# Asthmatic symptoms and air pollution: a panel study on children living in the Italian Po Valley

Andrea Ranzi,[1] Anna Freni Sterrantino,[1,2] Francesco Forastiere,[3] Claudio Sartini,[1] Giovanna Casale,[4] Rino Cavallini,[5] Aldo De Togni,[6] Lorenza Gallo,[6] Paolo Lauriola[1]

[1]Reference Centre for Environment and Health, Regional Agency for Environmental Protection in Emilia Romagna, Modena; [2]Department of Statistics, University of Bologna, Bologna; [3]Epidemiology Department, Regional Health Service, Lazio Region, Rome; [4]Local Health Unit, Rovigo; [5]Local Health Unit, Adria; [6]Local Health Unit, Ferrara, Italy

## Abstract

The Po Valley (Northern Italy) has elevated levels of air-pollution due to various sources of pollution and adverse weather conditions. This study evaluates the short-term effects of exposure to particulate matter with a diameter of 10 microns or less ($PM_{10}$) on asthma symptoms in school-aged children. An initial cross-sectional survey was conducted in the area to estimate asthma prevalence in children. Out of a total of 250 asthmatic children identified by the study, 69 agreed to participate in a panel study. The $PM_{10}$ exposure assessment was based on a combination of geographic and environmental measurements leading to a focus on three different areas, each characterised by its own daily $PM_{10}$ level. Participants were monitored daily for respiratory symptoms for eight weeks (January-March 2006). We assessed the relationship between daily $PM_{10}$ exposure and occurrence of asthma symptoms with a generalised linear model based on a total of 3864 person-days of observation. Exposure to $PM_{10}$ per $m^3$ was found to be particularly associated with cough (OR=1.03, CI 95% 0.99; 1.08) and phlegm (OR=1.05, CI 95% 1.00; 1.10). In the most polluted area, exposure to $PM_{10}$ was also associated with wheezing (OR=1.18, CI 95% 1.02; 1.37).

Correspondence: Andrea Ranzi, Reference Centre for Environment and Health, Regional Agency for Environmental Protection in Emilia Romagna, via Begarelli 13, 41121 Modena, Italy.
Tel: +39.059.433625 - Fax: +39.059.4226462.
E-mail: aranzi@arpa.emr.it

Key words: Childhood asthma; GIS; $PM_{10}$ exposure; Asthma symptoms; Italy.

Contributions: AR and CS took part in the design of the study, the acquisition of data (*e.g.* traffic flows and other GIS information), statistical analysis and interpretation of data. AFS was involved in statistical analysis. AR and AFS drafted the manuscript. FF performed a critical revision of the manuscript and offered precious technical advice on how the study might be improved. GC, RC, LG, AD and PL conceived the study, and took part in its design. GC, RN, LG, AD were also active in the acquisition of panel data and helped to interpret the health data. PL was the research group's overall coordinator. All authors read and approved the final manuscript.

Funding: Province of Rovigo.

Ethical statement: the study has been reviewed and approved by the Ethical Committee of the Local Health Authority of Rovigo (AZ. ULSS n° 19).

Conflict of interest: the authors declare no potential conflict of interest.

Received for publication: 8 April 2015.
Revision received: 19 August 2015.
Accepted for publication: 24 August 2015.


*Geospatial Health 2015; 10:366*
*doi:10.4081/gh.2015.366*



## Introduction

Asthma is a common chronic condition in childhood and results in onerous costs for families and society (Bahadori *et al*., 2009). Several phenotypes and age-related disease manifestations are known (GINA, 2005; van Gent *et al*., 2007) and increases in bronchial responsiveness are due to different type of stimuli (Holt *et al*., 1999). Scientific evidence suggests an association between traffic air pollution, such as particulate matter and nitrogen dioxide, and aggravation of asthma. Air pollutants act individually or in combination with ozone and allergens in the atmosphere, provoking acute asthma attacks (Mortimer *et al*., 2008; Anderson *et al*., 2011).

Effects of particulate matter with a diameter of 10 microns or less ($PM_{10}$), generally due to traffic-related pollutants, are known to influence the occurrence of asthma aggravation, wheezing episodes, risk of incident asthma and symptoms (Shima *et al*., 2003; McConnell *et al*., 2006, 2010; Jerret *et al*., 2008). Less evidence is available on acute lung function changes. Air pollution is a general problem that must be taken seriously (Faruque *et al*., 2014; Lary *et al*., 2014). Many studies have attempted to characterise the particulate air pollution from industrial and traffic sources (Contini *et al*., 2014; López *et al*., 2011) by using source apportionment approaches that identify different sources in the receptor points of sampling (Herrera Murillo *et al*., 2013; Gugamsetty *et al*., 2012; Khodeir *et al*., 2012). Marchetti *et al*. (2014) evaluated children breathing symptoms in relation to industrial atmospheric pollution based on geographical proxy measures for exposure. Still, knowledge of sources for particulate effect is limited.

