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Relationship between air quality and asthma-related emergency hospital admissions in Mexico City 2017–2019

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ABSTRACT

Background Previous studies found exposure to air pollution leads to exacerbations of asthma in paediatric and adult patients and increases asthma-related emergency hospital admissions (AREHA).

Methods AREHAs and levels of air pollutants (PM_{10}, $PM_{2.5}$ and NO_2) were obtained from Mexico City for the period 2017–2019. A time-series approach was used to explore the relationship between air pollutants and AREHA. Relative risks of AREHA were estimated using a negative binomial regression in young children (less than 5 years) and adults (greater than 18 years).

Results There was a positive association between AREHA and PM_{10}, $PM_{2.5}$ and NO_2 in adults, which remained after mutual adjustment for these pollutants. The relative risk (RR) of admission in adults increased by 3% (95% CI 1% to 4%) for a 10 µg/m^3 increase in PM_{10}, 1% (0.03% to 3%) for a 5 µg/m^3 increase in $PM_{2.5}$ and by 1% (0.06% to 2%) for a 5 µg/m^3 increase in NO_2. In contrast, in young children, AREHAs were negatively associated with PM_{10} after adjustment for NO_2 (RR 0.97 (0.95 to 0.99) for a 10 µg/m^3 and with NO_2 after adjustment for PM_{10} and $PM_{2.5}$ (RR 0.98 (0.96 to 0.99) and 0.97 (0.96 to 0.99), respectively, for a 5 µg/m^3 increase in NO_2). AREHAs in children were not associated with $PM_{2.5}$ after adjustment for NO_2.

Conclusions Ambient air pollution, within the previous week, was associated with emergency hospital admissions for asthma to public hospitals in adults in Mexico City. The relationship in children was less consistent. Further work is needed to explore why differences between adults and children exist to inform appropriate interventions to benefit public health.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Globally measures are being implemented to reduce air pollution in cities due to its negative impact on the respiratory health of the population. Mexico was previously identified as the most polluted city in the world and interventions to improve air quality have been implemented over the past 30 years. Previous work found that ambient $PM_{2.5}$, O_3 and NO_2 were associated with emergency asthma admissions in Mexico City in 2010-2015.

WHAT THIS STUDY ADDS

⇒ This study demonstrated that in the period 2017-2019 levels of air pollution remain associated with emergency asthma admissions in adults in Mexico City.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This study shows that despite improvements in air quality as a result of interventions put in place in Mexico City further air quality improvements are needed.

INTRODUCTION

Asthma is defined as inflammation of the airways associated with wheeze, chest tightness, coughing and breathlessness.[1] Moderate or severe asthma exacerbations, an important health outcome for individuals with asthma, typically require attendance at a hospital emergency department (ED) and/or hospital admission.[2] Asthma is a leading cause of emergency hospitalisation in children aged less than 5 years and its prevalence has increased over the last 20 years, especially in developing countries.[3 4]

Previous research has suggested that outdoor air pollution is an established risk factor for asthma exacerbations in children[5] and adults,[6] although the evidence remains equivocal.[7]

Fine particulate matter ($PM_{2.5}$), coarse particulate matter (PM_{10}) and nitrogen dioxide (NO_2) are widely used by international bodies as indicators of air pollution.[8] Several previous studies from a range of different settings have reported that higher levels of $PM_{2.5}$, PM_{10} and NO_2 are associated with poor respiratory health in both children and adults and are positively associated with asthma-related ED visits.[7 9–11] However, a systematic review and meta-analysis concluded that $PM_{2.5}$ and NO_2, but not PM_{10} show significant associations with asthma exacerbations.[12]

Previous work has also demonstrated the role of meteorological factors in exacerbations of asthma. For example, it has been reported that asthma admissions increase in cold temperatures[13 14] and

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both high and low humidity are associated with an increase in asthma admissions.[15]

A recently published study demonstrated that respiratory health (defined as respiratory ED visits) was associated with levels of $PM_{2.5}$, O_3 and NO_2 in Mexico City in the period 2010-2015.[16] The aim of this study was to explore the relationship between $PM_{2.5}$, PM_{10} and NO_2 and asthma-related emergency hospital admissions (AREHA) for children aged less than 5 years and adults aged greater than 18 years, in Mexico City between 2017 and 2019. This was of particular interest in the context of city-wide interventions to improve air quality (AQ), including the recent introduction of a health-based AQ index to communicate information on levels of pollution to the population, to explore if this relationship still persisted.

