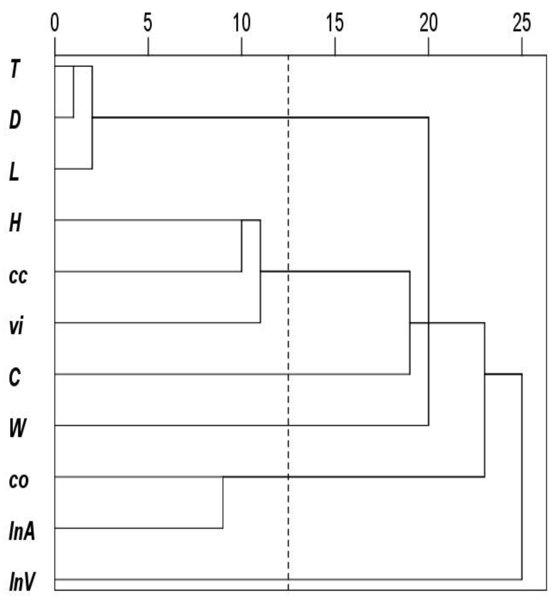
Supplementary I. Cluster analysis for selection of independent variables in multiple regressions

To assess the spatial relationship of AOT and $PM_{2.5}$, we developed models using annual mean data from 40 cities. We used cluster analysis based on nearest neighbor Pearson correlation method to identify clusters of highly correlated variables of the satellite and meteorological data. Then we used line-parsing method at 50% full distance on a dendrogram to select one variable from each cluster for reduction of multi-collinearity in regression model.[21] AOT was regarded as the key independent variable so that any other variables within the same cluster was excluded in this method. We fitted multiple regression models based on the combinations of the selected independent variables from the cluster analysis. In addition, three multiple regression models using stepwise, forward and backward selection methods for all selected independent variables.[21]



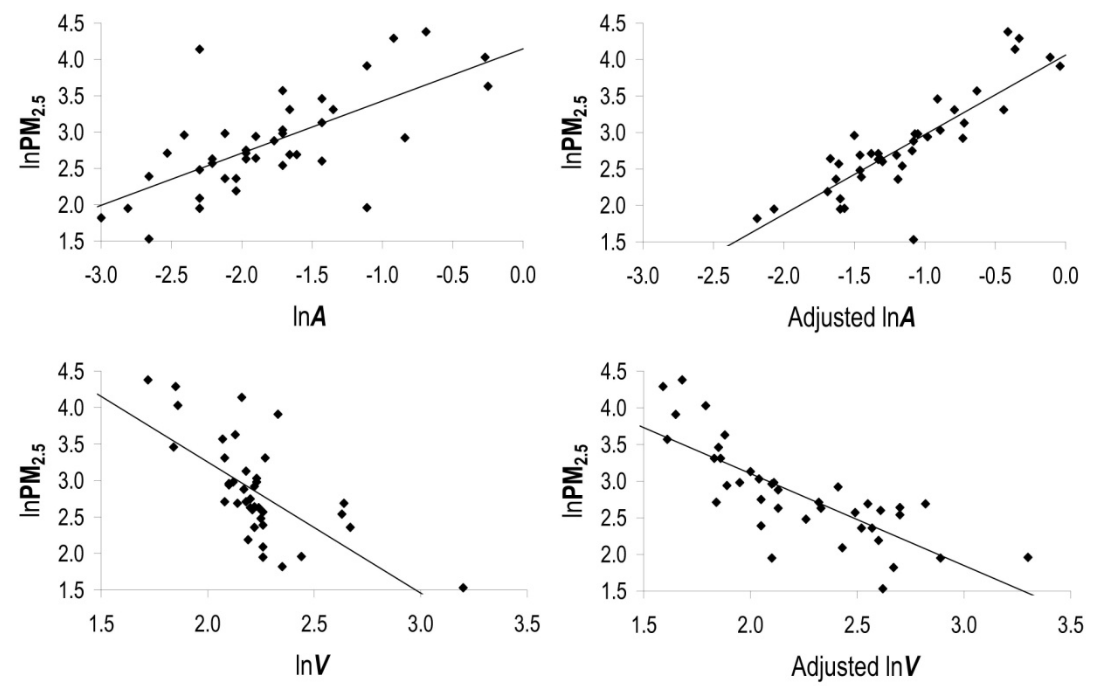
Note. T=air temperature, D=dew point, L=land surface temperature, H=relative humidity, cc=cloud cover, vi=vegetation index, C= cloud optical thickness, W=wind speed, co=carbon monoxide, A=aerosol optical thickness, V=visibility. Line-parsing method at 50% full distance on a dendrogram is a proven method that helps to select one variable from each line-parsed cluster (six clusters were parsed on the left of the dotted line) for reduction of multi-collinearity in regression modeling.

