Socioeconomic status and exposure to outdoor NO$_2$ and benzene in the Asturias INMA birth cohort, Spain

Ana Fernández-Somoano,[1,2] Adonina Tardon[1,2]

[1]Spanish Consortium for Research on Epidemiology and Public Health (CIBERESP), Instituto de Salud Carlos III, Madrid, Spain
[2]Department of Preventive Medicine and Public Health, University of Oviedo, Oviedo, Asturias, Spain

Correspondence to
Ana Fernández-Somoano, Área de Medicina Preventiva y Salud Pública, Facultad de Medicina, Universidad de Oviedo, C/Julián Clavería s/n, Oviedo, Asturias 33006, Spain; capua.uo@uniovi.es

ABSTRACT

Background It is commonly assumed that low socioeconomic levels are associated with greater exposure to pollution, but this is not necessarily valid. Our goal was to examine how individual socioeconomic characteristics are associated with exposure levels in a Spanish region included in the INfancia y Medio Ambiente (INMA) cohort.

Methods The study population comprised 430 pregnant women from the Asturias INMA cohort. Air pollution exposure was estimated using land-use regression techniques. Information about the participants' lifestyle and socioeconomic variables was collected through questionnaires. In multivariate analysis, the levels of NO$_2$ and benzene assigned to each woman were considered as dependent variables. Other variables included in the models were residential zone, age, education, parity, smoking, season, working status during pregnancy and social class.

Results The average NO$_2$ level was 23.60 (SD=6.50) μg/m^3. For benzene, the mean value was 2.31 (SD=1.32) μg/m^3. We found no association of any pollutant with education. We observed an association between social class and benzene levels. Social classes I and II had the highest levels. The analysed socioeconomic and lifestyle variables accounted for little variability in air pollution in the models; this variability was explained mainly by residential zone (adjusted R^2: 0.27 for NO$_2$; 0.09 for benzene).

Conclusions Education and social class were not clearly associated with pollution. Administrations should monitor the environment of residential areas regardless of the socioeconomic level, and they should increase the distances between housing and polluting sources to prevent settlements at distances that are harmful to health.

INTRODUCTION

Air pollution is a great hazard in the developing and developed world[1,2] and has been linked to a wide array of harmful effects on health.[3–6] Even moderately or relatively low levels of pollutants can still negatively affect health.[7] The first stages of human development are the most sensitive ones to environmental agents.[8,9] Environmental exposure begins at conception and plays an important role in fetal growth[10–13] as well as later, during infancy, in the development of respiratory diseases[14,15] and adverse neurological effects.[16,17] In addition to environmental exposure and the possible presence of contaminants in food, children can suffer the consequences of harmful atmospheric substances that reach the fetus through the mother's exposure to them.[18] Environmental exposure in utero or during the early stages of life is associated with neurological, immune and sexual development problems.[19–21] The physical, cognitive and psychosocial development of children from conception to adolescence thus requires non-polluted environments.[22]

To understand the effect of air pollution on child health, it is necessary to obtain information about the role of important environmental contaminants during pregnancy and childhood, as well as the effects they have on growth and development.[23] It is imperative to assess and reduce the exposure of children to environmental hazards from the moment of conception through adolescence, taking into account important environmental contaminants, susceptibility and lifestyle or activity patterns.

Socioeconomic inequalities in health are well understood,[24–28] particularly in maternal and child health.[7] Further, a lower socioeconomic level is conventionally associated with greater atmospheric pollution exposure.[27,29] However, this does not always appear to be the case. Recent studies demonstrated different directions and associations for different pollutants and populations. Some studies have identified greater exposure to air pollution among more deprived people. Thus, Chaix et al[30] reported environmental injustice in Sweden. Similarly, Næss et al[31] found air pollution exposure associated with neighbourhood-level deprivation. In the same way, Havard et al[32] demonstrated socioeconomic disparities in traffic-related air pollution exposure in France. Similarly, Rotko et al[33] pointed out that people of lower occupational status, as well as the less educated and young population in Finland, had greater exposure than those of upper occupational status and the more educated and older population. Also in Spain, Llop et al[34] observed greater air pollution exposure to those belonging to a lower social class (SC). Moreover, Wheeler and Ben-Shlomo[35] found that urban lower SC households in England were more likely to be located in areas of poor air quality, although the associations in rural areas were reversed. Furthermore, Briggs et al[36] reported environmental inequity in England but evidenced a wide variation of the associations depending on the pollutant chosen, the socioeconomic index studied and the geographic scale used. In this line, Stroh et al[37] reported contradictory results in Sweden, especially with education. Also, Vrijheid et al[38] found associations to be generally weak and inconsistent in direction between socioeconomic status indicators and different pollutants in Spain. On the other hand, a higher socioeconomic position was found to be

associated with greater air pollution exposure by Cesaroni *et al*[39] and Forastiere *et al*[40] in Italy. Likewise, Hoek *et al*[41] reported greater air pollution exposure for individuals with higher educational and occupational levels in the Netherlands. Therefore, it is essential to establish which socioeconomic characteristics are associated with exposure to environmental pollution in each particular geographical area and to understand how those relationships interact.[42] This will not only enable reduction of environmental inequalities according to the identified social factors, but will also allow correct adjustment of these social factors in epidemiological studies on the relationship between air pollution and health effects.[43]

Airborne ultrafine and fine particulate matter is currently one of the principal air pollutant health concerns in urban areas. Vehicle exhausts are an important source of particulates, and they are consistently associated with mortality and morbidity.[44 45] Outdoor nitrogen dioxide (NO_2) is widely used to measure traffic-related air pollution,[46–48] and benzene, in addition to being a marker for the presence of other sources of pollution,[49] is also an indicator for traffic pollutants.[50]

The aim of this study was to analyse the association between social factors and individual exposure to air pollution within the birth cohort of Asturias INfancia y Medio Ambiente (INMA: 'Environment and Childhood') in northern Spain. The specific objectives were to identify the degree of individual exposure to outdoor traffic-related air pollution and the level of exposure during pregnancy according to different social factors. We also aimed to identify which sociodemographic and socioeconomic factors contributed to higher NO_2 and benzene exposure levels during pregnancy. These findings could be helpful in improving child development and health and in developing preventive measures for certain diseases.