METHODS

Study location

Mexico City is the capital and largest city in Mexico, situated at an average altitude of 2240 m above sea level. It is also the most densely populated city in North America with a population of 21 828 944 and a high population density of 2559.8 inhabitants per km². It was once the most polluted city in the world. Mexico City's Metropolitan Environmental Commission implemented several policies, under two programmes (Comprehensive Programme Against Air Pollution: PICCA, 1990–1995; and ProAire, from 1995) aimed at reducing air pollution. For example, since 1990 catalytic converters have been required in new cars, cleaner unleaded fuels have been widely distributed, natural gas has been substituted for heavy oil in industry and power plants, liquefied petroleum gas has been reformulated for residential use, driving restrictions within the city were strengthened in 2006 and the public transport infrastructure was improved with the introduction of the Metrobus system that uses environmentally friendly buses, which also began in 2006. Data from Mexico City's automatic atmospheric monitoring network suggests that these measures have reduced air pollution levels by 58% by 2017.[17] Despite this significant improvement in AQ, current $PM_{2.5}$, PM_{10} and NO_2 levels are frequently found to exceed Mexican AQ standards.[18] The Ministry for the Environment in Mexico City continues to take public health measures to reduce the impact of pollution on health, including the recent introduction of a health-based AQ index to communicate information on levels of pollution to the population.[16] It is anticipated that this information tool will encourage the population to take measures to reduce their exposure to air pollution when it is indicated that levels are high.

AQ indicators and meteorological data

Ambient ground-level concentrations of $PM_{2.5}$, PM_{10} and NO_2 were obtained fromten fixed-site AQ monitoring stations in different geographical areas across Mexico City from the automatic atmospheric monitoring network (RAMA).[17] All measurements were taken by precision AQ monitoring equipment with quality assurance and quality control protocols for data sampling, analysis and calibration. Daily average concentrations were calculated from data downloaded at hourly intervals. The monitoring sites included were selected because they provided data from across Mexico City for at least 80% of the days and time period covered.

Humidity and temperature data were obtained from the Mexico City meteorological network stations for the period 2017–2019.[19] The climate in Mexico City is temperate, with a wet season in summer, from May to October.

AREHA data

Data on all public hospital admissions in Mexico City during the period 2017–2019, including age, sex and International Classification of Diseases (ICD-10) code for diagnosis were obtained from the Registry Department of the Instituto Mexicano del Seguro Social (IMSS). Cases with a primary diagnosis of asthma (ICD-10 J45 and J46) were included in the study. The IMSS is the largest health institution in Mexico, and covers 42.4% of the population of Mexico City.[20] All the IMSS Hospitals of the Greater Valley of Mexico were included in the present analysis. Records of daily AREHA were available for the study period.

Statistical analysis

Descriptive statistics (means or medians, as appropriate) were produced to summarise the number of admissions during the study period and average $PM_{2.5}$, PM_{10}, NO_2 and selected environmental variables. As the number of admissions was not normally distributed, Spearman correlations were calculated to explore the relationship between these and the AQ and environmental variables. We conducted an ecological time series study. Time series analysis was conducted using generalised linear models with negative binomial (type II) regression, to take account of overdispersion of the data,[21] while allowing model comparison using Akaike Information Criterion (AIC). The method was adapted from that described by Tadano *et al*.[22] Mean daily relative humidity, wind speed, temperature and season (calendar day) were controlled for using a smooth function in the analyses. In addition, day of the week and public holidays were controlled for. Relative risks of an AREHA associated with a 10 unit increase in PM_{10}, and a 5 unit increase in $PM_{2.5}$ and NO_2 were calculated. In addition, relative risks for an IQR increase in the pollutants were calculated. Lag times of 0–7 days were considered. The AIC was used to identify the best-fitting model. The best fitting model was identified as that with the lowest AIC. Multipollutant models were used to study the effect of adjusting for the other pollutants on hospital admissions. Due to collinearity (variance inflation factor>4) in regression analysis between PM_{10} and $PM_{2.5}$ in children each of these pollutants were adjusted only for NO_2 in separate two pollutant models.