In this framework we designed a longitudinal study to investigate the association between $PM_{10}$ exposure and respiratory symptoms in school-age asthmatic children using daily health data from questionnaires on symptoms and indicators of exposure to air pollution arising from measures of air quality monitoring and geographic information on environmental pressure factors of the study area

## Materials and Methods

### Study population

The study was conducted in the provinces of Rovigo and Ferrara (Figure 1), located in the Po Valley (Northeast Italy), declared by the Italian Ministry of the Environment as one of the 15 Italian areas at *high risk for environmental crisis* (Martuzzi *et al*., 2002), because of extensive industrialisation, intense road traffic, specific orographic and climatic features. The European Commission Directives define districts with higher density population and human development and where policy makers predict significant worsening of air pollution with a risk of exceeding the air-quality alarm threshold. Italy have implemented these directives with DLgs. 351, 1999 and DM 2/4/2002 No. 60.

The study area includes a major power plant (Porto Tolle) whose fallout extends over a wide area. A previous survey was conducted on the resident school population in 2004 to estimate asthma prevalence and use of anti-asthma medications (Bechtold *et al*., 2013). In the screening phase, 12,523 questionnaires were administered to parents whose children were attending the first and second years of Italian primary school (6 and 7 years old) and the third year of middle school (13 years old). Eligibility criteria were the same as those used in the 1997 study on Italian Studies on Respiratory Disorders in Childhood and Environment (SIDRIA) (SIDRIA Collaborative Group, 1997) an extension of the International Study on Asthma and Allergies in Childhood (ISAAC). Children's parents filled the screening questionnaire that inquired about respiratory problems, asthma symptoms, asthma-related risk factors, if asthma had been diagnosed and the use of anti-asthma medications. The number of valid questionnaires received was 10,252 (82% response rate). From the screening phase results, we defined the eligible participants: children with an asthma diagnosis from a physician. Of the 250 eligible children aged 6-7 years, 69 parents agreed to participate in the panel study (Figure 2). We excluded middle school-age children for suspected habit of early smoking.

### Geo-code of residences

Each address reported in the questionnaire was geocoded (coordinate system: UTM32, datum ED50) through record-linkage by street name and street number to the Regional Database for the Emilia-Romagna and Veneto Regions. In case of failure in record-linkage (<5% of the entire dataset), addresses were geocoded using a global positioning system (GPS) and then converted to the coordinate system.

### Environmental and exposure data

Each participant's exposure to air pollutants was assessed on the basis of the residential address, using geographical information systems (GIS) variables as indicated below. The study area was divided into three distinct areas, defined as: A=urban, B=urban-industrial, and C=rural (Figure 1), to distinguish between different environmental risk factors. This also permitted visual inspection of various environmental pressure indicators (Table 1).

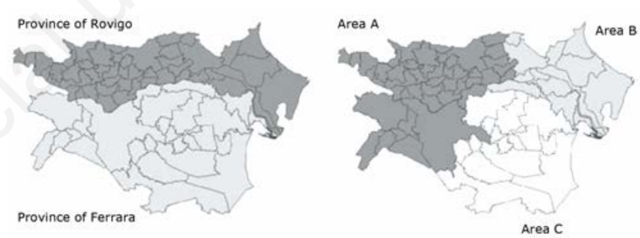


**Figure 1. The study area with administrative boundaries (left) and subdivided by main environmental-pressure factors (right).**

**Table 1. Descriptive statistics of environmental indicators and sample characteristics in Ferrara and Rovigo Provinces by geographical information system-identified areas.**

| Variable | Area A | Area B | Area C |
|---|---|---|---|
| Total area surface (km$^2$) | 1839 | 974 | 1585 |
| Roads (km)* | 193 (10.4%) | 37 (3.79%) | 67 (4.22%) |
| Industrial area (km$^2$)° | 19.8 (1.07%) | 6.78 (0.69%) | 3.09 (0.19%) |
| Total number of urban areas | 112 | 40 | 46 |
| Inhabitants per km$^2$ | 206 | 94 | 79 |
| Total number of villages | 48 | 13 | 15 |
| Villages at risk# | 48 | 10 | 5 |
| $PM_{10}$ (μg/m$^3$) (mean±SD) | 66±33 | 49±31 | 38±21 |
| Number of study subjects | 41 | 19 | 9 |
| Age (mean) | 6.5 | 6.3 | 6.4 |
| Females (%) | 34.1 | 31.6 | 22.2 |
| Parent education level 1 (%)§ | 62.5 | 61.1 | 66.7 |
| Parent education level 2 (%)^ | 10.0 | 5.6 | 11.1 |

SD, standard deviation. *Total length (and percentage) of roads with a daily, average traffic flow exceeding 10,000 vehicles; °total industrial surface (and percentage); #areas with high-density populations and industrial development at risk of exceeding the air-quality alarm threshold set by the European Commission Directives; §at least one parent with high school diploma or university degree; ^at least one parent with university degree.

