Reduction in fine particulate air pollution and mortality: extended follow-up of the Harvard Six Cities Study

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Online Supplement

Methods

Study population

The study population has been described previously (1). Briefly, random samples of adults were recruited in 1974 in Watertown, Massachusetts; in 1975 in Kingston and Harriman, Tennessee, and from specific census tracts of St. Louis, Missouri; in 1976 from Steubenville, Ohio, and Portage, Wyocena, and Pardeeville, Wisconsin; and in 1977 in Topeka, Kansas. The sample for the mortality analyses was restricted to the 8,096 white subjects who were 25 through 74 years of age at enrollment, had height and weight measurements, and complete information on age, gender, education, and smoking history from a questionnaire. This study was conducted with the approval of the human subjects committee at the Harvard School of Public Health.

Mortality follow-up

Vital status was determined by searching the National Death Index (NDI) for calendar years 1979 (when the NDI began) through 1998. Deaths between 1974 and 1978 were identified in the original study by annual mailings with return postcards, searches of social security records, and home visits. Underlying cause of death was extracted from NDI records for deaths in 1979 and later. For deaths before 1979 a certified nosologist defined cause of death based on death certificate review (1).

Survival Time

For subjects who died, survival times were calculated as death date minus enrollment date. For surviving participants who were not lost to follow-up before 1979, censored survival times were defined as end of study (December 31, 1998) minus enrollment date. For the six people lost to

follow-up before 1979, censored survival times were estimated as either last follow-up contact plus six months or first day of NDI search (January 1, 1979), whichever came first, minus enrollment date. Information on residence was only available through 1991. Because censoring the participants who moved out of the study cities did not affect the results in the original analysis (2), we did not account for moving in this analysis. However, we did perform sensitivity analyses restricting to those participants known to have stayed in the same city through 1991.

Air Pollution Concentration Estimates

Each participant's exposure to air pollution was defined by city-specific concentrations of $PM_{2.5}$. During the original follow-up, ambient concentrations of fine particulate matter were measured at a centrally located air-monitoring station in each community (1). Air pollution monitoring began in 1979 for all cities except Kingston/Harriman where it began in 1980. Sampling ended in 1985 in Watertown, 1986 in St. Louis, 1987 in Portage, Kingston/Harriman, and Steubenville, and 1988 in Topeka. $PM_{2.5}$ and PM_{10} concentrations were extracted from a dataset of daily measurements in these cities (3). We calculated city-specific annual mean $PM_{2.5}$ concentrations as the average of four quarterly means of daily data for each available year. For years before sampling, $PM_{2.5}$ values were assumed equal to the earliest sampling year.

We estimated $PM_{2.5}$ concentrations for the years after the shutdown of the Harvard Six City monitoring using city-specific regression calibration equations based on PM_{10} concentrations and extinction coefficient. PM_{10} data were extracted from the Environmental Protection Agency Aerometric Information Retrieval System (AIRS) for the years 1985 through 1998, selecting

monitors within an 80 Km (50 mile) radius of the study city. We chose representative, nonagricultural, nonindustrial monitors, taking into account the natural topography of the area (e.g. valleys and major bodies of water) in order to best capture the location of the original Six Cities monitors. We excluded monitors reporting for less than two years during the study period. In Figure E1, we have mapped the locations of the selected AIRS monitors (pink circles) and the Six Cities monitors (green triangles). See Table E1 for a detailed listing of the selected AIRS monitor sites. For each city, the mean of all measurements available on a given day was calculated. The daily data were then averaged over the quarter; city- and year-specific annual averages were calculated as averages of quarterly means.

To estimate $PM_{2.5}$ concentrations in the missing years we fit no-intercept regression models for the years of overlap of AIRS and Six Cities monitoring (1985-1987). We predicted daily $PM_{2.5}$ concentrations as a function of the daily AIRS PM_{10} measurements, humidity corrected extinction coefficient, and four indicator variables for season. Relative humidity (RH) and visibility (V) were obtained from local airports. The extinction coefficient [B_{ext}=(18.6*RH)/V] measures the scattering of light predominantly by fine particles and has been shown to be a good predictor of $PM_{2.5}$ (4). City-specific annual means were calculated for the extrapolated $PM_{2.5}$ values by averaging the daily estimated-values over the quarter and then calculating the average of the quarterly means. Topeka had no overlapping data available; therefore, we regressed Six Cities $PM_{2.5}$ against Six Cities PM_{10}, and the local extinction coefficient in 1985 through 1987.

