NATIONAL CENTER FOR
ENVIRONMENTAL ECONOMICS

# Comparing exposure metrics in the relationship between $PM_{2.5}$ and birth weight in California

Rupa Basu, Tracey J. Woodruff, Jennifer D. Parker, Louise Saulnier, Katherine Heck, Kenneth C. Schoendorf

Working Paper Series

Working Paper # 03-08
November, 2003

U.S. Environmental Protection Agency
National Center for Environmental Economics
1200 Pennsylvania Avenue, NW (MC 1809)
Washington, DC 20460
http://www.epa.gov/economics

# Comparing exposure metrics in the relationship between $PM_{2.5}$ and birth weight in California

Rupa Basu, Tracey J. Woodruff, Jennifer D. Parker, Louise Saulnier,
Katherine Heck, Kenneth C. Schoendorf

Correspondence:

Rupa Basu
U.S. Environmental Protection Agency
1200 Pennsylvania Ave., NW (1809T)
Washington, DC 20460
phone: (202) 566-2362
basu.rupa@epa.gov

NCEE Working Paper Series

Working Paper # 03-08
November, 2003

# Comparing exposure metrics in the relationship between $PM_{2.5}$ and birth weight in California

Rupa Basu[1], Tracey J. Woodruff[1], Jennifer D. Parker[2], Louise Saulnier[2], Katherine Heck[2], Kenneth C. Schoendorf[2]

ABSTRACT

Although studies suggest that air pollution is linked to perinatal outcomes, the geographic characterization of exposure to pollution differs between the studies. Thus, we compared neighborhood and county-level measures of air pollution exposure, while examining the association between particulate matter less than 2.5 micrometers in aerodynamic diameter ($PM_{2.5}$) and birth weight among full-term births in California in 2000. Our analysis was limited to two populations of 8,579 non-Hispanic white and 8,114 Hispanic mothers who were married, between 20 and 30 years of age, completed at least a high school education, and gave birth for the first time to reduce the effects of demographic variability. Measurements from the nearest monitor, average and distance-weighted average of monitors within a five-mile radius from each mother's residence (defined as neighborhood metrics) and the mean of monitors within each mother's county of residence were considered. $PM_{2.5}$ measurements, provided by the California Air Resources Board, were calculated to correspond to each mother's nine-month gestation period. Although metrics within the five-mile radii and the county were highly correlated ($r^2$ = 0.78), the county-level metric provided a stronger association between $PM_{2.5}$ and birth weight (beta = -4.04, 95% confidence interval = -6.71, -1.37) than the metric for the average of all monitors within five-miles (beta = -1.38, 95% confidence interval = -3.36, 0.60) among non-Hispanic white mothers; similar results were observed among the Hispanic sample of mothers. Consequently, inferences from studies using different definitions of air pollution exposure may not be comparable.

Keywords: air pollution, birth outcomes, birth weight, fine particulate matter, metrics, $PM_{2.5.}$

Subject area classifications: air pollution (4), exposure assessment (68)

[1] US Environmental Protection Agency, National Center for Environmental Economics, Washington, DC 20460.
[2] National Center for Health Statistics, Centers for Disease Control and Prevention, Hyattsville, MD 20782.

## INTRODUCTION

Previous studies have suggested an association between air pollutants and adverse birth outcomes, including low birth weight, pre-term delivery, and infant mortality [1-12]. Although the biological mechanism remains unknown, particulate matter may have systemic influences among pregnant women, including effects on placental development or trans-placental effects, that may result in adverse birth outcomes[13]. Prior analyses indicate that particulate matter with less than ten micrometers in aerodynamic diameter ($PM_{10}$) may be associated with pre-term birth in southern California[4]; in the Czech Republic, exposure to high levels of $PM_{10}$ and particulate matter with less than 2.5 micrometers in aerodynamic diameter ($PM_{2.5}$) were found to reduce intrauterine growth[9]. $PM_{2.5}$ appears to be the more potent portion of the particulate matter mixture, resulting in different adverse health risks than those from exposure to $PM_{10}$ or coarse particles ($PM_{10}$-$PM_{2.5}$)[14,15]. Furthermore, $PM_{2.5}$ offers a measure for pollutant exposure with relatively high correlations between ambient and indoor concentrations[16].

