

Emergency room visits of asthmatic children, relation to air pollution, weather, and airborne allergens

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Background: The worldwide increase in the incidence, prevalence, and severity of asthma may suggest that environmental factors play a role in these epidemiologic changes.

Objective: To examine the correlations between air pollutants, weather conditions, airborne allergens, and the incidence of emergency room (ER) visits of children with acute asthma attacks.

Design: One-year prospective study. Data of daily concentration of air pollutants, weather conditions, and selective airborne allergens were collected and compared with the number of ER visits of asthmatic children.

Subjects: 1076 asthmatic children (aged 1 to 18 years) who presented at the Pediatric ER between January 1 and December 31, 1993.

Results: Correlations between fluctuations in ER visits of asthmatic children and various environmental parameters were more relevant for weekly than for daily values. Emergency room visits correlated positively with concentrations of NO_x, SO₂ and with high barometric pressure; and negatively with O₃ concentration and minimal and maximal temperature. There were no significant correlations with concentrations of particulates, humidity, or airborne pollen and spores. An exceptionally high incidence of ER visits of asthmatic children was observed during September. This peak coincided with the beginning of the school year and the Jewish holidays. The correlations between ER visits and the environmental factors increased significantly when the September peak was excluded, revealing that 61% of the variance in ER visits was explained by NO_x, SO₂, and O₃ concentrations, 46% by weather parameters, 66% by NO_x, SO₂ and barometric pressure, and 69% by the combination of air pollutants and weather parameters.

Conclusion: The major factors found to be associated with ER visits of asthmatic children were high NO_x, high SO₂, and high barometric pressure. Negative correlation was found between ER visits of asthmatic children and ozone concentrations. The particularly high number of ER visits at the beginning of the school year and the Jewish holidays was probably associated with an increase in the number of viral infections and/or emotional stress.

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INTRODUCTION

There is evidence of a worldwide increase in the incidence and prevalence

of asthma among children and adolescents.^{1–5} Lung function studies suggest that the bronchial airways of children

have become more hyperresponsive during the last decades.³ There is also an increase in asthma-related morbidity, hospitalization, and deaths.^{6,7}

A seasonal variability in the incidence of asthma attacks, especially in children, is recognized by many physicians.^{8–10} Exacerbation of asthma may be associated with respiratory infections, stress, exposure to allergens such as plant pollen and fungal spores, air pollution, and extreme weather conditions.^{14–18}

The present study investigates the possible correlations of some of these factors with the morbidity of asthma among Israeli children.

SUBJECTS AND METHODS

Patients

The study population included all 1,076 children (out of 22,331) who presented at the Pediatric Emergency Room (ER) of the Schneider Children's Medical Center of Israel from January 1 to December 31, 1993 with wheezing and were diagnosed as having an acute asthma attack. They included 664 boys (62%) and 412 girls (38%) ranging in age from 1 to 18 years. Children under the age of 1 year were excluded from the study because of the possible confusion of asthma with viral infections such as bronchiolitis. In all, 197 of the asthmatic children (18.3%) were hospitalized.

The availability of public medical services in Israel differs through the week: on Sundays and Tuesdays most public clinics are open in the morning and afternoon; on other days, mainly in the morning; and on Fridays and Saturdays, only local emergency services are available. The ER data were com-

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piled into clusters of different time periods ranging from 1 to 7 days. We assume that the best comparable time period will be 7 days and this was further justified by the results of the statistical analysis.

Environmental Factors

The environmental factors studied were air pollutants, weather conditions, and airborne pollen and fungal spores in the areas of residence of the patients.

Air Pollutants

These included nitrogen oxides (NO_x), sulfur dioxide (SO₂), ozone (O₃), and particulates.

Figures for air pollution were obtained from the Institute for Research of Environmental Quality and the Electric Company of Israel which operates a web of monitoring stations in the coastal plain. The parameters were measured every half-hour, and the data were calculated as the daily average. Measurements of NO_x were performed by chemiluminescence with an NO_x Analyzer (Model 8840, ML Monitoring Labs). Sulfur dioxide was measured with a pulse fluorescence SO₂ analyzer (Model 43A, Thermo Electron Instruments). Ozone was monitored with a UV photometric ozone analyzer (Model 8810, Motor Labs) and particulates were measured with an ambient particle monitor (Team Series 14001).

