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Original Article

Impact of Seasonal Smog on Asthma Exacerbations in Urban Pakistani Adults

Shahreen Arif[1], Dr. Tanzeel u Rehman[2], Aiman Waheed[3], Rizwan Ali Tunio[4], Dr. Farhan Muhammad Qureshi[5], Kashaf Fatima Khan[6], Huma Tabassum[7]

[1] Demonstrator, CMH Kharian Medical College, Kharian, Pakistan
[2] Jinnah Post Graduate Medical Centre (JPMC), Karachi, Pakistan
[3] Respiratory Therapist, University of Lahore, Lahore, Pakistan
[4] Assistant Professor, Chandka Medical College, Shaheed Mohtarma Benazir Bhutto Medical University, Larkana, Pakistan
[5] Professor, Department of Community Medicine & Public Health, Karachi Institute of Medical Sciences (KIMS), National University of Medical Sciences (NUMS), Karachi, Pakistan
[6] MBBS Student, Avicenna Medical College, Lahore, Pakistan
[7] Visiting Faculty, Department of Public Health, University of Punjab, Pakistan

Corresponding author: Shahreen Arif, shahreen967@gmail.com

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ABSTRACT

Background: Seasonal smog is a recurrent environmental hazard in urban Pakistan and may aggravate asthma through short-term exposure to particulate matter and irritant gases. Objective: To determine the frequency of asthma exacerbations during the smog season, examine the relationship between AQI and hospital admissions, and evaluate medication adherence and preventive behaviours among urban Pakistani adults with asthma. Methods: This prospective cohort study followed 250 adults with physician-diagnosed asthma from October through January. Participants underwent baseline assessment and weekly follow-up for exacerbations, emergency visits, hospital admissions, medication adherence, preventive behaviours, and AQI exposure. Categorical associations were assessed using the chi-square test, while weekly mean AQI and admission counts were examined using Pearson correlation. Results: At least one exacerbation occurred in 137 participants, corresponding to 54.8% (95% CI: 48.6–60.9), and 202 exacerbation episodes were recorded. December had the highest mean AQI (318), exacerbation count (71), emergency visits (39), and admissions (27). Of 66 admissions, 51 (77.3%) occurred on unhealthy, very unhealthy, or hazardous AQI days. Weekly mean AQI correlated positively with admissions (r=0.72; p=0.003). Exacerbations occurred in 63.4% of participants with poor adherence and 44.8% with good adherence (RR=1.42; 95% CI: 1.11–1.80; p=0.003). Only 19.2% regularly checked AQI, 36.4% used masks, and 30.4% avoided outdoor activity during severe smog. Conclusion: Asthma morbidity increased during periods of poorer air quality, while inadequate controller adherence was associated with a higher exacerbation risk. These findings support AQI-informed asthma planning and improved adherence during the smog season. Keywords: Seasonal smog; asthma exacerbation; air quality index; PM2.5; medication adherence; hospital admission; Pakistan.

INTRODUCTION

Asthma is a heterogeneous chronic inflammatory airway disorder characterized by variable respiratory symptoms and airflow limitation. Although many patients remain clinically stable with appropriate treatment, acute exacerbations can result in increased reliever use, systemic corticosteroid treatment, unscheduled clinical consultations, emergency department attendance, hospitalization, and, in severe cases, death. Environmental exposures are important determinants of asthma control, and evidence from systematic reviews indicates that short-term exposure to ambient air pollutants is associated with increased asthma exacerbations, emergency visits, and hospital admissions in both adult and paediatric populations (1–3).

Seasonal smog has become a recurrent environmental and public-health concern in Pakistan, particularly during the cooler months in densely populated urban centres. Smog represents a complex mixture of suspended particulate matter and gaseous pollutants rather than fog alone. Important constituents include fine particulate matter with an aerodynamic diameter of ≤2.5 µm, particulate matter ≤10 µm, nitrogen dioxide, sulphur dioxide, ozone, carbon monoxide, and other products of combustion. Traffic emissions, industrial activity, brick kilns, crop-residue burning, waste combustion, construction activity, rapid urbanization, and unfavourable winter meteorological conditions contribute to the accumulation of these pollutants in Pakistani cities (4–9). Lahore experiences particularly severe winter air pollution, although Karachi, Faisalabad, Rawalpindi, Islamabad, Multan, and other urban centres also experience periods of unhealthy air quality.