Supplementary II. Regression models of $PM_{2.5}$ and sensitivity of the model predictions.

Model	R	VIF	Regression models	Temporal sensitivity D_1[min,max]	Spatial sensitivity D_2[min,max]	Overall sensitivity $0.5D_1+0.5D_2$
M1	0.845	1.2-1.7	7.802+0.627(ln**A**)***-0.997(ln**V**)**-0.045(**C**)-0.030(**W**)-0.018(**T**)-0.003(**H**)	5.3 [0.3,14.6]	10.3 [0.6,18.2]	7.8
M2	0.847	1.2-1.5	7.759+0.615(ln**A**)***-0.990(ln**V**)**-0.045(**C**)*-0.030(**W**)-0.020(**T**)-0.044(**cc**)	5.1 [0.3,14.3]	11.3 [3.3,21.5]	8.2
M3	0.845	1.1-1.8	7.700+0.618(ln**A**)***-1.001(ln**V**)**-0.044(**C**)-0.032(**W**)-0.018(**T**)-0.209(**vi**)	5.1 [0.3,12.5]	10.0 [0.3,17.0]	7.6
M4	0.846	1.2-1.7	7.353+0.628(ln**A**)***-0.997(ln**V**)**-0.044(**C**)-0.030(**W**)-0.020(**D**)-0.002(**H**)	10.1 [1.0,27.9]	18.4 [5.3,33.0]	14.2
M5	0.846	1.2-1.5	7.507+0.607(ln**A**)***-1.022(ln**V**)**-0.040(**C**)-0.028(**W**)-0.018(**D**)-0.022(**cc**)	4.9 [0.1,13.7]	9.9 [0.0,17.5]	7.4
M6	0.846	1.2-1.8	7.476+0.616(ln**A**)***-1.017(ln**V**)**-0.041(**C**)-0.029(**W**)-0.018(**D**)-0.034(**vi**)	4.8 [0.1,12.9]	9.7 [1.3,16.9]	7.3
M7	0.845	1.2-1.8	8.281+0.622(ln**A**)***-1.015(ln**V**)**-0.046(**C**)-0.035(**W**)-0.018(**L**)-0.007(**H**)	5.0 [0.2,15.5]	10.2 [0.0,17.5]	7.6
M8	0.847	1.1-1.8	8.097 +0.613(ln**A**)***-0.987(ln**V**)**-0.048(**C**)*-0.037(**W**) -0.020(**L**)-0.068(**cc**)	4.5 [0.3,14.9]	9.8 [1.2,17.1]	7.1
M9	0.845	1.1-1.8	7.962 +0.605(ln**A**)*** -1.021(ln**V**)** -0.045(**C**)-0.038(**W**) -0.016(**L**)-0.436(**vi**)	4.9 [0.2,12.8]	9.7 [0.3,16.2]	7.3
M10 stepwise	0.865	1.1-1.9	5.042 +0.312(ln**A**)* -1.001(ln**V**)*** -0.053(**C**)**+0.013(**co**)**	4.2 [0.7,7.8]	12.0 [0.1,20.9]	8.1
M11 forward	0.865	1.1-1.9	5.042 +0.312(ln**A**)* -1.001(ln**V**)*** -0.053(**C**)**+0.013(**co**)**	4.2 [0.7,7.8]	12.0 [0.1,20.9]	8.1
M12 backward	0.878	1.1-2.0	5.359 +0.350(ln**A**)** -0.953(ln**V**)*** -0.047(**C**)**-0.030(**W**) +0.012(**co**)**	2.7 [0.4,8.7]	13.0 [0.2,28.8]	7.9