Weather Parameters

Included maximal and minimal ambient temperatures, relative humidity, and barometric pressure. Data were obtained from the Meteorological Services of Israel.

Airborne Allergens

Special attention was addressed to the pollen of *Artemisia*, *Cupressus*, *Olea*, *Parietaria*, and members of the *Poaceae* and *Chenopodiaceae*-*Amaranthaceae* families, as well as to the spores of *Alternaria*, *Cladosporium* and *Stemphylium*, which are believed to be dominantly involved in allergic disorders in Israel.

Monitoring was performed with Rotorod samplers (Model 1987, Sampling Technologies, Inc, Los Altos Hills, CA, USA); whenever needed, several samplers were used concomitantly. The pollen and spores were identified and counted by light microscopy, and their concentration was calculated according to the manufacturer's instructions.

Statistical Analysis

Data analysis was performed with the Statistix 3.5 software package.¹⁹ Pearson's analysis was used to establish the correlations (*r*) between the number of ER visits and each of the environmental parameters. Multiple correlation coefficients (*R*) (multiple regression analysis) were used to explain how much of the variance in the ER visits could be explained by a given set of

environmental parameters. Partial correlations were used to evaluate the contribution of each environmental parameter to the improvement in the estimation of variance in the number of patients.

The running mean gives a better estimate of the regression relationship at each time period,²⁰ and was used here for two purposes:

1. To identify the pattern of the relationships between the environmental effectors and the ER visits of asthmatic children without subjectively fixating on an artificial period of time.
2. To explore the possibility that the relationship between the effector and the results is not instantaneous, but is spread over an unknown period of time.

We defined the running mean of a variable for *n* days as follows: Let *x*₁, *x*₂, *x*₃ be the values of the variable "x" measured on the first day, second day, third day, and so on, then the running mean (*rx*) for *n* days of the variable "x" consists of:

$$rx_1 = \frac{x_1 + x_2 + \dots + x_n}{n};$$

$$rx_2 = \frac{x_2 + x_3 + \dots + x_{n+1}}{n};$$

$$rx_3 = \frac{x_3 + x_4 + \dots + x_{n+2}}{n}, \text{ etc.}$$

For example, for *n* = 7 (1 week), the running mean of a variable is the mean from Monday to Sunday, then from Tuesday to Monday, and so on. The dependent variable was the running mean of the number of ER visits. Various sets of independent variables were formed from the corresponding running means of each of the environmental parameters.

P values (for *F*-statistics) were calculated to determine the significance of the regression relationships.

RESULTS

Figure 1 shows the total number of children with acute asthma seen in the ER each week during 1993 and Figure

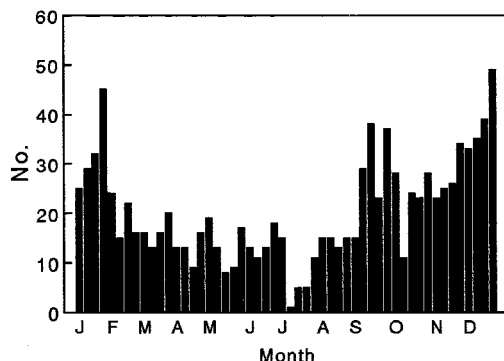


Figure 1. Total number of asthmatic children seen in the ER during 1993. Each column represents 1 week.

2 shows the percentage of children with acute asthma seen in the ER each week. In general, asthma morbidity was higher in the autumn and winter and lower during late spring and summer.

The running mean of the number of ER visits over n days was compared with the corresponding running mean of each of the environmental parameters (Table 1). The Pearson's correlations gradually increased from $n = 1$ day to $n = 7$ days, indicating that the fluctuations in the number of visits in relation to the environmental parameters was more relevant for weekly than for daily (1-day to 6-day) values.

Two major environmental parameters, NO_x and SO_2 , were highly correlated with each other for the daily ($r_1 = 0.95$) and for the weekly running means ($r_7 = 0.96$).

A positive correlation was found between ER visits and the mean ambient concentrations of NO_x (Fig 3), SO_2 (Fig 4), and the mean barometric pressure (Fig 5). A negative correlation was found with O_3 concentration (Fig 6) and mean minimal and maximal temperatures (Figs 7 and 8) (Table 1).