Adults with asthma may be particularly susceptible to smog because inhaled particulate matter and oxidant gases can induce airway epithelial injury, oxidative stress, inflammatory-cell recruitment, mucus hypersecretion, bronchial hyper-responsiveness, and impaired pulmonary defence mechanisms. Fine particulate matter can penetrate the distal airways, whereas ozone, nitrogen dioxide, and sulphur dioxide may intensify airway irritation and reduce the threshold for bronchoconstriction. These effects can occur shortly after exposure, and systematic reviews and observational studies have demonstrated associations between same-day or short-lag increases in ambient pollutants and asthma-related emergency visits, hospital admissions, and clinical exacerbations (10–13). The health effects of smog may also be amplified during winter by cold-air exposure, respiratory infections, reduced household ventilation, and increased indoor crowding.

Evidence from Pakistan has established that ambient air pollution represents a substantial and increasing respiratory-health burden. A Lahore-based study reported an association between ambient air pollution and the distribution of asthma across population groups, while national reviews have documented persistently high concentrations of particulate matter and other pollutants in several Pakistani cities (4,6,7,14). However, much of the available evidence is based on ecological assessments, cross-sectional surveys, retrospective hospital records, or general evaluations of respiratory symptoms. Prospective patient-level evidence linking daily or weekly variations in AQI with asthma exacerbations and healthcare utilization during an actual smog season remains comparatively limited. Consequently, the temporal relationship between deteriorating air quality and clinically important asthma outcomes among Pakistani adults has not been sufficiently characterized.

Medication adherence may modify the relationship between environmental exposure and asthma outcomes. Regular use of prescribed controller therapy reduces airway inflammation and contributes to sustained asthma control, whereas missed doses, premature discontinuation of treatment, reliance on reliever medication alone, incorrect inhaler use, treatment costs, and concerns regarding inhaled corticosteroids may increase vulnerability to severe exacerbations. Previous evidence has demonstrated that poor adherence to asthma medication is associated with an increased risk of severe exacerbations, although adherence remains difficult to measure and is frequently suboptimal in routine clinical practice (15–17). During periods of severe air pollution, inadequate controller use may leave patients less protected against additional environmentally induced airway inflammation.

Exposure-reduction practices may provide supplementary protection during high-pollution periods. These practices include monitoring local AQI reports, limiting unnecessary outdoor activity, avoiding strenuous outdoor exercise, reducing exposure to tobacco smoke and household combustion, keeping prescribed rescue medication available, maintaining controller therapy, and using an appropriately fitted particulate-filtering mask when outdoor exposure cannot be avoided. Respiratory masks can reduce inhaled particulate exposure when their filtration performance and facial fit are adequate, although effectiveness is influenced by product quality, correct use, comfort, affordability, and duration of wear (18,19). In Pakistani urban settings, the feasibility of preventive behaviour may also be constrained by employment, commuting requirements, socioeconomic conditions, household responsibilities, and limited access to timely environmental-health information.

A prospective cohort approach provides an opportunity to document asthma outcomes close to the time at which they occur and to relate those outcomes to concurrent variations in air quality. Accordingly, the present study prospectively followed adults with physician-diagnosed asthma recruited from urban Pakistani clinical settings during a single October–January smog season. The objectives were to determine the proportion of participants experiencing at least one asthma exacerbation, describe the monthly distribution of exacerbation episodes and asthma-related healthcare utilization, assess the relationship between weekly mean AQI and hospital admissions, and evaluate medication adherence and preventive behaviours among adults at risk of smog-related asthma worsening.

MATERIALS AND METHODS

This prospective, multicentre observational cohort study followed adults with physician-diagnosed asthma during a single seasonal smog period extending from October through January. Participants were recruited from outpatient pulmonology and general medicine departments of tertiary-care hospitals and selected private clinics in urban Pakistan. Recruitment was concentrated in Lahore and surrounding urban areas because of the recurrent severity of winter smog in this region, while a smaller proportion of participants was recruited from other urban centres for which routine AQI observations were available. The study was observational, and no treatment or exposure was assigned by the research team. Participants continued to receive asthma management from their treating physicians throughout follow-up.

Adults aged 18 years or older were eligible when they had an established diagnosis of asthma made by a registered medical practitioner, had resided in the same urban area for at least six months before enrolment, were available for follow-up by telephone, clinic attendance, or both, and provided written informed consent. Patients were excluded when they had chronic obstructive pulmonary disease, active pulmonary tuberculosis, lung cancer, interstitial lung disease, severe heart failure, or another chronic cardiorespiratory condition likely to interfere with the identification or interpretation of asthma exacerbations. Pregnant women were excluded because pregnancy-related physiological changes could affect respiratory symptoms and clinical management. Patients planning to relocate from the study area during the follow-up period were also excluded.

