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VARIATIONS IN PM-10 CONCENTRATIONS WITHIN TWO METROPOLITAN AREAS AND THEIR IMPLICATIONS FOR HEALTH EFFECTS ANALYSES

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Temporal variations of PM-10 levels at multiple sites between 1985 and 1990 in two major metropolitan areas, Cook County, IL, and Los Angeles County, CA, were characterized, and sensitivity of mortality–PM-10 associations to the choice of alternate sites was examined. In both cities, the correlation of PM-10 levels among multiple sites decreased as their distance increased. While averaging PM-10 concentrations over multiple sites generally improved the significance of PM-10–mortality associations, the highest PM-10–mortality association in Cook County was found for an individual site. In Cook County, the magnitude of the mortality association for the average of 6 PM-10 sites, as expressed as "relative risk" per 100 μg/m³ PM-10, was similar (RR = 1.06, 95% CI 1.01–1.10) to those reported in other PM-10 studies with similar model specifications. However, the significance of regression coefficients for individual PM-10 sites varied considerably (t ratios range –0.62 to 3.30). Furthermore, every-6-days subsamples of the daily data at a site in Cook County showed a wide range in the significance of regression coefficients (t ratios range –0.17 to 3.44). This variability of significance among the six sites may be partly due to their small sample sizes (n ≈ 300), which raises concern regarding the potential for compromised statistical power of health effects analyses in "short" study periods (<6 yr) at the current every-6-days sampling frequency used for most PM-10 monitors in the United States. Also, the qualitative site information available, such as land use, location setting, and monitoring objective, did not show any coherent influence on the site's PM-10–mortality association's significance. Overall, it was found that the choice of PM-10 sites and sampling frequency can make a substantial difference in the calculated significance of such health effects time-series analysis.

Recent time-series epidemiological studies have reported associations over time between PM-10 and mortality in various U.S. cities. Pope et al. (1992) found significant increases in mortality associated with daily PM-10 levels measured at a single site in Utah Valley during the period 1985–1989. Dockery et al. (1992) found a significant association between PM-10 measured at a single site in St. Louis, MO, and the total nonaccidental mortality for the entire Metropolitan Statistical Area (MSA); they also reported a similar magnitude of association between PM-10 levels monitored at a sta-

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tion in Harriman, TN, and the mortality of surrounding counties during the 1985–1986 study period. Schwartz (1993) reported an association between mortality in metropolitan Birmingham, AL, and the average of PM-10 measured at two sites (single site in 1985–1986; two sites in 1987–1988). In these studies, the PM-10 concentrations analyzed were either from a single site or the average of two stations.

Health effects outcomes such as mortality or morbidity are usually aggregated for a boundary (e.g., county, city, etc.) that has uneven population densities in relation to air monitoring stations. PM-10 monitoring stations are not necessarily located to represent exposure within such a boundary. To further complicate the problem, levels of PM-10, a chemically nonspecific pollution index, can be more strongly influenced by local sources than regional secondary pollutants, such as sulfates. Thus, errors involved in the representativeness of population exposure covering a large area are inevitable if a single or just a few PM-10 stations are used for health-related exposure analyses. When measurement errors are random, they are assumed to bias the regression coefficient and correlation coefficient of a health effects/pollution relationship downward (Snedecor & Cochran, 1980). However, the extent of such bias has not been quantified in past analyses, nor has it been clarified that measurement errors are in fact random, rather than systematic, probably due to the lack of data for multiple sites.

In this study, the variabilities of PM-10 concentration at multiple sites in two large metropolitan areas, Los Angeles County, CA, and Cook County, IL, were characterized, and each individual site, as well as the average of multiple sites, was examined for associations with daily mortality of entire MSA areas.