Analyses were conducted separately for adults (aged>18 years) and for children aged 0–4 years. This group of young children was studied because of their high asthma prevalence and increased risk of asthma-related hospitalisation.[3]

All analyses were conducted in Stata V.17.[23] A p value of <0.05 was used to indicate statistical significance.

RESULTS

A total of 50 723 AREHA (41 787 adults and 8936 children) were recorded in the period 2017–2019. The median number of AREHA per day was 7 in children and 35 in adults (table 1).

Table 2 shows descriptive data for the pollutants considered in this study and for meteorological variables. Recommended 24-hour thresholds (online supplemental table S1) were exceeded for the vast majority of days during the study period for $PM_{2.5}$ and NO_2 (81% and 97%, respectively). PM_{10} thresholds were exceeded on 44% of days during this period.

Daily emergency hospital admissions for asthma showed a clear seasonal pattern, with a greater number of cases recorded in the cold season (October–February) (figure 1). The median number of cases recorded per day in the cold season was 58 compared with 35 and 37 in the rainy and hot seasons, respectively ($p<0.001$). Seasonal patterns in PM_{10}, $PM_{2.5}$ and NO_2 were also apparent. Mean daily PM_{10} concentrations were

Table 1 Asthma-related hospital admissions for the period 2017–2019

	Annual number of cases		Range, per day		Median (Q1, Q3), per day			
Year	0-4 years	>18 years	0-4 years	>18 years	0-4 years		>18 years	
2017	3078	13 512	0–28	7–120	7	(5, 11)	34	(26, 45)
2018	3137	14 242	0–29	10–122	7	(5, 12)	35	(26, 48)
2019	2721	14 033	0–25	9–115	6	(4, 10)	37	(28, 48)
Overall	8936	41 787	0–29	7–122	7	(4,11)	35	(27, 47)

Q1=quartile 1; Q3=quartile 3.

highest in the cold season and lowest in the rainy season (June–September). Mean daily $PM_{2.5}$ concentrations were lowest in the rainy season and consistently higher between November and May. The pattern for NO_2 was similar to that for PM_{10} (figure 1).

Daily asthma admissions were positively correlated with PM_{10} and NO_2 concentrations in both adults and children. However, $PM_{2.5}$ was positively correlated with asthma admissions in adults only. Mean wind speed was negatively associated with asthma admission in both adults and children. Mean temperature and humidity were negatively associated with asthma admissions in adults, but not in children (table 3).

The AIC values for models with 1–7 day lags indicated that in adults the model with the effect of a 1-day lag fitted the data best for PM_{10} and for $PM_{2.5}$ the best fitting model had a 2-day lag. For NO_2, the best fitting model was that with a 6-day lag. In children, the model with a 6-day lag was the best fitting model for PM_{10} and $PM_{2.5}$ and for NO_2 the best fitting model had a 5-day lag (online supplemental table S2).

Statistically significant increased relative risks of asthma admissions were found in the single pollutant models for increased PM_{10}, $PM_{2.5}$ and NO_2 in adults. The relative risk (95% CI) for an increase of 10 μg/m^3 in PM_{10} was 1.04 (1.02, 1.05) and for an IQR increase was 1.10 (1.06–1.14) (table 4). For $PM_{2.5}$ the relative risk (95% CI) of an asthma-related hospital admission was 1.03 (1.02 to 1.04) and 1.06 (1.04 to 1.09) for a 5 μg/m^3 and IQR increase, respectively. The figures for NO_2 were 1.02 (1.01 to 1.03) and 1.06 (1.03 to 1.09).

Statistically significant decreased relative risks of asthma admissions were found for increased PM_{10}, $PM_{2.5}$ and NO_2 in children aged less than 5 years (0.96 (0.94 to 0.98), 0.98 (0.96 to 0.99) and 0.97 (0.96 to 0.99), respectively) (table 4).

