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Indoor air pollution and respiratory health in a metropolitan city of Pakistan

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Ethical considerations: Ethical approval for the study was taken from Ethical Review Committee of Aga Khan University (ERC Ref #: 2311-CHS-ERC-12). Written, informed consent was obtained from each participant.

Short title: Indoor air and respiratory health

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Abstract

Objective: We assessed the association of formaldehyde, Carbon Monoxide (CO) and Particulate Matter (PM2.5) with respiratory symptoms, asthma and post-bronchodilator reversibility.

Methods: We included 1629 adults in a community-based cross-sectional study in Karachi, in 2015. Data was collected using American Thoracic Society respiratory questionnaire, and spirometry (available for 930 participants). YesAir 8-channel monitor was used for measuring concentrations of formaldehyde and CO while $PM_{2.5}$ was measured using UCB-PATS.

Results: Higher levels of formaldehyde and CO were associated with cough, phlegm and wheeze whereas those of $PM_{2.5}$ were associated with shortness of breath and presence of any of the respiratory symptoms (combined), as well as a 'lower' risk of cough, phlegm and bronchitis..

Conclusion: Poorer household air quality was associated with poorer respiratory health in this population; however further studies are required with robust exposure assessment.

Key Words: Indoor air; pollution; respiratory health; spirometry; Pakistan

Introduction

Respiratory illnesses including COPD and asthma are considered one of the leading cause of morbidity and mortality across the globe, with an estimated 7% of global mortality and 10% of disability adjusted life years (DALYs) attributable to these illnesses (1, 2).

Air pollution is a major risk factor for respiratory illnesses (2, 3). About 50% of lower respiratory tract infections and 47% of deaths associated with major respiratory diseases including pneumonia, COPD and lung cancer, are attributable to air pollution (4). About 29% of deaths due to COPD globally are due to indoor air pollution (4). Generally people spend more time indoors then outdoors therefore, for some populations, the risks associated with indoor air pollution may be greater than those from pollution in outdoor settings (5). In lower and middle income countries (LMICs) countries, where there is a limited access to cleaner fuels, women and children are at a higher risk of exposure, more so as they spend greater time indoors (6).

Common indoor air pollutants associated with respiratory illnesses include particulate matter (PM), Carbon Monoxide (CO), Sulphur Oxides (SOx), Nitrogen Oxides (NOx), Ozone (O_3), Volatile organic compounds (VOCs), formaldehyde and molds (3). These pollutants can trigger patho-physiological responses in the respiratory tract and ensuing inflammatory changes can lead to acute and chronic respiratory symptoms and decrements in lung function (7). These pollutants have been linked with exacerbation and poor prognosis of respiratory illnesses such as asthma, bronchitis and respiratory infections (7, 8). It has been postulated that indoor air pollutants, even at lower concentrations, may cause adverse health outcomes on prolonged exposure (9).

Sources of formaldehyde in the indoor environment include; smoking and combustion, building material, wooden furniture, paints and varnishes, household cleaning products and cosmetic products. Major indoor source of CO is combustion of fossil or biomass fuel, smoking, incense burning and outdoor infiltration. Indoor PM originates from outdoor infiltration, smoking and combustion of biomass and fossil fuel for cooking and heating (9). Studies have shown disparities between countries (high/low income) and within countries (urban/rural) in terms of pollutants levels in indoor environments (10-12).

There is a large gap in literature on the association of indoor air pollution and respiratory symptoms or illnesses, particularly in LMICs. Furthermore, many previous studies used proxy measures of indoor air pollution such as type of cooking fuel used and second-hand smoke exposure (13-15). We conducted this study to determine the association between selected indoor air pollutants including $PM_{2.5}$, formaldehyde, and CO, with respiratory symptoms and illnesses in Karachi, Pakistan.

