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Air Pollution and Total Mortality in Cancer Prevention Study Cohort Reanalysis

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Abstract:	Background. The EPA National Ambient Air Quality Standard (NAAQS) was established in 1997 for fine particulate matter (PM2.5), largely because of its positive relationship to total mortality in the 1982 American Cancer Society (ACS) Cancer Prevention Study (CPS II) cohort. Independent reanalysis showed no relationship between PM2.5 and total mortality in the CPS II cohort. This additional reanalysis tested the validity of other CPS II findings related to air pollution and total mortality. Methods. The original CPS II questionnaire data, including 1982-1988 mortality follow-up, was analyzed using Cox proportional hazards regression. Results were obtained for 169,405 subjects in 44 U.S. counties with 1979-1983 EPA Inhalable Particulate Network (IPN) PM2.5 data and 1980-1981 sulfate ($SO4^{2-}$) data. Results. The 1982-1988 relative risk of death from all causes (RR) and 95% confidence interval (CI) adjusted for age, sex, race, education, and smoking status was 1.021 (0.984–1.058) for a 10 μg/m³ increase in PM2.5 and 1.017 (0.965-1.072) for a 10 μg/m³ increase in $SO4^{2-}$. This CPS II reanalysis revealed that the original 1995 analysis, the 2000 reanalysis, and the 2009 extended follow-up selectively presented positive findings relating PM2.5 and $SO4^{2-}$ to total mortality and omitted null findings. Conclusions. PM2.5 and $SO4^{2-}$ had no significant relationship with total mortality in the CPS II cohort when the best available data were used. This independent reanalysis raises serious doubts about the CPS II epidemiologic evidence relating PM2.5 and $SO4^{2-}$ to total mortality. It provides strong justification for independent reassessment of CPS II findings and the PM2.5 NAAQS.

Air Pollution and Total Mortality in Cancer Prevention Study Cohort Reanalysis

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Abstract

Background. The EPA National Ambient Air Quality Standard (NAAQS) was established in 1997 for fine particulate matter ($PM_{2.5}$), largely because of its positive relationship to total mortality in the 1982 American Cancer Society (ACS) Cancer Prevention Study (CPS II) cohort. Independent reanalysis showed no relationship between PM2.5 and total mortality in the CPS II cohort. This additional reanalysis tested the validity of other CPS II findings related to air pollution and total mortality.

Methods. The original CPS II questionnaire data, including 1982-1988 mortality follow-up, was analyzed using Cox proportional hazards regression. Results were obtained for 169,405 subjects in 44 U.S. counties with 1979-1983 EPA Inhalable Particulate Network (IPN) $PM_{2.5}$ data and 1980-1981 sulfate (SO_4^{2-}) data.

Results. The 1982-1988 relative risk of death from all causes (RR) and 95% confidence interval (CI) adjusted for age, sex, race, education, and smoking status was 1.021 (0.984–1.058) for a 10 $\mu g/m^3$ increase in $PM_{2.5}$ and 1.017 (0.965-1.072) for a 10 $\mu g/m^3$ increase in SO_4^{2-}. This CPS II reanalysis revealed that the original 1995 analysis, the 2000 reanalysis, and the 2009 extended follow-up selectively presented positive findings relating $PM_{2.5}$ and SO_4^{2-} to total mortality and omitted null findings.

Conclusions. $PM_{2.5}$ and SO_4^{2-} had no significant relationship with total mortality in the CPS II cohort when the best available data were used. This independent reanalysis raises serious doubts about the CPS II epidemiologic evidence relating $PM_{2.5}$ and SO_4^{2-} to total mortality. It provides strong justification for independent reassessment of CPS II findings and the $PM_{2.5}$ NAAQS.

Key Words

Epidemiology PM2.5 Deaths CPS II Reanalysis

Introduction

Independent reanalysis of the 1982 American Cancer Society (ACS) Cancer Prevention Study (CPS II) cohort recently found no relationship between fine particulate matter ($PM_{2.5}$) and total mortality (Enstrom 2017) (1). This null finding is important because the EPA National Ambient Air Quality Standard (NAAQS) was established in 1997 for $PM_{2.5}$, largely because of its positive relationship to total mortality in the CPS II cohort, as published in 1995 (Pope 1995) (2). Also, CPS II findings played a major role in justifying the 2012 tightening of the 1997 $PM_{2.5}$ NAAQS. EPA has used this positive relationship to claim that $PM_{2.5}$ *causes* premature deaths. However, the validity of this claim has been continuously challenged since 1997 (3-7). No etiologic mechanism has ever been established to prove that $PM_{2.5}$ can *cause* premature deaths, particularly since it involves the lifetime inhalation of only about 1-5 gm of particles that are less than 2.5 μm in diameter (5). The $PM_{2.5}$-mortality relationship has been further criticized because the small increased risk is based on selective and nontransparent analyses that have not properly accounted for well-known epidemiological biases (5). There are now two major national cohorts that show no $PM_{2.5}$-mortality relationship (8). In addition to the null CPS II findings (1), there are 2016 null findings for the National Institutes of Health-American Association of Retired Persons (NIH-AARP) Diet and Health Cohort (9).