References

E1. Dockery DW, Pope CA, 3rd, Xu X, Spengler JD, Ware JH, Fay ME, Ferris BG, Jr.,Speizer FE. An association between air pollution and mortality in six U.S. cities. *N Engl J Med* 1993;329:1753-9.

E2. Krewski D, Burnett RT, Goldberg MS, Hoover K, Siemiatycki J, Jerrett M, Abrahamowicz M,White WH. Reanalysis of the Harvard Six Cities Study and the American Cancer Society Study of Particulate Air Pollution and Mortality: A Special Report of the Institute's Particle Epidemiology Reanalysis Project. Health Effects Institute, Cambridge, MA. 2000.

E3. Schwartz J, Dockery DW,Neas LM. Is daily mortality associated specifically with fine particles? *J Air & Waste Manage Assoc* 1996;46:927-939.

E4. Abbey DE, Ostro BE, Fraser G, Vancuren T,Burchette RJ. Estimating fine particulates less than 2.5 microns in aerodynamic diameter (PM2.5) from airport visibility data in California. *J Expo Anal Environ Epidemiol* 1995;5:161-80.

Figure Legends

Figure E1. The original Six City monitors (▲) and AIRS monitors (●) used for $PM_{2.5}$ extrapolation

Figure E2: Kaplan Meier Curves for all-cause mortality

Figure E3. Estimated adjusted rate ratios for cardiovascular disease mortality and $PM_{2.5}$ levels in the Six Cities by period. P denotes Portage, WI (reference for both periods); T Topeka, KS; W Watertown, MA; L St. Louis, MO; H Harriman, TN; S Steubenville, OH. A term for Period 1 (1 if Period 2, 0 if Period 1) was included in the model. Bold letters represent Period 1 (1974-1989) and italicized letters represent Period 2 (1990-1998). In Period 1, $PM_{2.5}$ ($\mu g/m^3$) is defined as the mean concentration during 1980-1985, the years where there are monitoring data for all cities (18). In Period 2, $PM_{2.5}$ is defined as the mean concentrations of the estimated $PM_{2.5}$ in 1990-1998.

Table E1: Selected AIRS Monitors

City	Monitor ID	Location (as reported by AIRS)
Portage	55-025-0025-81102-1	Water Reservoir, Dayton & Livingson St., Madison
	55-025-0037-81102-1	Rodefeld SE Site, Cnty AB & Hwy 12/18, Madison
	55-073-0013-81102-1	106 River St, Wausau
	55-111-0003-81102-1	206 2nd St-North Side Park Rock Springs
	55-133-0018-81102-1	Melendez Site, 1238 The Strand, Waukesha
	55-133-0027-81102-1	1310 Cleveland Ave, Waukesha
Topeka	20-177-0007-81102-1	Quincy School, 1500 N.Quincy, Topeka
	20-177-0009-81102-1	Fire Sta.#8; Shunga & Fairlawn; Topeka
	20-177-0010-81102-1	1125 W. 14th/Robinson Middle School, Topeka
	20-177-0012-81102-1	Washburn Campus, Just SW Of FB Stadium, Topeka
Watertown	25-009-0005-81102-1	High Street, Storrow Park, Lawrence
	25-017-3002-81102-1	100 To 120 Main Street, Medford
	25-025-0002-81102-1	Kenmore Square, 590 Commonwealth Avenue, Boston
	25-025-0027-81102-1	One City Square, Charlestown
Harriman	47-093-0022-81102-1	800 Townview Place/Green Elementary Sch., Knoxville
	47-093-1015-81102-1	3323 Division Street near Liberty St., Knoxville
	47-093-1017-81102-1	1919 Vermont Avenue, Knoxville
St. Louis	29-510-0006-81102-1	14th & Market, St. Louis
	29-510-0007-81102-1	8227 South Broadway, St. Louis
	29-510-0080-81102-1	Newstead & Cotebrilliant, St. Louis
	29-510-0081-81102-1	Chain Of Rocks Water Department, St. Louis
	29-510-0084-81102-1	Hall St and Carrie, St. Louis
Steubenville	39-081-0016-81102-1	227 North 5TH St., Steubenville
	39-081-1001-81102-1	Mingo City Hall 501 Commerical St, Mingo Junction
	39-081-1012-81102-1	County Services Building 814 Adams Street, Steubenville