The air pollution exposure measures in previous research of perinatal outcomes vary by study, and may affect the resulting inferences. The majority of studies used ecologic averages as measured in a city, county, or other large geographic area, as a proxy for personal exposures [1-8]. The ecologic air pollution measure assumes that all individuals who are in a specified geographic area experience the same levels of exposures. While ecologic exposures are more easily obtained with low costs to investigators, some degree of misclassification of individual exposure is expected, as personal exposures vary within a city or a county. The degree of misclassification of ecologic exposures and comparability of various metrics is unknown, and depends on the correlation between the ecologic measures and microenvironmental models, which defines personal exposure as the time-weighted sum of the pollutant concentrations in places where each individual spends his/her time [17]. The difficulty, expense, and confidentiality concerns associated with linking local air quality data to individual addresses limit the utility of pollution data from smaller geographic areas. Few studies have relied on air pollution exposures based on zip codes or neighborhood monitors[2,4,10,11]. Prior investigators have not analyzed various air pollution exposure metrics in relation to perinatal outcomes to assess whether the resulting inferences are comparable.

Thus, the primary objective of our study was to compare neighborhood-level (e.g., within a five mile radius from each mother's residence) and county-level metrics in the association between $PM_{2.5}$ and birth weight. Small differences between the results from the neighborhood and county-level metrics would suggest consistency in the conclusions from studies using different exposure measures, while larger differences would suggest that the geographic specificity of exposures need to be considered in evaluating the studies.

## METHODS

### Study Population

Singleton births with gestation periods between 37 and 44 weeks born from 1 January 2000 to 31 December 2000 in the state of California were eligible for inclusion in this study (n = 423,238 births). Our study was limited to mothers living in 40 counties in California that recorded $PM_{2.5}$ measurements. Of these, only mothers who had monitors within five miles of their residences and at least one monitor in the county of their residences were included (n = 197,100 births). Because we limited the study to births within five miles of a monitor, births in urban areas comprise 99.4% of our eligible study population.

To account for demographic variability and minimize potential confounding by socioeconomic status on the association between $PM_{2.5}$ and birth weight, we limited our analysis to two sample sub-populations: non-Hispanic white (n = 8,579) and Hispanic (n = 8,114) women who were married, between 20 and 30 years of age, completed at least a high school education, and gave birth for the first time. This selection allowed for a more accurate comparison of exposure metrics by using relatively homogeneous study populations, while representing the two largest racial/ethnic groups of births in California.

Data Sources

Birth weight and several maternal characteristics, including marital status, maternal age, racial/ethnic group, educational attainment, and parity, were obtained from birth certificates registered in California in 2000. The California Air Resources Board provided 24-hour average $PM_{2.5}$ data every sixth day from monitors in California in 1999 and 2000.

Statistical Methods

Using specific latitude and longitude locations for both mothers' residences and air pollution monitors in 1999 and 2000, we identified $PM_{2.5}$ monitors within a five-mile radius of each mother's residence as neighborhood monitors, and compared them to monitors corresponding to each mother's county of residence. The mothers' residences were defined as their residences at the time of giving birth. We used the same births for analysis in our comparison of estimates of $PM_{2.5}$ exposure from metrics within five miles of each mother's residence to estimates from county-level data. $PM_{2.5}$ exposure measures were estimated for the entire gestation period of each birth, consisting of a mean of all available measurements taken from the date of birth to exactly nine months previous to the birth. Monitors that recorded representative concentrations of $PM_{2.5}$ exposure with values for at least 75% of the days that the monitor was scheduled to take measurements during the nine-month averages were included in our study (n = 84 monitors with at least 34 measurements per monitor). Measurements within the top and bottom fifth percent of the residuals of the means for each monitor were excluded to eliminate outliers that may have been caused by error or were not representative of the overall measurements.

