ASSOCIATIONS OF PARTICULATE MATTER AND DAILY MORTALITY IN BANGKOK, THAILAND

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Abstract. The association between airborne particles and daily mortality has been reported in many locations, but mainly in western countries. There is a need to investigate the association in locations where the emission sources, weather, and other environmental conditions differ from those in western countries. In this study, the acute effects of PM10 and visibility on daily mortality in Bangkok, Thailand, from 1992 to 1997, were examined. A Poisson regression model was developed to estimate the excess daily mortality associated with PM10 and visibility, while controlling for long-term trends, season, and variations in weather. It was found that increasing PM10 and decreasing visibility levels were independently associated with increasing daily mortality from all non-external causes, cardiovascular, respiratory, and other diseases. The observed associations were stronger for respiratory diseases than for cardiovascular and other diseases and were stronger for persons aged ≥65 years than for those in the younger age group. The results of the PM10/mortality and visibility/mortality models were consistent, suggesting that visibility may be considered as a surrogate marker for the assessment of the adverse health effects of fine particulate matter when data from direct gravimetric measurements are not available.

INTRODUCTION

Studies in cities in the US have demonstrated associations between daily mortality and various measures of particulate matter at concentrations lower than the current ambient US standards (Schwartz, 1991; Schwartz and Dockery, 1992a,b; Dockery *et al*, 1992). When specific causes and ages have been evaluated, a significantly excessive number of deaths from respiratory and cardiovascular diseases, and deaths in the elderly have been observed (Pope *et al*, 1992; Verhoeff *et al*, 1996). As in the US, studies in Europe and Latin America countries have found positive association between particulate matter and mortality (Katsouyanni *et al*, 1996; Ostro *et al*, 1996; Borja-Aburto *et al*, 1997).

Current knowledge of the acute effects of particulates, and of their affecting mortality, has relied on the studies in regions with temperate climates. For this reason Bangkok, one of the largest cities in Southeast Asia, with high traffic and a hot humid climate throughout the year, was chosen to evaluate the relationship between PM10 (fine particulate mater less than 10 microns in aerodynamic diameter) and daily mortality. The ambient particle mixtures, other background exposures, and potential confounders in Bangkok, may differ greatly from the cities mentioned in the earlier studies due to differences in meteorology, geographical location, source emissions, population age structure, and general health status. A distinct advantage of choosing Bangkok as the study site was the opportunity for studying the effects of PM10 at higher concentrations (a mean of 68 $\mu g/m^3$ and maximum of 230 $\mu g/m^3$) than those generally

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found in the US and Europe.

The first study evaluating the influence of PM10 on daily mortality in Bangkok was reported recently (Ostro *et al*, 1999). This study analyzed data gathered in Bangkok during the period 1992-1995: the authors reported significant positive relationships between PM10 and daily mortality from all causes, and from cardiovascular and respiratory diseases after adjusting for periodic cycle, temperature, and relative humidity.

A significant common problem encountered in previous studies was the scarcity of daily data on PM10. It has been reported that fine particles with diameters of 0.1-1 μm can be major contributors to the attenuation of visibility in the atmosphere because they are the most efficient scatterers of visible light (Pitchford, 1991). This suggests that visibility may be a good surrogate marker of the presence of fine particles. Visibility is routinely monitored at airports throughout the world, making it possible to evaluate the health effects of particulate matter when direct gravimetric measurements are not available.

In this analysis, we examined the associations between PM10 and visibility and daily mortality in Bangkok; this study analysed data gathered over a period longer than that of the previous Bangkok study (Ostro *et al*, 1999), *ie*, from 1992 to1997, and used a different approach to control the effects of time trends and weather on the association between mortality with PM10 and visibility. We also examined the possibility of using visibility in an assessment of health effects of fine particles.