The $PM_{2.5}$ premature death claim is important because it has been used to provide a public health justification for many costly EPA regulations, most recently the Clean Power Plan. Indeed, 85% of the total estimated benefits of all EPA regulations have been attributed to reductions in $PM_{2.5}$-related premature deaths (5). With the presumed benefits of $PM_{2.5}$ reductions playing such a major role in EPA regulatory policy, it is essential that the relationship of $PM_{2.5}$ to total mortality be independently verified with transparent data and reproducible findings.

Unfortunately, ACS has refused to confirm or refute my peer-reviewed null CPS II evidence. Also, they refuse to address the above criticisms and they continue to oppose independent analysis of the CPS II data. Instead, for almost 25 years, ACS has willingly collaborated with a small group of non-epidemiologists who have conducted selective and non-transparent epidemiologic analyses based on CPS II subjects who were enrolled in 1982, 35 years ago. ACS ignored numerous 2011-13 requests for CPS II data and transparency from the U.S. House Science, Space, and Technology Committee (10). Then they ignored the August 1, 2013 subpoena for CPS II data from this Committee (11). Instead, since August 1, 2003 ACS has collaborated in the publication of eight non-transparent CPS II analyses that did not address the above criticisms of the $PM_{2.5}$-mortality relationship (12).

It is now clear that the Health Effects Institute (HEI) in Boston did not conduct or publish a proper 2000 reanalysis of the original Pope 1995 findings (HEI 2000) (13), particularly regarding the mandated sensitivity analysis. The 31-member HEI Reanalysis Team (Team) consisted mainly of Canadian statisticians and geographers, headed by Daniel Krewski, who had no expertise in U.S. epidemiologic studies. The Team did not show that the Pope 1995 results were robust to alternative $PM_{2.5}$ data. It has now been shown that there is no $PM_{2.5}$-mortality relationship in the CPS II cohort when it is based upon the 1979-1983 EPA Inhalable Particulate Network (IPN) $PM_{2.5}$ data (14,15). The IPN $PM_{2.5}$ data were fully published by EPA as of 1986 and were the best available $PM_{2.5}$ data as of 1995. Furthermore, Lipfert specifically brought

these $PM_{2.5}$ data to the attention of the Team in 1998 (16). The Team did not present meaningful results based on these data and they did not use all of the CPS II counties that had IPN $PM_{2.5}$ data. In addition, HEI and its investigators did not conduct or publish a proper 2009 extended mortality follow-up of the CPS II cohort (HEI 2009) (17). HEI 2009 continued to ignore the IPN $PM_{2.5}$ data, which was again brought to their attention in 2005 (18). HEI 2009 did not address the geographic variation in $PM_{2.5}$ mortality risk, particularly the evidence that, when analyzed separately, there was no risk in the Ohio Valley states or the other than Ohio Valley states (1), or in California (1,18). ACS and its investigators have never addressed the above criticism and they have never cooperated with independent analysis of the CPS II data.

Methods

Computer files containing the original 1982 ACS CPS II de-identified questionnaire data and six-year follow-up data on deaths from September 1, 1982 through August 31, 1988, along with detailed documentation, were obtained from a source with appropriate access to these data, as previously explained (1). This research is exempt from human subjects or ethics approval because it involved only statistical analysis of existing de-identified data. Human subjects approval was originally obtained by ACS in 1982 from each subject at the time they enrolled in CPS II.

