentration (275µg/m^3 & 990µg/m^3).

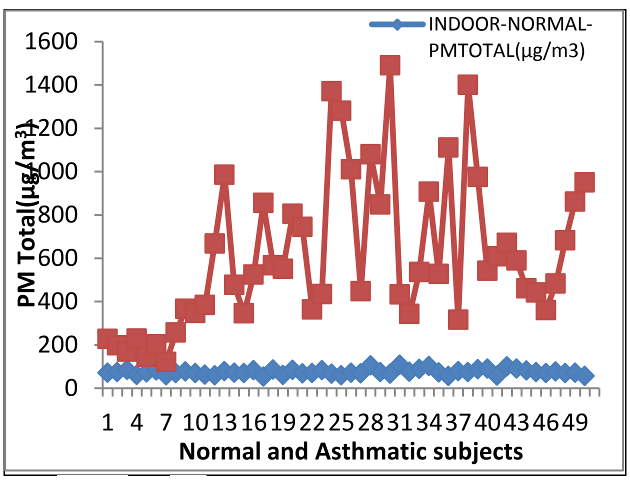

Fig 5: PM $_{Total}$ concentration (indoor) of normal and asthmatic subjects

Table I: Household Data

Size of House in m^2	Number of Occupants	Town Location	Distance from road in km
418.1	8-12	Sabzazar, Iqbal town, Model town, Johar town, Gulberg, Wapda town, Valencia, Behria, Cantt, Gulshan ravi	0.5-1.75
211.4	6-8	Muslim town, Iqbal town, sabzazar, Green town, Model town, Faisal town, Johar town, Township, Link road, Shadman	0.5-2.0
104.5	6-9	Ichra, Samanabad, Yateem khana, Faisal town, Chouburgi, Sabzazar, Islam pura, Muslim town, Iqbal town, Samanabad, Green town, Township, Chouburgi, Mauzang, ShapurKanjraan, Badami bagh, Mughalpura, Railway station, U E T, Shadara	0.5-2.0
62.7	3-7	Anarkali, Baghbanpura, Mughalpura, Shalimar town, Shah Alam, Akbari, Gawal mandi, Shahi mohallah, Data darbar, Badami bagh	0.5-2.0

The difference in minimum and maximum indoor concentration of normal subjects for PM $_{Total}$ was (53µg/m^3 & 107µg/m^3) and outdoor concentration (82µg/m^3 & 383µg/m^3. Difference in minimum and maximum indoor concentration of asthmatic subjects for PM $_{Total}$ was (120µg/m^3 & 1490µg/m^3) and outdoor concentration (360µg/m^3 & 1530µg/m^3) (Fig 3-6).

Table II: Paired sample T test (p-value) against different house size and room size

Parameters	Independent sample T test Value (p value)	95% Confidence Interval of the Difference	
		Lower	Upper
House size	9.804(.000)	143.2872	217.1768
Room size	17.650(.000)	44.7704	56.2751

Table III: Correlation between levels of PM_{10} & PM_{Total} indoor and outdoor of normal and asthmatics

PARAMETERS	NORMAL		ASTHMATIC	
	Indoor	Out door	Indoor	Out door
PM_{10} Pearson Correlation Sig. (2-tailed)	-.109 .452	- .060 .0681	.253 .076	**.939**** .000
PM_{TOTAL} Pearson Correlation Sig. (2-tailed)	-.044 .761	-.158 .273	.276 .052	**.941**** .000

******Correlation is significant at the 0.01 level (2-tailed).

Statistical analysis

Table shows the Pearson correlation coefficients between indoor and outdoor PM_{10}, & PM_{Total}. Indoor and outdoor levels of PM_{10} & PM_{Total} were correlated with each other *(P*< 0.05). There was a certain degree of co linearity among the indoor and outdoor levels PM of asthmatic houses between PM_{10}(r=0.939) PM Total (r=0.941) and data was highly significant. There was found negative correlation between indoor and outdoor PM levels of normal subjects (Table III).