A non-probability consecutive sampling strategy was used. All patients presenting to participating clinical services during the recruitment period were screened against the eligibility criteria and invited to participate when eligible. The planned sample size was estimated using a single-population proportion approach based on an expected frequency of asthma exacerbation during polluted months, a 95% confidence level, 5% absolute precision, and an allowance for possible loss to follow-up. Consecutive recruitment continued until 250 eligible participants had been enrolled.

Baseline information was collected at enrolment using a structured data-collection form. Recorded variables included age, sex, educational status, occupation, smoking status, residential area, duration of asthma, prescribed asthma medications, previous asthma-related emergency attendance or hospitalization, coexisting medical conditions, usual mode of transport, and average duration of daily outdoor exposure. Baseline clinical-control indicators included the frequency of daytime symptoms, nocturnal awakening, reliever-inhaler use, activity limitation, and previous exacerbations. Inhaler technique was observed during the clinical encounter where feasible. These variables were collected to characterize the cohort and identify factors potentially associated with asthma worsening during the smog season.

Participants were followed weekly throughout the study period through telephone contact, scheduled clinic attendance, or both. During each follow-up assessment, participants were asked about cough, wheezing, chest tightness, breathlessness, increased reliever use, unscheduled medical consultations, emergency department attendance, nebulization, oral corticosteroid treatment, and hospital admission since the preceding contact. Dates of healthcare encounters were recorded, and asthma-related emergency visits and admissions were verified against available clinical documentation where feasible. For hospitalized participants, the duration of admission and principal treatment received were documented.

The primary participant-level outcome was the occurrence of at least one asthma exacerbation during follow-up. An asthma exacerbation was operationally defined as worsening respiratory symptoms requiring an increase in reliever medication for more than 24 hours, an unscheduled clinical consultation, emergency department treatment, nebulization, oral corticosteroid therapy, or hospital admission. Emergency treatment, systemic corticosteroid use, and hospitalization were considered indicators of a severe exacerbation and were also retained as separate healthcare-utilization outcomes. Multiple healthcare contacts arising from the same uninterrupted period of symptom worsening were treated as components of one exacerbation episode, with the highest level of treatment or healthcare utilization recorded for that episode. A new event was counted when symptom worsening represented a clinically distinct episode rather than continuing management of the preceding event.

Daily AQI observations were obtained from publicly accessible air-quality monitoring platforms and official environmental sources when available. Each participant was linked to the monitoring station nearest to the recorded residential area. For every reported exacerbation, the AQI recorded on the event date and on the preceding day was documented to capture immediate and short-lag exposure patterns supported by previous air-pollution research (10–13). Weekly mean AQI was calculated to evaluate its temporal relationship with weekly asthma-related hospital admissions. Monthly mean AQI values were also calculated to describe seasonal changes from October through January.

AQI observations were categorized according to the descriptive classifications reported by the monitoring source: good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous. For descriptive comparison, good, moderate, and unhealthy-for-sensitive-groups observations were classified as lower-AQI periods, whereas unhealthy, very unhealthy, and hazardous observations were classified as high-AQI periods. Hospital admissions and exacerbation events were linked to the AQI category recorded on the corresponding event date. Same-day and preceding-day AQI values were retained separately rather than being combined into a single exposure measure.

Medication adherence was assessed by self-report. Participants were asked about missed doses of prescribed controller inhalers or oral asthma medication during the preceding two weeks, discontinuation of treatment after symptomatic improvement, use of controller medication only when symptomatic, and barriers such as treatment cost or concerns about corticosteroid therapy. Good adherence was operationally defined as use of at least 80% of prescribed controller doses, whereas use of less than 80% or discontinuation without medical advice was classified as poor adherence. Regular controller-inhaler use and medication adherence were retained as related but distinct variables because use of a prescribed controller and consistency of dose-taking do not represent identical constructs.

Preventive behaviours were assessed through a structured questionnaire covering regular monitoring of AQI, avoidance of unnecessary outdoor activity during severe smog, use of a face mask, closure of windows during peak smog periods, avoidance of smoke and dust in the home, regular controller-inhaler use, availability of rescue medication, and early consultation when symptoms worsened. Responses were recorded as yes, sometimes, or no and summarized separately for each behaviour. An affirmative-behaviour count was calculated by assigning one point to each consistently reported preventive practice, with higher totals indicating adoption of a broader range of exposure-reduction and asthma-management behaviours. Individual behaviours remained available for separate analysis to avoid obscuring potentially important differences between specific practices.