Of the 1.2 million total CPS II subjects, analysis has been done on 292,277 subjects residing in 85 clearly defined counties in the continental U.S. with 1979-1983 EPA IPN $PM_{2.5}$ (IPN $PM_{2.5}$) measurements (1). Among these subjects there were 18,612 total deaths from September 1, 1982 through August 31, 1988; 17,329 of these deaths (93.1%) had a known date of death. These 292,277 subjects had age at entry of 30-99 years and sex of male [1] or female [2]; 269,766 had race of white [1,2,5] or black [3,4]; education level of no or some high school [1,2], high school graduate [3], some college [4,5], college graduate [6], or graduate school [7]; and smoking status of never [1], former [5-8 for males and 3 for females], or current [2-4 for males and 2 for females]. Those subjects reported to be dead [D,G,K] but without an exact date of death have been assumed to be alive in this analysis. The unconfirmed deaths were randomly distributed and did not impact relative comparisons of death in a systematic way. The computer codes for the above variables are shown in brackets.

This analysis used IPN $PM_{2.5}$ data extracted from the easily accessible EPA Reports (14,15). Close examination of HEI 2000 Appendix D "Alternative Air Pollution Data in the ACS Study" (13) revealed that the $PM_{2.5}$ values in the column labeled '$PM_{2.5}$(DC)' are very similar to the IPN $PM_{2.5}$ data. For 58 cities with HEI $PM_{2.5}$(DC) values, 46 had $PM_{2.5}$ values identical to the IPN $PM_{2.5}$ values, as shown in Appendix Table 1 below. The correlation coefficient between IPN $PM_{2.5}$ and HEI $PM_{2.5}$(DC) values was 0.957. However, essentially all of the $PM_{2.5}$ calculations in Pope 1995 and HEI 2000 are based on the original investigator data in the column labeled '$PM_{2.5}$(OI)'. Close examination of data for the 50 cities used in Pope 1995 and HEI 2000 revealed that IPN $PM_{2.5}$ data were not measured in three of these cities: Raleigh, NC; Allentown, PA; and Huntington, WV. Huntington, WV was the city with the highest $PM_{2.5}$(OI) value (33.4 $\mu g/m^3$) used in Pope 1995 and HEI 2000. Among the 85 cities with IPN $PM_{2.5}$ data, the city with the highest value was Rubidoux in Riverside County, CA (42.0 $\mu g/m^3$) and the city

with the lowest value was Lompoc in Santa Barbara County, CA (10.6 µg/m³). Neither of these California cities/counties were used in Pope 1995 or HEI 2000.

CPS II subjects were organized in the master data file geographically. Since this de-identified data file does not contain home addresses, the Division number and Unit number assigned by ACS to each CPS II subject were used to define their county of residence. For instance, ACS Division 39 represents the state of Ohio and its Unit 041 represents Jefferson County, which includes the city of Steubenville, where the IPN $PM_{2.5}$ measurements were made. Based on indirect CPS II information, at least 90% of the 575 subjects in Unit 041 lived in Jefferson County as of September 1, 1982. This indicates that the ACS Division-Unit number is a good measure of the county of residence of CPS II subjects. All CPS II subjects in Unit 041 were assigned the IPN $PM_{2.5}$ value of 29.6739 µg/m³, the weighted average of 191 measurements made in Steubenville, as previously explained (1). The Unit 041 subjects were also assigned the HEI $PM_{2.5}$(DC) value of 29.7 µg/m³ and the HEI $PM_{2.5}$(OI) value of 23.1 µg/m³, based on the values shown in HEI 2000 Appendix D. Appendix Table 1 contains up to three $PM_{2.5}$ values for the 85 counties that include a city with CPS II subjects and IPN $PM_{2.5}$ data.

Also analyzed were the 1980-81 sulfate (SO_4^{2-}) measurements that were used in Pope 1995 and HEI 2000 and that are shown in the column labeled 'SO_4(OI)' of HEI 2000 Appendix D. Appendix Table 1 shows the HEI SO_4^{2-} data, which were available for 55 of the 85 cities/counties with IPN $PM_{2.5}$ data and for 44 of the 47 cities/counties with IPN $PM_{2.5}$ and HEI $PM_{2.5}$(OI) data. Pope 1995 determined this relationship using 151 cities with HEI SO_4^{2-} data, but 96 of these cities did not have IPN $PM_{2.5}$ data. HEI SO_4^{2-} was used as a confounding variable in the calculation of the $PM_{2.5}$-mortality relationship.