Results from the analysis with mutual adjustment for the pollutants are shown in table 5 (adults) and tables 6A and 6B (children). The associations between the pollutants and asthma-related hospital admissions observed in the single pollutant models remained statistically significant in the adjusted models for PM_{10}, $PM_{2.5}$ and NO_2 in adults. Relative risks (95% CI) of 1.03 (1.01 to 1.04), 1.01 (1.00 to 1.03) and 1.01 (1.01 to 1.02) for a 10 μg/m^3 in PM_{10} increase in PM_{10} and a 5 μg/m^3 in $PM_{2.5}$ and NO_2 respectively, were found, suggesting an independent effect of these pollutants on asthma-related admissions. In children, after adjustment for NO_2, PM_{10} remained statistically significantly negatively associated with asthma-related admissions (relative risk (95% CI): 0.97 (0.95 to 0.99) for a 10 μg/m^3 increase) and NO_2 remained statistically significantly negatively associated with asthma-related admissions after adjustment for PM_{10} (0.98 (0.96 to 0.99) for a 5 μg/m^3 increase). $PM_{2.5}$ was no longer statistically significantly associated with asthma-related admissions after adjustment for NO_2, although NO_2 remained statistically significantly negatively associated with asthma-related admissions (relative risk (95% CI): 0.97 (0.96 to 0.99) for a 5 μg/m^3 increase) after adjustment for $PM_{2.5}$. Relative risks associated with an IQR increase in each of the pollutants are shown in table 4 (single pollutant model) and table 6A, table 6B (two-pollutant models).

DISCUSSION

Main findings

The main findings of this study suggest that, in Mexico City in recent years, risk of hospital admission for an exacerbation of asthma in adults, aged over 18 years, increases with increasing ambient levels of $PM_{2.5}$, PM_{10} and NO_2. The relationship between these pollutants and hospital admissions for asthma in children (aged less than 5 years) was less clear. A negative and statistically significant relationship between PM_{10} and NO_2 and asthma-related admissions was observed in both single pollutant analysis and after adjustment for the other pollutants. A negative association between asthma-related admissions and $PM_{2.5}$ was found when this pollutant was considered separately. This relationship was no longer statistically significant after adjustment for NO_2.

Table 2 Descriptive data for PM_{10} concentration, $PM_{2.5}$ concentration, NO_2 concentration, temperature, humidity and wind speed in Mexico City, 2017–2019

	Mean	(SD)	Median	(Q1, Q3)	Min	Max	Days exceeded WHO AQG
PM_{10} μg/m^3	43.97	(17.31)	41.60	(30.34, 55.39)	9.71	119.36	484 (44.4%)
$PM_{2.5}$ μg/m^3	23.01	(9.53)	21.82	(16.49, 27.98)	5.46	78.94	886 (81.4%)
NO_2 μg/m^3	44.75	(12.72)	43.69	(35.24, 51.74)	15.41	99.91	1061 (97.4%)
Temperature (°C)	17.80	(2.49)	17.94	(16.39, 19.33)	6.22	24.5	
Humidity (%)	51.48	(13.70)	52.20	(41.60, 61.80)	12.40	89.30	
Wind speed (m/s)	2.07	(0.42)	2.00	(1.77, 2.26)	1.23	4.29	

μg/m^3, micrograms per cubic metre.
*World Health Organisation Air Quality Guidelines (AQG) (https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health#:~:text=ThecurrentWHOguidelinevalue,effectsofgaseousnitrogendioxide): PM_{10}=45 μg/m^3; $PM_{2.5}$ =15 μg/m^3; NO_2=25 μg/m^3.