DATA AND METHODS

Daily deaths for Los Angeles County and Cook County were obtained from the National Center for Health Statistics for the period 1985–1990. Los Angeles County had the nation's largest population (8.3 million people) in 1986, and Cook County had the second largest (5.3 million people) (U.S. Bureau of the Census, 1988). Accidental deaths (International Classification of Diseases Codes ≥800) and deaths that occurred outside of each county of residence were excluded from this analysis.

Pollution data were obtained from U.S. Environmental Protection Agency's Aerometric Information Retrieval System (AIRS). The emphasis of this study is on the variabilities of PM-10 levels at multiple monitoring sites, but hourly carbon monoxide (CO) and ozone (O_3) observations were also obtained as reference pollution variables for health effects analysis. The averages of daily maximum 1-h values of multiple CO sites (9 for Los Angeles and 3 for Cook County) and O_3 sites (8 for Los Angeles and 5 for

Cook County) were then used for the analysis. In order to have a "sufficient" sample size for the analysis, the sites that had more than 4 yr, out of the 6-yr study period, were used for the analysis. The application of this criterion resulted in four PM-10 sites for Los Angeles, and six PM-10 sites in Cook County. The hourly surface observations of meteorological parameters for Los Angeles Airport and Cook County's O'Hare Airport were obtained from the National Climatic Data Center.

Each site was identified on the map, based on the address and latitude/longitude provided by the AIRS database, and the distance between each pair of sites was computed. While the database also provided qualitative site information such as adjacent land use, location setting, etc., this information was not used to exclude any site from this analysis, but rather used to aid in the interpretation of results. First the site-to-site correlation was computed, and its dependency on the intervening distance was examined. Second, each site's time-series was regressed on (1) seasonal cycles (sine/cosine with periodicities of 2 yr, 1 yr, 6 mo, 1 mo), (2) day-of-week dummy variables, and (3) a linear trend. This was done in order to examine the extent to which each component of the variation contributed to the difference/similarity among the time series at the PM-10 sites.

While the dependency on these three factors may explain differences in the temporal fluctuations of PM-10 levels observed within a metropolitan area, these factors are "controlled" in most health effects analyses either by including the factors as dependent variables in the regression of health effect outcome on pollution or by removing them (via regression) from dependent and independent variables prior to the regression or correlation analysis. Therefore, the sensitivity of using different PM-10 sites in mortality analysis was examined via two approaches: (1) correlation analysis after removal of trends from both pollution and mortality, and (2) Poisson regressions of mortality on pollution and trends. In assessing the correlation between the pollutants and mortality, cross-correlation (correlation with lagged days) was also examined to identify the temporal lag structure of the association.

In addition to each individual PM-10 site data, two possible types of averages of PM-10 site data were computed: (1) average of all sites, as available, and (2) average of all sites after each site's missing values had been filled in by regressing the site on the rest of the sites' data, where available. The first average can be strongly influenced by a single site's levels when the other sites are missing, whereas the second average is, in effect, weighted to account for the average difference among sites even on days when only single site values are available.

Since a daily, rather than every-6-days, sampling schedule was in effect at one of the Cook County sites, 6 every-6-days subsamples of this series were analyzed, in order to examine any possible effect of every-6-days subsamples versus daily samples.

RESULTS

Figure 1 shows the temporal fluctuations of two of the selected PM-10 sites in Los Angeles and Cook County. The Azusa site has the strongest seasonal (long-wave) component, which peaks in the summertime. The Long Beach site's seasonal trend peaks in the wintertime. The high short-term peaks tend to occur in the wintertime in all Los Angeles sites with the exception of Azusa, where they can also occur in late summer. In contrast