METHODS
Study population
The Asturias INMA cohort is a birth cohort study in Asturias (northern Spain); it is part of the INMA Project, which has studied pregnant women and their newborns since 2004. The Asturias INMA study area covers 483 km^2, includes nine municipalities, and had a reference population of 154 634 inhabitants in 2007. The Asturias INMA area is an industrial zone, and the principal sources of air pollution are the aluminium, steel, glass and chemical industries as well as road traffic.[23] Currently, there are no studies with information about the relative contribution of the various sources of pollution in the area. However, what seems obvious is that the particulate and benzene exposure levels here are higher than those set by the European regulations partly due to the high percentage of diesel vehicles, and also due to the potential contribution of volatile organic compound emissions mainly by the steel industry.

The study protocol was approved by the Asturias Regional Ethics Committee and informed consent was obtained from every participating woman and her partner. The research conformed to the principles of the Declaration of Helsinki.

Participant recruitment and follow-up procedures for the INMA Project—a Spanish multicentre birth cohort study—have been reported elsewhere.[51 52] Briefly, the inclusion criteria were age ≥16 years, singleton pregnancy, enrolment at 10–13 weeks of gestation, no assisted conception, delivery scheduled at the reference hospital and no communication handicap.

In Asturias, 494 eligible pregnant women were recruited at their first routine prenatal care visit between May 2004 and June 2007 at the reference hospital, San Agustin (Avilés) and agreed to participate in the study. Four of these women had a spontaneous abortion or fetal death, 5 withdrew from the study and 485 delivered a live, singleton infant from May 2004 to August 2008. The study area covered the home addresses of all participants. Approximately 88% lived in typically urban areas and 12% in typically rural ones.

Air pollution exposure assessment
In the INMA Project, a protocol was designed to assess individual exposure during pregnancy to NO_2 and benzene as markers of outdoor air pollution from road traffic.[53] Ambient concentrations were measured using passive samplers (Radiello, Fondazione Salvatore Maugeri, Padua, Italy) distributed over the study area according to geographical criteria, taking into account the expected pollution gradients and distribution of participants' residences. The samplers were exposed during two 7-day sampling periods (June 2005 and November 2005). The methodology has been described in detail elsewhere.[12 23] Briefly, 1-week measurements were carried out at 67 sampling sites in the two sampling campaigns. Concentrations of both sampling campaigns were averaged to represent the annual mean levels of each pollutant, and linear regression models were fitted for NO_2 and benzene using geographical characteristics (land coverage, altitude and distance to roads) as predictor variables. The best land-use regression (LUR) model was used to predict the outdoor NO_2 ($R^2=0.4$) and benzene ($R^2=0.7$) levels at unmonitored sites, including outside the participants' residences.

The individual NO_2 exposure was assigned as the estimated ambient NO_2 level at the home address which had been adjusted temporally using the daily NO_2 levels obtained from Principality of Asturias Air Quality Network stations covering the study area in order to obtain estimates for each woman's specific pregnancy period. Some stations in the study area also monitored the benzene levels, but they had a high degree of missing data. Thus, as in previous studies,[54 55] data from the monitored air pollutant that exhibited the best correlation in this area with benzene (SO_2) was used to adjust for seasonal variability of benzene. The same procedure was used to calculate air pollution exposure for each trimester of pregnancy. Changes in residential address during pregnancy were considered only when participants spent at least 2 months of the pregnancy period at the new residence, which occurred in 3% of cases.

Exposure to outdoor NO_2 and benzene was assessed for 482 of the 485 pregnant women in the study. Owing to the scarcity of geographical information for rural sites, women who lived farther than 1 km from a passive sampler were excluded. In urban areas, women who lived 2 km or more away from a sampler site were also excluded. Thus, the final study population comprised 430 pregnant women.

Sociodemographic variables
The participants completed a validated, detailed questionnaire about sociodemographic characteristics, environmental exposures and lifestyle variables twice during their pregnancy (weeks 10–13 and 28–32).[52] The questionnaires were administered via personal interviews by previously trained interviewers. The questions included maternal and paternal age, education, working status, occupation, country of birth, previous pregnancies, smoking history, residence zone and season of last menstruation.