The indicators used for this classification were the annual means of air pollutants (such as $PM_{10}$, $NO_2$ and $SO_2$), land use data by the CORINE Land Cover (http://www.epa.ie/soilandbiodiversity/soils/land/corine/#.VdHiof_ouig), km of roads with high traffic (HTR) defined as roads with more than 10,000 vehicles per day (SIDRIA Collaborative Group, 1997) and population density. Each participant's residence was assigned to one area based on his residence. For each participant, the exposure assessment was based on a combination of geographic and environmental measurements that incorporates industrial and traffic sources and on a identification of three areas with different background levels of air pollution.

The Environmental Protection Agencies of the Veneto Region (Department of Rovigo) and the Emilia-Romagna Region (Department of Ferrara) provided assments of $PM_{10}$ concentrations and other environmental data. Pollutant measures, derived from a 17 monitoring stations (12 fixed and 5 mobile) and any missing data in mobile stations, were reconstructed with a reliable degree ($R^2$>0.75) of correlation (Choi *et al*., 2006). Daily $PM_{10}$ concentration averages were calculated from January 9th 2006 to March 5th 2006 for each area, and area-specific daily $PM_{10}$ exposure levels were assigned to each child. To better characterise each residence, other geographical (time-invariant) variables were calculated in the residence's neighborhood, such as industrial pollution (Mitchell and Popham, 2007; Luo *et al*., 2011) and proximity to significant sources of road traffic (Cook *et al*., 2011; Nuvolone *et al*., 2011). Proximity to HTR was recorded within buffers of a 50, 100 and 200 m radius and industrial zones within a radius of two km of the residence and the size of each industrial area (surface area less than 500 $m^2$, between 500 and 1000 $m^2$). All geographical analyses were based on GIS (ArcGIS v.9.3, post-elaboration with Stata SE v.12 and R v.3.1.3).

## Health and questionnaire data

Participants were monitored daily for respiratory symptoms over a period of eight weeks (from January 9th to March 5th 2006); everyday parents reported by questionnaire if any of the following symptoms had occurred: cough, phlegm, stuffed nose, waking up with breathing problems, shortness of breath, attacks of shortness of breath, wheezing, eye irritation, sore throat, use of any anti-asthma medication, fever or headache. The latter symptoms were included as a possible confounder to adjust for epidemic influenza and to evaluate the possible tendency towards over-reporting symptoms. Parents were instructed to carry out Peak Expiratory Flow (PEF) measurements with portable peak flow meters: once in the morning (between 8 a.m. and 10 a.m.) and once in the evening before bedtime.

The expression *wheezing* was defined as the sum of an asthma attack and episodes of wheezing, while *bronchospasm* (an abbreviation of bronchial spasm) meant at least one episode of waking up with breathing problems, such as shortness of breath or attacks of shortness of breath. Individual questionnaires also included the following items that were used in the analysis as deprivation index proxy: passive smoking (at least one parent smokes at home), daily use of anti-asthma medication, day of the week (*i.e*. working days and weekend days), gender and highest level of education of the parents.

## Statistical analyses

From the daily questionnaires on asthma symptoms, we defined the following outcomes: wheezing, stuffed nose, phlegm, PEF, one episode of bronchospasm, cough and phlegm or cough only. At least one symptom was required. For each outcome we fitted a conditional logistic model, to answer: i) how likely external variables, such as $PM_{10}$ (with a 0-3 days lag), temperature, relative humidity, use of daily medication and the day of the week would affect the individual by experiencing an asthmatic symptom.

Then, for the same outcomes (except PEF), we estimated a generalised linear mixed model to understand: ii) how time varying and subject characteristics are related to the occurrence of an asthmatic symptom. As cofounders, to the covariates specified in conditional logit models, we added: school level, parental smoking habit, presence of industry, closeness to a highly trafficked road.

For i), a conditional logistic regression equivalent to a log-linear model, where the main effect of response is represented in terms of the covariates, was used. We had a stratum on each child, to evaluate association and within subject variability, between asthma symptoms and time-varying covariates. In detail, we express the probability as:

$$P_{ij} = \frac{\exp\,(\beta' c_{ij})}{\sum_{y=1}^{n} \exp\,(\beta' c_{iy})} \qquad \text{eq. 1}$$

where $P_{ij}$ is the probability of subject j and outcome i-th, $c_{ij}$ the vector of characteristics. In conditional logit the values of the variables (temperature, $PM_{10}$, *etc*.) vary across the possible outcome, while parameters are common across choices.

To evaluate ii) within and between subject variability, a generalised linear mixed model (GLMM) modeled individual propensity for asthmatic symptom occurrence (Yij=1) with exposed time-varying and invariant covariates:

$$logit\left(P_{ij}(x_i)\right) = \log\left(\frac{P_{ij}(x_i)}{1-P_{ij}(x_i)}\right) = \beta_0 + \beta_1 x_{ij1} + \cdots + \beta_p x_{ijp} + b_i \qquad \text{eq. 2}$$

where $b_i$ $N(0,\theta^2 b)$ represents subject-specific random effects (a subject with higher bi will have higher disease probability Pij). $x_{ijp}$ (i=1, ..., n subject; j=1, ..., T as time, p=1, …, P covariates).