Several procedures were used to reduce measurement error and information bias. The prospective design and weekly follow-up schedule shortened the recall period for respiratory symptoms and healthcare encounters. Event dates were recorded to permit linkage with daily AQI observations, and hospital or emergency visits were verified from clinical documentation where available. Participant names and contact details were stored separately from the analytical dataset, and each participant was assigned a unique study identification number. Participants with incomplete weekly contacts remained eligible for analysis when their primary outcome and relevant exposure information were available; denominators were reported according to the data available for each analysis.

Categorical variables were summarized as frequencies and percentages, while continuous variables were summarized as means and standard deviations. The primary exacerbation frequency was calculated as the proportion of enrolled participants who experienced at least one exacerbation during follow-up. Recurrent exacerbation episodes, emergency visits, and hospital admissions were summarized by month, but participant-level association analyses used one binary outcome per participant to avoid treating repeated events within the same individual as statistically independent observations.

The association between medication-adherence category and occurrence of at least one exacerbation was assessed using the chi-square test of independence. Unadjusted risk ratios and odds ratios with 95% confidence intervals were calculated from the corresponding two-by-two contingency table to quantify the magnitude and precision of the association. Preventive behaviours were summarized individually, and the relationship between the cumulative preventive-behaviour count and emergency-care utilization was examined using appropriately categorized contingency tables. AQI values and asthma-related healthcare events were summarized by month and AQI category. The linear relationship between weekly mean AQI and weekly hospital-admission counts was assessed using Pearson's correlation coefficient after examination of the weekly observations for approximate linearity and influential outliers. Correlation estimates were reported with two-sided p-values and 95% confidence intervals. Statistical significance was defined as $p<0.05$. Data were analysed using IBM SPSS Statistics version 26.0.

All participants provided written informed consent before enrolment. Participation was voluntary, and clinical management remained under the direction of the treating physician. Identifying information was separated from research data, study identification numbers were used in the analytical dataset, and participant information was handled confidentially throughout data collection and analysis.

RESULTS

A total of 250 adults with physician-diagnosed asthma were included in the analysis. The mean age was 41.6±13.2 years, and the mean duration of asthma was 7.4±5.1 years. Women accounted for 56.8% of the cohort. Most participants were non-smokers, although 15.2% were current smokers and 11.6% were former smokers. A previous asthma-related emergency visit during the preceding year was reported by 82 participants (32.8%).

Controller-medication use and preventive practices were suboptimal. Regular controller-inhaler use was reported by 116 participants (46.4%), while 134 (53.6%) met the study definition of poor medication adherence. Regular AQI monitoring was reported by 48 participants (19.2%), mask use during smog by 91 (36.4%), and avoidance of outdoor activity during severe smog by 76 (30.4%) (Table 1).

At least one asthma exacerbation occurred in 137 participants, giving a cumulative exacerbation proportion of 54.8% (95% CI: 48.6–60.9). The remaining 113 participants (45.2%) did not report an exacerbation during follow-up. A total of 202 distinct exacerbation episodes were recorded, equivalent to a mean of 1.47 episodes among participants who experienced at least one event. The cohort generated 99 asthma-related emergency visits and 66 hospital admissions during the observation period.

Of the 66 admissions, 51 (77.3%) occurred on days categorized as unhealthy, very unhealthy, or hazardous, while 15 (22.7%) occurred on days in the lower AQI categories. Because the total number of person-days or observation-days in each AQI category was unavailable, these proportions describe the distribution of admissions and do not constitute category-specific admission rates (Table 2).

Table 1. Baseline and Preventive Characteristics of the Study Participants

Characteristic	Value
Total participants	250
Age, years	41.6±13.2
Male	108 (43.2)
Female	142 (56.8)
Duration of asthma, years	7.4±5.1
Current smoker	38 (15.2)
Former smoker	29 (11.6)
Non-smoker	183 (73.2)
Previous emergency visit during the preceding year	82 (32.8)
Regular controller-inhaler use	116 (46.4)
Poor medication adherence	134 (53.6)
Face-mask use during smog	91 (36.4)
Regular AQI monitoring	48 (19.2)
Avoidance of outdoor activity during severe smog	76 (30.4)

Values are presented as n (%) or mean±SD. AQI: air quality index; SD: standard deviation.

Table 2. Asthma Exacerbations and Healthcare-Utilization Outcomes During Follow-Up

Outcome	n/N	% or statistic
Participants with at least one exacerbation	137/250	54.8
95% CI for participants with an exacerbation	—	48.6–60.9
Participants without an exacerbation	113/250	45.2
Total exacerbation episodes	202	—
Mean episodes among participants with an exacerbation	202/137	1.47
Emergency visits	99	—
Hospital admissions	66	—
Admissions on high-AQI days	51/66	77.3
Admissions on lower-AQI days	15/66	22.7
Weekly mean AQI versus weekly admissions	—	r=0.72
Correlation significance	—	p=0.003

High-AQI days comprised unhealthy, very unhealthy, and hazardous categories. Lower-AQI days comprised good, moderate, and unhealthy-for-sensitive-groups categories. CI: confidence interval.