The SAS 9.4 procedure PHREG was used to conduct Cox proportional hazards regression (19). Relative risks for death from all causes (RR) and 95% confidence intervals (CI) were calculated using age-sex adjustment and full adjustment (age, sex, race, education, and smoking status, as defined above). Each of the five adjustment variables had a strong relationship to total mortality. Race, education, and smoking status were the three adjustment variables that had the greatest impact on the age-sex adjusted RR. Pope 1995 and HEI 2000 used four additional adjustment variables that had a lesser impact on the age-sex adjusted RR: body-mass index, alcohol use, exposure to passive cigarette smoke, and occupational exposure. To test the impact of a co-pollutant, the $PM_{2.5}$-mortality relationship was analyzed including HEI SO_4^{2-} [SO_4(OI)] as an additional confounding variable. Finally, CPS II mortality follow-up results by time period were extracted from Table 34 of HEI 2009 (17). These results show the relationship between $PM_{2.5}$ and total mortality during the original follow-up period of 1982-1989 and the extended follow-up periods of 1990-1998 and 1999-2000.

In the interest of transparency and reproducibility, and depending upon future cooperation with ACS, the goal is to post on the Scientific Integrity Institute website a version of the CPS II data that fully preserves the confidentiality of all the subjects and that contains enough information to verify my findings. Also, the goal is to post the SAS computer programs and outputs that have used in the statistical analyses described below.

Results

Table 1 shows basic demographic characteristics for the CPS II subjects, as stated in Pope 1995 (2), HEI 2000 (13), and this current analysis. There is excellent agreement among the three sources for the adjustment variables of age, sex, race, education, and smoking status. Table 2 shows the RR for total mortality in the CPS II cohort during 1982-1988 based on four measures of air pollution: IPN $PM_{2.5}$, HEI $PM_{2.5}$(DC), HEI $PM_{2.5}$(OI), and HEI SO_4^{2-} . The fully adjusted RR and 95% CI was 1.023 (0.997–1.049) for a 10 μg/m³ increase in IPN $PM_{2.5}$ in all 85 counties, 1.025 (0.988–1.062) for a 10 μg/m³ increase in HEI $PM_{2.5}$(DC) in 58 counties, and 1.017 (0.965-1.072) for a 10 μg/m³ increase in HEI SO_4^{2-} in 55 counties.

The fully adjusted RR for total mortality was 1.081 (1.036-1.128) when based on the HEI $PM_{2.5}$(OI) values in 47 counties with IPN $PM_{2.5}$ data. This RR agrees quite well with the fully adjusted RR of 1.067 (1.037-1.099) for 1982-1989, which is shown in HEI 2009 Table 34 (17). This was the most important RR in Pope 1995 and it was confirmed in HEI 2000 and HEI 2009. Table 2 clearly shows that the positive RRs in the CPS II cohort were not robust and depended upon the use of HEI $PM_{2.5}$(OI) data. The null RRs based on IPN $PM_{2.5}$ and HEI $PM_{2.5}$(OI) were not presented in Pope 1995, HEI 2000, or HEI 2009.

Table 2 also shows the fully adjusted RR for total mortality was 1.028 (0.979-1.080) when based on HEI SO_4^{2-} data for the 55 CPS II counties with IPN $PM_{2.5}$ data. This null sulfates-mortality is not consistent with the positive relationship found in 151 Metro Areas, as described in Pope 1995 and confirmed in HEI 2000 and HEI 2009. This finding indicates that the SO_4^{2-} relationship with total mortality depends upon the specific CPS II counties used in the calculation. Finally, Table 2 shows that the small positive fully adjusted RRs based on IPN $PM_{2.5}$ data decline slightly below 1.0 when controlled for confounding by SO_4^{2-} . This finding indicates the importance of controlling for co-pollutants, which was not done in Pope 1995, HEI 2000, and HEI 2009.

Table 3 shows that the positive RR between HEI $PM_{2.5}$(OI) and total mortality during 1982-1989 in Pope 1995, becomes insignificant during 1990-2000, based on the RRs in HEI 2009 Table 34. This finding indicates that many of positive RRs in the CPS II cohort may be insignificant after 1989.

Conclusions

This independent analysis of the CPS II cohort adds significantly to the initial independent analysis in Enstrom 2017. It found that both $PM_{2.5}$ and SO_4^{2-} were not related to mortality from all causes during 1982-1988, when based on IPN $PM_{2.5}$, HEI $PM_{2.5}$(DC), and HEI SO_4(OI) data. A positive $PM_{2.5}$-total mortality relationship was found only when the HEI $PM_{2.5}$(OI) data were used to reproduce the original findings in Pope 1995. The null relationships were found for all 85 CPS II counties with IPN $PM_{2.5}$ data and for the 50 original counties used in Pope 1995, HEI 2000, and HEI 2009. This null evidence demonstrates that the $PM_{2.5}$-mortality relationship is not robust and is indeed sensitive to the $PM_{2.5}$ data and CPS II subjects used in the analysis.