Four $PM_{2.5}$ metrics corresponding to the nine-month average of exposure for each mother in the analysis were defined as follows: 1) mean of the measurements collected from the nearest monitor within a five-mile radius of the mother's residence; 2) mean of the measurements collected from each monitor within a five-mile radius of the mother's residence; 3) distance-weighted mean of the measurements collected from each monitor within a five-mile radius of the mother's residence; and 4) mean of the measurements from all monitors in each mother's county of residence. The distance-weighted mean was based on weights inversely proportional to the square of the distance from the mother's residence to the monitor. Since eighty-nine percent of non-Hispanic white and Hispanic mothers considered in this study had a single monitor within five miles of her residence, the five-mile exposure measurements for these mothers were essentially identical, regardless of weighting criteria used.

Data Analysis

First, we calculated the correlation coefficients between the five-mile and county-level metrics of exposure to $PM_{2.5}$ separately in the non-Hispanic white and Hispanic sample populations. Next, we compared the relationships between each exposure metric and birth weight using univariate linear regression models (proc reg in SAS Software)[18], keeping both $PM_{2.5}$ and birth weight continuous. Linear regression was justified since we evaluated two subset populations, with similar demographic characteristics. Each beta coefficient corresponds to the average change in birth weight in grams associated with each $\mu g/m^3$ increase in $PM_{2.5}$ for the specified sample population.

To evaluate exposure metrics using monitors closer to the maternal residences in an effort to better characterize neighborhood monitors, we repeated the analyses in both subset populations with mothers who had monitors within a one-mile radius of their residences as a sensitivity analysis of the neighborhood metrics (n = 796 non-Hispanic white births; n = 787 Hispanic births).

RESULTS

Our analysis included two sample populations of 8,579 non-Hispanic white births and 8,114 Hispanic births who had both $PM_{2.5}$ monitors within five miles of their residences and county-monitored data at the time of giving birth. As shown in Table 1, the means for measurements calculated for monitors within five miles and by county were similar, with an overall range of $PM_{2.5}$ exposure nearly the identical for the sample of non-Hispanic white and Hispanic populations (approximately 4 $\mu g/m^3$ to 34 $\mu g/m^3$). The $PM_{2.5}$ metrics calculated using monitors within a five-mile radius were highly correlated among the non-Hispanic white births ($r^2$ = 0.98-99), with very similar correlations found for the sample of Hispanic births ($r^2$ = 0.97-0.99). The high correlation between the five-mile metrics can be attributed to the substantial overlap between the data used to calculate each measure; among the non-Hispanic white births, 7,661 births had only one monitor within five miles, 915 births had two monitors, and only three births had three monitors within five miles. Similarly, only 921 (11%) of the Hispanic births had more than one monitor within five miles. Compared to the correlation between the metrics within five miles, a relatively lower correlation was found between the five-mile metrics and the county-level metric ($r^2$ = 0.77-0.78), and the correlation was still very high in non-urban areas ($r^2$ = 0.93). Among births with two or more monitors available within five miles (Table 2), the five-mile metrics were still highly correlated with each other as well as with the county metric.

Because the three metrics of $PM_{2.5}$ exposure derived from monitors within a five-mile radius were identical in most locations, the betas and corresponding 95% confidence intervals are depicted for the average of measurements from all monitors within five miles to represent the neighborhood exposure metric in the following tables and figures. As shown in Figure 1[19], the county-level data produced a stronger negative association than the neighborhood-monitored data for both the non-Hispanic white [five miles: beta=-1.52 (95% confidence interval: -3.52, 0.48), county: beta=-4.04 (-6.71, -1.37)] and Hispanic sample populations [five miles: beta = -2.49 (-4.53, -0.45), county: –4.35 (-7.47, -1.23)]. The estimates found for the Hispanic population suggest a slightly stronger association between $PM_{2.5}$ and birth weight compared to those found for the non-Hispanic white population.