Table E2. Adjusted cardiovascular mortality rate ratios* and 95% confidence intervals estimated from Cox Proportional Hazards Model for each by follow-up period (1974-89 and 1990-98) and for complete follow-up (1974-98).

	Period 1 1974-89	Period 2 1990-98	Complete 1974-98
Person-Years of Follow-up	104,243	54,735	158,978
Deaths	626	570	1,196
	RR (95% CI)	RR (95% CI)	RR (95% CI)
City-specific model†			
Portage	1.00		1.00
Topeka	1.03 (0.74-1.42)	1.00 (0.74-1.35)	1.01 (0.81-1.26)
Watertown	1.19 (0.89-1.58)	0.82 (0.60-1.11)	1.02 (0.84-1.26)
Harriman	1.33 (1.00-1.77)	1.23 (0.92-1.64)	1.30 (1.06-1.58)
St. Louis	1.21 (0.92-1.59)	0.96 (0.72-1.26)	1.08 (0.89-1.32)
Steubenville	1.48 (1.13-1.93)	1.21 (0.92-1.58)	1.34 (1.11-1.62)
Period	1.00	0.94 (0.58-1.53)	

*Rate ratios have been adjusted for age in one-year categories, gender, current smoker, current pack-years of smoking, former smoker, former pack-years of smoking, less than high school education, and linear and quadratic terms for body mass index.

†City-specific rate ratios are all expressed in relation to Portage.

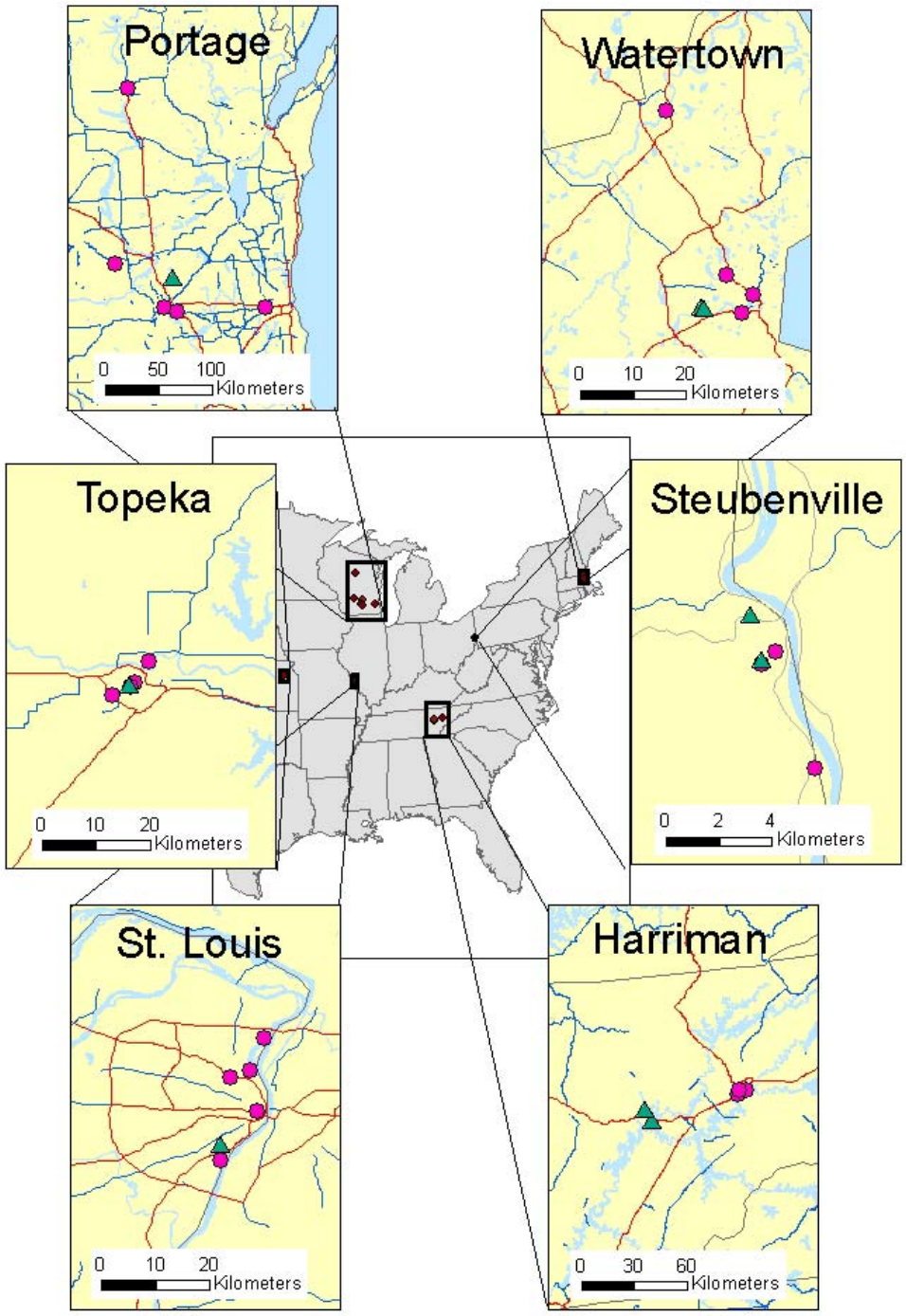
Portage
0 50 100
Kilometers
Watertown
0 10 20
Kilometers
Topeka
0 10 20
Kilometers
Steubenville
0 2 4
Kilometers
St. Louis
0 10 20
Kilometers
Harriman
0 30 60
Kilometers

