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Air pollution levels, meterological conditions and asthma symptoms

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ABSTRACT: We wanted to assess relations between the daily occurrence of asthma symptoms and fluctuations of air pollution concentrations and meteorological conditions.

In a panel of 31 asthmatic patients residing in the town of Piteå in northern Sweden, severe symptoms of shortness of breath, wheeze, cough and phlegm were recorded in an asthma diary together with suspected causes. Sulphur dioxide, nitrogen dioxide, black smoke, relative humidity and temperature were used to evaluate the relationship to the environment.

By using multivariate analyses, we found that daily variations in the particulate pollution levels, indicated by black smoke levels below the criteria limits, had significant effects on the risk of developing severe symptoms of shortness of breath. This association was stronger among 10 subjects, who had at least five incident days with severe shortness of breath. Meterological conditions were not significant in the multivariate models. Cough and phlegm did not show significant relationships to any environmental condition that was evaluated. Only one-third of the subjects reported, at least once during the study, symptoms believed to be related to air pollutants, although we found significant correlations between the pollution levels and the frequency of pollution-related symptoms.

We conclude that an association has been established for black smoke as pollutant and shortness of breath as respiratory symptom, and that in certain asthmatics, effects were occuring at lower particulate levels than suggested previously.
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An earlier postal questionnaire, performed in Piteå in 1986, concerning annoyance and ill-health, showed that almost one-third of the group with asthma-like symptoms claimed that air pollution sometimes affected their respiratory health. Piteå town, with 28,000 inhabitants, is situated on the west coast of the Gulf of Bothnia in northern Sweden (fig. 1), where winters are usually cold. The prevalent temperatures during the coldest months are -9°C in January and -8.5°C in February. Air pollution levels correlate to temperature and, at the monitoring station in the centre of town, the levels have fallen below Swedish air quality standards and suggested threshold levels for acute effects during a long series of winters. The existence of a pollution effect on asthmatic subjects has, therefore, been considered unlikely. In addition to traffic and the heating systems in Piteå, two paper mills outside the town may affect air pollution levels when certain wind and other conditions prevail. The paper mills also generate a large amount of traffic, with heavy diesel vehicles. The use of wood for heating purposes is common.

The relationship between asthma events, such as acute symptoms, medication requirements and respiratory admissions, on the one hand, and levels of air pollutants, on the other, have been studied in metropolitan areas, with somewhat conflicting results. Differences in study design, response variables, exposure assessment, study populations and environmental conditions may explain the discrepancies. Many studies have been performed in large cities, mainly in the USA. Many of these have tested correlations between hospital visits for acute respiratory problems and urban air pollution levels. An association between air pollutants and asthma admissions has been found in some [1–7], whilst others have allotted no role to urban air pollutants [8–13].

Since the hospital attendance for asthma necessarily reflects only severe asthma events, and often takes place one or two days after the patients become worse, panel studies have become important in asthma epidemiology. In such studies, positive associations have been reported between the risk of having an asthmatic attack or the frequency of symptoms among asthmatic subjects and oxidants [14], sulphur dioxide [15, 16], sulphates [17], fine particulate pollution [18], fine nitrates [19], and several pollutants [20, 21]. The panelists' asthma status may vary considerably between these studies, and patients with other respiratory diseases have also been included [15].

The present study was designed to investigate whether daily environmental fluctuations, as evidenced by levels below the suggested threshold values for acute symptoms, might in this environment show positive correlations with airway symptoms among asthmatic subjects.