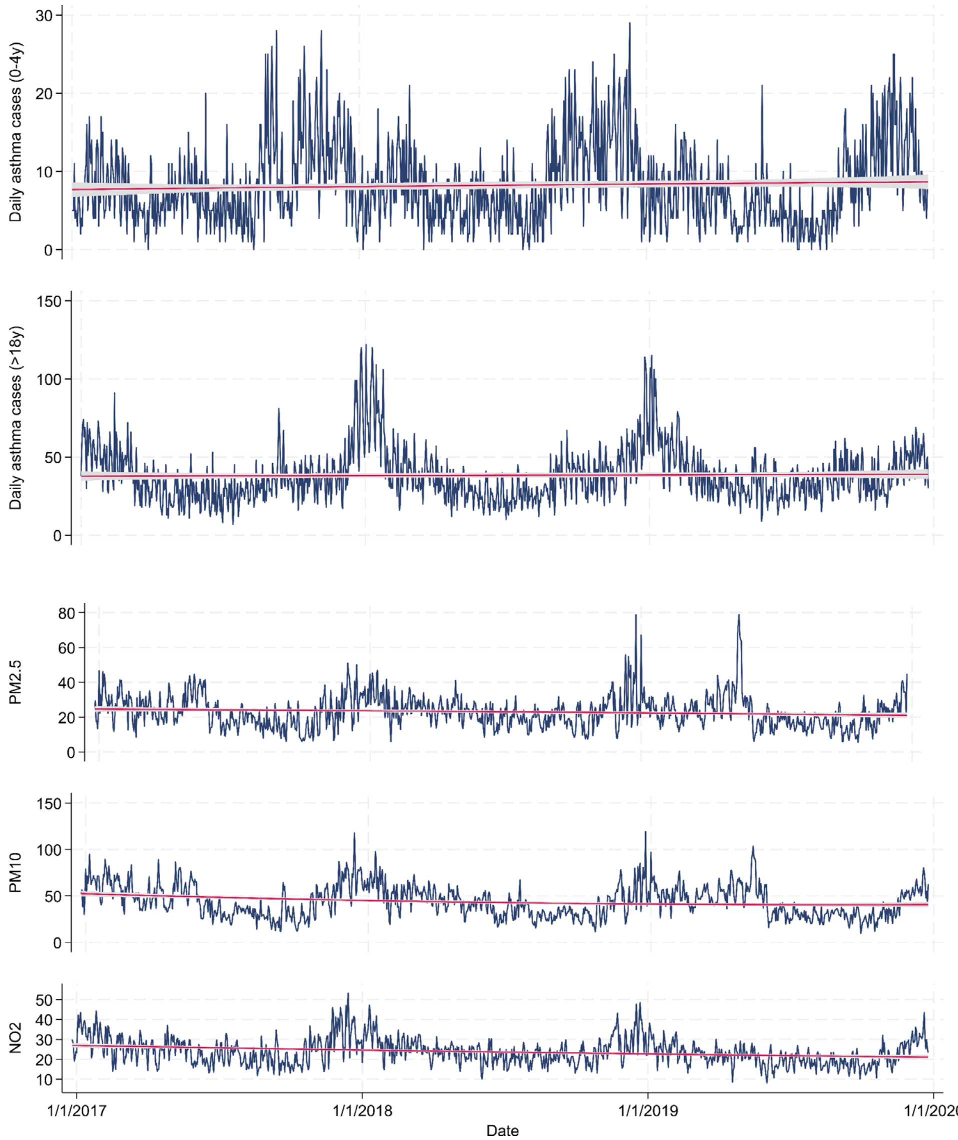

Figure 1 Time series plots of daily asthma admissions and pollutant concentrations, 2017–2019.

Models using different lag days were found to best fit the data for different pollutants and for children compared with adults. This was particularly notable for NO_2, where a 6-day lag was identified as providing the best fit in adults compared with a 1-day and 2-day lag, respectively, for PM_{10} and $PM_{2.5}$. For children, the relationship between ambient NO_2 and asthma-related admissions differed according to lag days. However, a comparison of results from the best fitting model (5 lag days) and the next best fitting model (6 lag days), based on AIC, has very similar findings.