The monthly distribution demonstrated a parallel rise in AQI, exacerbations, emergency visits, and admissions between October and December, followed by a partial decline in January. Mean AQI increased from 176 in October to 242 in November and reached 318 in December before decreasing to 286 in January. December accounted for 35.1% of all exacerbation episodes, 39.4% of emergency visits, and 40.9% of hospital admissions. October accounted for the smallest proportion of each outcome. Weekly mean AQI demonstrated a strong positive correlation with weekly asthma-related admissions ($r=0.72$; $p=0.003$), indicating that weeks with higher average AQI generally had more admissions (Table 3).

Table 3. Monthly AQI and Distribution of Asthma-Related Events

Month	Mean AQI	Exacerbation episodes, n (%)	Emergency visits, n (%)	Hospital admissions, n (%)
October	176	28 (13.9)	11 (11.1)	6 (9.1)
November	242	47 (23.3)	21 (21.2)	14 (21.2)
December	318	71 (35.1)	39 (39.4)	27 (40.9)
January	286	56 (27.7)	28 (28.3)	19 (28.8)
Total		202 (100.0)	99 (100.0)	66 (100.0)

Percentages were calculated using the respective column totals. AQI: air quality index.

Medication adherence was significantly associated with the occurrence of at least one exacerbation. Among participants with poor adherence, 85 of 134 (63.4%) experienced an exacerbation compared with 52 of 116 participants (44.8%) with good adherence. The absolute risk difference was 18.6 percentage points (95% CI: 6.4–30.8). Participants with poor adherence had 1.42 times the risk of an exacerbation compared with those with good adherence (RR=1.42; 95% CI: 1.11–1.80). The corresponding odds ratio was 2.14 (95% CI: 1.29–3.55). The association was statistically significant (χ^2=8.69; df=1; p=0.003) (Table 4).

Table 4. Association Between Medication Adherence and Asthma Exacerbation

Medication adherence	Exacerbation, n (%)	No exacerbation, n (%)	Risk ratio (95% CI)	Odds ratio (95% CI)	p-value
Poor adherence, n=134	85 (63.4)	49 (36.6)	1.42 (1.11–1.80)	2.14 (1.29–3.55)	0.003
Good adherence, n=116	52 (44.8)	64 (55.2)	1.00	1.00	—

Good adherence was the reference category. Pearson chi-square: χ^2=8.69; df=1. Absolute risk difference: 18.6 percentage points (95% CI: 6.4–30.8). CI: confidence interval.

DISCUSSION

This prospective cohort study identified a substantial burden of asthma morbidity during the seasonal smog period among urban Pakistani adults. More than half of the participants experienced at least one exacerbation, and the monthly distributions of exacerbation episodes, emergency visits, and hospital admissions increased as mean AQI rose from October to December. Weekly mean AQI was positively correlated with hospital admissions, while poor medication adherence was associated with a clinically and statistically higher risk of experiencing an exacerbation. Preventive behaviours, including regular AQI monitoring, mask use, and avoidance of outdoor activity during severe smog, were adopted by relatively small proportions of the cohort.

The cumulative exacerbation proportion of 54.8% indicates that symptom deterioration was common during the observation period. Direct numerical comparison with previous Pakistani studies is difficult because much of the national literature has evaluated general respiratory symptoms, ambient pollutant concentrations, ecological patterns, or retrospective healthcare utilization rather than prospectively following adults with established asthma. Nevertheless, the present findings are directionally consistent with Pakistani evidence identifying seasonal smog, particulate pollution, traffic emissions, industrial activity, brick kilns, crop-residue burning, and rapid urbanization as important respiratory-health threats (4–9,20,21,23–25). They also extend Lahore-based evidence associating ambient pollution with asthma burden and earlier reports of asthma-related healthcare utilization in Karachi by documenting events prospectively across an October–January smog period (14,22).