Methods:

This was a cross sectional study conducted in Karachi, the largest city and the economic hub of Pakistan. Full study details have been published earlier, elsewhere (16). In brief, we used a multistage cluster sampling approach, and in the first stage, selected 75 clusters (primary sampling units) out of 9400 in Karachi. We conducted line listing of 250 to 300 households in each of the selected clusters, and in the second stage, selected 40 households in each cluster, using a simple random sampling approach. In each of the selected household, all the eligible participants (adults living in the same household for at least six months) were invited to participate in the study.

We used a structured questionnaire for data collection that was administered by trained interviewers in Urdu language. Variables included: socio-demographic and economic characteristics (age, gender, income and educational status), household related variables (type of house, number of rooms, number of household members, use of air conditioning and carpet in the house, presence of molds or wet spots or birds and animals, use of incense and coil burning, new furniture brought in the house and recent polish or paint in the house, and kitchen type and ventilation), cooking time and frequency, smoking habits, and exposure to second-hand smoke.

We added questions regarding respiratory symptoms and illnesses (cough, sputum, wheeze, shortness of breath (defined as having to walk slower than persons of the same age, at an ordinary pace on level ground, because of breathlessness) and any pre-existing respiratory conditions) including asthma, family history of asthma and other respiratory diseases from the American Thoracic Society (ATS-DLD-78A) respiratory questionnaire (17), that has been validated in Pakistan (18).

We trained field staff to perform spirometry using Vitalograph Alpha spirometer (Vitalograph New Alpha 6000; Vitalograph Ltd., Buckingham, England) following ATS guidelines (19). Technicians explained the procedure to participants who performed spirometry in sitting position, with a nose clip on. Forced Vital Capacity (FVC) and Forced Expiratory Volume in first second (FEV_1) were recorded in liters, FEV_1/FVC was also recorded. Post-bronchodilator reversibility in FEV_1 was assessed by administering salbutamol (200 µg) through a 500-mL spacer device and repeating the test after 15 minutes. Three maneuvers were performed and acceptable readings were recorded for both pre- and post-bronchodilator test. Anthropometric measurements including height and weight were taken.

YesAir 8-channel indoor air quality monitor (Critical Environment Technologies Canada Inc.) was used for the measurement of formaldehyde, CO and NO_2, temperature and relative humidity. UCB PATS version 8.0 (Berkeley Air Monitoring Group, University of California, Berkeley USA) was used for measurement of particulate matter ($PM_{2.5}$). All measurements were carried out using standard procedures defined by the manufacturers. Detailed procedures for indoor air pollutant have been published previously (20). In brief, measurements were done in the living room, kitchen and the bedroom five minutes at each of the sites. The instruments were kept above the ground level at a height of 1–1.5 m and away from windows, exhausts and air conditioners. All the measurements were carried out by trained data collectors. These instruments have previously been used in different studies and found to provide useful data on common indoor air pollutants (21, 22).

For this analysis we categorized participants with two conditions as having ‘asthma’: (1) ‘self-reported, physician-diagnosed asthma’ based on information from the questionnaire; and (2) presence of post-bronchodilator reversibility ≥ 200 ml in FEV_1 (23). ‘Acute’ cough or phlegm was defined as symptoms as much as 4 to 6 times a day in a week and/or first thing in morning and/or at all during the rest of the day or at night. ‘Chronic’ cough or phlegm was defined as symptoms for at least 3 consecutive months a year, for at least 2 years. ‘Chronic wheeze’ was defined as whistling sounds from chest (with or without cold), for at least 2 years. Shortness of breath was defined according to the Medical Research Council breathlessness scale which represent a spectrum of respiratory disability based on severity ranging from grade 1 to grade 5 (24).