Monitors within a one-mile radius from the mother's residence had similar ranges and correlations to monitors within a five-mile radius (Table 1). As depicted in Figure 2, the county-level metric resulted in stronger associations between $PM_{2.5}$ and birth weight than the metric corresponding to monitors within one-mile of the mother's residence in both sample populations [non-Hispanic white one mile: -6.37 (-13.05, 0.31), county: -9.44 (-17.97, -0.91); Hispanic one mile: -1.37 (-7.31, 4.57), county: -4.06 (-12.29, 4.17)]. Although stronger associations were found for the non-Hispanic white population compared to the Hispanic population, the neighborhood metrics within a one-mile radius and the average within a five-mile radius had more similar associations with each other compared to those found for the county-level metrics. Because of the relatively small number of births with a monitor available within a one-mile radius (less than 800 births for each subset population), large confidence intervals surround the beta estimates.

We further investigated the difference in the beta estimates found for the $PM_{2.5}$-birth weight association between the neighborhood and county-monitored data. For the county-level analysis, we conducted separate regression models deleting the data for one county each time, to assess whether an individual county overwhelmingly influenced the overall beta coefficient for the county metric. We also evaluated the regression coefficients by fitting another model after eliminating the three counties with the largest variances in monitor measurements to observe whether these counties may have biased the $PM_{2.5}$-birth weight relationship. These analyses produced beta coefficients near the original beta coefficient for both the neighborhood and county level metrics (not shown).

## DISCUSSION

The primary purpose of our study was to compare neighborhood and county-level $PM_{2.5}$ exposure metrics to distinguish whether the results of studies using different air pollution metrics are comparable. We first evaluated several approaches for estimating $PM_{2.5}$ exposures using measurements from monitors within five miles of each residence. Next, we examined associations using the exposure variables based on measurements within five-miles of each mother's residence to those recorded for the entire county. Similar correlations and beta coefficients were produced for monitored data within five miles of the mothers' residences, including the nearest monitor, average of monitors, and distance-weighted average of monitors and the county monitors. Since 89% of the neighborhood metrics were based on only one monitor, it is not necessary to take averages of air pollutants within short distances (e.g., five-mile radius). As we did not address this question for larger geographic areas, it is unclear whether distance-weighting or averaging would change the results.

We did not have enough births within one mile in our sample populations to conduct a thorough examination of a narrower definition of neighborhood monitors, evident from the large uncertainty surrounding the beta estimates for the analysis within one-mile (Figure 2). After examining associations between $PM_{2.5}$ exposure and birth weight among births linked to a monitor within one mile, and comparing those associations to the corresponding associations based on the five-mile and county-level metrics, we found consistent evidence that exposure based on county-level monitors produced stronger associations than the metrics defined by neighborhood monitors. Furthermore, the similarity of the differences between the neighborhood metric, regardless of whether the one-mile and five-mile metrics were used, and the county-level metric indicated that the five-mile exposure measure was adequate to capture the effect of neighborhood data. The actual beta estimates from the populations within one mile, however, were different than those produced within five miles. Furthermore, the associations within one mile were stronger for the non-Hispanic white population than the Hispanic population, contradicting what we observed for the comparison with more births and a broader definition of neighborhood monitors in the five-mile metrics. Inferences from the estimates within a one-mile radius may, therefore, be less generalizable to other study areas.

Previous investigators have not focused on the variations by geographic specificity in the assessment of air pollution exposure and adverse birth outcomes, although they have compared correlations between multiple monitors using other health outcomes. In New York City, for example, measurements of sulfur dioxide at one aerometric monitoring station was not found to be representative of overall exposure in the city in studies of acute effects[20,21]. Another study examining monitor-to-monitor correlations in the North-Central U.S. reported that correlations varied by location for $PM_{10}$, gaseous criteria pollutants, and several weather variables[22].