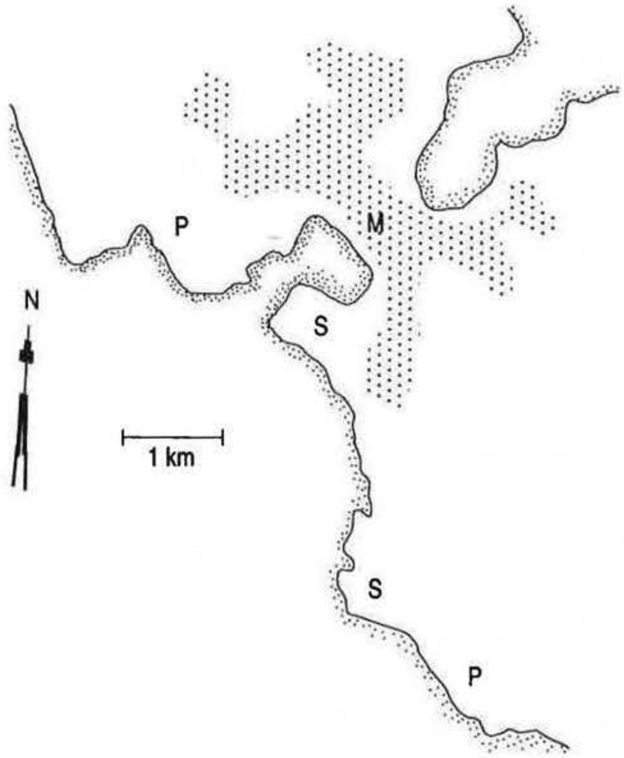

Fig. 1. – Map of the Swedish town Piteå. ⬚ : study area; M: monitoring station; P: pulp mill; S: saw mill.

Patients and material

Study subjects

Since the monitoring of air pollution, in this study, was restricted to the centre of town, only residents in central Piteå were eligible to be study subjects. People living or working further than 3 km from the city's central air pollution monitoring station could not, with respect to exposure conditions, be included in the study.

Together with the local Association against Asthma and Allergy, we advertised in the newspapers for suitable subjects to take part in the study. A total of 60 persons volunteered. Of these, 42 fulfilled our area restrictions. A medical examination (by a lung physician) identified 31 subjects with bronchial asthma. All of the subjects had symptoms of asthma with variable bronchial obstruction. The diagnosis was confirmed by a positive methacholine provocation test (Provocative concentration producing a 20% fall in forced expiratory volume in one second (PC_{20}) <4 $mg \cdot ml^{-1}$) in 13 subjects with normal lung function (forced expiratory volume in one second (FEV_1 ≥80% of predicted value), by a reversible obstruction (FEV_1 increase of >20%) after the administration of bronchodilators in 9 subjects with an obstructive spirometry (FEV_1 <80% of predicted value), and by medical records in the remaining 9 subjects. There were 13 men and 18 women, aged 9–71 yrs. Four subjects were ≤15 yrs of age, whilst six were ≥65 yrs old. Twenty five subjects were in employment or in school. Only one subject was a current smoker, and five others had stopped smoking several years before the examination. Of the 31 subjects with asthma, 19 had developed asthma as adults. Inhalation steroids in combination with bronchodilators were used by 15 subjects, bronchodilator spray alone by 14, and one used no anti-asthmatic medication. Another subject was on general steroids, together with bronchodilators. Initial spirometry showed obstruction in 10 subjects.

Air pollution and weather data

The study period, March and April, was chosen to include variations in the weather and the air pollution levels, but without pollen in the air. Air pollution readings and meteorological conditions were taken from the town centre. Twenty four hour averages (daily means 00–24 hr) were obtained for sulphur dioxide (volumetric), nitrogen dioxide (volumetric), and black smoke (British Smoke). Measurement methods for the pollutants and station location met the recommendations of the Swedish National Environmental Protection Board, and were implemented by the accredited laboratory of the Swedish Environmental Research Institute (IVL). The air pollution monitoring station was situated in a central street for pedestrians only, and the sampling height was about 5 m above the ground.

Temperature and relative humidity were read three times a day. The lowest temperature, usually at 7 a.m., and the median value of the relative humidity were used as daily observation values.