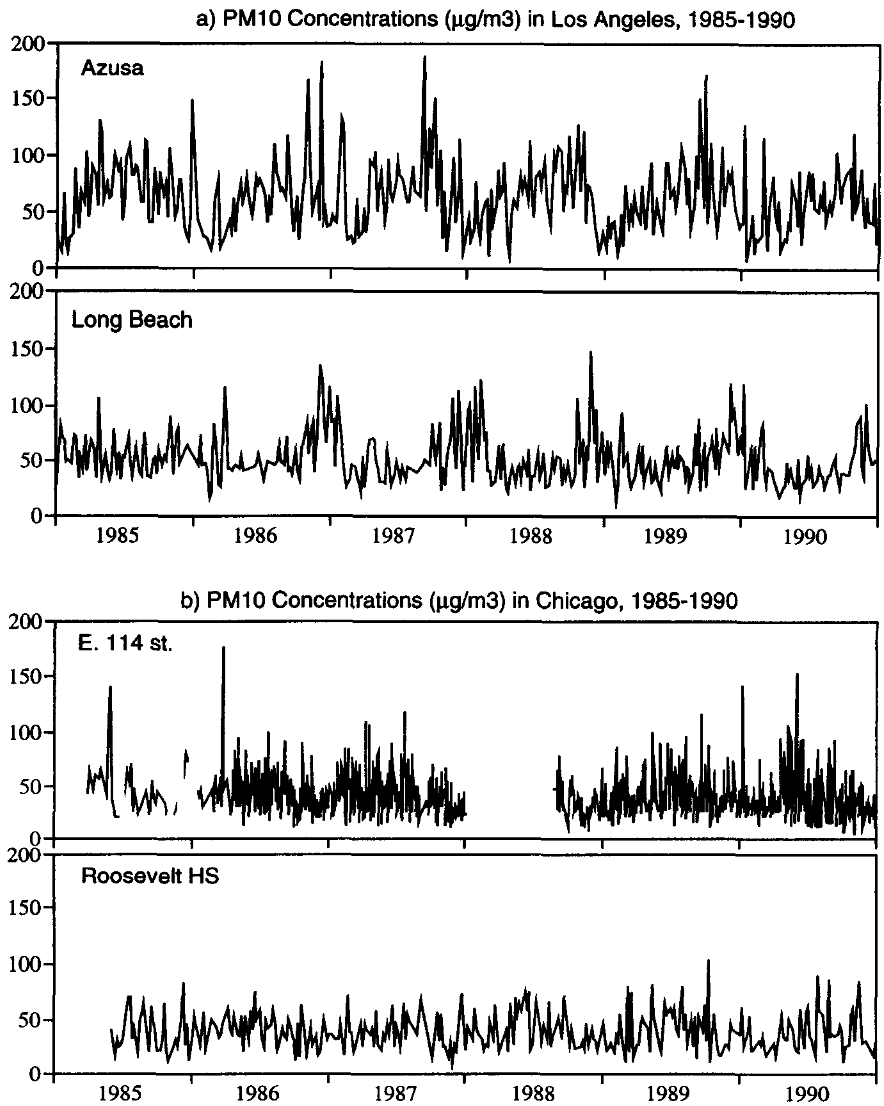

FIGURE 1. Time-series plots of Los Angeles and Cook County PM-10 levels at selected sites. (a) PM-10 concentrations ($\mu g/m^3$) in Los Angeles, 1985–1990. (b) PM-10 concentrations ($\mu g/m^3$) in Cook County, 1985–1990.