Exposure to airborne pollutants is well established as contributing to poor health, including increased hospital admissions

Table 3 Spearman correlations between monthly or daily asthma admissions and PM_{10} concentration, $PM_{2.5}$ concentration, NO_2 concentration, temperature, humidity and wind speed, 2017–2019

	Admissions>18 years	Admissions 0–4 years	PM_{10}	$PM_{2.5}$	NO_2	Temperature	Humidity	Wind speed
Admissions>18 years	1.00							
Admissions 0–4 years	0.375*	1.00						
PM_{10}	0.362*	0.094*	1.00					
$PM_{2.5}$	0.232*	0.035	0.855*	1.00				
NO_2	0.386*	0.198*	0.728*	0.730*	1.00			
Temperature	−0.387*	−0.243	−0.066*	−0.069*	−0.338*	1.00		
Humidity	−0.176*	0.046	−0.664*	−0.358*	−0.286*	−0.266*	1.00	
Wind speed	−0.175*	−0.090*	−0.203*	−0.427*	−0.596*	0.396*	−0.253*	1.00

*p<0.05.

Table 4 Relative risks (RR) for asthma-related hospital admissions for a 10 (PM_{10}) or 5 unit ($PM_{2.5}$ and NO_2) and IQR, adjusted for day of the week, national holiday, temperature, humidity, season and wind speed, 2017–2019

	Adults >18 years*			Children 0–4 years†		
	RR	95% CI	P	RR	95% CI	P value
PM_{10} (10 µg/m^3 increase)	1.04	1.02 to 1.05	<0.001	0.96	0.94 to 0.98	<0.001
$PM_{2.5}$ (5 µg/m^3 increase)	1.03	1.02 to 1.04	<0.001	0.98	0.96 to 0.99	0.028
NO_2(5 µg/m^3 increase)	1.02	1.01 to 1.03	<0.001	0.97	0.96 to 0.99	<0.001
PM_{10} (IQR; 25.1 µg/m^3)	1.10	1.06 to 1.14	<0.001	0.90	0.85 to 0.96	<0.001
$PM_{2.5}$ IQR; 11.5 µg/m^3)	1.06	1.04 to 1.09	<0.001	0.95	0.91 to 0.99	0.028
NO_2(IQR; 16.5 µg/m^3)	1.06	1.03 to 1.09	<0.001	0.91	0.86 to 0.96	<0.001

*Best fitting model for adults for PM_{10} was 1-day lag, for $PM_{2.5}$ was 2-day lag and for NO_2 was 6-day lag.
†Best fitting model for children for PM_{10} was 1-day lag, for $PM_{2.5}$ was 2-day lag and for NO_2 was 6-day lag.

and emergency room visits for patients experiencing respiratory symptoms and exacerbation of chronic respiratory diseases.[24] Our findings in adults are consistent with those reported in other settings. There is a large body of evidence from studies conducted in a range of settings that asthma-related hospital visits increase as levels of particulate matter and NO_2 increase.[7 25–29]

Albalawi *et al* reported that ambient levels of $PM_{2.5}$, PM_{10} and NO_2 were associated with asthma-related visits to the ED independently of one another in Jubail Industrial City in Saudi Arabia.[30] In Albalawi's study, data on all age groups were combined, in contrast to the present study in which young children and adults were considered separately, so a comparison with our findings in young children is not possible. However, these findings are broadly consistent with our findings in adults.

A systematic review and meta-analysis published in 2015 found a significant positive association between PM_{10}, $PM_{2.5}$ and NO_2 with asthma-related emergency visits or hospitalisations for all ages.[31] In contrast, a 2017 systematic review and meta-analysis concluded that $PM_{2.5}$ but not PM_{10} was associated with asthma exacerbations in both children and adults.[12] This conflicts with our finding that NO_2, but not $PM_{2.5}$ nor PM_{10}, was positively associated with asthma admissions in young children. A possible explanation for this is that we considered only asthma-related hospital admissions, while studies included in these systematic reviews included asthma-related emergency visits and asthma exacerbations.