It is important to note that the HEI $PM_{2.5}$(DC) data is published in HEI 2000 Appendix D and is essentially identical to the IPN $PM_{2.5}$ data, but it is not labeled in a way that identifies it as IPN $PM_{2.5}$ data. This finding strongly indicates that the HEI Reanalysis Team was clearly aware of the IPN $PM_{2.5}$ data but never presented null RRs based on IPN $PM_{2.5}$, HEI $PM_{2.5}$(DC) in either HEI 2000 or HEI 2009. Furthermore, the statement on page 80 of HEI 2000 that "air quality monitoring data could not be accurately accessed and accurately described" indicates that the Team did not properly use the readily available IPN $PM_{2.5}$ data. Thus, the Team did not "evaluate the sensitivity of the original findings to the indicators of exposure to fine particle air pollution used by the Original Investigators."

Evidence from HEI 2009 Table 34 shows that the positive $PM_{2.5}$-total mortality relationship based on HEI $PM_{2.5}$(OI) values was significant during 1982-89 but not during 1990-2000. It is misleading and inappropriate for all CPS II analyses in HEI 2009 to be based on mortality follow-up beginning in 1982. It is very important to determine all $PM_{2.5}$-total mortality relationships since 1989. It must be kept in mind that 1982 is 35 years ago.

It is very disturbing that ACS investigators, Pope, HEI officials, and key HEI Reanalysis Team members have all refused to confirm or refute the peer-reviewed evidence of no $PM_{2.5}$-total mortality relationship in the CPS II cohort in Enstrom 2017. Indeed, they have consistently refused to cooperate with anyone in clarifying the $PM_{2.5}$-mortality relationship in the CPS II cohort. Instead they continue to publish selective positive CPS II findings that are not transparent and not reproducible. These investigators need to cooperate with critics on completely transparent epidemiologic analyses of the CPS II cohort.

In summary, numerous null $PM_{2.5}$-total mortality findings in the CPS II cohort directly challenge the original positive Pope 1995 findings and they raise serious doubts about the CPS II epidemiologic evidence supporting the $PM_{2.5}$ NAAQS. These findings demonstrate the importance of independent and transparent analysis of underlying data. Finally, these findings provide strong justification for complete independent analysis of CPS II cohort and reassessment of the EPA $PM_{2.5}$ NAAQS.

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Table 1. Summary Characteristics of CPS II Subjects in 1) Pope 1995 Table 1 (2), 2) HEI 2000 Table 24 (13), and 3) current analysis based on CPS II subjects in 47 and 85 counties with IPN $PM_{2.5}$ data

Characteristic	Pope 1995 Table 1 HEI $PM_{2.5}$(OI)	HEI 2000 Table 24 HEI $PM_{2.5}$(OI)	Current CPS II Analysis N=47 HEI $PM_{2.5}$(OI)	N=47 IPN $PM_{2.5}$	N=85 IPN $PM_{2.5}$
Number of metro areas	50	50			
Number of counties	not stated	not stated	47	47	85
Age-Sex Adjusted Subjects			206,379	206,397	292,277
Fully Adjusted Subjects	295,223	298,817	189,676	189,676	269,766
Age-Sex Adjusted Deaths			12,082	12,082	17,231
Fully Adjusted Deaths	20,765	23,093	10,621	10,621	15,593
Values Below are for Subjects in Fully Adjusted Results					
Age at enrollment (mean years)	56.6	56.6	56.66	56.66	56.64
Sex (% females)	55.9	56.4	56.72	56.72	56.61
Race (% white)	94.0	94.0	94.58	94.58	95.09
Less than high school education (%)	11.3	11.3	11.71	11.71	11.71
Never Smoked Regularly (%)			41.69	41.69	41.57
Former smoker (%)			33.25	33.25	33.67
Former cigarette smoker (%)	29.4	30.2	30.43	30.43	30.81
Current smoker (%)			25.06	25.06	24.76
Currrent cigarette smoker (%)	21.6	21.4	21.01	21.01	20.76
Fine particles ($\mu g/m^3$)					
Average	18.2	18.2	17.8	21.37	21.16
SD	5.1	4.4	4.5	5.30	5.98
Range	9.0 – 33.5	9.0- 33.4	9.0- 25.2	10.77- 29.67	10.63- 42.01

Table 2. Age-sex adjusted and fully adjusted relative risk of death from all causes (RR and 95% CI) from September 1, 1982 through August 31, 1988 associated with change of 10 μg/m³ increase in $PM_{2.5}$ for CPS II subjects residing in 47, 58, and 85 counties in the continental United States with 1979-1983 IPN $PM_{2.5}$ data. Similar RRs for sulfates (1980-1981 SO_4^{2-}) are shown for 44 and 55 counties with IPN $PM_{2.5}$ data.