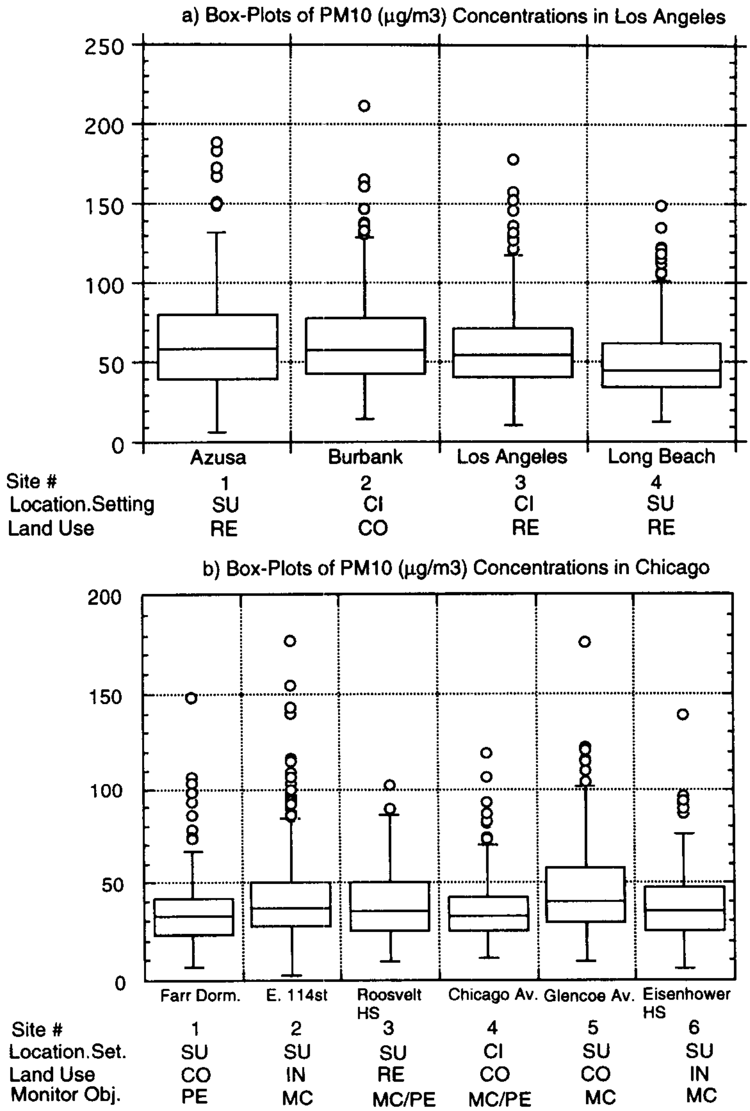

FIGURE 2. Box plots of PM-10 levels for all the sites used in the study. (a) Box plots of PM-10 concentrations ($\mu g/m^3$) in Los Angeles. (b) Box plots of PM-10 concentrations ($\mu g/m^3$) in Cook County. The upper quartile, Q(.75), and lower quartile, Q(.25), of the data are the top and bottom of a rectangle, and the median is the horizontal line within the rectangle. The upper whisker is the largest observation less than or equal to 1.5[Q(.75)–Q(.25)] plus Q(.75). The lower whisker is the smallest observation greater than or equal to 1.5[Q(.75)–Q(.25)] plus Q(.25). Open circles are actual outside values. Key: SU, suburban; CI, city; RE, residential; CO, commercial, IN, industrial; MC, maximum concentration; PE, population exposure.

to Los Angeles PM-10, seasonal cycles are less obvious in Cook County PM-10. The distributions of all the selected PM-10 sites are compared in Figure 2. The location setting and land use, as described in the AIRS database, are also indicated. PM-10 levels are generally lower in Cook County than in Los Angeles.

Figure 3 shows the correlation coefficients (before detrending) of PM-10 temporal fluctuations between each pair of PM-10 sites, as a function of corresponding distance. The lowest association was that between Azusa and Long Beach sites, as expected from their opposite signs of seasonal trends. Detrending generally did not appreciably affect the correlations for both Los Angeles and Cook County sites, with the exception of the Azusa–Long Beach case, in which the correlation increased from .36 to .57, making the correlations a better (negative) linear function of distance for Los Angeles. In both cities, correlation generally decreased as the distance between a pair of sites increased.