Also in contrast to our findings, a study of ambient air pollutants and asthma-related hospitalisations in Hong Kong, including almost 70 000 admissions over a 5-year period, found that the relative risk of admission as $PM_{2.5}$ and PM_{10} increased was slightly higher (1.024 compared with 1.018 for $PM_{2.5}$ and 1.023 compared with 1.014 for PM_{10}) in children (aged 0–14 years) than in adults aged 15–65 years.[32] Other studies in children have reported similar findings of a positive association between ambient PM_{10}[33–36] and $PM_{2.5}$[35 37] and asthma admissions. In our study, we included only children aged under 5 years, which raises the possibility that, in this group of very young children, the relationship between particulate matter and asthma exacerbation does not exist. Silverman found that age was important in terms of risk of asthma-related hospital admissions associated with AQ in children, and that children aged 6–18 years have the highest risk.[38] This might help to explain the lack of or inverse association we found in children as we focused only on children aged less than 5 years in the present study, due to the high and increasing levels of asthma and related hospital admissions in this group. We cannot, however, discount the possibility that we did not observe a relationship between $PM_{2.5}$ and asthma admission in children aged less than 5 years because statistical power was limited due to fewer hospitalisations in this group nor that unmeasured confounders masked this relationship.

The recent introduction of a health-based AQ index to communicate information on levels of pollution to the population[16] might also account for the lack of association between fine particulate matter and paediatric asthma admissions. It is possible that parents are acting on the information provided on pollution levels within Mexico City and taking measures to limit their young children's exposure to pollution, for example, by keeping them indoors during periods when pollution is high.

Table 5 Relative risks (RR) for asthma admissions for a 10 (PM_{10}) or 5 unit ($PM_{2.5}$ and NO_2) and IQR, adjusted for day of the week, national holiday, temperature, humidity, season and wind speed, 2017–2019: mutually adjusted* results (adults, >18 years)

	RR	95% CI	P value
PM_{10} (10 µg/m^3 increase)	1.03	1.01 to 1.04	0.003
$PM_{2.5}$ (5 µg/m^3 increase)	1.01	1.00 to 1.03	0.016
NO_2(5 µg/m^3 increase)	1.01	1.01 to 1.02	0.001
PM_{10} (IQR; 25.1 µg/m^3)	1.06	02 to 1.11	0.003
$PM_{2.5}$ IQR; 11.5 µg/m^3)	1.03	1.01 to 1.06	0.015
NO_2 (IQR; 16.5 µg/m^3)	1.05	1.02 to 1.08	<0.001

*Each pollutant mutually adjusted for the other two pollutants; collinearity of variables was not found (variance inflation factors (VIF)<4 observed in linear regression analysis).

Table 6A Relative risks (RR) for asthma admissions for a 10 (PM_{10}) or 5 unit (NO_2) and IQR, adjusted for day of the week, national holiday, temperature, humidity, season and wind speed, 2017–2019: two-pollutant model* results (children; 0–4 years)

	RR	95% CI	P value
PM_{10} (10 µg/m^3 increase)	0.97	0.95 to 0.99	0.028
NO_2 (5 µg/m^3 increase)	0.98	0.96 to 0.99	0.011
PM_{10} (IQR; 25.1 µg/m^3)	0.93	0.87 to 0.99	0.029
NO_2 (IQR; 16.5 µg/m^3)	0.93	0.88 to 0.99	0.012

*PM_{10} and NO_2 mutually adjusted for; collinearity of variables was not found (variance inflation factors (VIF)>4 observed in linear regression analysis when PM_{10} and $PM_{2.5}$ included in the same model).

Table 6B Relative risks (RR) for asthma admissions for a 5 unit increase in PM_{10} and NO_2 and IQR, adjusted for day of the week, national holiday, temperature, humidity, season and wind speed, 2017–2019: two-pollutant model* results (children)

	RR	95% CI	P value
$PM_{2.5}$ (5 µg/m^3 increase)	0.99	0.97 to 1.01	0.458
NO_2 (5 µg/m^3 increase)	0.97	0.96 to 0.99	0.002
$PM_{2.50}$ (IQR; 11.5 µg/m^3)	0.98	0.94 to 1.03	0.461
NO_2 (IQR; 16.5 µg/m^3)	0.92	0.87 to 0.97	0.003

*$PM_{2.5}$ and NO_2 mutually adjusted for; collinearity of variables was not found (variance inflation factors (VIF)>4 observed in linear regression analysis when PM_{10} and $PM_{2.5}$ included in the same model).

It could be speculated that adults are less able to avoid exposure due to the need to be outdoors for work, travel to work and other commitments. This is an important area for future research to address.