Symptoms diary

Each subject was instructed in the use of the diary form. An individual diary had space for 14 consecutive days, and the subjects recorded the presence or absence of "severe symptoms", including shortness of breath, wheezing, cough and phlegm. Severe symptoms were defined as more severe than the subject's normal asthmatic symptoms. When the symptoms were severe, the respondent was instructed to fill in suspected causes, if any, choosing between common cold/influenza, weather conditions, allergy, exercise, air pollutants and other causes.

The subjects also recorded the time spent out of the study area, the medication taken, and visits to a doctor in connection with asthma attacks. In order to ensure valid answers and include a more objective measure of airway obstruction, subjects were also instructed to use a mini-Wright peak flow meter, if possible at the same time every morning and night, before medication. On each occasion three measurements of peak expiratory flow (PEF) had to be made and reported in the diary. Several panelists commented on their peak flow data during the study period. When the subjects developed very severe symptoms, they tended not to use their flow meters, or they paid more attention, for obvious reasons, to their medication. This made PEF values selective and biased in an uncontrolled way. Therefore, this report focuses on an analysis of the studied symptoms.

Analysis of the diaries

Criteria for inclusion in the analysis meant that each subject had to spend at least six hours a day, between 7 a.m. and 6 p.m., in the study area of central Piteå. The panel event rates, by day, are therefore based on a varying number of panelists. Panel rates could thus be biased if, for example, the healthiest panelists tended to travel outside the study area during warm days, or if panelists with the severest asthma tended to be hospitalized at the regional lung clinic in Boden (90 km from Piteå) during cold periods.

Linear regression of the daily panel attack rate against levels of air pollution has been the commonest approach in this kind of panel study, but it does not tackle the missing response problem [21]. A high correlation between attack status in successive observation days has also been reported [19, 21]. We have used two methods of analysis. Firstly, a comparison of the air pollution and the weather conditions for high-, intermediate- and low-risk days, according to the prevalence-based, daily, observed/expected (O/E) ratio. With this approach, the initial step was to calculate, among the included panelists, the daily ratios between the observed and the expected number of panelists with each symptom. This gave us four symptom-specific O/E ratios for each day of the study. The expected value is based entirely on the subjects included on the day in question, and is calculated as the sum of their individual symptom frequencies during the study period. Since no weekday pattern was identified in this population, the individual probability for each kind of symptom was set at the same value on all days. High-risk days were defined as those with the 10 highest O/E ratios, and low-risk days with the 10 lowest O/E ratios. In case of equal ratios for days ranked numbers 10 and 11 from the top or bottom, 11 days were clustered. Two tailed t-tests were used to evaluate the differences between the means during the high-risk days and the low-risk days.

Secondly, a multivariate analysis using only incident episodes that included severe symptoms of shortness of breath was performed by means of logistic regression (SPSS/PC), to estimate the effect of each variable. Incident cases were used, in order to exclude the effects of autocorrelated responses on successive days. This means that only panelists who were not positive (severe symptoms of shortness of breath) on the day before were at risk on a given day. The analysis included subject-specific indicator variables, and estimated regression coefficients, with 90% confidence intervals for the five air pollution and weather variables. This random intercept model with common slopes was used instead of a random effect model, since the number of observations per subject and also the incidence were low [22].

Diary information concerning 1,527 person-days that satisfied the inclusion criteria was obtained, which corresponds to 81% of the potential number of person-days. Complete environmental data were recorded for 55 out of 61 days.

Results

The study period was windy and warmer than normal in this region, and, therefore, air pollution levels were even lower than expected on the basis of previous measurements. Table 1 shows the air pollution levels and weather readings during the study period. Pollutants from the paper mills, according to wind direction analysis, never directly affected the study area, as was also indicated by the sulphur dioxide levels. Traffic and heating were, therefore, the dominating air pollution sources during the study period. Correlations between pollutants and weather variables existed, as shown by the correlation matrix in table 2. However, nitrogen dioxide did not significantly correlate to sulphur dioxide, or relative humidity.