Table 1 shows the percent variance explained by season (sine/cosine), day of week, and linear trends for all the variables. In Los Angeles, seasonal cycles explained about half the CO and O_3 variance, while only 10–20% of the PM-10 variance was attributed to seasonal cycles. In Cook County, an even lower percentage of variance of PM-10 levels was explained by seasonal cycles, whereas as much as 58% of variance for O_3 was accounted for by seasonal cycles. A small, but often significant, percentage of PM-10 variance was explained by day-of-week variables in both Los Angeles and Cook County. In most cases, PM-10 was lowest on Sundays. While both Cook County and Los Angeles CO levels were lower on Sundays, O_3 levels in both cities were lower during weekdays. Only a small percentage of variance was ever attributed to the linear trend, and when it was significant, the trend was downward over the study period.

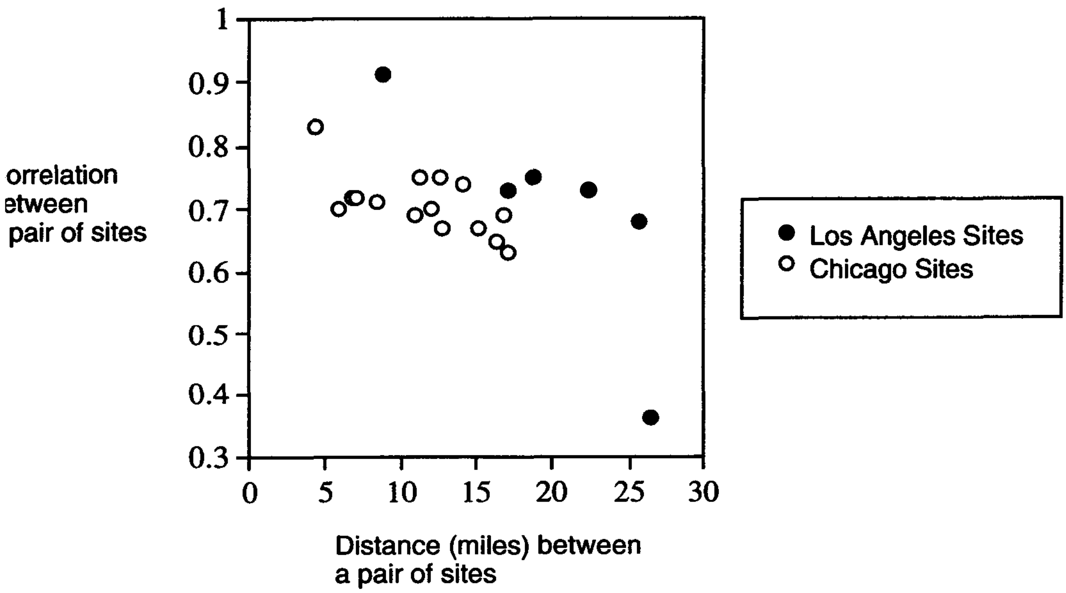

FIGURE 3. Relationship between correlation of PM-10 levels between sites versus corresponding distance.

TABLE 1. Summary of Percent Variance Explained by Trends and the Same Day Mortality–Pollution Associations

	Percent variance explained by trends			The same day mortality association after detrending		
Variable	Seasonal[a]	Day of week	Linear trend	r	p Value	n
			Los Angeles			
Mortality	47	0	0	—	—	2191
Temperature	26	0	1	0.121	0.0001	2191
CO maximum	54	3	0	0.137	0.0001	2191
O_3 maximum	48	1	1	0.106	0.0001	2191
PM_{10}						
Site 1	20	4	0	0.073	0.169	356
Site 2	13	2	1	0.072	0.179	352
Site 3	10	2	1	0.049	0.377	330
Site 4	23	1	2	0.084	0.117	349
Average A[b]	11	2	0	0.077	0.120	405
Average B[c]	11	2	0	0.087	0.079	405
			Chicago			
Mortality	22	1	0	—	—	2191
Temperature	78	0	0	0.061	0.0004	2191
CO maximum	2	1	0	0.031	0.1466	2191
O_3 maximum	58	0	0	0.107	0.0001	2191
PM-10						
Site 1	6	2	1	0.199	0.0008	281
Site 2	7	1	2	0.121	0.0001	1251
Site 2-6,[d] 1[e]	8	4	2	0.250	0.0001	246
Site 2-6,[d] 2[e]	7	2	1	−0.006	0.9284	198
Site 2-6,[d] 3[e]	11	5	1	0.073	0.2848	214
Site 2-6,[d] 4[e]	8	5	1	0.106	0.1378	197
Site 2-6,[d] 5[e]	10	3	2	0.115	0.1014	203
Site 2-6,[d] 6[e]	14	4	2	0.106	0.1440	193
Site 3	8	4	0	0.024	0.6720	309
Site 4	7	4	6	0.145	0.0243	243
Site 5	9	6	0	0.110	0.0702	272
Site 6	11	4	0	0.159	0.0064	292
Average A[b]	7	1	1	0.102	0.0002	1357
Average B[c]	8	1	1	0.106	0.0001	1357
Average A,[b] 6[d]	10	4	0	0.154	0.0038	351
Average B,[c] 6[d]	9	4	0	0.147	0.0057	351