The temporal pattern was clinically important. December had the highest mean AQI and accounted for the largest proportions of exacerbations, emergency visits, and hospital admissions. Weekly mean AQI was strongly correlated with weekly hospital-admission counts, supporting a temporal relationship between worsening ambient air quality and severe asthma-related healthcare utilization. This finding is consistent with systematic reviews and time-series studies demonstrating increased asthma exacerbations, emergency visits, and hospital admissions after short-term exposure to particulate matter, ozone, nitrogen dioxide, sulphur dioxide, and other pollutants (1–3,10–13,19,26,27,29–31). However, the observed correlation was ecological and unadjusted. It demonstrates that AQI and admissions varied together over time but does not establish that AQI independently caused each admission.

The distribution of admissions further supports concern regarding periods of severe pollution: 77.3% of admissions occurred on days categorized as unhealthy, very unhealthy, or hazardous. This percentage should be interpreted cautiously because the number of observation-days, participant-days, and exposure time within each AQI category was not available. Therefore, the study cannot estimate an admission rate or relative risk for high- versus lower-AQI days. Future analyses should compare event rates using the number of days or person-days in each exposure category and should consider distributed-lag or time-series models that account for temporal trends, weather, respiratory infections, and repeated events within participants.

Several biological mechanisms may explain the observed pattern. Fine particulate matter can penetrate the distal airways and promote oxidative stress, epithelial injury, inflammatory-cell recruitment, and mucus production. Ozone and nitrogen dioxide may increase airway hyper-responsiveness and reduce the threshold for bronchoconstriction, while pollutant mixtures may impair mucociliary and immune defence mechanisms. These effects may occur over short lag periods and can aggravate cough, wheezing, chest tightness, and breathlessness in susceptible patients (3,11,12,19,27). Cold weather, reduced atmospheric dispersion, respiratory infections, indoor crowding, and exposure to household smoke may also coincide with winter smog and contribute to the seasonal increase in respiratory morbidity.

Medication adherence emerged as an important potentially modifiable factor. Participants with poor adherence had a 63.4% exacerbation risk compared with 44.8% among those with good adherence. The relative risk of 1.42 and absolute risk difference of 18.6 percentage points indicate both statistical and potential clinical importance. These findings agree with previous evidence showing that inadequate adherence to controller therapy increases the likelihood of severe asthma exacerbations and that treatment discontinuation, concerns about corticosteroids, medication costs, and reliance on reliever treatment remain common barriers to effective asthma management (15–17). Nevertheless, adherence was measured by self-report rather than pharmacy-refill data, electronic monitoring, or a validated multidimensional instrument; consequently, some participants may have overestimated their medication use.

Preventive practices were also limited. Fewer than one in five participants regularly monitored AQI, approximately one-third used a mask during smog, and fewer than one-third avoided outdoor activity during severe pollution. These findings suggest that environmental-health information was not consistently translated into protective behaviour. Properly fitted particulate-filtering masks may reduce inhaled particulate exposure, although filtration performance, facial fit, duration of use, affordability, and tolerability influence effectiveness (18,19). Avoiding exposure may also be impractical for people who commute by motorcycle, work outdoors, provide family care, or depend on daily wages. Individual counselling should therefore complement, rather than replace, broader emission-control and public-health measures.

The findings have implications for clinical services and environmental-health planning. Smog-season asthma management should emphasize continuation of controller therapy, correction of inhaler technique, availability of rescue medication, recognition of early deterioration, and communication of AQI-based precautions. Hospitals and emergency departments may also use periods of persistently poor AQI as an operational signal for increased respiratory demand. At the population level, Pakistan's substantial ambient-air-pollution burden indicates that individual protective behaviours alone are insufficient and must be accompanied by sustained action addressing transport emissions, industrial sources, waste burning, brick kilns, crop-residue burning, and urban air-quality monitoring (20,23,28).

The study has several strengths. Its prospective design reduced long-term recall error, weekly follow-up allowed events to be documented close to their occurrence, and the linkage of event dates with AQI observations provided a clinically meaningful temporal exposure framework. The study also assessed medication adherence and preventive behaviour alongside environmental exposure, allowing interpretation of patient-level vulnerability within the broader smog context.

Several limitations should be considered. AQI exposure was assigned using the nearest available monitoring station and may not represent personal exposure at home, work, or during travel. AQI was assessed as a composite index, preventing evaluation of pollutant-specific effects. Medication adherence, symptoms, and preventive behaviours were partly self-reported and therefore susceptible to recall and social-desirability bias. The non-probability consecutive sampling strategy may limit generalizability beyond the participating urban clinical populations. The analysis was predominantly unadjusted and did not account for baseline asthma severity, inhaler technique, smoking intensity, socioeconomic factors, respiratory infections, temperature, humidity, occupational exposure, or indoor air pollution. Recurrent exacerbations and healthcare contacts may also have occurred within the same participants, but the available aggregate results did not permit recurrent-event or multilevel modelling. These limitations preclude causal inference, although the consistency of the temporal and clinical patterns supports further investigation using individual exposure measurements and adjusted longitudinal analyses.