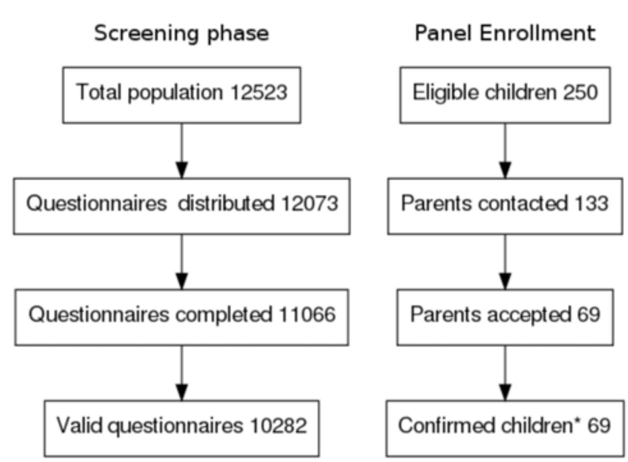


**Figure 2. Identification of the pupil subpopolation in the selected Ferrara/Rovigo geographical area.**

For both models i) and ii), we calculated odds ratio (OR) and confidence interval (CI). The latter model was then fitted on each area, separately. Odds ratios were used to compare the relative odds of the occurrence of an asthmatic symptom given exposure to variables of interest. It determines whether a particular exposure is a risk factor for a particular outcome and to compare magnitude of various risk factors for outcome. If OR=1 exposure does not affect odds of outcome, while OR>1 indicates that exposure is associated with higher odds of outcome and OR<1 that exposure is associated with lower odds of outcome. The prevalence of respiratory symptoms was calculated daily, dispersion graphs and correlations investigated relationships between symptoms, $PM_{10}$, temperature, and humidity. All statistical analyses were carried out using the Stata 12.0 and R 2.15 (R Development Core Team, 2008).

## Results

### Descriptive statistics

Table 1 reports the descriptive statistics for each area and for the 69 participants of the panel study. Urban area (area A) presented higher levels of $PM_{10}$, percentage of high-traffic roads, industrial areas and population density. A total of 41 subjects (59.5% of the panel) were living in urban area A; the mean age of the total panel was 6.4, with 22 female; 63% of children had at least one parent with high-school diploma, and 9% of them had a parent with a university degree.

Table 2 presents descriptions of child-days for all symptoms. Only three symptoms were reported as greater than or equal to 10% per child-day: cough, phlegm and stuffed nose. Waking up with breathing problems was observed only for 1% in child-day occurrence. At least one symptom (between waking up with breathing problems, shortness of breath, breath with wheeze, attacks of shortness of breath) was recorded in 31% of days of follow-up.

### Regression analyses

We found a significant increase of asthma symptoms in relation to exposure to $PM_{10}$: an increase of 10 mg/m$^3$ of $PM_{10}$ was associated in children with diagnosed asthma with increases of 6.8% in the occurrence of at least one symptom, 5.3% for cough and 10.1% for phlegm. These associations were larger for children living in most polluted area and with highest increase in risk factors (18.4% for wheezing). The ORs for conditional logistic models are shown in Figure 3. An increase of 10 mg/m$^3$ of $PM_{10}$ was associated with at least one symptom (OR=1.07: 95% CI 1.02-1.12). Also cough and phlegm show statistically significant associations with $PM_{10}$ presence (OR=1.05: 95% CI 1.00-1.11 and OR=1.10: 95% CI 1.03-1.18 respectively). All symptoms result were significantly associated with daily use of medication, and no statistically significant association was found with daily temperature, relative humidity or day of the week. Except PEF that had an OR lower than zero and was discarded from further analysis. $PM_{10}$ and use of daily medication were associated with symptoms occurrence. The results of OR for generalised linear mixed models can be seen in Figure 4 that shows OR for overall data being close to the OR obtained in the conditional logit model. When the analysis was restricted to area A, significant associations were seen for: wheezing (OR=1.18: 95% CI 1.02-1.37), phlegm (OR=1.11: 95% CI 1.02-1.21), episodes of bronchial spasm (OR=1.18: 95% CI 1.01-1.38) and cough (OR=1.09: 95% CI 1.01-1.17). The HTR variable showed positive association with phlegm, cough and phlegm, episodes of bronchospasm and wheezing. Some levels of industry were associated with cough and episodes of bronchospasm, but all symptoms are positively associated with daily medication. For smoking parents, 19% of the total, no association was found with any of the symptoms analysed. Day of the week was statis-