Statistical analysis

We entered and validated data using Epi-Data version 3.1 and conducted analysis using SPPS version 19.0. A high correlation between the concentrations of pollutants at different locations within households was found therefore, in this manuscript we report results only from the kitchens for multivariable analyses. The data on air pollutants was skewed therefore, we used quartiles for categorizing these variables, and these were eventually dichotomized as ‘low’ (up to third quartile) or ‘high’ level (fourth quartile). Spirometry-based outcomes included post-bronchodilator reversibility (defined as increase in FEV_1 ≥200 ml after bronchodilator administration). We created a composite variable of respiratory symptoms that was coded as ‘yes’ if the participant had at least one of the symptoms and ‘no’ if none of the symptoms was reported. Univariate and multivariable logistic regression analyses were carried out to assess the unadjusted and adjusted associations of respiratory outcomes with indoor pollutants. Variables in the final regression models were retained based on their effects on -2 log likelihood and p-values.

Ethical considerations

Ethical approval for the study was taken from Ethical Review Committee of Aga Khan University (ERC Ref #: 2311-CHS-ERC-12). Prior to the interview, written informed consent was obtained from each respondent regarding all components of data collection; including interviews, spirometry, and pollutant measurements.

Results:

Characteristic of the study sample and pollutants level have been published earlier (16, 20). In brief, out of approximately 3000 participants who were approached, a total 1629 participated in the study giving a response rate of 55%; acceptable spirometry data was available for 930 participants. Analyses in this manuscript considered 1629 participants for questionnaire-based data and 930 participants with spirometry data, representing all the 75 clusters. The two groups (with or without acceptable spirometry) were generally comparable in terms of socio-demographic, anthropometric, household, lifestyle and occupational factors and key outcome variables (Supplementary table 1). About 43% of the overall participants were ≥38 years old (range 18-99) and 60% were female. Around 86% never smoked and 28% were exposed to environmental tobacco smoke at home or workplace. Self-reported asthma was found to be 1.8% and reversibility in FEV_1 was present in 11%. Prevalence of respiratory symptoms was: SOB grade I and II were 25% and 22% respectively, acute cough 4.4%, chronic cough 3.0%, acute and chronic wheeze 10% and 8.0 % respectively, and acute and chronic phlegm 6.6% and 3.7% respectively. The prevalence of any of the respiratory symptom was 38% based on composite variable. Median (IQR) levels of measured pollutants were: formaldehyde; 0.03 (0.00 – 0.090) ppm, CO; 0.00 (0.00 – 1.00) and $PM_{2.5}$; 0.279 (0.160 – 0.518) mg/m^3 in the kitchen. 'High' concentration of pollutants was classified as: formaldehyde >0.090ppm; CO > 1.00ppm; and $PM_{2.5}$ > 0.518 mg/m^3.

We found higher levels of formaldehyde to be associated with a higher risk of acute and chronic cough, aOR 2.78 (95% CI: 1.69 – 4.60) and 1.87 (95% CI: 1.02 – 3.43), respectively. Similarly, those exposed to higher levels of formaldehyde, had more than two times higher risk of acute and chronic phlegm, aOR 2.46 (95% CI:1.63 – 3.72) and 2.08 (95% CI:1.30 – 3.13) compared to those with lower exposure. We did not find any significant association of formaldehyde levels with bronchitis, wheeze, SOB and presence of any of the respiratory symptoms. (Table 1).

Like formaldehyde, higher levels of carbon monoxide were associated with acute and chronic cough, aOR 2 (95% CI:1.15 – 3.48) and 2.24 (95% CI:1.18 – 4.26), respectively. There was a significant association of carbon monoxide with acute phlegm and acute wheeze, aOR 1.85 (95% CI:1.17 – 2.93) and 1.50 (95% CI:1.01 – 2.22), respectively. We did not find an association between CO and other respiratory symptoms (Table 2).

Higher level of $PM_{2.5}$ was found to be associated with a higher risk of SOB, aOR 1.83 (95% CI:1.42 – 2.36) and presence of any of respiratory symptom aOR 1.28 (95% CI: 1.01 – 1.64). High $PM_{2.5}$ exposure was also associated with a lower risk of acute and chronic cough, and acute phlegm aOR, 0.19 (95% CI:0.07 – 0.53), 0.28 (95% CI:0.10 – 0.80) and 0.52 (95% CI:0.30 – 0.92), respectively. No significant association was observed with chronic phlegm, acute and chronic bronchitis and wheeze(Table 3).