[a]Sine/cosine with periodicity of 2 yr, 1 yr, 6 mo, and 1 mo.

[b]Average of any available sites.

[c]Average of all the sites after each site's missing values had been filled in by regressing the site on the rest of sites' data where available.

[d]Every-6-days subsample.

[d]Subsample number: 1, scheduled every 6 days; 2, the following day; etc.

In cross-correlation analysis (after detrending each series) of mortality versus pollution variables, the strongest association between PM-10 and mortality was observed on the same day in both Los Angeles and Cook County. In both cities, O_3 showed associations up to 2 day lagged with mortality. In Los Angeles, CO showed both associations and lag structure similar to those of O_3, while in Cook County, CO was virtually nonsignificant. The temperature association was similar to that of O_3 in Los Angeles. In Cook County, the temperature association varied with season, being negatively associated with lagged mortality in the winter but positively associated in the summer. Since PM-10–mortality associations were strongest on the same day in both cities, and the purpose of this study was to examine the sensitivity of the association to the choice of PM-10 sites, the comparison of strength of association was made for the same day only, as summarized in Table 1. In Cook County, the significance of PM-10–mortality associations ranged widely both among the 6 sites and among the 6 possible every-6-days subsamples of site 2, but various average PM-10 series all showed significant associations with mortality. In Los Angeles data, one of the multisite PM-10 series showed the highest significance. The PM-10–mortality associations in Los Angeles were mostly weaker than those for Cook County, but 95% confidence intervals (via Fisher's Z-transformation) of these PM-10–mortality correlations overlapped.

Because there are more sites available in Cook County, the sensitivity of using alternate PM-10 sites, as well as alternate every-6-days subsamples for one PM-10 site, in regression analyses was examined further in Cook County. In our basic model, mortality was regressed on the same-day PM-10, temperature, and 1-day lagged O_3, in addition to sine/cosine variables with 4 periodicities (2 yr, 1 yr, 6 mo, and 1 mo), day-of-week dummy variables, and a linear trend. More elaborate models, such as season-specific models, could be examined. For example, in the application of seasonal specifications for two periods in which temperature effects are different in signs and lags (October–February lagged negative; March–September same day positive), both lower the significance and size of PM-10 coefficients somewhat (e.g., for average PM-10 = 100 $\mu g/m^3$, RR = 1.05, 95% CI 0.97–1.13; and RR = 1.03, 95% CI 0.98–1.09, respectively). However, the focus here is on sensitivity of results to the choice of PM-10 sites, and therefore only one basic model was used in this study. The correlations of the estimates of these covariates were generally small (PM-10 vs. ozone ≈ −0.2; PM-10 vs. temperature ≈ −0.2). Autocorrelation of the residuals for the daily PM-10 regression was of borderline significance (Durbin–Watson statistic = 1.83 for n = 1357). The autoregressive model resulted in nonsignificant autocorrelation of the residuals, but slightly reduced the t ratio of PM-10 coefficient from 2.66 to 2.45. Sensitivity of results using various alternative models for Los Angeles data can be found elsewhere (Kinney et al., 1995), and a similar model-sensitivity analysis for Cook County is in progress by the authors. The regression results are summarized in Figure 4