In this analysis, the mother's highest education level was categorised into three groups: first 4 years of (compulsory) secondary education or less; further secondary or vocational education (high school) and university. The country of birth was

Fernández-Somoano A, *et al*. *J Epidemiol Community Health* 2014;**68**:29–36. doi:10.1136/jech-2013-202722

categorised as Spain or other. Maternal SC was coded using the longest-held job during pregnancy or, if the mother did not work during pregnancy, the last job before the pregnancy. In the few cases of mothers never having worked, the last job of the father was used (n=16). Occupations were coded using the four-digit Spanish National Classification of Occupations (CNO94),[56] which is closely related to the international ISCO88 coding system. Five SC categories were created following the methodology proposed by the Spanish Epidemiological Society[57]: SCI included managers of companies with 10 or more employees, senior technical staff and higher-level professionals; SCII included managers of companies with fewer than 10 employees and intermediate-level professionals; SCIII included administrative and financial management supporting personnel, other self-employed professionals, supervisors of manual workers and other skilled non-manual workers; SCIV included skilled and partly skilled manual workers; and SCV included unskilled manual workers. Working status (working or not) was assessed in the first and third trimesters. Women were divided into four smoking categories: never smokers, smokers except during pregnancy; smokers during the first trimester but not after week 12 and still smoking after week 12. Parity was defined as the number of previous pregnancies that lasted at least 22 weeks; participants were categorised as women without children or women with one or more children.

Statistical analysis

We conducted a descriptive analysis of the population under study with regard to the sociodemographic and lifestyle variables considered (age, educational level, SC, working status, smoking, parity and country of origin), as well as season of last menstruation. Next, we performed a descriptive analysis of NO_2 and benzene levels as a function of the established social factors and used the Mann-Whitney and Kruskal-Wallis tests to compare differences in the distribution of NO_2 and benzene levels.

We chose which covariates to include in the analysis based on previous knowledge of their influence on maternal NO_2 and benzene exposure. We finally included the type of residential zone, residential building age, participant's age, parity, SC, country of origin, smoking, working status and educational level. Atmospheric pollution levels vary seasonally. Thus, we thought it necessary to adjust the multivariate model of NO_2 and benzene exposure by including the variable 'season of last menstruation'. We assumed that parity as a variable was possibly related to age and social status and therefore included it in the models. We also tested for collinearity between these variables and found none.

Association between exposure to residential outdoor NO_2 or benzene and social variables was assessed by means of linear regression for continuous variables. Two multiple linear regression models were then constructed; the dependent variables were outdoor NO_2 exposure and outdoor benzene exposure on a continuum. The models were made based on the variables with a level of significance of p<0.2 in the univariate analysis while those with a level of significance of p<0.1 were maintained in the model as part of the likelihood ratio test. SC and educational level were forced to stay in the regression models.

Statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) V.15.0 for Windows and Stata V.8.0.

RESULTS

Of the women in the cohort, 83% lived in a town centre. Only 5% were under 25 years and 45% had completed secondary school. Most of them were born in Spain (96%). Study participants working in their third term of pregnancy accounted for 26%. The most frequent SC was SCIV (48%), followed by SCIII (21%). Regarding pregnancy history, 61% were primiparous. Over 50% of the participants were non-smokers (table 1). When we sectioned the database based on residential type (rural vs urban), we obtained similar percentages for the above variables. Women in the cohort were geographically distributed with no differences relating to educational level or SC.

Estimated levels of NO_2 and benzene in the cohort varied between rural and urban locations. Values for participants living in town centres were clearly higher than those for women living in residential zones or the countryside (mean NO_2: 25.07, 18.91 and 14.94 µg/m³, respectively; mean benzene: 2.43, 2.13 and 1.34 µg/m³, respectively; table 1).

We found no associations between education and the two air pollutants. An association between SC and air pollution was found only for benzene but with no clear trend. Higher levels were found for SCI and SCII (mean benzene: 2.45 µg/m³; table 1). Statistically significant differences in NO_2 were found for season of last menstruation, whereas higher NO_2 values were evident in women who conceived in summer (table 1). No other statistically significant association was observed except for residential building age: older buildings had higher outdoor NO_2 levels (table 1).

Multivariate analysis showed a low association between SC and lifestyle variables and variability in NO_2 and benzene levels. When considering NO_2 as the dependent variable, the regression model for all women in the study included the variables of residential zone, residential building age, education, SC, working status, smoking history and season of last menstruation; taking benzene as the dependent variable, the variables included were residential zone, residential building age, participant's age, education, SC, working status, parity, smoking and season of last menstruation (table 2). Adjusted R^2 was 0.27 in the first model and 0.09 in the second. Residential zone and age of the residential building accounted for most of the total variability of the models.

The variables included in the models were almost the same, and we obtained similar regression coefficients when we restricted the analysis to participants living in urban areas. However, since there was just one variable in each case, the outcomes were less clear when we assessed only women living in rural zones.

DISCUSSION

In the Asturias INMA cohort, the residential zone had an influence on the exposure to NO_2 and benzene.[23] The mean values estimated for participants in the study were 23.60 (SD=6.50) µg/m³ for NO_2 and 2.31 (SD=1.32) µg/m³ for benzene. Moreover, pregnant women who lived in urban areas were exposed to higher levels of air pollution, as evident in the NO_2 and benzene levels. In general, in terms of NO_2 levels, the study participants lived in a slightly polluted area; that was also true for benzene, except for some participants who lived near industrial areas (65% of whom belonged to the most disadvantaged SC). Education was not found to be associated with environmental exposure at home. SC, however, was slightly associated with benzene levels, although there was no definite trend.