The number of ER visits was exceptionally high during September. When the variables for this month are omitted from the annual calculation, the correlation coefficients changed dramatically for all the variances: ER visits correlated even more strongly with NO_x concentrations ($r = 0.74$), SO_2 concentrations ($r = 0.64$), and high barometric pressure ($r = 0.65$); and the negative correlations with O_3 concentrations ($r = -0.52$), minimal temperatures ($r = -0.45$) and maximal temperatures also augmented ($r = -0.41$) (Table 1). This shows that additional factors played a role in the number of ER visits of asthmatic children during September.

The concentration of airborne particulates (50% with size less than 10 μm) fluctuated around a rather constant level throughout the year, with no outstanding peaks or troughs; it did not correlate with asthma morbidity (Fig 9). There was also no correlation between ER visits and mean relative hu-

midity which was high during most of the year (average weekly humidity was between 40% and 80%) (data not shown).

The concentration of total airborne pollen was maximal during the spring (Fig 10); airborne spore concentrations had several peaks (data not shown); neither factor, however, correlated with the asthma peaks. The concentrations of the specific pollen varied according to the flowering season of each plant species but none significantly correlated with ER visits (data not shown).

The deviation from the mean ER visits during the entire year is expressed by variance. Approximately 38% of the variance in the number of ER visits was explained by fluctuations in NO_x (Table 2); 28% by SO_2 , 21% by O_3 , and 28% by barometric pressure. Changes in the minimal and maximal temperatures explained only

10% and 8% of the variance, respectively. When the data for September were omitted from the annual calculations, NO_x alone explained 55% of the variance ($\text{SO}_2 = 41\%$ and $\text{O}_3 = 27\%$). The corresponding results for the weather parameters were barometric pressure, 42%; minimal temperature, 20%; and maximal temperature, 17%.

The dependence of the ER visits of asthmatic children on a combined set of environmental parameters is expressed by the multiple correlation coefficient (R). The value of R for $\text{NO}_x + \text{SO}_2 + \text{O}_3$ for 1 week (R^2_7) was 0.45, meaning that 45% of the variance of the ER visits can be explained by the regression relationships with the combination of NO_x , SO_2 , and O_3 (Table 2). For the set of weather parameters (barometric pressure, temperature, and humidity) the R was relatively low ($R^2_7 = 0.34$) whereas for $\text{NO}_x + \text{SO}_2 + \text{barometric pressure}$, R was 0.48. The

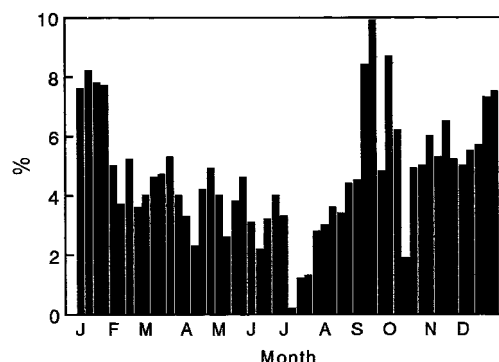


Figure 2. Percentage of asthmatic children of the total number of patients seen each week in the ER.

Table 1. Pearson Correlation Coefficient (r) Between Emergency Room Visits of Asthmatic Children and the Various Environmental Parameters

Factor	Daily Data (r_1)		Running Mean for 7 Days (r_7)	
	12 months	11 months*	12 months	11 months*
NO_x	0.30	0.37	0.62	0.74
SO_2	0.24	0.31	0.53	0.64
O_3	-0.21	-0.25	-0.46	-0.52
Particulates	0.04	0.06	0.08	0.12
Barometric pressure	0.32	0.39	0.53	0.65
Minimal temperature	-0.19	-0.27	-0.34	-0.45
Maximal temperature	-0.22	-0.22	-0.29	-0.41
Humidity	-0.02	-0.03	-0.02	-0.02

* Excluding September.

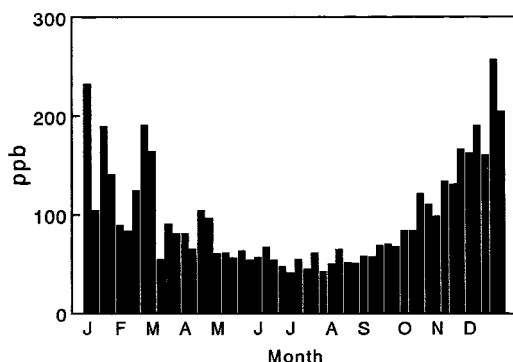


Figure 3. Weekly mean NO_x concentration in the air.