**Figure 3. Outcomes odds ratios for an increase of 10 μg/m$^3$ in PM10 exposure (lag 0-3) for the within-subject model with 95% confidence interval. Odds ratios *vs* reference categories, adjusted daily by the different variables investigated (temperature, humidity, use of anti-asthma medication, and day of the week). The dashed line represents an odds ratio equal to 1 corresponding to no effect. The odds ratios to the right of the dashed line indicate outcomes that presented significant results.**

**Table 2. Summary of symptoms during the panel study period.**

| Symptom | Child-day occurrence | Percentage |
|---|---|---|
| Wheeze | 145 | 3.88 |
| Cough | 594 | 15.89 |
| Phlegm | 438 | 11.72 |
| Stuffed nose | 597 | 15.97 |
| Wake-up breathing problem | 36 | 0.96 |
| Shortness of breath | 89 | 2.38 |
| Fever | 56 | 1.49 |
| Eye irritation | 70 | 1.87 |
| Sore throat | 182 | 4.87 |
| Headache | 94 | 2.51 |
| Cough and phlegm | 728 | 19.48 |
| Episode(s) of bronchial spasm* | 161 | 4.30 |
| At least one symptom* | 1153 | 30.85 |

*At least once when waking up with breathing problems, shortness of breath, breath with wheeze or attack of shortness of breath, excluding headache and fever.

tically significant associated with: phlegm, cough and phlegm, episodes of bronchospasm and wheezing. School level was associated with: cough, phlegm, cough and phlegm and at least one symptom. Comparing OR for the three areas, area A resulted as close to all OR data but with wider intervals, while area B and C had large intervals due to lower number of observations, with no significant results for area C. For area B, only phlegm had a positive association with $PM_{10}$, daily use of medication, day of the week and negative association with highly trafficked roads and school level.

## Discussion

In this panel study, we assessed the short-term effects of air pollution on symptoms of asthmatic children in relation to pre-defined environmental indicators. We combined data on asthma symptoms from the daily questionnaires filled in by the participants' parents, with indicators of exposure to air pollution, resulting from monitoring stations of air quality and geographic information on the characteristics of the area of residence of each subject. We found statistically significant increases for occurrence of at least one symptom, cough and phlegm. Our results are consistent with previous studies showing an increase in asthma symptoms for urban areas, (Yu *et al*., 2000; Escamilla-Nunez *et al*., 2008; Lewis *et al*., 2013).

The results are comparable with studies with a GIS approach (Jerrett *et al*., 2008; McConnell *et al*., 2010) for wheezing and use of daily medication. Evidence shows that air pollution may aggravate asthma symptoms (Anderson *et al*., 2011), but changes in association strength, for different environmental context, are unknown. Exposure to pollutants was determined by a geographic approach. There is a strong correlation between personal measurements and environmental data (Sarnat *et al*., 2006) when employed in association with different health endpoints, such as mortality, hospital discharge, and respiratory symptoms (Janssen *et al*., 1998).

The industrial area identification was based on air pollution qualitative analysis. $SO_2$ is linked with industrial pollution and therefore we accounted for areas where pollution-monitoring stations displayed $SO_2$-normalised values higher than $PM_{10}$ (data not shown). As for particulates, it is challenging to separate traffic and industrial contributions. Industrial sources contribute most to $PM_{10}$ or $PM_{2.5}$ compared to the ultrafine particulates, while there are no significant differences between traffic and industrial sites related to the ratio $PM_{2.5}/PM_{10}$ (Contini *et al*. 2014). For industrial sites, seasonal difference on the average concentration of $PM_{2.5}$ and $PM_{10}$ is not significant because industrial environmental pollution is constant in time, while it is significantly different for urban sites due to the variation in traffic flow (Gugamsetty *et al*., 2012). For $PM_{10}$, significant concentrations of trace metals are detectable, *e.g*. cadmium, lead, and chromium (Contini *et al*., 2014; Gugamsetty *et al*., 2012; Khodeir *et al*, 2012), but for $PM_{2.5}$ there is an unclear pattern when comparing different sites. We are aware that a detailed particulate characterisation could improve results.

The uneven distribution of subjects induced, with regard to fixed-station air-pollution data, additional environmental and cartographic analyses. GIS techniques applied for the analysis of dispersion models or land-use regression (Clougherty *et al*., 2008) proved to be useful in creating new indicators. Dividing provinces into three areas based on distinct environmental indicators enhanced the accuracy by implementing GIS methods. Assessing exposure by residence offers a reliable approximation of actual exposure, because it was conducted during winter, when children spend most of their time at home. An official Italian report on Ferrara (Soggiu *et al*., 2005), covering the period from December 1st 2003 to January 31st 2004, indicated that children spend the greatest part of their time, both at weekends and on school days, at home. On average, children (aged 6 to 10 years, with negligible differences for gender) spend more than 15 hours at home during the week and 18 hours on Sundays.