Younger participants and those of lower SC tended to live in older buildings, and therefore younger participants were exposed to lower levels of benzene and those of higher SC to higher levels of this pollutant. Older residences are generally located farther away from industrial areas and are therefore less

Table 1 Asturias INfancia y Medio Ambiente (INMA) cohort characteristics and estimated pollution levels

	NO₂						Benzene					
	N	Mean	SD	Minimum	Maximum	p Value*	N	Mean	SD	Minimum	Maximum	p Value*
Residential zone												
Town centre	356	25.01	5.40	8.30	39.06	<0.001	356	2.43	1.29	0.34	7.91	<0.001
Residential zone	35	18.91	7.10	8.08	30.52		35	2.13	1.36	0.47	5.58	
Countryside	39	14.94	6.61	7.56	35.82		39	1.34	1.08	0.04	4.26	
Residential building age												
<5	94	22.14	6.17	9.09	38.27	0.001	94	2.65	1.53	0.51	6.76	0.109
5–14	67	22.67	7.14	9.56	37.89		67	2.44	1.41	0.04	5.76	
15–29	66	24.79	5.75	8.30	39.06		66	2.20	1.24	0.34	7.91	
>29	160	24.68	6.03	7.56	37.30		160	2.13	1.11	0.19	5.97	
Missings	43						43					
Participant's age												
<25	21	21.48	7.54	8.30	32.95	0.503	21	1.84	1.21	0.34	5.76	0.055
25–29	117	23.61	6.20	8.68	36.88		117	2.10	1.12	0.45	5.80	
30–34	183	23.98	6.45	8.30	38.27		183	2.37	1.36	0.05	6.76	
35+	109	23.36	6.68	7.56	39.06		109	2.51	1.42	0.04	7.91	
Country of birth												
Spain	413	23.57	6.42	7.56	39.06	0.409	413	2.31	1.33	0.04	7.91	0.893
Other	17	24.42	8.37	8.08	36.88		17	2.18	0.89	0.97	4.83	
Education												
Primary	80	23.29	6.24	8.30	34.58	0.793	80	2.26	1.21	0.34	5.76	0.117
Secondary	194	23.49	6.88	7.56	38.27		194	2.19	1.31	0.19	7.91	
University	156	23.90	6.16	8.08	39.06		156	2.47	1.36	0.04	6.76	
Social class (SC, mother)												
SCI+II	92	23.96	6.18	8.05	39.06	0.949	92	2.45	1.28	0.45	5.32	0.026
SCIII	90	23.02	7.26	7.56	34.50		90	2.06	1.38	0.04	7.91	
SCIV+V	247	23.67	6.34	8.30	38.27		247	2.33	1.30	0.19	6.76	
Missings	1						1					
Working status (third term)												
Yes	106	24.43	6.18	8.68	37.89	0.132	106	2.43	1.25	0.04	5.97	0.126
No	298	23.33	6.59	7.56	39.06		298	2.27	1.33	0.05	7.91	
Missings	26						26					
Parity												
Primiparous	262	23.83	6.35	8.05	39.06	0.524	262	2.36	1.29	0.34	6.76	0.175
Multiparous	168	23.24	6.73	7.56	37.78		168	2.22	1.36	0.04	7.91	
Smoking												
Never smoking	204	23.09	6.54	7.56	38.27	0.196	204	2.30	1.28	0.04	5.97	0.022
No smoking during pregnancy	129	24.67	5.94	10.24	39.06		129	2.47	1.40	0.05	7.91	
Smoking but not after 12th week	2	27.13	0.37	26.87	27.39		2	4.18	0.18	4.05	4.31	
Smoking after 12th week	69	23.12	7.23	8.30	37.78		69	1.98	1.15	0.34	5.76	
Missings	26						26					
Season of last menstruation												
Winter	122	22.72	6.04	8.30	36.88	0.014	122	2.27	1.31	0.38	5.80	0.108
Spring	95	24.04	6.89	8.52	39.06		95	2.55	1.39	0.19	6.76	
Summer	93	24.99	6.36	8.46	37.78		93	2.11	1.31	0.05	7.91	
Autumn	120	23.07	6.61	7.56	38.27		120	2.30	1.25	0.04	5.97	

*Kruskal-Wallis or Mann-Whitney test.

exposed to benzene. By contrast, there are more roads around older residences, and therefore the NO₂ levels are higher.

These results are in agreement with our findings in a previous investigation.[58] There, we identified quite weak associations between estimated NO₂ values and educational level and also between estimated NO₂ values and a socioeconomic index (based on occupation, calculated at the census tract level). In the present study, once we adjusted the models for sociodemographic and lifestyle variables, we found no association between air pollution and educational level and a very weak association

between benzene levels and SC. This result corroborates those of recent studies in comparable populations, which found weak, inconsistent associations between socioeconomic variables and levels of exposure to environmental pollutants.[38] Similar approaches have been used to study social inequalities in Europe and produced different findings.[27 29] Some authors identified environmental disadvantages for more deprived people: for example, Chaix *et al*[30] found evidence of environmental inequality in Malmö, Sweden. Similarly, Llop *et al*[34] concluded that lower social status was associated with higher air pollution

Table 2 Associations between NO$_2$ and benzene ($\mu g/m^3$), and social factors