*Note. A=aerosol optical thickness, V=visibility,C= cloud optical thickness, W=wind speed, T=air temperature, H=relative humidity, cc=cloud cover, vi=vegetation index, D=dew point, L=land surface temperature, co=carbon monoxide. VIF=Variance inflation factor, in which VIF less than 2.5 are indicative of non-collinearity. D1=Mean absolute difference between predicted and observed $PM_{2.5}$ based on temporal sensitivity. D2=Mean absolute difference between predicted $PM_{2.5}$ and 70% observed PM_{10} concentration in PRD based on spatial sensitivity. *p<0.05, **p<0.01, ***p<0.001*

Visual inspection of the major independent variables: ln-transformed data of $PM_{2.5}$ versus AOT and visibility in 40 cities.



Note. A=aerosol optical thickness, V=visibility. lnA and lnV on the left were unadjusted whereas on the right were adjusted for all other covariates in M8.

Supplementary III. Excess risks of all-cause mortality for $PM_{2.5}$ in all age groups due to air pollution in the selected literatures

Country	City	Period	Lag	ER	SE	Author, year	Ref
America							
Canada	8 cities	1986-1996	1	1.20	0.41	Burnett *et al.*, 2000	63
Mexico	Mexico City	1993-1995	0	1.34	0.60	Borja-Aburto et al., 1998	64
United States	112 cities	1999-2005	0-1	0.98	0.12	Zanobetti and Schwartz, 2009	65
United States	Coachella Valley	1989-1998	1	-1.00	2.10	Ostro et al., 2000	66
United States	Portage	1979-1987	0-1	1.20†	0.77	Schwartz et al., 1996	67
United States	Topeka	1979-1988	0-1	0.80†	1.43	Schwartz et al., 1996	67
Pooled ER				*1.01*^{F}	*0.11*		
Europe							
Czech Republic	5 cities	1992-1994	1	0.59 †	0.40	Peters et al., 2000	68
Czech Republic	Prague	2006-2006	1	0.40 †	0.61	Branis et al., 2010	69
Germany	Erfurt	1995-2001	0	0.49 †	0.66	Peters et al., 2009	70
Spain	Barcelona	2003-2007	1	1.40	0.41	Ostro et al., 2011	71
Spain	Madrid	2003-2005	1	3.00	0.77	Tobias et al., 2011	72
Sweden	Stockholm	2000-2008	0-1	1.46	0.71	Meister et al., 2012	73
United Kingdom	London	2000-2005	1	0.24 †	0.32	Atkinson et al., 2010	74
United Kingdom	West Midlands	1994-1996	0-1	0.30 †	0.61	Anderson et al., 2001	75
Pooled ER				*0.88*	*0.28*		
Asia-Pacific							
Australia	3 cities	1996-1999	0-1	0.90 †	0.82	Simpson et al., 2005	76
China	Beijing	2007-2008	0	0.53	0.08	Chen et al., 2011	77
China	Chongqing	1995-1995	0	0.00†	0.36	Venners et al., 2003	78
China	Guangzhou	2007-2008	1	1.26	0.10	Yang et al., 2011	61
China	Shanghai	2004-2008	0	0.47	0.13	Chen et al., 2011	79
China	Shenyang	2006-2008	0-1	0.49	0.15	Ma et al., 2011	80
China	Xian	2004-2008	1	0.16	0.04	Cao et al., 2012	81
Japan	Tokyo	2003-2008	0	0.30 †	0.20	Yorifuji et al., 2011	16
Korea	Seoul	2008-2009	1	0.50 †	0.37	Son et al., 2012	82
Pooled ER				*0.50*	*0.16*		
Overall ER				***0.69***	***0.12***		

"ER" represents excess risk (%) per 10 μgm^{-3} increase in pollutant concentration. "SE" represents standard error. All the pooled ER are random effects otherwise specified.