$PM_{2.5}$ Years and Source	Number of Counties	Number of Subjects	Number of Deaths	RR	95% CI Lower	95% CI Upper
Age-sex adjusted RR for Both Sexes and All Causes of Death						
1979-1983 $PM_{2.5}$						
IPN $PM_{2.5}$	85	292,277	17,321	1.038	(1.014 – 1.063)	
HEI $PM_{2.5}$(DC)	58	229,915	13,654	1.050	(1.015 – 1.087)	
IPN $PM_{2.5}$	47	206,379	12,082	1.040	(1.005 – 1.076)	
HEI $PM_{2.5}$(OI)	47	206,379	12,082	1.125	(1.075 – 1.164)	
1980-1981 SO_4^{2-}						
HEI SO_4(OI)	55	211,411	12,466	1.087	(1.038 – 1.138)	
HEI SO_4(OI)	44	184,182	10,621	1.077	(1.025 – 1.131)	
Fully adjusted RR for Both Sexes and All Causes of Death						
1979-1983 $PM_{2.5}$						
IPN $PM_{2.5}$	85	269,766	15,593	1.023	(0.997 – 1.049)	
HEI $PM_{2.5}$(DC)	58	211,584	12,246	1.025	(0.988 – 1.062)	
IPN $PM_{2.5}$	47	189,676	10,836	1.021	(0.984 – 1.058)	
HEI $PM_{2.5}$(OI)	47	189,676	10,836	1.081	(1.036 – 1.128)	
1980-1981 SO_4^{2-}						
HEI SO_4(OI)	55	194,729	11,211	1.028	(0.979 – 1.080)	
HEI SO_4(OI)	44	169,405	9,552	1.017	(0.965 – 1.072)	
Fully adjusted RR for Both Sexes and All Causes of Death, controlling for 1980-1981 SO_4^{2-}						
1979-1983 $PM_{2.5}$						
IPN $PM_{2.5}$	55	194,729	11,211	0.990	(0.948 – 1.035)	
IPN $PM_{2.5}$	44	169,405	9,552	0.972	(0.909 – 1.040)	

Table 3. Fully adjusted relative risk of death from all causes (RR and 95% CI) from September 1, 1982 through August 31, 2000 associated with change of 10 μg/m³ increase in $PM_{2.5}$ for CPS II subjects residing in 50, 58, or 61 Metro Areas with 1979-1983 HEI $PM_{2.5}$(OI) data. Most RRs were taken from Table 34 of HEI 2009. RRs indicated with * were calculated from Table 34 RRs, using standard formulas for combining RRs with 95% CI.

Follow-up Years	Number of Metro Areas	Number of Subjects	Number of Deaths	RR	95% CI Lower	95% CI Upper
Fully adjusted RR for Both Sexes and All Causes of Death						
Standard Cox with Different Metro Areas						
1982-1989	50	298,825	23,180	1.067	(1.037 – 1.099)	
1990-1998				1.013	(0.995 – 1.031)*	
1982-1998	61	360,682	80,819	1.027	(1.012 – 1.043)	
Random Effects Cox with Different Metro Areas						
1982-1989	50	298,825	23,180	1.101	(1.046 – 1.157)	
1990-1998				1.007	(0.966 – 1.050)*	
1982-1998	61	360,682	80,819	1.044	(1.011 – 1.078)	
Standard Cox with Same Metro Areas						
1982-1989	58	342,521		1.048	(1.022 – 1.076)	
1990-1998	58			1.021	(1.002 – 1.041)*	
1999-2000	58			1.014	(0.980 – 1.049)*	
1982-1998	58	342,521		1.031	(1.015 – 1.047)	
1982-2000	58	342,521	90,783	1.028	(1.014 – 1.043)	
Random Effects Cox with Same Metro Areas						
1982-1989	58	342,521		1.074	(1.028 – 1.122)	
1990-1998	58			1.017	(0.971 – 1.064)*	
1999-2000	58			1.017	(0.940 – 1.101)*	
1982-1998	58	342,521		1.046	(1.014 – 1.080)	
1982-2000	58	342,521	90,783	1.042	(1.012 – 1.073)	