Figure E1

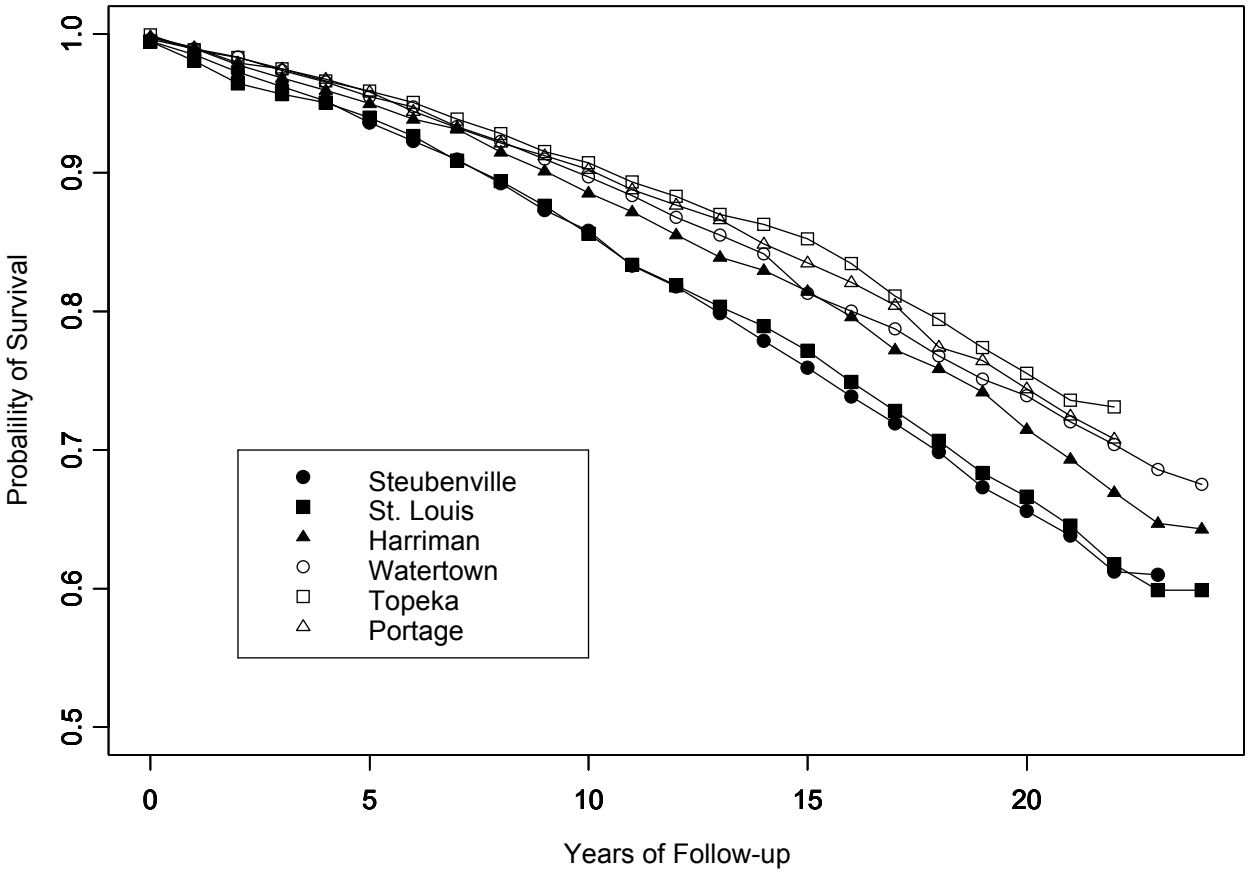
Probalility of Survival
1.0
0.9
0.8
0.7
0.6
0.5
0
5
10
15
20
Years of Follow-up
Steubenville
St. Louis
Harriman
Watertown
Topeka
Portage