	NO$_2$*				Benzene†			
	β	SD	CI 95%		β	SD	CI 95%	
Residential zone	Partial Corr^2: 0.2364				Partial Corr^2: 0.0436			
Town centre	Ref				Ref			
Residential zone	−5.50	1.06	−7.57	−3.43	−0.47	0.25	−0.96	0.02
Countryside	−9.57	0.98	−11.50	−7.64	−0.88	0.23	−1.33	−0.42
Residential building age	Partial Corr^2: 0.0391				Partial Corr^2: 0.0207			
<5	Ref				Ref			
5–14	0.63	0.88	−1.10	2.36	−0.19	0.21	−0.60	0.21
15–29	2.40	0.91	0.62	4.18	−0.39	0.21	−0.80	0.03
>29	2.75	0.74	1.30	4.21	−0.46	0.17	−0.80	−0.12
Participant's age					Partial Corr^2: 0.0143			
<25					Ref			
25–29					0.27	0.32	−0.36	0.91
30–34					0.37	0.32	−0.26	1.01
35+					0.66	0.34	0.00	1.32
Education	Partial Corr^2: 0.0063				Partial Corr^2: 0.0015			
Primary	Ref				Ref			
Secondary	0.74	0.78	−0.79	2.27	0.05	0.18	−0.31	0.41
University	1.53	0.92	−0.28	3.35	0.21	0.22	−0.23	0.64
Social class (SC, mother)	Partial Corr^2: 0.0028				Partial Corr^2: 0.0074			
SCI+II	Ref				Ref			
SCIII	0.34	0.88	−1.40	2.07	−0.16	0.21	−0.57	0.24
SCIV+V	1.13	0.88	−0.60	2.85	0.34	0.21	−0.07	0.74
Working status (third term)	Partial Corr^2: 0.0056				Partial Corr^2: 0.0026			
Yes	Ref				Ref			
No	−0.98	0.70	−2.35	0.39	−0.16	0.16	−0.48	0.16
Parity					Partial Corr^2: 0.0053			
Primiparous					Ref			
Multiparous					−0.15	0.14	−0.43	0.13
Smoking	Partial Corr^2: <0.0001				Partial Corr^2: 0.0003			
Never smoking	Ref				Ref			
No smoking during pregnancy	1.64	0.62	0.41	2.86	0.19	0.15	−0.09	0.48
Smoking but not after 12th week	1.32	3.88	−6.30	8.94	1.69	0.9	−0.09	3.47
Smoking after 12th week	−0.39	0.80	−1.95	1.18	−0.12	0.19	−0.49	0.24
Season of last menstruation	Partial Corr^2: 0.0053				Partial Corr^2: 0.0003			
Winter	Ref				Ref			
Spring	1.78	0.79	0.23	3.32	0.33	0.18	−0.03	0.69
Summer	2.29	0.80	0.73	3.86	−0.05	0.19	−0.42	0.32
Autumn	1.03	0.74	−0.43	2.49	0.18	0.17	−0.16	0.52

*Adjusted R^2=0.2734.
†Adjusted R^2=0.0908.

exposure in Valencia, Spain; however, as in the present study, they found no association between educational level and exposure. Likewise, Havard et al[32] recognised a positive association between deprivation and traffic-related pollution exposure in Strasbourg, France. Briggs et al[36] found evidence, albeit generally weak, of environmental inequities being related to social status in Britain. Rotko et al[33] identified greater air pollution exposures as being associated with lower occupational status and educational level in Helsinki, Finland. However, other authors have suggested the reverse relationship between air pollution and socioeconomic characteristics. Cesaroni et al[39] observed that areas with residents in high and medium socioeconomic positions tended to be more exposed to air pollution. Similarly, Hoek et al[41] determined that individuals living near a major road had slightly higher educational and occupational levels and were exposed to greater air pollution levels in the Netherlands. Therefore, we cannot prove with certainty that social deprivation results in higher pollution levels—at least in cities or rural areas in Europe that were investigated using a similar approach. The differences between European and American cities in their structure and SC distribution do not allow our results to be easily compared with US studies.

Although the relationship between air pollution and health effects is complex since different pollutants act simultaneously and the health risk depends on the type of chemical agent and the outcome of interest, it is clear that environmental hazards cause several adverse effects on health.[7] It is necessary, though, to gather as much information as possible about the behaviour of air pollution, particularly with regard to vulnerable population groups such as pregnant women and children in the present study; they may be affected by numerous problems[11 59] such as fetal growth restriction,[10 60] premature births,[61 62] low birthweight,[63–65] congenital malformation,[9] neurological problems[16] and asthma or allergies,[14] even resulting in death.[66] Including

information about socioeconomic characteristics is very important because of its complex nature.[67]

To lessen a population's exposure to adverse chemical substances, it is necessary to control source emissions.[68] It is also important to gather information from different scenarios: results from one area cannot always be extrapolated to other areas owing to differences in environmental characteristics, especially the availability and suitability of geographical data.

As a study limitation, it should be noted that we collected data from a comparatively small area: there was little variability and the residential areas were not so well defined. Therefore, we were not always able to find clear associations with statistical significance. Moreover, SC was self-reported, which could lead to some imprecision. Furthermore, it was not always obvious whether the factor 'SC' accurately represented the study participants' employment during pregnancy. Younger women often have lower status jobs or ones demanding lesser qualifications. Additionally, pregnant women or younger participants frequently purchased housing only shortly before the investigation, but that determined their residential location.

In studying disease outcomes, it is necessary to take into account the associations with educational level and SC as indicators of socioeconomic status if no income information is available. Along the lines of Forastiere,[40] we found no difference in susceptibility but different exposure with varying socioeconomic status.