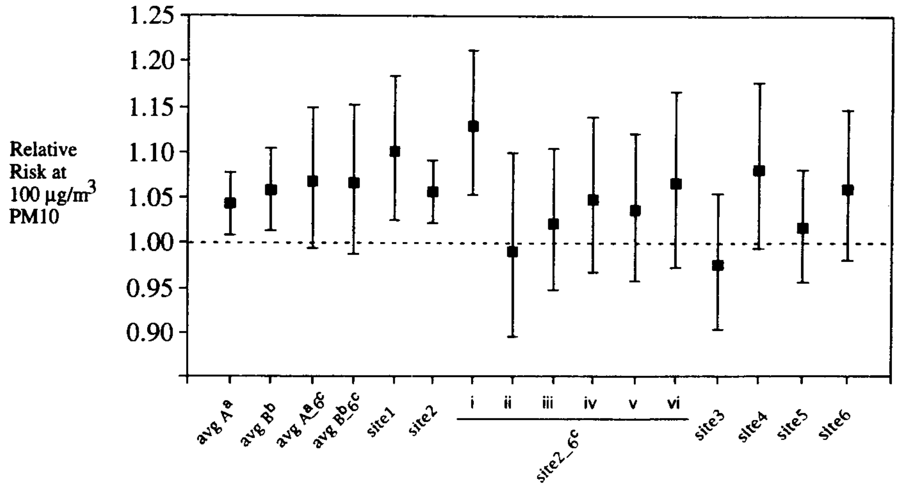

FIGURE 4. "Relative risk" and 95% CI for 100 $\mu g/m^3$ PM-10 increase, calculated from regressions of mortality on PM-10, ozone, temperature, seasonal cycles, day of week, and linear trend for data period 1985–1990, Cook County. Key: [a]Average of any available sites. [b]Average of all the sites after each site's missing values had been filled in by regressing the site on the rest of the sites' data where available. [c]Every-6-days subsample (i = the scheduled every-6th-day; ii = following day, etc.).

in terms of the "relative risk" calculated for an increase of 100 $\mu g/m^3$ in PM-10, an index often used in recent PM-10–mortality studies (Dockery et al., 1992; Pope et al., 1992; Schwartz, 1991, 1993). It can be seen that the individual sites' significance, as well as those for the 6 possible every-6-days subsamples of the site 2 PM-10, range widely.

DISCUSSION

The results of this study indicate that the choice of PM-10 sites can make a difference in the degree of significance reported in health effects analyses. Averaging over multiple PM-10 sites appeared to help increase the level of the significance of mortality–PM-10 associations, even when individual site(s) alone did not approach significance. However, in some cases, individual sites gave more significant results than for the multisite average of concentrations. It is not clear, from this analysis, whether the sensitivity of the result is due to exposure errors in assigning different PM-10 levels among the multiple sites to the entire metropolitan area population, or is due to exposure errors added at an immediate vicinity of each site, possibly from local sources, or both. Because mortality data for smaller boundaries than county level were not available in this analysis, this issue could not be examined further.

The qualitative site description, such as land-use and location setting, available from the AIRS database (see Figure 2) appears to have no coherent influence on a site's PM-10–mortality associations. Therefore, without information on actual local source emission inventories, it is difficult to justify elimination of a site prior to health effects data analysis based on these qualitative site information. Relative distance of monitoring sites to population density in the study area may be also important, and systematic evaluation of this factor is needed.