This study had several limitations that should be considered in interpreting the results. We could not distinguish between the five-mile metrics to enable a full assessment of the proposed neighborhood metrics because of the large overlap of values of monitors within five miles. Since a relationship between $PM_{2.5}$ and birth weight has not been established from previous studies, it is unclear whether neighborhood or county-level data better predict personal exposures for the $PM_{2.5}$-birth weight association. The exposures based on the county monitors may be more representative of actual maternal exposure, since using monitored data closer to a mother's residence assumes that she generally spends most of her time at or near her home, which is unlikely. Nearest-monitored data relevant to each mother's workplace or elsewhere were not available. In addition, exposure was characterized according to the residence of each mother at the time of giving birth, and we could not consider exposures based on the possibility of changing residences during the pregnancy. After defining our relatively homogeneous sample populations, we could not further control for additional potential confounders of the $PM_{2.5}$-birth weight relationship not provided in the California birth certificate data; however, since we do not expect the effect of potential confounders, such as maternal smoking, to be different between the neighborhood and county $PM_{2.5}$ exposure measures, our conclusions should remain unchanged.

Although the main objective of our study was not to quantify the association between $PM_{2.5}$ and birth weight, the methods and results can be used to refine our understanding of the relationship in future studies. We will use the average metric within five miles to expand our analyses of $PM_{2.5}$ and birth weight and other perinatal outcomes, in addition to examining metrics for other air pollutants, such as carbon monoxide. Furthermore, we will examine exposures by trimesters and other relevant exposure windows to more closely evaluate the associations between air pollutants and adverse birth outcomes. Other states that can provide neighborhood and county-level air pollution data will also be considered in future analyses, although California has a greater density of neighborhood monitors to capture residential air pollutant levels.

In summary, we were able to compare several exposure metrics for $PM_{2.5}$, since neighborhood and county-level data for mothers who gave birth in California in 2000 were available. We were able to examine two subsets of births in California that were relatively homogeneous, therefore reducing the effect of confounding from demographic variability and socioeconomic status. We found a difference between the estimates produced by the neighborhood and county-level metrics; the county monitors produced consistently stronger negative associations than the neighborhood monitors in the relationship between $PM_{2.5}$ and birth weight. This result was replicated in both the sample non-Hispanic white and Hispanic populations in the original analysis comparing metrics within a five-mile radius and county-level data (Figure 1) as well as in the analysis for data within a one-mile radius (Figure 2). Therefore, associations between $PM_{2.5}$ and birth weight may depend on the geographic area used to define $PM_{2.5}$ exposure. Alternatively, there may be another explanation for the observed differences between the exposure measures that we have not considered. We do not know whether neighborhood or county-level data better depict personal exposures. However, inferences from studies using various approaches for estimating pollutant exposure may not be comparable.

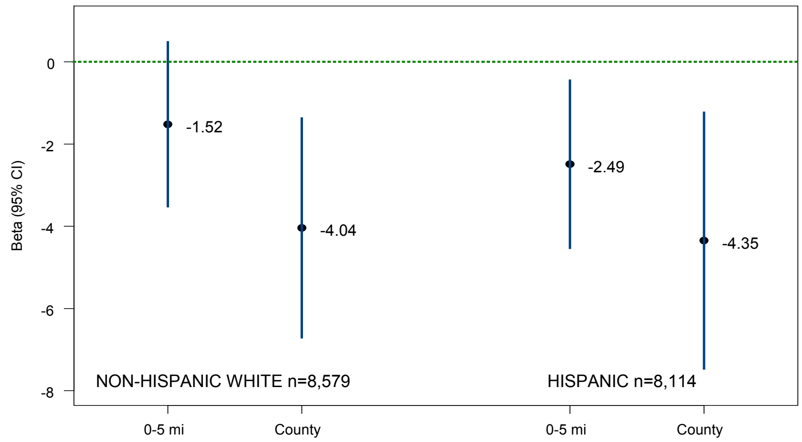
TABLE 1: Distribution of $PM_{2.5}$ ($\mu g/m^3$) exposure metrics in California, 2000