We did not find an association between indoor air pollutants and asthma determined through spirometry, or post-bronchodilator reversibility (Supplementary Table 2).

Discussion:

This is one of the few studies from Pakistan assessing the association of respiratory symptoms and illnesses with indoor air pollutants. We found higher levels of formaldehyde, CO and $PM_{2.5}$ to be associated with one or more of the respiratory symptoms; on the contrary, an inverse association was also found with higher levels of $PM_{2.5}$.

Although there is little evidence on sources of indoor formaldehyde exposure in Pakistan, a study based on remote sensing data in South Asia reported that shipping, fossil fuel burning and industrial emissions are major sources of formaldehyde in ambient air in Karachi. This outdoor formaldehyde may result in infiltration into the indoor environments as a major source of exposure, in addition to indoor sources such as wooden products, paints resins and cleaning products (25). We found formaldehyde to be associated with higher risk of acute and chronic cough. This finding is similar to a study from the United Arab Emirates (UAE) that found a significant association between higher levels of formaldehyde and cough aOR 3.59 (26). This study however used longer (7-days) measurement of air pollutants. It is thought that formaldehyde causes irritation of upper respiratory tract that may lead to coughing and sneezing (9). We also found an association of higher levels of formaldehyde with more than two-fold increased risk of acute and chronic phlegm. A meta-analysis on respiratory effects of occupational formaldehyde exposure had also reported a relationship between formaldehyde exposure and phlegm, pooled OR: 2.37 (95% CI: 2.29 – 4.47) (27). However, in contrast to this meta-analysis, we did not find significant association with wheeze, bronchitis and SOB. This could be because exposure in the occupational setting may be higher than household exposure, leading to a more pronounced effect. Association of formaldehyde and asthma has been inconsistent in literature (28) and we did not find a significant association of higher formaldehyde levels with asthma or post-bronchodilator reversibility. This finding is similar to a previous study (29).

Main sources of CO in urban households in LMICs include; tobacco smoking, proximity to main roads, and fuel burning for cooking and heating (12, 30). We found higher levels of CO to be associated with a two-fold increased risk of acute cough, chronic cough and 50% higher risk of acute wheeze, but not with other symptoms. A finding that is similar to the study from UAE that found no association between CO and cough (26). Epidemiological evidence on chronic CO exposure is scarce, and available studies suggest an increased risk of hospital emergency visits due to respiratory complaints after exposure to CO (9). No association was observed with asthma and reversibility in our study, but Pan et al. (31) found that CO was associated with a decline in lung function parameters, although this is likely due to high levels of association between CO and PM concentrations from cooking fuel (31).

Although biomass fuel burning was identified as a major source of indoor particulate matter in LMICs, however in urban areas such as Karachi, where natural gas is the primary fuel, other sources such as smoking, cleaning activities, kitchen type and location, incense burning and outdoor infiltration are the major sources (30, 32). A large body of evidence exists on the association of particulate matter with respiratory health outcomes (5, 33, 34). In this study, we found $PM_{2.5}$ to be associated with 28% higher risk of presence of any respiratory symptom. On the other hand, there was an inverse relationship between higher $PM_{2.5}$ levels and risk of individual symptoms such as cough, phlegm and bronchitis. A study from UAE which measured PM levels over a seven-day period, also reported an apparently protective, but non-significant, effect of higher PM level on respiratory signs and symptoms (26). We did not find a significant association of $PM_{2.5}$ with asthma or post-bronchodilator reversibility. This finding is also consistent with a cohort study from California, US, where the ambient air pollutant data of ten years was obtained from air monitoring sites of 12 communities. In that study, researchers did not find a significant association between increased PM levels and risk of asthma (35). It is possible that the potential protective effect found in our study could be due to early life exposure to PM resulting in better lung structure and respiratory health (35). However, other studies have shown a detrimental association of particulate matter with asthma and lung function (31, 36). On balance, we consider it is more likely that this finding in our study is due to exposure misclassification as we only carried out short ‘spot’ sampling to characterize individual $PM_{2.5}$ exposure. Furthermore, some confounding factors such as specific exposures at workplaces, time spent outdoors, and proximity to outdoor sources such as main roads, industries and trash burning sites, were not taken into consideration.