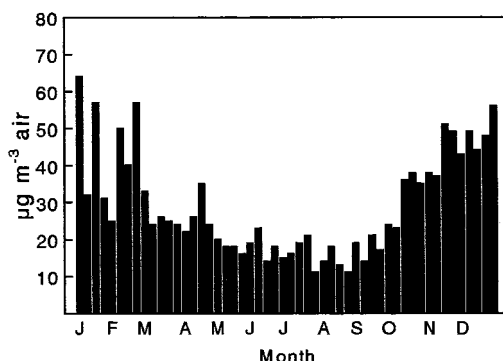


Figure 4. Weekly mean SO₂ concentration in the air.

combination of all the environmental parameters (air pollution and weather conditions) explained 54% of the weekly variance.

When these data were calculated without September, much higher correlations were obtained; 61% of the variance of the running mean of ER visits for 1 week ($R^2_7 = 0.61$) was explained by the regression analysis of NO_x + SO₂ + O₃, compared with 45% for the 12-month values. The set of weather parameters explained 46% of the variance, and NO_x + SO₂ + barometric pressure explained 66%. The set of all air pollution and weather parameters calculated for the 11-month period explained 69% of the weekly variance (Table 2).

Emergency room visits were negatively correlated with ambient O₃ concentrations. The percent of variance for the whole year explained by O₃ alone increased from 21% to 27% when September was excluded.

Statistical analysis (F-statistics) of the correlations between the mentioned individual environmental factors and ER visits, and multiple regression analysis of all the sets of environmental factors and ER visits of asthmatic children were highly significant ($P < .001$) (Table 2).

DISCUSSION

Air pollution has been recognized for centuries as a serious health hazard, especially for people with allergic diseases.²¹ A significant association between air pollution and respiratory symptoms, or the use of bronchodilators, has been reported repeatedly.^{11,17,22-25}

In the present study, we investigated the possible effects of specific environmental parameters on the incidence of acute asthma attacks (warranting a visit to the ER) in children. We found a positive correlation between ER visits of asthmatic children and high con-

centrations of ambient NO_x, SO₂, and high barometric pressure, and a negative correlation with O₃ concentrations and temperature. There were no correlations between ER visits of asthmatic children and airborne particulates, relative humidity, airborne pollen or spores. In general, the effect of air pollutants was stronger than that of weather.

When the values for September were deducted from the annual figures because of the special conditions during that month (beginning of school or kindergarten and Jewish holidays causing higher levels of psychologic stress, increased incidence of viral infections and reduced availability of public health services): 69% of the variance was explained by the combined environmental conditions.

Polluted air contains a mixture of various substances, the most important being NO_x, SO₂, O₃, and particulates. Exposure to NO_x may cause increased bronchial reactivity in asthmatic children.¹¹ In addition, NO_x seems to potentiate the effects of SO₂, O₃ and airborne allergens on bronchial airways.^{11,25} NO_x is also a major indoor pollutant, released by gas heaters and stoves; however, epidemiologic studies of the relationship between asthma morbidity and indoor NO_x concentration are inconsistent. In the present study we found high correlation between ER visits and outdoor NO_x concentration.

People with asthma are also very sensitive to high SO₂ concentrations. A study from Birmingham, UK showed that proximity to a major traffic artery, and thus to high levels of ambient SO₂, was associated with an increase in ER visits of asthmatic patients.²⁴ Exposure to SO₂ is known to cause prominent airway inflammation manifested by increased numbers of mast cells, alveolar macrophages, and lymphocytes in the bronchoalveolar lavage.²⁶ Sulfur dioxide inhalation can cause bronchoconstriction, even in healthy individuals. These effects may be potentiated by other physical stimuli, such as cold air.²⁷ The correlation between SO₂ and asthma morbidity is also emphasized by our study.

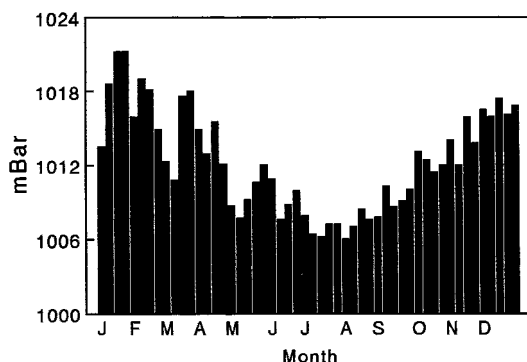


Figure 5. Weekly mean barometric pressure.