| Exposure Metric | NON-HISPANIC WHITE n = 8,579 Mean (SD) | Range | HISPANIC n = 8,114 Mean (SD) | Range |
|---|---|---|---|---|
| Average monitors 0-5 miles | 15.8 (4.9) | 4.4, 34.1 | 18.2 (5.0) | 4.6, 33.9 |
| County monitors | 15.6 (3.7) | 4.6, 26.3 | 16.9 (3.3) | 4.6, 26.3 |
| Monitor 0-1 mile | 14.5 (5.3)<br>n = 796 | 4.4, 32.4 | 16.4 (5.4)<br>n = 787 | 5.9, 33.7 |

TABLE 2: Correlation coefficients ($r^2$) between $PM_{2.5}$ ($\mu g/m^3$) metrics within five miles and county averages for births with more than one monitor within five miles

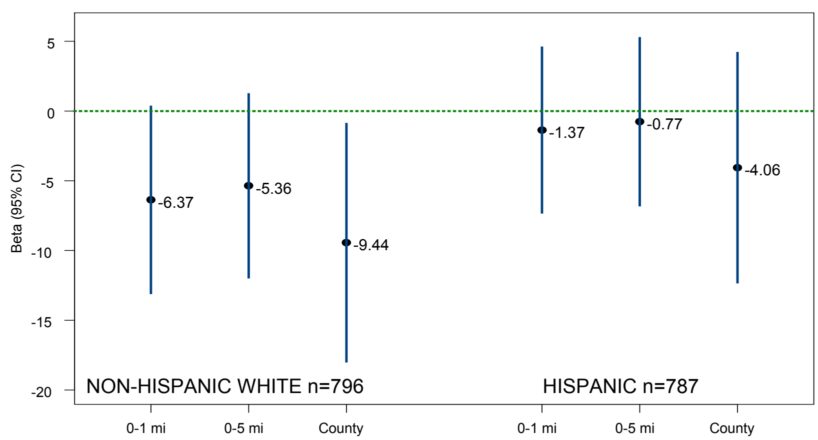
| | NON-HISPANIC WHITE (n = 918) | | | | HISPANIC (n =921) | | | |
|---|---|---|---|---|---|---|---|---|
| | Nearest | Average | Wt Avg | County | Nearest | Average | Wt Avg | County |
| Nearest | 1.0 | - | - | - | 1.0 | - | - | - |
| Average | 0.90 | 1.0 | - | - | 0.92 | 1.0 | - | - |
| Wt Avg | 0.97 | 0.96 | 1.0 | - | 0.98 | 0.96 | 1.0 | - |
| County | 0.81 | 0.91 | 0.86 | 1.0 | 0.85 | 0.92 | 0.88 | 1.0 |

FIGURE 1: Beta coefficients* and 95% confidence intervals between $PM_{2.5}$ ($\mu g/m^3$) metrics and birth weight (grams) in California, 2000




* Each beta coefficient represents the average change in birth weight in grams associated with one $\mu g/m^3$ increase in $PM_{2.5}$ in the specified population.
0-5 mi: average of measurements from monitors within a five-mile radius
County: average of monitor-specific measurements within each county

FIGURE 2: Beta coefficients* and 95% confidence intervals between $PM_{2.5}$ ($\mu g/m^3$) metrics and birth weight (grams) for births with mothers' residences within one mile of a monitor in California, 2000




* Each beta coefficient represents the average change in birth weight in grams associated with one $\mu g/m^3$ increase in $PM_{2.5}$ in the specified population.
0-1 mi: measurement from nearest monitor within a one-mile radius
0-5mi: average of measurements from monitors within a five-mile radius
County: average of monitor-specific measurements within each county