MATERIALS AND METHODS

Air pollution and weather data

24-hour PM10 measurements from 1992-1997 were obtained from the Pollution Control Department. To ensure the representativeness of 24-hour PM10 on each day, estimates were based on the readings obtained during at least 18 hour of every 24-hour period. Multi-site average PM10, based on data obtained on the same day at each of the three monitoring sites across Bangkok (Chulalongkorn Hospital, Ministry of Science and Technology, and Odean Circle) was used to consider the association with daily mortality. During the study period, PM10 data were available for 1,460 days (67% of the study days); the missing PM10 data were estimated from visibility data using a linear regression model with an R^2 of 0.51; details of the estimation method and the precision of the regression model are described elsewhere (Vajanapoom *et al*, 2001).

Weather data (daily temperature, relative humidity, and visibility) were obtained from the Sirikit Convention Center and airport sites operated by the Department of Meteorology. The same-day measurements from the two sites were averaged and used in this analysis. Weather data were available for nearly all days during the study period; missing values were replaced by the daily value for the available site, with a site-specific correction factor applied as suggested by Kinney and Ozkaynak (1991). By this means, we were able to use complete data on temperature, relative humidity, dew point, and visibility during the study period.

Mortality data

The mortality data (1992 to 1997) were extracted from a computerized file of individual death certificates provided by the Bureau of Registration Administration. Each record contained: age, sex, date of death, and cause of death coded according to the 9th Revision of the International Classification of Disease (ICD9). The mortality data were grouped into four cause-specific categories: i) all cause mortality, except that caused by injuries and poisoning (ICD9 <800); ii) respiratory diseases (ICD9 460-519); iii) cardiovascular diseases (ICD9 390-459); iv) other diseases (all causes except injuries, poisoning, respiratory and cardiovascular diseases). Four age groups (all ages, 55-64 years, 65-74 years, and 75 years and older) were given for each cause-specific category.

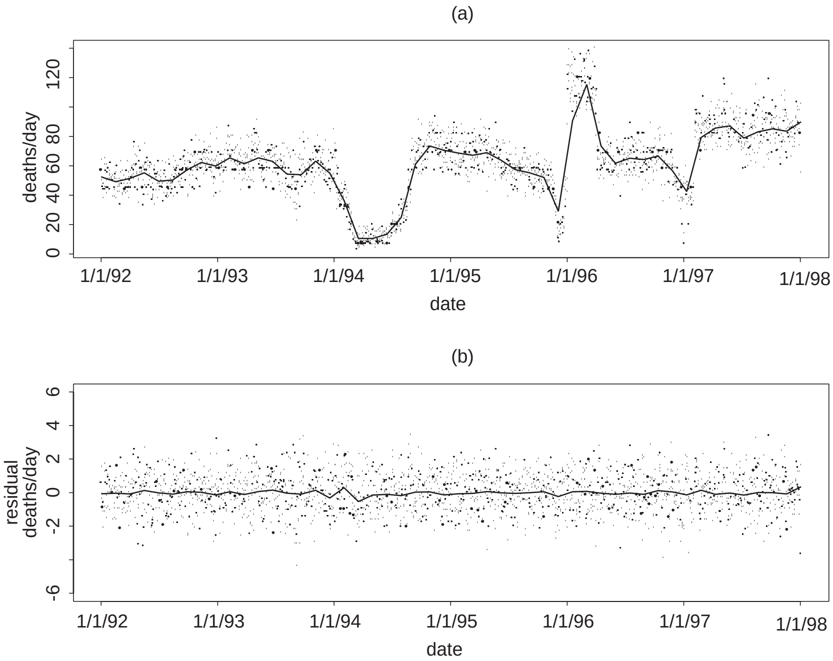

Fig 1–Plots of daily mortality: (a) the residuals of the smoothed daily mortality adjusted for time indicator variables (time 0 - time 5) at the problematic periods; (b) solid lines are the loess smoothed the mortality with 3% span.