The home location was characterised by major proximal pressure factors such as road traffic, industrial sources, and whether the setting was rural or urban. This approach, based on GIS techniques, presents the main advantages of being able to assess exposure regardless of administrative boundaries and relate the geographical proximity to different environmental pressures to health outcomes. Panel studies on short-term effects of air pollution focus on urban settings, maintaining administrative boundaries as limits for validity of air-pollution data from fixed, city-wide monitoring networks (Atkinson *et al*., 2001; Faustini *et al*., 2011). This approach was not well suited to our study, since we encountered various environmental pressures and land uses within boundaries of a single administrative area. Our GIS-based combined approach – yielding, as it does, information on land use, environmental-pressure sources, the location of fixed pollution control units and the geographical location of the subjects' homes – led to differentiation of children's exposure. Differences based on risk estimation between areas, despite limitations of unbalanced area sample size,

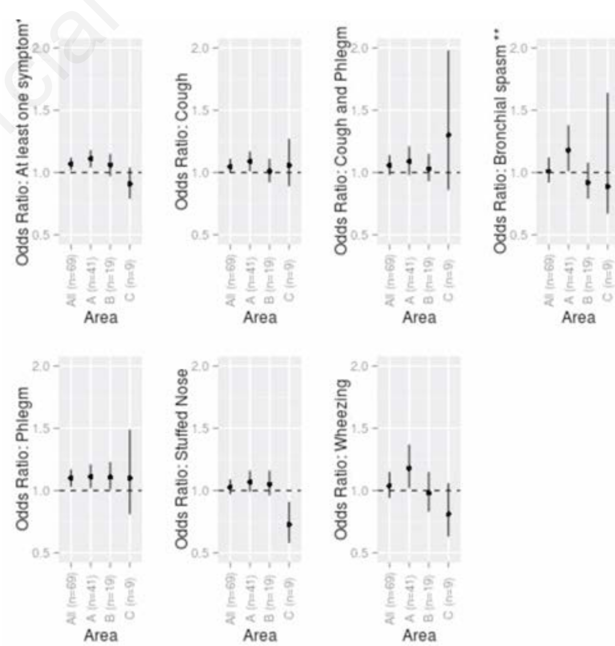


**Figure 4. Outcomes odds ratios for an increase of 10 μg/m³ in $PM_{10}$ exposure (lag 0-3) for the generalised mixed model by area with 95% confidence interval. Odds ratios *vs* reference categories, adjusted daily by the different variables investigated (sex, daily use of anti-asthmatic medication, daily temperature and humidity, day of the week, parents' educational level, industry, distance from roads with heavy traffic, passive smoking). The dashed line in each panel represents an odds ratio equal to 1 corresponding to no effect. Odds ratios above the dashed line indicate outcomes that presented significant result. Within each panel, outcomes are reported for all areas together in the first column followed to the left by areas A, B and C separately.**

revealed that a GIS-based approach can capture the differential effects of pollution in a given environmental context. Using GIS, we computed proximity of environmental pressures, such as heavy traffic and industry, and correlated to investigated outcomes. Geographic buffer size varies according to the variables investigated, and complies with recent studies, which quantitatively associate these variables with air pollution distributions (Choi *et al*., 2006).

A positive association between concentration of heavy industry and episodes of bronchospasm emerged. The day of the week variable suggests a greater risk during workdays, when pollution due to both traffic and industrial activity is higher than during weekends. Our study suffered from potential bias in PEF measurements made by each patient at home and difficulties in handling PEF instrument and/or in recording measurements (Chowienczyk *et al*., 1994; Quirce *et al*., 1995). The negative association between parents' education and cough is consistent with data from findings from a study in USA (McEntee *et al*., 2008) that found by a geographic approach a negative association between asthma and low schooling level, defined as less than nine years (OR=0.59, CI 95%: 0.44-0.78). SIDRIA Collaborative Group study (1998) highlighted the negative association between asthma/respiratory symptoms and education and socio-economic status. This association is controversial and available published data are not consistent (Morgenstern *et al*., 2007). Possible problems of selection bias are related to non-respondents in the panel enrollment, and we are aware that participants are not a random sample from the list of eligible children.

## Conclusions

We found a significant increase of at least one asthma symptom, cough and phlegm, with major association for children living in traffic and industrial polluted areas. We applied GIS to a visual and reasoned for area clustering and defined three-scaled polluted areas to characterise children exposure. The geographical approach led to a differentiation of population exposure according to environmental indicators. These results could explain the heterogeneity among subjects. Aggregation criteria are based on environmental conditions and a differential effect in exposure to environmental pollution among was detected. Even if information about characteristics of the group of non-responders was unavailable, results showed that relations with deprivation indexes are consistent with expected associations. Finally, also in view of a more consistent and effective decision making, the present experience supports the use of GIS in environmental epidemiology to better characterise exposure to air pollutants. This approach can help researchers to analyse situations with poor environmental measured data and thus potential misclassification of exposure.

## References

Anderson H, Favarato G, Atkinson R, 2011. Long-term exposure to air pollution and the incidence of asthma: meta-analysis of cohort studies. Air Qual Atmos Health 6:47-56.