We believe that our study has several strengths, including the fact that this was based on objective assessment of exposures through indoor pollutant measurements using appropriate instruments, and spirometry, as well as use of a validated questionnaire. Another strength is a large representative community-based sample from a rapidly expanding megacity. However, certain limitations should be considered while interpreting results of our study. We did spot sampling (five minutes at each of the sites in home i.e., kitchen, living room and bedroom) to characterize exposure to indoor air pollutants, while measurements over longer duration (such as 24-hours) are known to provide more accurate estimates. The concentrations measured, may be affected by participant behavior during the time the instruments were in use. Although this is less likely to affect our estimates as type of fuel used in our study setting was similar across all clusters and we adjusted our regression models for cooking at the time of measurements. Other studies have used more robust exposure assessment approaches (29, 37) which were not possible in our study due to financial and logistic limitations. Secondly, comparison with other studies should be interpreted cautiously as there are several differences between such studies including exposure and outcome assessment tools and techniques, and study settings, which may make comparison difficult. Our sample was generally adequate to determine the associations found in this study as post-hoc calculations showed values well above 80% for most of the significant associations, with the exception of some (formaldehyde with chronic cough, CO with acute and chronic cough and acute wheeze and, $PM_{2.5}$ with acute phlegm and chronic bronchitis). Finally, a cross-sectional study design may not be appropriate to establish causal association between outcome and exposure variables and did not allow measurement of seasonal and temporal variations and changes in exposures across the life course.

Conclusions

This study found a significant association between some respiratory symptoms and higher concentrations of formaldehyde, CO and $PM_{2.5}$ in urban Pakistani households; we also report an inverse association between $PM_{2.5}$ concentrations and respiratory symptoms. Considering certain limitations of our study, we recommend larger-scale studies with more comprehensive, longer exposure assessment methods to establish the extent of associations between indoor pollutant concentrations and respiratory health in LMICs. A better understanding of the exposure dynamics and relationship with respiratory health outcomes will help in identifying locally relevant prevention strategies.

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Table 1: Adjusted models for association of formaldehyde with respiratory symptoms among adults in Karachi, Pakistan

Outcome	Formaldehyde OR (95% Confidence Interval)
Acute cough	2.78 (1.69 – 4.60)[a]
Chronic cough	1.87 (1.02 – 3.43)[b]
Acute phlegm	2.46 (1.63 – 3.72)[c]
Chronic phlegm	2.08 (1.30 – 3.13)[d]
Acute bronchitis	1.38 (0.76 – 2.49)[e]
Chronic bronchitis	1.33 (0.72 – 2.44)[f]
Acute wheeze	1.07 (0.73 – 1.58)[g]
Chronic wheeze	0.85 (0.53 – 1.34)[h]
SOB	0.93 (0.70 – 1.22)[i]
Any symptom [j]	1.03 (0.80 – 1.32)[k]

Adjusted for

[a] age, cluster, education, type of house, coil use as mosquito repellent, family history of asthma

[b] age, gender, cluster, kitchen ventilation, coil use as mosquito repellent, family history of asthma

[c] age, gender, socio-economic status, number of rooms in the house, incense burning

[d] age, gender, Socio-economic status, number of rooms in the house

[e] age, gender, socio-economic status, number of rooms in the house, kitchen ventilation

[f] age, gender, socio-economic status, coil use as mosquito repellent, kitchen ventilation