It should be noted that NO_2 and benzene are considered as markers of toxic traffic-driven air pollutants rather than as potential causative agents themselves. Thus, another limitation of our study was that only NO_2 and benzene were measured—not ultrafine particles (particularly the trace metal content of these particles) that seem to be the most harmful residential air pollutants.[20 44 45 69]

Some strong points of this study are the prospective approach of the cohort, the estimation of individual exposure to traffic-related air pollutants based on temporally adjusted LUR models applied to geocoded home addresses, the technique of high predictive ability,[70–73] and the separate study of urban and rural areas, where little is known on this topic. Furthermore, we determined the stability of exposure models[74] and found that our data were consistent with those obtained in similar areas.[38 75 76] As expected, the factor 'season of last menstruation' was associated with air pollution exposure. This also proves the coherence of the measure.

In conclusion, it is certain that epidemiological surveillance is needed to develop effective health protection policies for air pollution. Therefore, administrative agencies should monitor the environment of residential areas, regardless of the socioeconomic level: they should increase the distances of housing from polluting sources to avoid harming health. This study will help governments prevent environmental inequality and control the most contaminated areas using different programmes for environmental discrimination.

What is already known on this subject?

▶ It is important to have as much information as possible about the role of the more important environmental contaminants during pregnancy and childhood in order to understand the effect of air pollution on child health. Socioeconomic inequalities in health are well established, particularly in maternal and child health.

What this study adds?

▶ This study is devoted in clarifying the association between social factors and individual exposure to air pollution in a birth cohort of northern Spain. It explores how the population is distributed with respect to socioeconomic characteristics and their exposure levels to NO_2 and benzene, and analyses the relationship between socioeconomic status and air pollution exposure. This study will help governments to prevent environmental inequality. Different programmes for environmental discrimination can be used to control the most contaminated areas.

CONCLUSIONS

Education and SC are not associated with air pollution exposure. The Administrations should monitor areas close to pollution sources regardless of their social characteristics and prevent settlements at distances that carry a risk to the population's health.

REFERENCES

1 Bell ML, Davis D, Cifuentes L, et al. International expert workshop on the analysis of the economic and public health impacts of air pollution: workshop summary. *Environ Health Perspect* 2002;110:1163–8.
2 Working Group on Public Health and Fossil-Fuel Combustion. Short-term improvements in public health from global-climate policies on fossil-fuel combustion: an interim report. *Lancet* 1997;350:1341–9.
3 Gotschi T, Heinrich J, Sunyer J, et al. Long-term effects of ambient air pollution on lung function: a review. *Epidemiology* 2008;19:690–701.
4 Kunzli N, Kaiser R, Medina S, et al. Public-health impact of outdoor and traffic-related air pollution: a European assessment. *Lancet* 2000;356:795–801.
5 Pope CA III, Dockery DW. Health effects of fine particulate air pollution: lines that connect. *J Air Waste Manag Assoc* 2006;56:709–42.
6 Simkhovich BZ, Kleinman MT, Kloner RA. Air pollution and cardiovascular injury epidemiology, toxicology, and mechanisms. *J Am Coll Cardiol* 2008;52:719–26.
7 Brunekreef B, Holgate ST. Air pollution and health. *Lancet* 2002;360:1233–42.
8 Knox EG. Childhood cancers and atmospheric carcinogens. *J Epidemiol Community Health* 2005;59:101–5.
9 Lacasaña M, Esplugues A, Ballester F. Exposure to ambient air pollution and prenatal and early childhood health effects. *Eur J Epidemiol* 2005;20:183–99.

10 Liu S, Krewski D, Shi Y, *et al*. Association between gaseous ambient air pollutants and adverse pregnancy outcomes in Vancouver, Canada. *Environ Health Perspect* 2003;111:1773–8.

11 Šrám RJ, Binková B, Dejmek J, *et al*. Ambient air pollution and pregnancy outcomes: a review of the literature. *Environ Health Perspect* 2005;113:375–82.

12 Estarlich M, Ballester F, Aguilera I, *et al*. Residential exposure to outdoor air pollution during pregnancy and anthropometric measures at birth in a multicenter cohort in Spain. *Environ Health Perspect* 2011;119:1333–8.

13 Dadvand P, Parker J, Bell ML, *et al*. Maternal exposure to particulate air pollution and term birth weight: a multi-country evaluation of effect and heterogeneity. *Environ Health Perspect* 2013;212:267–373.

14 Brauer M, Hoek G, Van Vliet P, *et al*. Air pollution from traffic and the development of respiratory infections and asthmatic and allergic symptoms in children. *Am J Respir Crit Care Med* 2002;166:1092–8.

15 Aguilera I, Pedersen M, Garcia-Esteban R, *et al*. Early life exposure to outdoor air pollution and respiratory health, ear infections, and eczema in infants from the INMA study. *Health Perspect* 2013;212:387–92.

16 Gomez-Mejiba SE, Zhai Z, Akram H, *et al*. Inhalation of environmental stressors & chronic inflammation: autoimmunity and neurodegeneration. *Mutat Res* 2009;674:62–72.

17 Guxens M, Aguilera I, Ballester F, *et al*. Prenatal exposure to residential air pollution and infant mental development: modulation by antioxidants and detoxification factors. *Environ Health Perspect* 2012;120:144–9.

18 Schwartz J. Air pollution and children's health. *Pediatrics* 2004;113:1037–43.

19 Barker DJ. The fetal and infant origins of adult disease. *BMJ* 1990;301:1111.

20 Grandjean P, Landrigan P. Developmental neurotoxicity of industrial chemicals. *Lancet* 2006;368:2167–78.

21 Patel MM, Miller RL. Air pollution and childhood asthma: recent advances and future directions. *Curr Opin Pediatr* 2009;21:235–42.