Figure 2 illustrates how the O/E ratio for severe shortness of breath, based on the observed and expected numbers of subjects with shortness of breath each day, varied during the study period. Exclusions from the analysis, due to time spent outside the study area, were more frequent around the Easter holidays and at the end of the study period.

Comparison with weather readings

Table 3 shows the comparison of air pollution levels and weather readings on days with high, intermediate and low risks of severe symptoms. The mean values for all air pollutants were highest for the high-risk days of severe symptoms with shortness of breath and (except for sulphur dioxide) with wheeze, and lowest during the corresponding low-risk days. The differences between the means were all significant ($p<0.05$) for shortness of breath, and all but sulphur dioxide levels for wheeze. There were no significant differences between the air pollution levels during the days characterized by a high risk and a low risk of cough or phlegm. The highest mean-value ratio for the high-risk

Table 1. – Pollution and weather variables during the study period

Variable	Minimum	Mean	Maximum	Upper quartile	Observation days
Sulphur dioxide 24 h $\mu g \cdot m^{-3}$	1.3	5.7	12.9	9.2	60
Nitrogen dioxide 24 h $\mu g \cdot m^{-3}$	7.4	20.0	55.8	22.0	59
Black smoke 24 h $\mu g \cdot m^{-3}$	1.0	7.1	21.4	10.3	55
Temperature °C	-22.4	-4.5	+6.2	-0.4	61
Relative humidity %	42	73	96	85	61

Table 2. – Pearson correlation coefficients of pollution and weather variables†

	Sulphur dioxide	Nitrogen dioxide	Black smoke	Temperature	Relative humidity
Sulphur dioxide	1.0	0.24NS	0.70**	-0.64**	0.68**
Nitrogen dioxide		1.0	0.58**	-0.46**	0.13NS
Black smoke			1.0	-0.63**	0.65**
Temperature				1.0	-0.39**
Relative humidity					1.0

†: based on 55 days with complete observations. *: $p<0.005$; **: $p<0.01$; NS: nonsignificant.

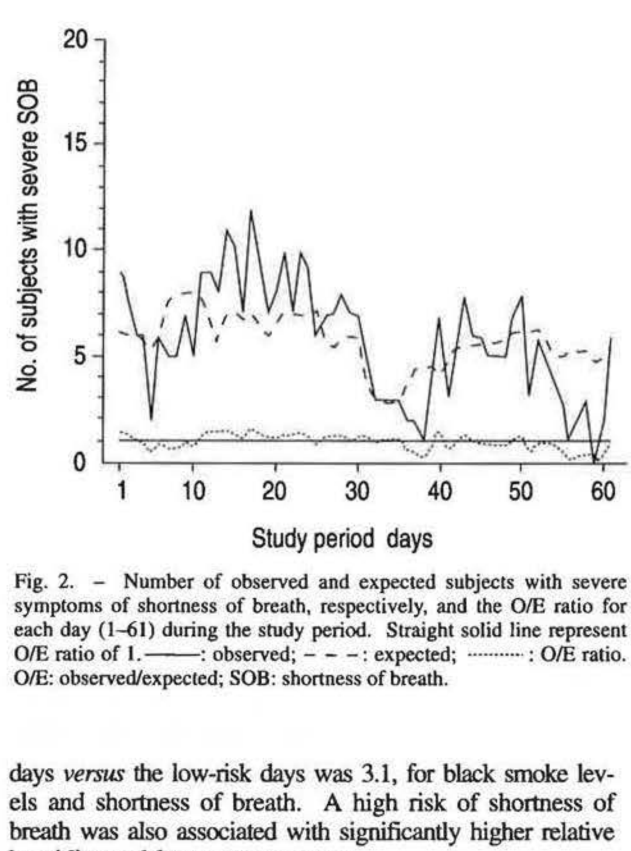

Fig. 2. – Number of observed and expected subjects with severe symptoms of shortness of breath, respectively, and the O/E ratio for each day (1–61) during the study period. Straight solid line represent O/E ratio of 1. ——: observed; – – –: expected; ·········: O/E ratio. O/E: observed/expected; SOB: shortness of breath.

days *versus* the low-risk days was 3.1, for black smoke levels and shortness of breath. A high risk of shortness of breath was also associated with significantly higher relative humidity and lower temperature.