Atkinson RW, Anderson HR, Sunyer J, Ayres J, Baccini M, Vonk JM, Boumghar A, Forastiere F, Forsberg B, Touloumi G, Schwartz J, Katsouyanni K, 2001. Acute effects of particulate air pollution on respiratory admissions: results from APHEA 2 project. Air pollution and health: a European approach. Am J Resp Crit Care 164:1860-6.

Bahadori K, Doyle-Waters MM, Marra C, Lynd L, Alasaly K, Swiston J, Fitzgerald M, 2009. Economic burden of asthma: a systematic review. BMC Pulm Med 9:24.

Bechtold P, Ranzi A, Gambini M, Capelli O, Magrini N, Cavallini R, Gallo L, Casale G, De Togni A, Cavagni G, Lauriola P, 2013. Assessing paediatric asthma occurrence through dispensed prescription data and questionnaires. Eur J Public Health 23:873-8.

Choi M, Afzal B, Sattler B, 2006. Geographic information systems: a new tool for environmental health assessments. Public Health Nurs 23:381-91.

Chowienczyk PJ, Parkin DH, Lawson CP, Cochrane GM, 1994. Do asthmatic patients correctly record home spirometry measurements. Brit Med J 309:1618.

Clougherty JE, Wright RJ, Baxter LK, Levy JI, 2008. Land use regression modeling of intra-urban residential variability in multiple traffic-related air pollutants. Environ Health 16:7-17.

Contini D, Cesari D, Donateo A, Chirizzi D, Belosi F, 2014. Characterization of PM10 and PM2.5 and their metals content in different typologies of sites in South-Eastern Italy. Atmosphere 5:435-53.

Cook AG, Jbm A, Pereira G, Jardine A, Weinstein P, 2011. Use of a total traffic count metric to investigate the impact of roadways on asthma severity: a case-control study. Environ Health 10:52.

Escamilla-Nunez MC, Barraza-Villarreal A, Hernandez-Cadena L, Moreno-Macias H, Ramirez-Aguilar M, Sienra-Monge JJ, Cortez-Lugo M, Texcalac JL, del Rio-Navarro B, Romieu I, 2008. Traffic-related air pollution and respiratory symptoms among asthmatic children, resident in Mexico City: the EVA cohort study. Resp Res 9:74.

Faruque FS, Li H, Williams WB, Waller LA, Brackin BT, Zhang L, Grimes KA, Finley RW, 2014. GeoMedStat: an integrated spatial surveillance system to track air pollution and associated healthcare events. Geospat Health 8:631-46.

Faustini A, Stafoggia M, Berti G, Bisanti L, Chiusolo M, Cernigliaro A, Mallone S, Primerano R, Scarnato C, Simonato L, Vigotti MA, Forastiere F, EpiAir Collaborative Group, 2011. The relationship between ambient particulate matter and respiratory mortality: a multi-city study in Italy. Eur Respir J 38:538-47.

GINA, 2005. The global strategy for asthma management and prevention. Global Initiative for Asthma. Available from: http://www.ginasthma.org/documents/5/documents_variants/30

Gugamsetty B, Wei H, Liu CN, Awasthi A, Hsu S-C, Tsai CJ, Roam GD, Wu YC, Chen CF, 2012. Source characterization and apportionment of PM10, PM2.5 and PM0.1 by using positive matrix factorization. Aerosol Air Qual Res 12:476-91.

Herrera Murillo J, Rodriguez Roman S, Rojas Marin JF, Campos Ramos A, Blanco Jimenez S, Cardenas Gonzalez B, Gibson Baumgardner D, 2013. Chemical characterization and source apportionment of PM10 and PM2.5 in the metropolitan area of Costa Rica, Central America. Atmos Pollut Res 4:181-90.

Holt PG, Macaubas C, Stumbles PA, Sly PD, 1999. The role of allergy in the development of asthma. Nature 402(Suppl.6760):12-7.

Janssen NA, Hoek G, Brunekreef B, Harssema H, Mensink I, Zuidhof A, 1998. Personal sampling of particles in adults: relation among personal, indoor, and outdoor air concentrations. Am J Epidemiol 147:537-47.

Jerrett M, Shankardass K, Berhane K, Gauderman WJ, Künzli N, Avol E, Gilliland F, Lurmann F, Molitor JN, Molitor JT, Thomas DC, Peters J, McConnell R, 2008. Traffic-related air pollution and asthma onset in children: a prospective cohort study with individual exposure measurement. Environ Health Persp 116:1433-8.