^{F} represented fixed effects. † indicated statistically not significant at alpha=0.05.

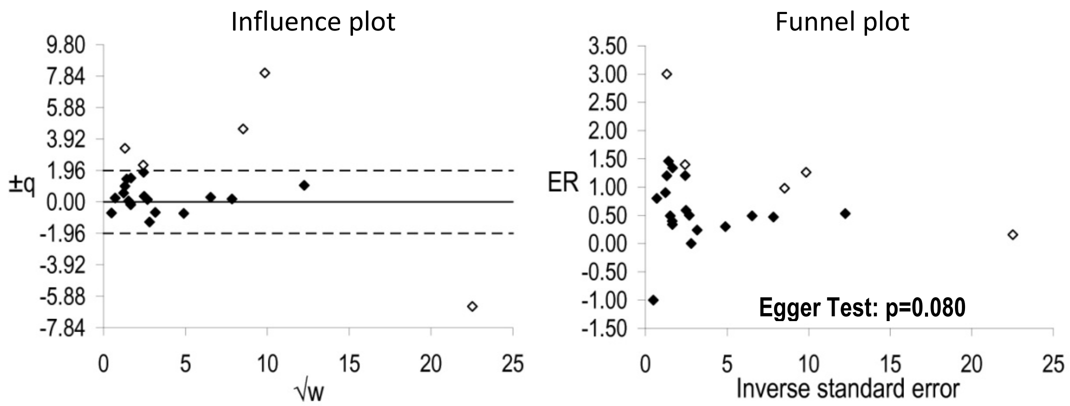
Supplementary IV. Excess risks of cardiovascular and respiratory mortality for $PM_{2.5}$ in all age groups due to air pollution in different reviewed studies

Country	City	Period	Lag	ER	SE	Author, year	Ref
Cardiovascular							
Australia	Melbourne	1991-1996	0	0.30 †	1.22	Simpson et al., 2000	83
Australia	Sydney	1989-1993	0	1.60	0.82	Morgan et al., 1998	84
Canada	Montreal	1984-1993	1	1.34 †	0.92	Goldberg et al., 2001	85
China	Beijing	2007-2008	0	0.58	0.12	Chen et al., 2011	77
China	Chongqing	1995-1995	0	0.00	0.68	Venners et al., 2003	78
China	Guangzhou	2007-2008	0	1.01	0.26	Yang et al., 2011	61
China	Shanghai	2004-2008	0	0.41	0.21	Chen et al., 2011	79
China	Shenyang	2006-2008	0-1	0.53	0.22	Ma et al., 2011	80
China	Xian	2004-2008	1	0.27	0.07	Cao et al., 2012	81
Czech Republic	Prague	2006-2006	1	0.90 †	0.92	Branis et al., 2010	69
Japan	Tokyo	2003-2008	0	0.60 †	0.36	Yorifuji et al., 2011	16
Korea	Seoul	2008-2009	0	0.92 †	0.79	Son et al., 2012	82
Spain	Barcelona	2003-2007	1	2.87	0.75	Ostro et al., 2011	71
United Kingdom	London	2000-2005	0	0.48 †	0.52	Atkinson et al., 2010	74
United Kingdom	West Midlands	1994-1996	0-1	0.51 †	0.86	Anderson et al., 2001	75
United States	9 California counties	2000-2003	0	0.46	0.21	Ostro et al., 2007	86
United States	Coachella Valley	1989-1998	1	-0.81	3.15	Ostro et al., 2000	66
United States	Phoenix	1995-1997	1	3.80	1.56	Wilson et al., 2007	87
United States	Washington	1995-1999	1	1.00 †	2.04	Slaughter et al., 2005	88
United States	Wayne	1992-1994	1	1.28 †	1.12	Lippmann et al., 2000	89
Pooled ER				***0.60***	***0.10***		
Respiratory							
Australia	Melbourne	1991-1996	0	-0.70 †	2.96	Simpson et al., 2000	83
Australia	Sydney	1989-1993	1	2.30 †	1.84	Morgan et al., 1998	84
Canada	Montreal	1984-1993	1	5.00	2.14	Goldberg et al., 2001	85
China	Beijing	2007-2008	0	0.66	0.23	Chen et al., 2011	77
China	Guangzhou	2007-2008	1	0.98	0.23	Yang et al., 2011	61
China	Shanghai	2004-2008	1	0.71 †	0.39	Chen et al., 2011	79
China	Shenyang	2006-2008	0-1	0.97	0.49	Ma et al., 2011	80
China	Xian	2004-2008	1	0.40	0.09	Cao et al., 2012	81
Czech Republic	Prague	2006-2006	0	-2.30 †	2.14	Branis et al., 2010	69
Japan	Tokyo	2003-2008	0	1.00 †	0.51	Yorifuji et al., 2011	16
Korea	Seoul	2008-2009	1	0.78 †	1.36	Son et al., 2012	82
United Kingdom	London	2000-2005	1	0.46 †	0.79	Atkinson et al., 2010	74
United Kingdom	West Midlands	1994-1996	0-1	-0.06 †	1.53	Anderson et al., 2001	75
United States	112 cities	1999-2005	0-1	1.68	0.33	Zanobetti and Schwartz, 2009	65
United States	Coachella Valley	1989-1998	1	-5.31 †	8.06	Ostro et al., 2000	66
United States	Wayne	1992-1994	0	0.92 †	2.52	Lippmann et al., 2000	89
Pooled ER				***0.83***	***0.17***		