[g] cluster, air conditioner, pack years of smoking

[h] age, air conditioner, pack years of smoking, family history of asthma

[i] age, gender, education, presence of mold in the house, coil use as mosquito repellent, pack years of smoking family history of asthma, kitchen ventilation

[j] Composite variable of respiratory symptoms by combining all respiratory symptoms' variables and coded as 'yes' if the participant had at least one of the symptoms and 'no' if none of the symptom was reported

[k] gender, ethnicity, education, number of rooms, type of house, wet spots in house, air conditioner, carpet, incense burning, coil use as mosquito repellent, paint in house, cooking, pack years of smoking family history of asthma, kitchen ventilation

Table 2: Adjusted models for association Carbon Monoxide with respiratory symptoms among adults in Karachi Pakistan

Outcome	Carbon Monoxide OR (95% Confidence Interval)
Acute cough	2.00 (1.15 – 3.48)[a]
Chronic cough	2.24 (1.18 – 4.26)[b]
Acute phlegm	1.85 (1.17 – 2.93)[c]
Chronic phlegm	1.35 (0.79 – 2.31)[d]
Acute bronchitis	1.14 (0.58 – 2.26)[e]
Chronic bronchitis	0.79 (0.36 – 1.71)[f]
Acute wheeze	1.50 (1.01 – 2.22)[g]
Chronic wheeze	1.35 (0.86 – 2.12)[h]
SOB	0.75 (0.55 – 1.03)[i]
Any symptom[j]	0.96 (0.73 – 1.72)[k]

Adjusted for;

[a] age, education, type of house coil use as mosquito repellent, family history of asthma

[b] age, gender, education, kitchen ventilation, coil use as mosquito repellent, family history of asthma

[c] age, gender, socio-economic status, education, incense burning, air conditioner

[d] age, gender, number of rooms in the house, air conditioner

e age, gender, socio-economic status, number of rooms in the house, kitchen ventilation

[f] age, gender, socio-economic status, kitchen ventilation, family history of asthma

[g] age, air conditioner, pack years of smoking, family history of asthma

[h] age, air conditioner, pack years of smoking, family history of asthma

[i] age, gender, education, presence of mold in the house, coil use as mosquito repellent, pack years of smoking family history of asthma, kitchen ventilation

[j] Composite variable of respiratory symptoms by combining all respiratory symptoms' variables and coded as 'yes' if the participant had at least one of the symptoms and 'no' if none of the symptom was reported

[k] gender, ethnicity, education, number of rooms, type of house, wet spots in house, air conditioner, carpet, incense burning, coil use as mosquito repellent, paint in house, cooking, pack years of smoking family history of asthma, kitchen ventilation

Table 3: Adjusted models for association of Particulate Matter with respiratory symptoms among adults in Karachi Pakistan

Outcome	Particulate Matter OR (95% Confidence Interval)
Acute cough	0.19 (0.07 – 0.53)[a]
Chronic cough	0.28 (0.10 – 0.80)[b]
Acute phlegm	0.52 (0.30 – 0.92)[c]
Chronic phlegm	0.62 (0.34 – 1.15)[d]
Acute bronchitis	0.30 (0.12 – 0.77)[e]
Chronic bronchitis	0.33 (0.13 – 0.84)[f]
Acute wheeze	0.71 (0.47 – 1.08)[g]
Chronic wheeze	0.75 (0.47 – 1.19)[h]
SOB	1.83 (1.42 – 2.36)[i]
Any symptom[j]	1.28 (1.01 – 1.64)[k]