Khodeir M, Shamy M, Alghamdi M, Zhong M, Sun H, Costa M, Chen L-C, Maciejczyk P, 2012. Source apportionment and elemental composition of PM2.5 and PM10 in Jeddah City, Saudi Arabia. Atmos Pollut Res 3:331-40.
Lary DJ, Faruque FS, Malakar N, Moore A, Roscoe B, Adams ZL, Eggelston Y, 2014. Estimating the global abundance of ground level presence of particulate matter (PM2.5). Geospat Health 1:611-30.
López ML, Ceppi S, Palancar G, Olcese Luis E, Tirao G, Toselli B, 2011. Elemental concentration and source identification of PM10 and PM2.5 by SR-XRF in Córdoba City, Argentina. Atmos Environ 45:5450-7.
Lewis TC, Robins TG, Mentz GB, Zhang X, Mukherjee B, Lin X, Keeler GJ, Dvonch JT, Yip FY, O'Neill MS, Parker EA, Israel BA, Max PT, Reyes A, 2013. Air pollution and respiratory symptoms among children with asthma: vulnerability by corticosteroid use and residence area. Sci Total Environ 448:48-55.
Luo J, Hendryx M, Ducatman A, 2011. Association between six environmental chemicals and lung cancer incidence in the United States. J Environ Public Health 2011:463701.
Marchetti P, Marcon A, Pesce G, Paolo G, Guarda L, Pironi V, Fracasso ME, Ricci P, de Marco R, 2014. Children living near chipboard and wood industries are at an increased risk of hospitalization for respiratory diseases: a prospective study. Int J Hyg Environ Health 217:95-101.
Martuzzi M, Mitis F, Biggieri A, Terracini B, Bertolini R, 2002. Environmental and health status in the population of the areas at high risk of environmental crisis in Italy. Epidemiol Prev 26:1-56.
McConnell R, Berhane K, Yao L, Jerrett M, Lurmann F, Gilliland F, Künzli N, Gauderman J, Avol E, Thomas D, Peters J, 2006. Traffic, susceptibility, and childhood asthma. Environ Health Persp 114:766-72.
McConnell R, Islam T, Shankardass K, Jerrett M, Lurmann F, Gilliland F, Gauderman J, Avol E, Künzli N, Yao L, Peters J, Berhane K, 2010. Childhood incident asthma and traffic-related air pollution at home and school. Environ Health 118:1021-6.
McEntee JC, Ogneva-Himmelberger Y, 2008. Diesel particulate matter, lung cancer, and asthma incidences along major traffic corridors in MA, USA: a GIS analysis. Health Place 14:817-28.
Mitchell R, Popham F, 2007. Greenspace, urbanity and health: relationships in England. J Epidemiol Commun H 61:681-3.
Morgenstern V, Zutavern A, Cyrys J, Brockow I, Gehring U, Koletzko S, Bauer CP, Reinhardt D, Wichmann HE, Heinrich J, 2007. Respiratory health and individual estimated exposure to traffic-related air pollutants in a cohort of young children. Occup Environ Med 64:8-16.
Mortimer K, Neugebauer R, Lurmann F, Alcorn S, Balmes J, Tager I, 2008. Early-lifetime exposure to air pollution and allergic sensitization in children with asthma. J Asthma 45:874-81.
Nuvolone D, Maggiore R, Maio S, Fresco R, Baldacci S, Carrozzi L, Pistelli F, Viegi G, 2011. Geographical information system and environmental epidemiology: a cross-sectional spatial analysis of the effects of traffic-related air pollution on population respiratory health. Environ Health 1:12.
Quirce S, Contreras G, Dybuncio A, Chan-Yeung M, 1995. Peak expiratory flow monitoring is not a reliable method for establishing the diagnosis of occupational asthma. Am J Resp Crit Care 152:1100-2.
R Development Core Team, 2008. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available from: http://www.R-project.org
Sarnat SE, Coull BA, Schwartz J, Gold DR, Suh HH, 2006. Factors affecting the association between ambient concentrations and personal exposures to particles and gases. Environ Health Persp 114:649-54.
Shima M, Nitta Y, Adachi M, 2003. Traffic-related air pollution and respiratory symptoms in children living along trunk roads in Chiba Prefecture, Japan. J Epidemiol 13:108-19.
SIDRIA Collaborative Group, 1997. Asthma and respiratory symptoms in 6-7 year old Italian children: gender, latitude, urbanization and socio-economic factors. Eur Respir J 10:1780-6.
SIDRIA Collaborative Group, 1998. Cigarette smoking among eight graders in different Italian areas. Epidemiol Prev 22:155-64.
Soggiu ME, Bastone A, Vollono C, Masciocchi M, Rago G, Sellitri C, 2005. Study of inhalation exposure assessment to atmospheric pollution in Ferrara. Second phase. Available from: www.iss.it/binary/publ/publi/05-9.1120812015.pdf
van Gent R, van Essen LE, Rovers MM, Kimpen JL, van der Ent CK, de Meer G, 2007. Quality of life in children with undiagnosed and diagnosed asthma. Eur J Pediatr 166:843-8.
Yu O, Sheppard L, Lumley T, Koenig JQ, Shapiro GG, 2000. Effects of ambient air pollution on symptoms of asthma in Seattle-area children enrolled in the CAMP study. Environ Health Persp 108:1209-14.