Although the daily data at site 2 and the average of 6 sites for PM-10 levels in Cook County showed significant mortality associations, the range of significance of mortality associations for the 6 every-6-days subsamples at site 2 was as wide as the range among the 6 sites. This result raises a concern for a statistical power achieved by the every-6-days PM-10 sampling schedule for health effects analysis when a study period is "short." It should be noted that, in recent published studies on particulate matter–mortality associations (Schwartz & Dockery, 1992a, 1992b; Dockery et al., 1992; Pope et al., 1992; Schwartz, 1993), daily measurements of particulate matter, either total suspended particles (TSP) or PM-10, were available for at least 1 yr, and when the sampling schedule was every-6-days, intervening missing values were predicted from the humidity-corrected visual range (Schwartz, 1991). Thus, the current every-6-days schedule used in most PM-10 monitors in the United States may compromise power required to detect any pollution–health effects relationships in many communities.

In both Los Angeles County and Cook County, the correlation of PM-10 levels among multiple sites decreased as their separation distance increased. Variability of levels at multiple sites needs to be examined similarly for other pollutants. Depending on the physicochemical characteristics and origins of a pollutant, the sensitivity of the choice of sites in examining health effects is likely to be different from pollutant to pollutant. For example, sulfate levels tend to be regionally uniform, while acid aerosols and O_3 levels may vary even within a metropolitan area if other pollutants such as ammonia (to neutralize acid) or nitric oxide (to react with O_3) are not uniformly distributed in the region (Thurston et al., 1994). Thus, identification of a single causal pollutant, based simply on the strength of association with a health effect outcome without evaluation of attenuation/enhancement due to random/systematic errors in exposure estimates, may be misleading.

This study characterized the variability of PM-10 levels in two large cities and assessed the sensitivity of observed associations to the choice of sites. However, we recognize that any reported associations of health effects cannot be attributable solely to particulate matter. An increasing number of epidemiological studies have shown associations between particulate pollution indices and health effect outcomes, but evidence from laboratory studies has been too circumstantial to conclude that respirable mass, without chemical specificity, causes health effects. Only after examining the various individual chemical constituents of particulate matter, the independent effects and/or influence of other copollutants, and the downward/upward bias introduced by errors in measurement and spatial representativeness can observational epidemiology do more than suggest causality for health effects of PM-10 exposures.

REFERENCES

Dockery, D. W., Schwartz, J., and Spengler, J. D. 1992. Air pollution and daily mortality: Associations with particulates and acid aerosols. *Environ. Res.* 59:362–373.

Kinney, P. L., Ito, K., and Thurston, G. D. 1995. Los Angeles daily mortality and particulate matter: New results and sensitivity analysis. *Inhal. Toxicol.* 7:59–69.

Pope, C. A. III, Schwartz, J., and Ransom, M. R. 1992. Daily mortality and PM-10 pollution in Utah Valley. *Arch. Environ. Health* 47:211–217.

Schwartz, J. 1991. Particulate air pollution and daily mortality in Detroit. *Environ. Res.* 56:204–213.

Schwartz, J. 1993. Air pollution and daily mortality in Birmingham, Alabama. *Am. J. Epidemiol.* 137:1136–1147.

Schwartz, J., and Dockery, D. W. 1992a. Particulate air pollution and daily mortality in Steubenville, Ohio. *Am. J. Epidemiol.* 135:12–19.

Schwartz, J., and Dockery, D. W. 1992b. Increased mortality in Philadelphia associated with daily air pollution concentrations. *Am. Rev. Respir. Dis.* 145:600–604.

Snedecor, G. E., and Cochran, W. G. 1980. *Statistical methods*, 7th ed. Ames: Iowa State University Press.

Thurston, G. D., Gorczynski, J. E., Currie, J. H., He, D., Ito, K., and Lippmann, M. 1994. Nature and origin of acid aerosol in metropolitan Toronto, Ontario. 1994. *Environ. Res.* 65:254–270.

U.S. Bureau of the Census. 1988. *County and City Data Book*. Washington, DC: U.S. Government Printing Office.