Appendix Table 1. List of the 85 counties containing the 50 cities used in Pope 1995, HEI 2000, and HEI 2009, as well as the 35 additional counties used in Enstrom 2017. Each location includes State, primary ACS Division-Unit number and an indication of additional numbers, Federal Information Processing Standards (FIPS) code, IPN/HEI county, IPN/HEI city with $PM_{2.5}$ measurements, 1979-1983 IPN $PM_{2.5}$ (weighted mean), 1979-1983 HEI $PM_{2.5}$(DC) (weighted mean), 1979-1983 HEI $PM_{2.5}$(OI) (median), and 1980-1981 HEI SO_4^{2-} (mean). All 85 counties have IPN $PM_{2.5}$ data, 58 counties have HEI $PM_{2.5}$(DC) data, and 47 counties have HEI $PM_{2.5}$(OI) data. Three of the 50 cities used in Pope 1995 and HEI 2000 (Raleigh NC, Allentown PA, and Huntington WV) were not part of IPN and the origin of the HEI $PM_{2.5}$(OI) data in HEI 2000 Appendix D for these three cities is unknown.

State	ACS Div-Unit SO_4^{2-}	FIPS Code	IPN/HEI County containing IPN/HEI City	IPN/HEI City with $PM_{2.5}$ Measurements	1979-83 IPN $PM_{2.5}$ ($\mu g/m^3$) (weighted mean)	1979-83 HEI $PM_{2.5}$(DC) ($\mu g/m^3$) (weighted mean)	1979-83 HEI $PM_{2.5}$(OI) ($\mu g/m^3$) (median)	1980-81 HEI SO_4^{2-} ($\mu g/m^3$) (mean)
AL	01037	01073	JEFFERSON	Birmingham	25.6016	28.7	24.5	13.1
AL	01049	01097	MOBILE	Mobile	22.0296	22.0	20.9	12.6
AZ	03700	04013	MARICOPA	Phoenix	15.7790	18.5	15.2	4.3
AR	04071+2	05119	PULASKI	Little Rock	20.5773	20.6	17.8	5.9
CA	06001	06001	ALAMEDA	Livermore	14.3882			
CA	06002	06007	BUTTE	Chico	15.4525			
CA	06003	06013	CONTRA COSTA	Richmond	13.9197			
CA	06004	06019	FRESNO	Fresno	18.3731	10.3	10.3	5.8
CA	06008	06029	KERN	Bakersfield	30.8628			
CA	06051+4	06037	LOS ANGELES	Los Angeles	28.2239	26.8	21.8	14.0
CA	06019	06065	RIVERSIDE	Rubidoux	42.0117			14.6
CA	06020	06073	SAN DIEGO	San Diego	18.9189	18.9		11.2
CA	06021	06075	SAN FRANCISCO	San Francisco	16.3522	16.4	12.2	6.6
CA	06025	06083	SANTA BARBARA	Lompoc	10.6277			
CA	06026	06085	SANTA CLARA	San Jose	17.7884	17.8	12.4	6.2
CO	07004	08031	DENVER	Denver	10.7675	10.8	16.1	5.2
CO	07047	08069	LARIMER	Fort Collins	11.1226			
CO	07008	08101	PUEBLO	Pueblo	10.9155	10.9		6.7
CT	08001	09003	HARTFORD	Hartford	18.3949	18.4	14.8	9.4
CT	08004	09005	LITCHFIELD	Litchfield	11.6502			
DE	09002	10001	KENT	Dover	19.5280			
DE	09004+2	10003	NEW CASTLE	Wilmington	20.3743	20.4		19.4