Relationship between pollution and shortness of breath

Since shortness of breath was more pollution-related than were the other symptoms and was probably the most rapid response to air pollution exposure, we performed an additional multivariate analysis with shortness of breath as a dependent variable. Table 4 shows beta-coefficients from the logistic regression analyses, based on all 28 subjects who had had at least one day with severe shortness of breath, and the 10 subjects with five or more incident episodes, respectively. The analyses are based on 848 and 322 person-days at risk, respectively. When a simultaneous adjustment had been made for all five variables, only black smoke remained significant. The association is most obvious in the more variable group, with at least five incident episodes of severe shortness of breath during the study period. If only black smoke and temperature are included in the 28 subject model, black smoke is significant ($p=0.003$) and temperature is not ($p=0.27$). When only the temperature is included, a negative relationship becomes evident ($\beta=-0.035$, $p=0.05$). If only black smoke is included, the positive relation becomes clear ($\beta=0.089$, $p=0.0001$). The same pattern, in a more pronounced manner, is found in the variable group, which includes subjects with at least five incident episodes. However, this variable (high incidence) group is heterogeneous and shows no clear differences from the rest of the subjects in terms of age distribution, medication, *etc.* The exclusion of subjects to make the group more homogeneous does not affect the results. If the subject who had no asthma medication and the subject who was on general steroids are excluded, or if one person over 65 yrs of age and one below 15 yrs of age are excluded from the group, black smoke again becomes the only significant variable ($p=0.009$ and 0.015, respectively).

An indicator coding with the lowest third as the reference category showed that the middle third of black smoke values was associated with odds ratios of 1.5 (90% confidence interval (90% CI)=0.7–2.9) and 2.2 (90% CI=0.9–5.6) and the upper third with odds ratios of 1.8 (90% CI=0.8–4.0) and 3.3 (90% CI=1.1–10.0) for the total and the more variable group, respectively.

Reported causes of symptoms

The daily frequencies of weather, air pollutants and exercise as reported causes of daily (prevalent) severe symptoms all correlated significantly to air pollution and weather variables (table 5). This was not the case for allergy and common cold/influenza as reported causes. The most commonly reported cause of symptoms was common cold/influenza. At some time during the study, a total of 11 subjects reported air pollution as a suspected cause of severe symptoms. In the group with shortness of breath, 10 out of 28 mentioned this cause at least on one day, and in the variable group, 5 out of 10 gave this answer.

Table 3. – Pollution levels and weather readings (means) during days with high, intermediate and low risk of severe symptoms according to O/E ratios, mean ratios (high risk/low risk) and t-values