"ER" represents excess risk (%) per 10 μgm^{-3} increase in pollutant concentration. "SE" represents standard error. All the pooled ER are random effects.
† indicated statistically not significant at alpha=0.05.

Electronic Supplementary Material (ESI) for Environmental Science: Processes & Impacts

Supplementary V. Literature review - detection of heterogeneity and publication bias.



Note. ±q is the square root of heterogeneity measure of Q^2 statistics.[25] √w is the square root of weights that based on estimate precisions. Solid and hollow dots represent studies with ±q<-1.96 and ≥1.96, respectively.

Supplementary VI. Summary of excess risks of different causes of mortality in all age groups due to $PM_{2.5}$

Health outcomes	**ER**	**SE**	**Ref**	**Number of studies**
All causes	**0.69**	0.12	16,61,63-78,80-82	21
Cardiovascular diseases	**0.60**	0.10	16,61,66,69,71, 74-75,77-78,80-89	19
Cerebrovascular diseases	**1.74** [F]	0.40	16,65	2
Ischemia heart diseases	**1.18**	0.57	16,67,90-91	4
Myocardial infarction	**1.19**	0.53	65,92	2
Arrhythmia	2.70†	1.53	16	1
Heart diseases	**0.90** [F]	0.19	65,92	2
Heart failure	2.51†	1.66	92	1
Respiratory diseases	**0.83**	0.17	16,61,65-67,69,74-75,77-78,80-82,83-85,89	17
Chronic obstructive pulmonary diseases	**1.53†**	0.89	16,67,78	3
Influenza and pneumonia	0.90 †	0.56	16	1
Pneumonia	4.00	1.12	67	1
Cardiopulmonary diseases	0.06†	0.71	93	1
Non-cardiopulmonary	0.00 †	0.26	16	1

"ER" with **Bold** represents pooled excess risk (%) per 10 $\mu g m^{-3}$ increase in pollutant concentration. "ER" not **Bold** was the ER of single study. "SE" represents standard error in 10^{-4}. All the pooled ER are random effects otherwise specified.

[F] represented fixed effects.

† indicated statistically not significant at alpha=0.05.