DC	10001+2	11001	DIST COLUMBIA	Washington	25.9289	25.9	22.5	14.9
FL	11044	12057	HILLSBOROUGH	Tampa	13.7337	13.7	11.4	10.3
GA	12027+4	13051	CHATHAM	Savannah	17.8127	17.8		
GA	12062	13121	FULTON	Atlanta	22.5688	22.6	20.3	12.0
ID	13001	16001	ADA	Boise	18.0052	18.0	12.1	
IL	14089+4	17031	COOK	Chicago	25.1019	23.0	21.0	
IL	14098	17197	WILL	Braidwood	17.1851			
IN	15045	18089	LAKE	Gary	27.4759	27.5	25.2	19.1
IN	15049	18097	MARION	Indianapolis	23.0925	23.1	21.1	12.6
KS	17287	20173	SEDGWICK	Wichita	15.0222	15.0	13.6	4.9
KS	17289	20177	SHAWNEE	Topeka	11.7518	11.8	10.3	6.8
KY	18010	21019	BOYD	Ashland	37.7700			
KY	18055	21111	JEFFERSON	Louisville	24.2134			
MD	21106+1	24510	BALTIMORE CITY	Baltimore	21.6922	21.7		13.0
MD	21101	24031	MONTGOMERY	Rockville	20.2009			
MA	22105+1	25013	HAMPDEN	Springfield	17.5682	17.6		12.8
MA	22136	25027	WORCESTER	Worcester	16.2641	16.3		10.7
MN	25001+2	27053	HENNEPIN	Minneapolis	15.5172	15.5	13.7	8.4
MN	25150+5	27123	RAMSEY	St Paul	15.5823			
MS	26086	28049	HINDS	Jackson	18.1339	18.1	15.7	8.8
MO	27001+3	29095	JACKSON	Kansas City	17.8488	17.8		10.2
MT	28009	30063	MISSOULA	Missoula	17.6212			
MT	28011	30093	SILVER BOW	Butte	16.0405			
NE	30028	31055	DOUGLAS	Omaha	15.2760	15.3	13.1	8.7
NV	31101	32031	WASHOE	Reno	13.1184	13.1	11.8	4.1
NJ	33004	34007	CAMDEN	Camden	20.9523			
NJ	33007	34013	ESSEX	Livingston	16.4775			
NJ	33009	34017	HUDSON	Jersey City	19.9121	19.9	17.3	13.8
NM	34201	35001	BERNALILLO	Albuquerque	12.8865	12.9	9.0	4.5
NY	36014	36029	ERIE	Buffalo	25.1623	26.5	23.5	11.7
NY	35001	36061	NEW YORK	New York City	23.9064	23.9		10.7
NC	37033	37063	DURHAM	Durham	19.4092			11.9
NC	37064	37119	MECKLENBURG	Charlotte	24.1214	24.1	22.6	11.5
OH	39009	39017	BUTLER	Middletown	25.1789			
OH	39018	39035	CUYAHOGA	Cleveland	28.4120	27.9	24.6	13.7
OH	39031	39061	HAMILTON	Cincinnati	24.9979	25.0	23.1	14.3
OH	39041	39081	JEFFERSON	Steubenville	29.6739	29.7	23.1	23.5
OH	39050	39099	MAHONING	Youngstown	22.9404	22.9	20.2	15.7
OH	39057	39113	MONTGOMERY	Dayton	20.8120	20.8	18.8	13.5
OH	39077	39153	SUMMIT	Akron	25.9864	26.0	24.6	14.1
OK	40055	40109	OKLAHOMA	Oklahoma City	14.9767	15.0	15.9	6.3
OR	41019+1	41039	LANE	Eugene	17.1653	17.2		

OR	41026	41051	MULTNOMAH	Portland	16.3537	19.8	14.7	7.7
PA	42101+1	42003	ALLEGHENY	Pittsburgh	29.1043	30.0		15.8
PA	42443	42095	NORTHAMPTON	Bethlehem	19.5265			
PA	43002+11	42101	PHILADELPHIA	Philadelphia	24.0704	24.1	21.4	11.5
RI	45001+6	44007	PROVIDENCE	Providence	14.2341	14.2	12.9	8.7
SC	46016+1	45019	CHARLESTON	Charleston	16.1635			
TN	51019+5	47037	DAVIDSON	Nashville	21.8944	22.6	20.5	8.7
TN	51088	47065	HAMILTON	Chattanooga	18.2433	20.4	16.6	13.9
TX	52811+2	48113	DALLAS	Dallas	18.7594	18.8	16.5	10.0
TX	52859+3	48141	EL PASO	El Paso	16.9021	16.9	15.7	
TX	52882+2	48201	HARRIS	Houston	18.0421	18.0	13.4	10.5
UT	53024	49035	SALT LAKE	Salt Lake City	16.6590	17.5	15.4	4.8
VA	55024	51059	FAIRFAX	Fairfax	19.5425			
VA	55002	51710	NORFOLK CITY	Norfolk	19.5500	19.5	16.9	14.8
WA	56017	53033	KING	Seattle	14.9121	14.9	11.9	7.5
WA	56032	53063	SPOKANE	Spokane	13.5200	13.5	9.4	5.6
WV	58130	54029	HANCOCK	Weirton	25.9181			
WV	58207	54039	KANAWHA	Charleston	21.9511	21.7	20.1	17.8
WV	58117	54069	OHIO	Wheeling	23.9840			
WI	59005	55009	BROWN	Green Bay	20.5462			
WI	59052	55105	ROCK	Beloit	19.8584			