REFERENCES


1. Ha EH, Hong YC, Lee BE, Woo BH, Schwartz J, Christiani DC. Is air pollution a risk factor for low birth weight in Seoul? Epidemiology 2001;12(6):643-8.
2. Alderman BW, Baron AE, Savitz DA. Maternal exposure to neighborhood carbon monoxide and risk of low infant birth weight. Public Health Rep 1987;102(4):410-4.
3. Bobak M, Richards M, Wadsworth M. Air pollution and birth weight in Britain in 1946. Epidemiology 2001;12(3):358-9.
4. Ritz B, Yu F, Chapa G, Fruin S. Effect of air pollution on preterm birth among children born in Southern California between 1989 and 1993. Epidemiology 2000;11(5):502-11.
5. Rogers JF, Thompson SJ, Addy CL, McKeown RE, Cowen DJ, Decoufle P. Association of very low birth weight with exposures to environmental sulfur dioxide and total suspended particulates. Am J Epidemiol 2000;151(6):602-13.
6. Wang X, Ding H, Ryan L, Xu X. Association between air pollution and low birth weight: a community- based study. Environ Health Perspect 1997;105(5):514-20.
7. Woodruff TJ, Grillo J, Schoendorf KC. The relationship between selected causes of postneonatal infant mortality and particulate air pollution in the United States. Environ Health Perspect 1997;105(6):608-12.
8. Maisonet M, Bush T, Correa A, Jaakkola J. Relation between ambient air pollution and low birth weight in the northeastern United States. Environ Health Perspect 2001;109(Supplement 3):351-356.
9. Dejmek J, Selevan SG, Benes I, Solansky I, Sram RJ. Fetal growth and maternal exposure to particulate matter during pregnancy. Environ Health Perspect 1999;107(6):475-80.
10. Ritz B, Yu F. The effect of ambient carbon monoxide on low birth weight among children born in southern California between 1989 and 1993. Environ Health Perspect 1999;107(1):17-25.

11. Ritz B, Yu F, Fruin S, Chapa G, Shaw GM, Harris JA. Ambient Air Pollution and Risk of Birth Defects in Southern California. Am J Epidemiol 2002;155(1):17-25.

12. Ha EH, Lee JT, Kim H, Hong YC, Lee BE, Park HS, Christiani DC. Infant susceptibility of mortality to air pollution in Seoul, South Korea. Pediatrics 2003;111(2):284-90.

13. Perera FP, Jedrychowski W, Rauh V, Whyatt RM. Molecular epidemiologic research on the effects of environmental pollutants on the fetus. Environ Health Perspect 1999;107 Suppl 3:451-60.

14. Cifuentes LA, Vega J, Kopfer K, Lave LB. Effect of the fine fraction of particulate matter versus the coarse mass and other pollutants on daily mortality in Santiago, Chile. J Air Waste Manag Assoc 2000;50(8):1287-98.

15. Schwartz J, Neas LM. Fine particles are more strongly associated than coarse particles with acute respiratory health effects in schoolchildren. Epidemiology 2000;11(1):6-10.

16. U.S. Environmental Protection Agency. Air Quality Criteria for Particulate Matter. Research Triangle Park, NC, 1996.

17. Committee on Advances in Assessing Human Exposure to Airborne Pollutants NRCN. Human exposure assessment for airborne pollutants: advances and opportunities. National Academy Press, 1991.

18. SAS Institute I. SAS Statistical Software: Version 8.0. Cary, NC. 2000.

19. MathSoft Engineering & Education I. S-PLUS Version 2000. Cambridge, MA. 2000.

20. Goldstein IF. Exposure data for the study of acute health effects of air pollution. Rev Environ Health 1979;3(1):97-111.

21. Goldstein IF, Fleiss JL, Goldstein M, Landovitz L. Methodological problems arising from the choice of an independent variable in linear regression, with application to an air pollution epidemiological study. Environ Health Perspect 1979;32:311-5.

22. Ito K, Thurston GD, Nadas A, Lippmann M. Monitor-to-monitor temporal correlation of air pollution and weather variables in the North-Central U.S. J Expo Anal Environ Epidemiol 2001;11(1):21-32.