22 Gluckman PD, Hanson MA. Living with the past: evolution, development, and patterns of disease. *Science* 2004;305:1733–6.

23 Fernández-Somoano A, Estarlich M, Ballester F, *et al*. Outdoor NO_2 and benzene exposure in the INMA (Environment and Childhood) Asturias cohort (Spain). *Atmos Environ* 2011;45:5240–6.

24 Gouveia N, Fletcher T. Time series analysis of air pollution and mortality: effects by cause, age and socioeconomic status. *J Epidemiol Community Health* 2000;54:750–5.

25 Jerrett M, Burnett RT, Brook J,, *et al* Do socioeconomic characteristics modify the short term association between air pollution and mortality? Evidence from a zonal time series in Hamilton, Canada. *J Epidemiol Community Health* 2004;58:31–40.

26 Lipfert FW. Air pollution and poverty: does the sword cut both ways? *J Epidemiol Community Health* 2004;58:2–3.

27 O'Neill MS, Jerrett M, Kawachi I, *et al*. Health, wealth, and air pollution: advancing theory and methods. *Environ Health Perspect* 2003;111:1861–70.

28 Samet JM, White RH. Urban air pollution, health, and equity. *J Epidemiol Community Health* 2004;58:3–5.

29 Laurent O, Bard D, Filleul L, *et al*. Effect of socioeconomic status on the relationship between atmospheric pollution and mortality. *J Epidemiol Community Health* 2007;61:665–75.

30 Chaix B, Gustafsson S, Jerrett M, *et al*. Children's exposure to nitrogen dioxide in Sweden: investigating environmental injustice in an egalitarian country. *J Epidemiol Community Health* 2006;60:234–41.

31 Næss Ø, Piro FN, Nafstad P, *et al*. Air pollution, social deprivation, and mortality: a multilevel cohort study. *Epidemiology* 2007;18:686–94.

32 Havard S, Deguen S, Zmirou-Navier D, *et al*. Traffic-related air pollution and socioeconomic status: a spatial autocorrelation study to assess environmental equity on a small-area scale. *Epidemiology* 2009;20:223–30.

33 Rotko T, Koistinen K, Hanninen O, *et al*. Sociodemographic descriptors of personal exposure to fine particles (PM2.5) in EXPOLIS Helsinki. *J Expo Anal Environ Epidemiol* 2000;10:385–93.

34 Llop S, Ballester F, Estarlich M, *et al*. Social factors associated with nitrogen dioxide (NO_2) exposure during pregnancy: the INMA-Valencia project in Spain. *Soc Sci Med* 2011;72:890–8.

35 Wheeler BW, Ben-Shlomo Y. Environmental equity, air quality, socioeconomic status, and respiratory health: a linkage analysis of routine data from the Health Survey for England. *J Epidemiol Community Health* 2005;59:948–54.

36 Briggs D, Abellan JJ, Fecht D. Environmental inequity in England: small area associations between socio-economic status and environmental pollution. *Soc Sci Med* 2008;67:1612–29.

37 Stroh E, Oudin A, Gustafsson S, *et al*. Are associations between socio-economic characteristics and exposure to air pollution a question of study area size? An example from Scania, Sweden. *Int J Health Geogr* 2005;4:30.

38 Vrijheid M, Martinez D, Aguilera I, *et al*. Socioeconomic status and exposure to multiple environmental pollutants during pregnancy: evidence for environmental inequity? *J Epidemiol Community Health* 2010;66:106–13.

39 Cesaroni G, Badaloni C, Romano V, *et al*. Socioeconomic position and health status of people who live near busy roads: the Rome Longitudinal Study (RoLS). *Environ Health* 2010;9:41.

40 Forastiere F, Stafoggia M, Tasco C, *et al*. Socioeconomic status, particulate air pollution, and daily mortality: differential exposure or differential susceptibility. *Am J Ind Med* 2007;50:208–16.

41 Hoek G, Brunekreef B, Goldbohm S, *et al*. Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. *Lancet* 2002;360:1203–9.

42 O'Neill MS, McMichael AJ, Schwartz J, *et al*. Poverty, environment, and health: the role of environmental epidemiology and environmental epidemiologists. *Epidemiology* 2007;18:664–8.

43 Buzzelli M. Bourdieu does environmental justice? Probing the linkages between population health and air pollution epidemiology. *Health Place* 2007;13:3–13.

44 Craig L, Brook JR, Chiotti Q, *et al*. Air pollution and public health: a guidance document for risk managers. *J Toxicol Environ Health A* 2008;71:588–698.

45 Mills NL, Donaldson K, Hadoke PW, *et al*. Adverse cardiovascular effects of air pollution. *Nat Clin Pract Cardiovasc Med* 2009;6:36–44.

46 Emenius G, Pershagen G, Berglind N, *et al*. NO_2, as a marker of air pollution, and recurrent wheezing in children: a nested case-control study within the BAMSE birth cohort. *Occup Environ Med* 2003;60:876–81.

47 Gilbert NL, Woodhouse S, Stieb DM, *et al*. Ambient nitrogen dioxide and distance from a major highway. *Sci Total Environ* 2003;312:43–6.

48 Brunekreef B. Health effects of air pollution observed in cohort studies in Europe. *J Expo Sci Environ Epidemiol* 2007;17(Suppl 2):S61–5.

49 World Health Organization (WHO). Air quality guidelines for Europe. *WHO Reg Publ Eur Ser* 2000:V-X,91:1–273.

50 Hoek G, Beelen R, de Hoogh K, *et al*. A review of land-use regression models to assess spatial variation of outdoor air pollution. *Atmos Environ* 2008;42:7561–78.