Figure E2

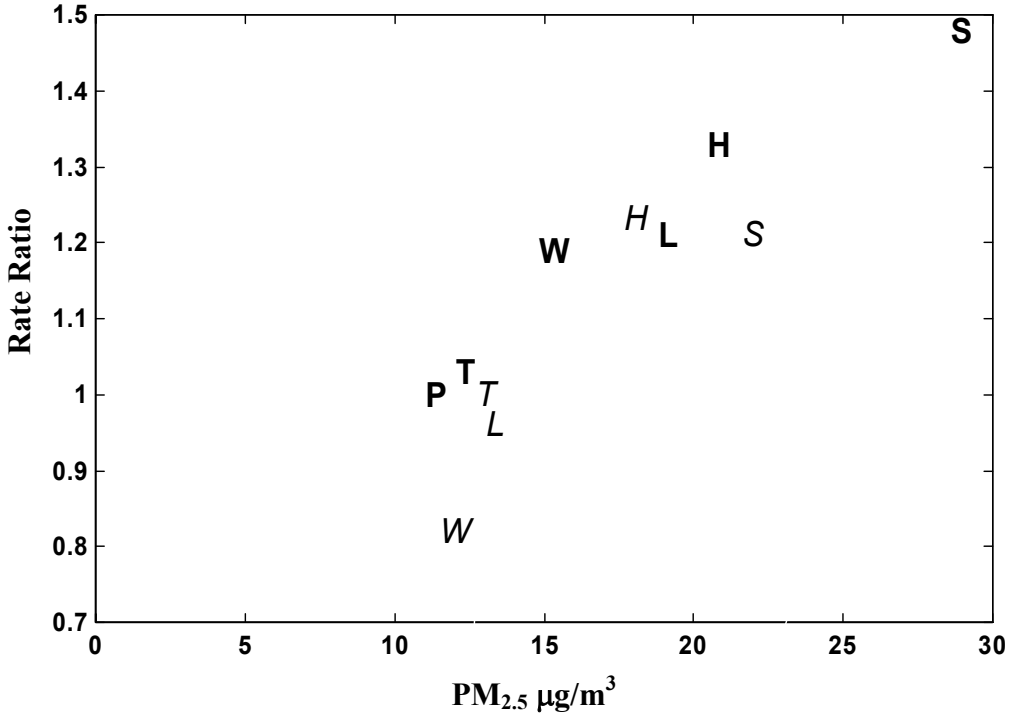
Rate Ratio
PM2.5 µg/m3
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0
5
10
15
20
25
30
S
H
H
L
S
W
P
T
T
L
W

Figure E3.