Risk of severe symptoms	Sulphur dioxide $\mu g \cdot m^{-3}$	Nitrogen dioxide $\mu g \cdot m^{-3}$	Black smoke $\mu g \cdot m^{-3}$	Temp. °C	Relative humidity %
Shortness of breath					
High	8.9	25.7	12.2	-7.8	81.6
Intermediate	5.5	19.2	6.8	-4.6	74.9
Low	3.3	17.5	3.9	+0.4	57.1
Ratio high/low	2.7	1.5	3.1	-	1.4
t-values	8.28***	3.43***	9.36***	3.47***	6.12***
Wheeze[b]					
High	5.7	24.3	7.8	-5.0	75.9
Intermediate	6.1	19.2	8.0	-4.8	74.8
Low	4.2	19.1	4.6	-2.5	64.1
Ratio high/low	1.4	1.3	1.7	-	1.2
t-value	1.99NS	2.12*	3.99***	0.95NS	3.96***
Cough[c]					
High	6.9	22.5	7.8	-6.7	69.0
Intermediate	5.8	24.5	7.5	-4.4	74.6
Low	3.7	16.5	6.1	-2.8	70.9
Ratio high/low	1.7	1.4	1.3	-	1.0
t-value	2.05NS	1.53NS	0.29NS	1.61NS	0.27NS
Phlegm[d]					
High	5.2	18.1	6.5	-3.3	65.6
Intermediate	5.8	19.8	7.6	-4.6	75.9
Low	5.6	22.7	7.2	-7.4	70.6
Ratio high/low	0.9	0.8	0.9	-	0.9
t-value	0.20NS	1.40NS	0.26NS	1.56NS	0.74NS

O/E ratios:- a: high risk >1.40, low risk <0.75; b: high risk >1.30, low risk <0.70; c: high risk >1.19, low risk <0.71; d: high risk >1.20; low risk <0.75. p values (t-test) high *vs* low risk days:- *: p<0.05; **: p<0.01; ***: p<0.001. O/E: observed/expected.

Table 4. – Associations between the probability for severe shortness of breath and environmental variables, among panelists with any severe shortness of breath and panelists with five or more incident episodes with severe shortness of breath

Independent variables*	All with SOB (n=28)+		Variable group (n=10)$	
	β-coefficient†	90% CI	β-coefficient†	90% CI
Sulphur dioxide	0.0345	(-0.049, 0.118)	-0.0266	(-0.140, 0.087)
Nitrogen dioxide	-0.0112	(-0.037, 0.015)	-0.0235	(-0.059, 0.012)
Black smoke	0.0837	(0.007, 0.161)	0.1892	(0.075, 0.303)
Temperature	0.0242	(-0.016, 0.064)	0.0222	(-0.044, 0.088)
Relative humidity	0.0160	(-0.010, 0.042)	0.0099	(-0.016, 0.036)

*: models included individual constants; +: 848 person days included; $: 322 person days included. †: the β-coefficients are interpreted as the relative change in the natural logarithm of the odds of severe shortness of breath (incident episodes) due to a unit change in the independent variable; SOB: shortness of breath; 90% CI: 90 confidence interval.

Table 5. – Pearson correlation coefficients of daily pollution levels, weather and frequency of reported cause related severe symptoms

Reported cause	Sulphur dioxide	Nitrogen dioxide	Black smoke	Temperature	Relative humidity
Weather	0.60**	0.26*	0.48**	-0.35**	0.62**
Air pollutants	0.41**	0.54**	0.44**	-0.42**	0.33**
Cold/influenza	0.04NS	-0.17NS	-0.13NS	0.04NS	0.07NS
Exercise	0.52**	0.43**	0.46**	-0.28*	0.26*
Allergy	0.11NS	0.02NS	0.11NS	-0.03NS	0.01NS

*: p<0.05; **: p<0.01; NS: nonsignificant.

Discussion

The present study has revealed a positive association between severe shortness of breath and particulate air pollution, as indicated by daily mean values for black smoke, a finding which also remained after evaluating the temperature and relative humidity. However, since the study group is heterogeneous and initially self-selected, it is difficult to estimate its representativeness.

The effect variable most commonly used in the diary studies of subjects with asthma has been the self-reported asthma attack. Asthma symptoms vary from person to person and from time to time. In this study we used several methods to describe asthma-related illnesses, which included severe symptoms with shortness of breath, wheeze, cough and phlegm. We had two reasons for this. In the first place, earlier studies had not shown that any single response variable was more appropriate to our purpose than others. Secondly, if over-reporting existed in the early stages of the study [21], or when air pollution may have been suspected, all four symptoms would probably have been affected in the same way. Likewise, we believe that any other reporting-bias is an unlikely explanation of the association between shortness of breath and particulate air pollution, since other symptoms, *e.g.* cough, did not result in the same pattern.