51 Guxens M, Ballester F, Espada M, *et al*. Cohort profile: the INMA—INfancia y Medio Ambiente—(Environment and Childhood) project. *Int J Epidemiol* 2012;41:930–40.

52 Ribas-Fitó N, Ramón R, Ballester F, *et al*. Child health and the environment: the INMA Spanish study. *Paediatr Perinat Epidemiol* 2006;20:403–10.

53 Esplugues A, Fernández-Patier R, Aguilera I, *et al*. Air pollutant exposure during pregnancy and fetal and early childhood development. Research protocol of the INMA [Childhood and Environment Project]. *Gac Sanit* 2007;21:162–71.

54 Aguilera I, Guxens M, Garcia-Esteban R, *et al*. Association between GIS-based exposure to urban air pollution during pregnancy and birth weight in the INMA Sabadell cohort. *Environ Health Perspect* 2009;117:1322–7.

55 Slama R, Morgenstern V, Cyrys J, *et al*. Traffic-related atmospheric pollutants levels during pregnancy and offspring's term birth weight: a study relying on a land-use regression exposure model. *Environ Health Perspect* 2007;115:1283–92.

56 INE. *Clasificación Nacional de Ocupaciones*. Instituto Nacional de Estadística, 1994.

57 Domingo-Salvany A, Regidor E, Alonso J, *et al*. Proposal for a social class measure. Working Group of the Spanish Society of Epidemiology and the Spanish Society of Family and Community Medicine. *Aten Primaria* 2000;25:350–63.

58 Fernández-Somoano A, Hoek G, Tardón A. The relationship between area-level socio-economic characteristics and outdoor NO_2 concentrations in rural and urban areas of northern Spain. *BMC Public Health* 2013;13:71–81.

59 Maisonet M, Correa A, Misra D, *et al*. A review of the literature on the effects of ambient air pollution on fetal growth. *Environ Res* 2004;95:106–15.

60 Salam MT, Millstein J, Li YF, *et al*. Birth outcomes and prenatal exposure to ozone, carbon monoxide, and particulate matter: results from the Children's Health Study. *Environ Health Perspect* 2005;113:1638–44.

61 Leem JH, Kaplan BM, Shim YK, *et al*. Exposures to air pollutants during pregnancy and preterm delivery. *Environ Health Perspect* 2006;114:905–10.

62 Ritz B, Wilhelm M, Hoggatt KJ, *et al*. Ambient air pollution and preterm birth in the environment and pregnancy outcomes study at the University of California, Los Angeles. *Am J Epidemiol* 2007;166:1045–52.

63 Gouveia N, Bremner SA, Novaes HMD. Association between ambient air pollution and birth weight in Sao Paulo, Brazil. *J Epidemiol Community Health* 2004;58:11–17.

64 Maisonet M, Bush TJ, Correa A, *et al*. Relation between ambient air pollution and low birth weight in the northeastern United States. *Environ Health Perspect* 2001;109:351–6.

65 Mannes T, Jalaludin B, Morgan G, *et al*. Impact of ambient air pollution on birth weight in Sydney, Australia. *Occup Environ Med* 2005;62:524–30.

66 Ritz B, Wilhelm M, Zhao Y. Air pollution and infant death in Southern California, 1989–2000. *Pediatrics* 2006;118:493–502.

67 Goodman A, Wilkinson P, Stafford M, *et al*. Characterising socio-economic inequalities in exposure to air pollution: a comparison of socio-economic markers and scales of measurement. *Health Place* 2011;17:767–74.

68 Leeuwen Cv, Vermeire T. *Risk assessment of chemicals—an introduction 2007*.

69 Block ML, Calderon-Garciduenas L. Air pollution: mechanisms of neuroinflammation and CNS disease. *Trends Neurosci* 2009;32:506–16.

70 Aguilera I, Sunyer J, Fernández-Patier R, *et al*. Estimation of outdoor NO_x, NO_2, and BTEX exposure in a cohort of pregnant women using land use regression modeling. *Environ Sci Technol* 2008;42:815–21.

71 Henderson SB, Beckerman B, Jerrett M, *et al*. Application of land use regression to estimate long-term concentrations of traffic-related nitrogen oxides and fine particulate matter. *Environ Sci Technol* 2007;41:2422–8.

72 Iñiguez C, Ballester F, Estarlich M, *et al*. Estimation of personal NO_2 exposure in a cohort of pregnant women. *Sci Total Environ* 2009;407:6093–9.

73 Sahsuvaroglu T, Arain A, Kanaroglou P, *et al*. A land use regression model for predicting ambient concentrations of nitrogen dioxide in Hamilton, Ontario, Canada. *J Air Waste Manag Assoc* 2006;56:1059–69.

74 Eeftens M, Beelen R, Fischer P, *et al*. Stability of measured and modelled spatial contrasts in NO_2 over time. *Occup Environ Med* 2011;68:765–70.

75 Parra MA, Elustondo D, Bermejo R, *et al*. Ambient air levels of volatile organic compounds (VOC) and nitrogen dioxide (NO_2) in a medium size city in northern Spain. *Sci Total Environ* 2009;407:999–1009.

76 Parra MA, González L, Elustondo D, *et al*. Spatial and temporal trends of volatile organic compounds (VOC) in a rural area of northern Spain. *Sci Total Environ* 2006;370:157–67.