DISCUSSION

Although coarse PM (PM_{10} & PM_{Total}) might be less toxic than fine PM (PM_{01} & $PM_{2.5}$) but their effects on the respiratory system are well-described. Currently the health risks of both short-term and long term exposure to $PM_{10\text{-}Total}$ are limited. This study showed the difference in minimum and maximum indoor concentration of normal subjects for PM_{10} was (42µg/m^3 & 98µg/m^3) and outdoor concentration (65µg/m^3 & 312µg/m^3). Similar study reported by WHO, 2005 showed mean daily average concentration of PM-$_{10}$ was 56µg/m^3 indoors to 247 µg/m^3 out doors of normal subjects in comparison to 854µg/m^3 indoors to 715 µg/m^3 out doors of asthmatic subjects. Which is about double of the yearly concentration level (50 pg/m^3) determined by Vietnam National Technical Regulation on Ambient Air Quality, greater than the European Air Quality Standards (40 pg/m^3) (EC, 2013) and five times greater than the WHO guideline (20 pg/m^3). But Balakrishnan *et al.,* (2011) reported that there is no strong proof of non-linearity in mortality rate on exposure to PM in India (Chennai city) on the basis of PM_{10} analysis. Similarly Rodopoulou *et al*., (2014) and Tramuto *et al*., (2011) depicted intense effects of PM_{10} on respiratory admissions risk which was estimated to increase (3.9%) for every 10 pg/m^3 PM concentration increase. Cheung *et al*., (2011) recorded from few minutes to many hours suspension lifetimes of PM_{10}. The difference observed by this study in minimum and maximum indoor concentration of asthmatic subjects for PM_{10} was (116µg/m^3 & 970µg/m^3) and outdoor concentration (275µg/m^3 & 990µg/m^3). Many time-series analyses run in the same area established considerable effects of PM_{10} on asthma emergency visits for asthmatics aged less than 18 years and more than 65 years old *(*Ward *et al., 2002)***.** Strong event of PM_{10} to asthma hospitalization and emergency visits were also found in Utah Valley (Tecer *et al*., 2008) and in Santa Clara County, California (Barnett *et al*., 2005). Many other researchers recorded low effect of PM_{10} with an increased hospitalization (1-2%) due to respiratory problems due to increase in PM_{10} concentration (10 pg/m^3) (Yi *et al*., 2010; Sousa *et al*., 2012; Zhang *et al*., 2015). Few studies have reported about no increase in risk with increased PM_{10} levels (Fusco *et al*., 2001; Slaughter *et al*., 2005). In two other studies at Vietnam, a 10 pg/m^3 gain in PM_{10} was linked with rise of 0.7% respiratory visit of all age class (Phung *et al.*, 2016).

Coarse PM mass concentrations are momentarily mutable but were comparatively stable for distances up to 50 km (Chen *et al*., 2007). In our study the distance from the main road was two km and difference in minimum & maximum indoor concentration of normal subjects for PM $_{Total}$ was (53µg/m^3 & 107µg/m^3) and outdoor concentration (82µg/m^3 & 383µg/m^3. Whereas, difference in minimum and maximum indoor concentration of asthmatic subjects for PM_{Total} was (120µg/m^3 & 1490µg/m^3) and outdoor concentration (360µg/m^3 & 1530µg/m^3) (Graph: 1-4). Our measured values found to be much higher than reported by Shahid *et al.,* (2007) for different cities of Pakistan. With the ambient levels exceeding the NEQS manifold, this fact cannot be ignored that indoor air quality may also be affected by outdoor levels of pollutants (Moorcroft & Barrowcliffe, 2015). In our study higher levels of both PM_{10} and PM_{Total} were found in hoses of low floor area 62.71 m^2 and high occupancy. Several internal and external factors affect indoor air quality such as the location and design of the building, ventilation practices in use, seasonal variation, meteorological factors, number of people occupying the room and use of room (Goyal & Khare, 2010; Massey *et al*., 2012). Personal activities have been associated with increased PM levels indoors. Source of PM includes human activity include sneezing, talking, walking, coughing, toilet flushing and washing release particulate matter. Other sources include flower pot and house plants, foodstuff, textile, wood material, carpets and furniture (Jaeschke *et al.,* 2008). Occupant's movement in a room has been linked associated with re-suspension of already deposited PM including PM deposited on surfaces (Ferro *et al*., 2004). So many conceivable arguments may explain the unlikeness in association between different size particles and respiratory problems. Occasional smokers were found at the residence of asthmatics as already reported smoking is known to increase PM levels significantly (He *et al*., 2004; Yeatts *et al*., 2006; Colbeck *et al*., 2008; Nafees *et al*., 2011; Nasir & Colbeck, 2013). Even though there is yet no practical implication to reduce or remove the load of pollutants present in the air. With the lack of any definite policies the area of indoor air quality has been ignored at large. It is recommended that more detailed studies must be conducted to monitor indoor air quality.

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