Adjusted for;
[a] age, cluster, type of house, coil use as mosquito repellent, family history of asthma
[b] age, education, kitchen ventilation, coil use as mosquito repellent
[c] age, gender, incense burning
[d] age, gender, number of rooms in the house, air conditioner
[e] age, gender, socio-economic status, number of rooms in the house
[f] age, gender, coil use as mosquito repellent, kitchen ventilation
[g] air conditioner, pack years of smoking, family history of asthma, passive smoking in the house
[h] air conditioner, pack years of smoking, family history of asthma
[i] age, gender, education, presence of mold in the house, coil use as mosquito repellent, pack years of smoking family history of asthma, kitchen ventilation
[j] Composite variable of respiratory symptoms by combining all respiratory symptoms' variables and coded as 'yes' if the participant had at least one of the symptoms and 'no' if none of the symptom was reported.
[k] gender, ethnicity, education, number of rooms, type of house, wet spots in house, air conditioner, carpet, incense burning, coil use as mosquito repellent, paint in house, cooking, pack years of smoking family history of asthma, kitchen ventilation

Supplementary table 1: Socio-demographic, anthropometric, household, lifestyle and occupational factors among adults ≥ 18 years, Karachi, Pakistan

Characteristics	n (%) Over all sample = 1629	n (%) spirometry sample = 930
Age		
18 to 27 years	531 (32.6)	256 (28.5)
28 to 37 years	399 (24.5)	231 (24.8)
≥ 38 years	699 (42.9)	434 (46.7)
Sex		
Male	658 (40.4)	461 (49.6)
Female	971 (59.6)	469 (50.4)
Birth Order		
1st	394 (24.2)	228 (24.5)
2nd	310 (19.0)	174 (18.7)
3rd	295 (18.1)	169 (18.2)
≥ 4th	630 (38.7)	359 (38.6)
Total number of children in household		
1 to 3	232 (14.3)	127 (13.7)
4 to 5	442 (27.1)	256 (27.5)
≥ 6	955 (58.6)	547 (58.8)
Ethnicity		
Urdu	715 (43.9)	423 (45.5)
Punjabi	469 (28.8)	263 (28.3)
Sindhi	295 (18.1)	164 (17.6)
Pushto	90 (5.5)	42 (4.5)
Baluchi	60 (3.7)	38 (4.1)
Educational level [a] (n=1626)		
Literate	1109 (68.2)	683 (73.6)
Illiterate	517 (31.8)	245 (26.4)
Socio-economic status [b] (n=1621)		
High-income	537 (33.0)	235 (25.3)
Middle-income	544 (33.4)	239 (25.8)
Low-income	540 (33.1)	454 (48.9)
Number of rooms in house		
1 room	293 (18.0)	166 (17.8)
≥ 2 rooms	1336 (82.0)	764 (82.2)
House ownership status		
Own	1223 (75.1)	694 (74.6)
Rented	407 (24.9)	236 (25.4)
Type of household		
Pakka	1579 (97.0)	903 (97.1)
Kacha-Pakka	50 (3.0)	27 (2.9)

Type of cluster [c]		
Planned	855 (52.5)	503 (54.1)
Unplanned	774 (47.5)	427 (45.9)
Wet spots inside house	844 (51.8)	488 (52.5)
Mold Inside house	81 (5.0)	44 (4.7)
Animal or birds inside house [d]	474 (29.0)	280 (30.1)
Carpeting inside house	528 (32.4)	313 (33.7)
Incense burning in house	767 (47.1)	440 (47.3)
Mosquito coil burning in house	739 (45.4)	434 (46.7)
Painted home in last 6 months	204 (12.5)	124 (13.3)
Cook food	894 (54.9)	447(48.1))
Frequency of cooking food		
No cooking at all	735 (45.1)	483 (51.9)
Occasionally	143 (8.8)	85 (9.1)
Daily	751 (46.1)	362 (38.9)
Presence of window in kitchen	491 (30.1)	215 (23.1)
Presence of exhaust fan in kitchen	227 (13.9)	141 (15.2)
Type of kitchen		
Outdoor	632 (38.7)	565 (60.8)
Indoor separate	268 (16.5)	161 (17.3)
Indoor non-separate	729 (44.8)	204 (21.9)
Smoking status [e]		
Never	1409 (86.5)	766 (82.4)
Ever	220 (13.5)	164 (17.6)
Pack years of smoking [f]		
Non smoker	1409 (86.5)	774 (83.2)
≤10	132 (8.1)	97 (10.4)
10 - 20	31 (1.9)	22 (2.4)
>20	57 (3.5)	37 (4.0)
Exposure to environmental tobacco smoke [g]	452 (28.1)	253 (27.2)
Body Mass Index [h] (n=1611)		
Underweight	673 (41.8)	327 (35.3)
Normal weight	575 (35.7)	361 (39.0)
Overweight and obese	363 (22.5)	238 (25.7)
History of any allergy	451 (27.7)	273 (29.4)
Family history of asthma	192 (11.8)	106 (11.4)
Family History of tuberculosis	44 (2.7)	31 (3.3)
Exposure to any dusty job		
Never worked	899 (55.2)	422 (45.4)
Working and no dust exposure	293 (18.0)	188 (20.2)
Working and dust exposure	437 (26.8)	320 (34.4)