Previous studies of the association between ambient NO_2 and paediatric asthma-related hospital admissions have generally provided evidence that admissions increase with increasing levels of NO_2, although the association has not always been as consistent as in our analysis. Samoli *et al*, for example, reported a non-statistically significant association between increasing levels of NO_2 and asthma admission in 0–14 year olds in Athens, Greece,[33] although others have reported that a significant association does exist.[34 37]

Mexico City was once the most polluted mega-city worldwide, although improvements in AQ have been achieved in recent years, pollutant levels still frequently exceed Mexican AQ standards.[18] This is not unexpected, given that the impact of measures to reduce air pollutants is typically seen on long-term pollutant concentrations, rather than on peaks. We found that asthma-related hospital admissions were higher in the cool, dry season in Mexico (November to February), which corresponds to the time of year when AQ is at its worst, reinforcing the need for continued action to address this.

Strengths of this study

The major strengths of this study are that we included data on AREHA to public hospitals in Mexico City during the period of interest and obtained precise data on AQ from monitoring equipment across the city that is consistently subject to strict assurance and control procedures. The AREHA data were obtained from the IMSS, which is the largest Health Institution in the country, and covers over 40% of the population of Mexico City. The strength of this is that individuals covered by IMSS are guaranteed access to treatment. The costs of medical care are paid directly by employers, meaning individuals are not denied care if they cannot pay. It must be noted, however, that a substantial proportion of the population receive their care outside this system and would not therefore be included in our analyses. It is possible that these individuals differ systematically from those who do receive care within the IMSS system, raising the possibility that our findings are not generalisable to the wider population of Mexico City.

Limitations of this study

Despite the high-quality data available on both pollutants and hospital admissions, our study is subject to some limitations. As with other similar studies, the ecological nature of the study means that information on individuals' exposure to pollutants and subsequent asthma exacerbation is not available. In addition, data on characteristics of individuals who were admitted to hospitals, such as occupation and other potential confounders, were not available for inclusion in our analyses. We did not include children aged 5–17 years in our study and focused on those aged less than 5 years and those aged greater than 18 years. The reasons for this are that children under 5 years of age are the population most susceptible to their lung capacity being compromised as a result of exposure to environmental pollution[39] and it has been demonstrated that those over 18 years of age require the greatest steroid use and experience the highest number of hospitalisations for asthma exacerbations, due, in part, to comorbidities, such as obesity and smoking.[40] In addition, in this study we did not differentiate between first and subsequent admissions. This is important as it is known that allergic factors are strongly associated with initial asthma admissions in children, but in adults the effect of environmental factors is more important at initial admission.[41]

The possibility exists that, although we included a large proportion of the adult population in our study, we had a smaller sample size for children under 5 years of age. This raises the possibility that the lower number of cases meant we lacked statistical power to detect associations in this age group.

Finally, our approach to analysis, in which pollutants were mutually adjusted for each other, while consistent with previous literature in this area and facilitating comparison, may not enable the effects of individual pollutants to be disentangled sufficiently due to their being correlated with one another.

CONCLUSIONS

This study of the relationship between air pollution and asthma-related hospital admissions in Mexico City indicates that ambient levels of NO_2 are associated with an increase in asthma-related admissions in both adults and young children and that $PM_{2.5}$ and PM_{10} levels are associated with asthma-related admissions in adults. These findings demonstrate the importance of continuing to implement measures to improve AQ and ways to minimise the impact of air pollution on the population's health in Mexico City. Since being identified by the United Nations as the world's most polluted city in 1992, improvements in AQ have been observed following the implementation of a wide range of measures including the introduction of low-emission transport zones, promotion of cycling and introduction of congestion charges. Today, Mexico is ranked as the 917th most polluted city. It is essential that work to improve AQ continues to reduce the global health burden associated with air pollution. It is imperative that the impact of interventions to improve AQ on pollutant levels is monitored and that research is undertaken to study if this translates into lower rates of asthma related hospital admissions. We suggest qualitative work to explore the barriers and motivators to individuals changing their behaviour in response to warnings of high pollutant levels being issued would be valuable.

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