Overall, the study demonstrates that asthma exacerbations and healthcare utilization were concentrated during the period of poorest air quality and that poor controller-medication adherence was associated with an appreciably greater exacerbation risk. The findings connect the environmental burden of seasonal smog with modifiable aspects of asthma management and support coordinated clinical, behavioural, and public-health approaches during high-pollution months.

CONCLUSION

Seasonal smog was associated with a substantial burden of asthma exacerbations and healthcare utilization among urban Pakistani adults, with the highest number of events occurring during the month with the poorest mean air quality. Weekly AQI was positively correlated with hospital admissions, while poor medication adherence was associated with a 42% higher exacerbation risk than good adherence. These findings identify the smog season as a period of increased vulnerability for adults with asthma and support anticipatory controller-medication management and AQI-informed clinical and public-health planning.

REFERENCES

1. Zheng XY, Ding H, Jiang LN, Chen SW, Zheng JP, Qiu M, et al. Association between air pollutants and asthma emergency room visits and hospital admissions in time series studies: a systematic review and meta-analysis. PLoS One. 2015;10(9). doi:10.1371/journal.pone.0138146.

2. Orellano P, Quaranta N, Reynoso J, Balbi B, Vasquez J. Effect of outdoor air pollution on asthma exacerbations in children and adults: systematic review and multilevel meta-analysis. PLoS One. 2017;12(3). doi:10.1371/journal.pone.0174050.

3. Zhou X, Chen Q, Wang W, Zhu Y, Zhang X. Effect of air pollution on asthma. Ann Allergy Asthma Immunol. 2024;132(5):553–563. doi:10.1016/j.anai.2024.01.017.

4. Iram S, Qaisar I, Shabbir R, Pomee MS, Schmidt M, Hertig E. Impact of air pollution and smog on human health in Pakistan: a systematic review. Environments. 2025;12(2):46. doi:10.3390/environments12020046.

5. Riaz R, Hamid K. Existing smog in Lahore, Pakistan: an alarming public health concern. Cureus. 2018;10(1). doi:10.7759/cureus.2111.

6. Anjum MS, Ali SM, Imad-ud-din M, Subhani MA, Anwar MN, Nizami AS, et al. An emerged challenge of air pollution and ever-increasing particulate matter in Pakistan: a critical review. J Hazard Mater. 2021;402:123943. doi:10.1016/j.jhazmat.2020.123943.

7. Bilal M, Mhawish A, Nichol JE, Qiu Z, Nazeer M, Ali MA, et al. Air pollution scenario over Pakistan: characterization and ranking of extremely polluted cities using long-term concentrations of aerosols and trace gases. Remote Sens Environ. 2021;264:112617. doi:10.1016/j.rse.2021.112617.

8. Bajwa AU, Sheikh HA. Road transport's contribution to Pakistan's air pollution in the urban environment. Air. 2023;1(4):237–257. doi:10.3390/air1040018.

9. Fatima M, Butt I, Nasar-u-Minallah M, Atta A, Cheng G. Assessment of air pollution and its association with population health: geo-statistical evidence from Pakistan. Geogr Environ Sustain. 2023;16:93–101. doi:10.24057/2071-9388-2022-155.

10. Huang J, Yang X, Fan F, Hu Y, Wang X, Zhu S, et al. Outdoor air pollution and the risk of asthma exacerbations in single lag0 and lag1 exposure patterns: a systematic review and meta-analysis. J Asthma. 2022;59(11):2137–2148. doi:10.1080/02770903.2021.2008429.

11. Zheng XY, Orellano P, Lin HL, Jiang M, Guan WJ. Short-term exposure to ozone, nitrogen dioxide, and sulphur dioxide and emergency department visits and hospital admissions due to asthma: a systematic review and meta-analysis. Environ Int. 2021;150:106435. doi:10.1016/j.envint.2021.106435.

12. Cheng CG, Wang CH, Chen BY, Chang TY. Short-term exposure effect of ambient fine particulate matter and ozone on asthma emergency visits. Toxics. 2023;11(2):94. doi:10.3390/toxics11020094.

13. Fang X, Liu W, Xiang P, He M, Li S, Xie J. Short-term exposure to ozone and asthma exacerbation in adults: a case-crossover study. Front Public Health. 2023;10:1070231. doi:10.3389/fpubh.2022.1070231.