Exposure to gas or fumes at work		
Never worked	899 (55.2)	422 (45.4)
Working and no gas exposure	592 (36.3)	405 (43.5)
Working and gas exposure	138 (8.5)	103 (11.1)
Current employment status [i]		
Unemployed	1000 (61.4)	480 (51.6)
Employed	629 (38.6)	450 (48.4)
ISCO Categories [j]		
Not working	1000 (61.4)	480 (51.7)
White collar worker	301 (18.5)	205 (22.0)
Blue collar worker	328 (20.1)	244 (26.2)

[a] Educational level: those who never attended school or did not know how to read or write were considered as illiterate while those who had been to school were categorized as literate.
[b] Socio-economic status was defined using the proxy indicator of monthly household income which included income of all members living in the same house as well as additional earnings based on any business or other investment.
[c] Type of cluster was defined as planned areas included those with permanent housing structure, sufficient living place, access to safe water and adequate sanitation system, while unplanned areas were densely populated areas of substandard housing, characterized by poverty, unsanitary and inferior living conditions and social disorganization.
[d] Animal or birds inside house included both pets as well as animals kept as livestock.
[e] Ever smoker was defined as smoking more than 20 packs of cigarettes in a lifetime or more than one cigarette a day for one year.
[f] Pack years of smoking was defined as the number of cigarettes smoked per day divided by 20 and multiplied by the number of years that the person smoked.
[g] Exposure to environmental tobacco smoke was defined as anyone who smoked cigarettes anywhere inside the house.
[h] Body mass index was defined according to WHO criteria for Asian population and categorized as: underweighted, <18.5 kg/m^2; normal, 18.5-23 kg/m2; overweight and obese, ≥ 23 kg/m^2
[i] Current employment status was defined as employed somewhere currently or self-employed, whereas, unemployed included students, housewives, those currently not working anywhere or retired
[j] The International Standard Classification of Occupations (ISCO) categories were three i.e. not working, high and low skilled blue collar workers (involved in manual work), high and low skilled white collar workers (involved in desk work)

Supplementary Table 2: Association of indoor air pollutants with spirometry outcomes among adults in Karachi Pakistan

Outcome	Formaldehyde	Carbon Monoxide	Particulate Matter
	OR (95% Confidence Interval)	OR (95% Confidence Interval)	OR (95% Confidence Interval)
Asthma (Reversibility + self-reported + Physician Diagnosed)	0.84 (0.43 – 1.64)[a]	0.80 (0.38 – 1.69)[a]	0.64 (0.32 – 1.28)[a]
Reversibility	0.80 (0.47 – 1.33)[b]	0.80 (0.44 – 1.45)[b]	0.70 (0.41 – 1.18)[b]

Adjusted for;
[a]age, education, pack years of smoking, family history of asthma, kitchen ventilation, cooking
[b]age, cluster, ethnicity, type of household, air conditioner, pack years of smoking