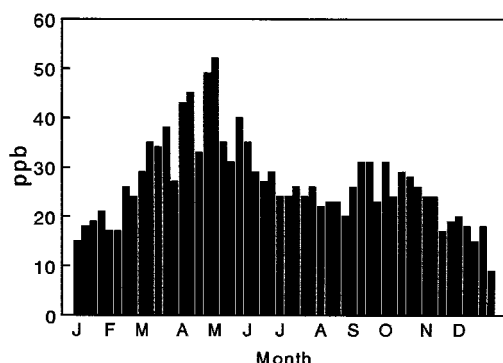


Figure 6. Weekly mean O₃ concentration in the air.

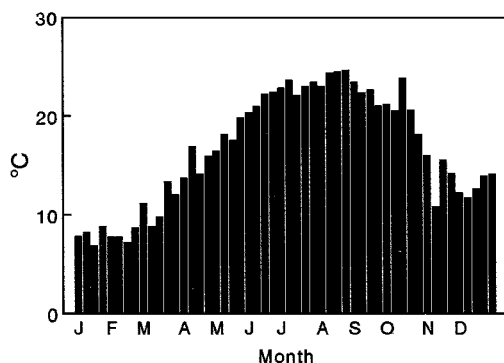


Figure 7. Mean weekly minimal temperature.

O₃ concentrations, on the other hand, correlated negatively with ER visits of asthmatic children in the present study. These findings disagree with several reports claiming that O₃ may have harmful influence on asthmatic subjects^{25,28,29} or may potentiate the effect of other air pollutants. The reasons for the discrepancy may be the relatively low O₃ concentrations in our study or the reverse relation between

O₃ concentration and the concentration of SO₂ and NO_x. A recent work from Heathrow (London) also demonstrated that certain concentrations of O₃ were associated with a low incidence of wheezing,³⁰ as in our study.

Particulates consist of varying mixtures of smoke and dust. The smaller ones (less than 10 μ m diameter or PM₁₀) may reach the lungs and threaten health.^{13,31} Nevertheless, we

could not establish any correlation between airborne particulates and ER visits. Since the concentration of particulates was rather constant throughout the year, we assume that they affected the "background" morbidity of asthma and not its variance.

Seasonal variations in the incidence of asthma attacks, especially among children, have been reported in England. One peak was noted in early summer and attributed to the high pollen count, and a second was noted in late summer and attributed to the airborne pollen of autumn flowers or fungal spores.⁹ A high rate of wheezing attacks during the high pollen seasons of the spring and fall has also been reported in Los Angeles,¹² New York,³¹ and Philadelphia.²³ In the present survey, as in some others,^{32,33} the levels of airborne pollen and molds did not correlate with the ER visits of asthmatic children.

Airborne pollen or spores may have influenced single patients but overall they were not a significant contributory factor. This finding is in accordance with our clinical experience that the majority of asthmatic children in Israel, unlike other countries, are allergic to indoor allergens such as dust mites, but not to pollen or spores.

Air pollution may precipitate asthma, either indirectly, by release of cytokines and inflammatory mediators from the respiratory epithelial cells, by potentiating the action of inhaled allergens, or directly, by acting on the immunologic system and increasing IgE production.^{10,34} The relative weight of individual environmental factors with regard to asthma may change when several factors are present together. In our study the combination of air pollution and certain weather conditions may have a cumulative effect on asthma.

Extreme weather conditions, such as thunderstorms, sudden rain, and a sudden fall in temperature^{15,16} have been related to epidemics of asthma. Some authors explain this finding by the release of large numbers of airborne pollen or mold spores under these conditions.^{35,36} Our study yielded a positive

correlation between ER visits and high barometric pressure (a similar phenomenon was observed in Philadelphia²³) and a negative correlation with temperature (as reported in a study from England³⁰). In our study there was no correlation between ER visits of asthmatic children and stormy days or days of eastern wind which brings hot air from the drier parts of the country. (This meteorologic phenomenon known as "Hamsin" causes general discomfort to the whole population, including asthmatics, but was not a cause of exceptional ER visits of asthmatics.)

An epidemiologic study of Israeli army recruits has revealed that asthma is significantly more prevalent in densely populated and highly industrialized areas than in rural regions.³⁷ These findings support the positive correlation found in our study between increased air pollution and asthma morbidity.