14. Aslam R, Sharif F, Baqar M, Nizami AS, Ashraf U. Role of ambient air pollution in asthma spread among various population groups of Lahore City: a case study. Environ Sci Pollut Res Int. 2023;30:8682–8697. doi:10.1007/s11356-022-19086-1.

15. Engelkes M, Janssens HM, de Jongste JC, Sturkenboom MCJM, Verhamme KMC. Medication adherence and the risk of severe asthma exacerbations: a systematic review. Eur Respir J. 2015;45(2):396–407. doi:10.1183/09031936.00075614.

16. Asamoah-Boaheng M, Osei Bonsu K, Farrell J, Oyet A, Midodzi WK. Measuring medication adherence in a population-based asthma administrative pharmacy database: a systematic review and meta-analysis. Clin Epidemiol. 2021;13:981–1010. doi:10.2147/CLEP.S333534.

17. De Keyser HH, Ramsey R, Federico MJ. They just don't take their medicines: reframing medication adherence in asthma from frustration to opportunity. Pediatr Pulmonol. 2020;55(3):818–825. doi:10.1002/ppul.24643.

18. Zhou SS, Lukula S, Chiossone C, Nims RW, Suchmann DB, Ijaz MK. Assessment of a respiratory face mask for capturing air pollutants and pathogens including human influenza and rhinoviruses. J Thorac Dis. 2018;10(3):2059–2069. doi:10.21037/jtd.2018.03.103.

19. Bronte-Moreno O, Cazzola M, Matera MG, Rogliani P. Impact of air pollution on asthma: a scoping review. J Clin Med. 2023;12(15):4987. doi:10.3390/jcm12154987.

20. Razzaq A, Zafar MM, Zahra LT, Qadir F, Qiao F, Ullah MH, et al. Smog: Lahore needs global attention to fix it. Environmental Challenges. 2024;16:100999. doi:10.1016/j.envc.2024.100999.

21. Malhi HM, Ahmed I, Nasim I, Khurshid I, Haider R, Nawaz R, et al. Monitoring of ambient air pollution in Lahore City. Pak J Emerg Sci Technol. 2023;4(3):65–73. doi:10.58619/pjest.v4i3.118.

22. Ahmed A, Ahmed F, Raza MZ, Ghani A, Rizvi N. A descriptive analysis of asthma exacerbations and its mortality in Karachi, Pakistan. J Allergy Ther. 2013;S11:004. doi:10.4172/2155-6121.S11-004.

23. Colbeck I, Nasir ZA, Ali Z. The state of ambient air quality in Pakistan: a review. Environ Sci Pollut Res Int. 2010;17:49–63. doi:10.1007/s11356-009-0217-2.

24. Colbeck I, Nasir ZA, Ali Z. The state of indoor air quality in Pakistan: a review. Environ Sci Pollut Res Int. 2010;17:1187–1196. doi:10.1007/s11356-010-0293-3.

25. Aziz A, Bajwa IU. Minimizing human health effects of urban air pollution through quantification and control of motor vehicular carbon monoxide in Lahore. Environ Monit Assess. 2007;135:459–464. doi:10.1007/s10661-007-9665-7.

26. Liu Y, Pan J, Zhang H, Shi C, Li G, Peng Z, et al. Short-term exposure to ambient air pollution and asthma mortality. Am J Respir Crit Care Med. 2019;200(1):24–32. doi:10.1164/rccm.201810-1823OC.

27. Espejo D, López-Ruiz M, Rojas-Martinez R, Riojas-Rodriguez H. Influence of outdoor air pollutants on asthma: a narrative review. Chronic Dis Transl Med. 2025. doi:10.1016/j.cdtm.2025.04.003.

28. Cohen AJ, Brauer M, Burnett R, Anderson HR, Frostad J, Estep K, et al. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. Lancet. 2017;389(10082):1907–1918. doi:10.1016/S0140-6736(17)30505-6.

29. Fan X, Yang C, Chen J, Chen Y, Chen G, Lin Z, et al. Impact of low PM2.5 exposure on asthma admission: age-specific differences and evidence from a low-pollution environment in China. Aerosol Air Qual Res. 2024;24:230195. doi:10.4209/aaqr.230195.

30. Dabrowiecki P, Mucha D, Adamkiewicz Ł, Badyda A. Ambient air pollution and risk of admission due to asthma in the Polish population. Int J Environ Res Public Health. 2022;19(10):5988. doi:10.3390/ijerph19105988.

31. Lin CH, Chen YC, Chiang TY, Tsai SS. Ozone exposure and asthma exacerbation requiring hospitalization: a case-control study in central Taiwan. BMJ Open. 2022;12(2). doi:10.1136/bmjopen-2021-050861.