A high dependence between the symptoms on successive observation days should have minimized, not created, associations. The logistic regression analysis, using only incident cases was intended to handle this situation accurately. However, we have also studied incident severe symptoms with shortness of breath (exacerbation to severe symptoms among panelists who had not had severe symptoms on the previous day), by the daily O/E ratio and have used the same method based on the individual's probabilities. The same conclusions were obtained with these O/E ratios in a linear regression, the coefficient of determination being $R^2 \approx 0.39$ ($p<0.001$) for the exacerbation O/E ratio, and the black smoke level being the only significant variable ($p=0.03$).

Delayed effects on asthmatic patients have been reported [15], where the sulphur dioxide levels on the preceding day were more strongly associated with the illnesses than were the levels on the day of the reported illness. In this study, when O/E ratios for severe symptoms and air pollutants on the previous day were evaluated by linear regression, the relationship became weaker. Logistic regression with incident severe symptoms of shortness of breath and lagged data showed no significant effects.

In a group of 10 subjects with the highest incidence of severe symptoms of shortness of breath, the relationship to black smoke was stronger. Apparently, the variability (incidence) in itself is a very important stratification approach.

In this study, about one third of the subjects reported air pollutants as a suspected cause of severe symptoms at least once. In the group of 10 subjects who had five or more incident episodes with severe shortness of breath, half of the subjects gave this answer at least once. Nevertheless, there are correlations between air pollution levels and the reported frequency of air pollution-related symptoms. Not surprisingly, it seems difficult to separate the effects of pollutants from the effects of weather and exercise.

One potential limitation of this study is that the exposure data are based on a city's central air pollution monitoring station rather than information about individual exposure. Another shortcoming is the shortness of the observation period and the number of incident episodes, which also made the random effect model inappropriate. However, regression coefficients obtained by different methods, when compared, have been satisfactorily consistent [21, 22].

Indoor exposure in wood-burning residences may be related to outdoor air pollution. However, only three panelists resided in homes with wood-burning stoves, and exclusion of these subjects does not change the results.

Peak flow values show somewhat higher non-response rates, which are believed to be biased. Peak flow, expressed as daily mean deviations in weighted least square regression models, showed no significant correlation to any of the five environmental variables.

In an important World Health Organization (WHO) publication on air quality [23], the starting-point was to define the lowest concentration of a pollutant at which adverse effects are observed. The lowest observed-effect levels for increased acute respiratory morbidity among adults was set at 250 $\mu g \cdot m^{-3}$ for SO_2, and 250 $\mu g \cdot m^{-3}$ for black smoke. The 24 h guideline was set at 125 $\mu g \cdot m^{-3}$ for black smoke and sulphur dioxide, respectively. According to this expert document, it is believed that the inhalation of an air pollutant in concentrations, and for exposure times, below a guideline value has no adverse health effects.

During the study period, a nearby (1 km NW) monitoring station for totally suspended particulates (TSP), recorded 12 h values about five times higher than the corresponding black smoke levels ($r=0.51$, $p<0.01$), with 34.9 $\mu g \cdot m^{-3}$ as the mean value and 100.8 $\mu g \cdot m^{-3}$ as the maximum 12 h value. This TSP monitoring station was sited in a school yard, but may be affected by one of the pulp mills and a highway.

Our study indicates that respiratory effects among asthmatic subjects may occur at lower particulate levels than have previously been suggested. Several other recent reports suggest acute respiratory effects [3, 7, 18], and also effects on admission rates for chronic obstructive pulmonary disease [24], at levels well below today's air quality guidelines for black smoke, or particulate matter with an aerodynamic diameter equal to or less than a nominal 10 µm (PM_{10}).

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