In Israel, schools and kindergartens open on the first of September, after 2 months of summer holiday. The number of ER visits of asthmatic children in September 1993 was the highest of the year, although the overall visits of children to the ER was higher during the late autumn and early winter months. This increase in asthma morbidity during September was observed also in 1994 and 1995 (data not shown). A similar peak of asthma morbidity in September, following the summer vacation, has been repeatedly observed in England,³² during an 11-year period. It was assumed that this pattern was mainly due to the rapid spread of viral respiratory tract infections. Although stress may also be an important precipitator of asthmatic attacks, the authors doubted that the effects of stress at the beginning of the school year last several weeks.³² In Israel, however, September 1993 was not only the beginning of the school year, but also the time of the Jewish High Holidays. Children therefore start school, have several days off for the first holiday, return to school, and have vacation again; this process is repeated several times during the month. Both viral infections and the prolonged stress of beginning school or kinder-

garten may play a role in the increased asthma morbidity in September. A third contributory factor may also be the reduced availability of medical services, other than ER, during the holidays.

The most serious limitation of epidemiologic studies of the effects of pollution on health is the absence of information about the personal exposure of the individual patient to outdoor or indoor pollutants and/or aller-

gens. Nevertheless, the data presented here support the hypothesis that high concentrations of certain air pollutants, in combination with weather parameters, are highly correlated with outbreaks of acute wheezing in children.

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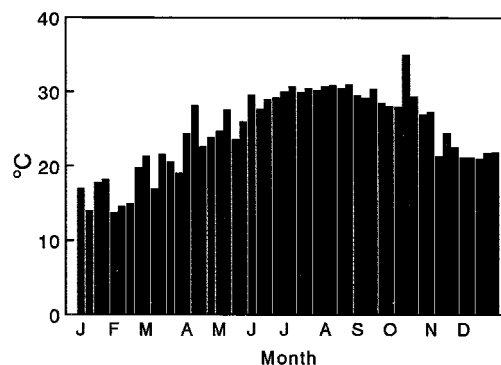


Figure 8. Mean weekly maximal temperature.

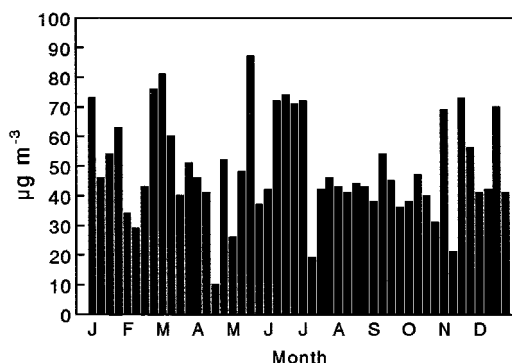


Figure 9. Weekly mean content of airborne particulates.

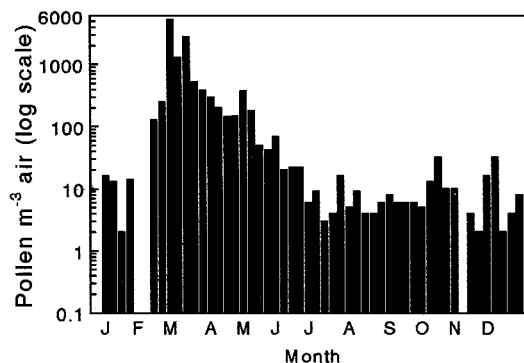


Figure 10. Weekly mean of total airborne pollen count.

Table 2. Effects of Individual and Combined Environmental Factors (multiple regression analysis) on Variance of 7-Day Running Mean of Emergency Room Visits of Asthmatic Patients

Factor	Percent of Variance Explained by the Factors for the Period of:	
	12 months	11 months*
NO _x	38	55
SO ₂	28	41
O ₃	21	27
NO _x + SO ₂ + O ₃	45	61
Barometric pressure	28	42
Minimal temperature	10	20
Maximal temperature	8	17
Barometric pressure + minimal temperature + maximal temperature + relative humidity	34	46
NO _x + SO ₂ + barometric pressure	48	66
NO _x + SO ₂ + O ₃ + particulates + barometric pressure + minimal temperature + maximal temperature + relative humidity	54	69

* Excluding September.

P values are less than .001 for all results of 12 months and 11 months.

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