We found sudden unexplained changes in mortality counts in 1994, late 1995, and early 1996 and 1997 (Fig 1a). The changes in mortality during late 1995 and early 1996 could have been due to a change in the death certificate recording system (a centralized paper system became a distributed online system) during this period. However, there is no clear explanation for the changes in the other periods. These problematic patterns were meticulously controlled in the analysis.

Data analysis

Since mortality are count data, Poisson regression is the appropriate model for the association between mortality and PM10. To allow for a possible non-linear relationship between mortality and predictors, we used generalized additive models (Hastie and Tibshirani, 1990) extending Poisson regression to model predictors' effects on the log of the expectation of mortality, *ie*, $\log E(Y_i) = \sum S_i(X_i)$ where Y_i is the daily mortality count, X_i are the predictor variables including time, and S_i are smooth functions of those predictors, in which loess smoothers were used. The models were fitted by maximum likelihood under a Poisson model (maximum quasi-likelihood) assuming constant over-dispersion with time (McCullagh and Nelder, 1989). The strategy of model development was first to develop the best predictive basic model for the long-term trends and the weather and then to assess the independent influence of PM10 on mortality. The model was systematically developed for total mortality from non-external causes; the same model was then applied to cause-specific mortality to assess whether the effects of PM10 were different among different causes of death. Akaike's Information Criterion (AIC), which penalizes for the inclusion of additional predictors into the model, was used to guide model improvement, *ie*, the model with lower AIC values is a better fit to the data than that with higher AIC values.

The first step in model development was to control for the effects of long-term trends and the unexplained patterns of daily mortality mentioned earlier. These temporal patterns were well controlled by fitting a loess-smoothed function of time with 3% span and six binary indicator variables created for those problematic periods; this was suggested by the horizontal distribution of the model residuals, as shown in Fig 1b. Subsequently, the model was improved by adding indicator variables for the day of the week to control for the short-wave time trends that were not captured by the smooth function of time. The loess smooth functions of time also helped to reduce the serial correlation of the model residuals which is common in time series data.

The second step was the addition of weather variables to improve the mortality prediction by fitting temperature and then relative humidity. The form of temperature used in the model was decided by examining the goodness of fit of the models with mean, maximum, and minimum temperatures on an index day and lagged up to 3 days, as well as a 3-day moving average of temperature. Based on the AIC values, index day mean temperature was the best predictor of daily mortality, and this was used throughout the analyses. We attempted to evaluate various forms of the association between mortality and weather by introducing linear and nonlinear functions, and the bivariate smooth function of the temperature and relative humidity, to the models.

The third step was to evaluate whether PM10 made any significant additional contribution to explaining the variation of daily mortality, after adjusting for time trends and weather. PM10 at lag0 to lag3, as well as with 3-day and 5-day moving averages of PM10 were separately fitted to the model.

The fourth step was the performance of sensitivity analyses to assess the potential influence of extreme values of PM10 and mortality, as well as values of imputed PM10. The estimates did not change after excluding values of PM10 greater than 150 $\mu g/m^3$ (US standard), predicted PM10 on days for which relative humidity was higher than 76.5%, or imputed PM10; conversely, we observed an approximate 10% change in the estimate when using a robust Poisson regression and, therefore, the coefficients of the regression models were re-estimated using robust Poisson regression to minimize the potential influence of a few extreme values of mortality on the regression coefficients.

Lastly, PM10 in all of the models was replaced by visibility to assess the independent influence of visibility on daily mortality. For simplicity in interpreting the independent influence of visibility, the regression coefficient was multiplied by the negative value of the interquartile range of visibility; as a result, it was interpreted as the change in daily counts for an interquartile decrease in visibility. All statistical analysis procedures were performed using S-PLUS (Statisical Sciences Inc, Seattle, Washington).

RESULTS

Descriptive analysis

Table 1 shows the pattern of mortality during the study period starting on January 1, 1992. Mean daily deaths were 61 from all non-external causes; 24% of mortality was from cardiovascular diseases; 4% was from respiratory diseases; 72% was from other diseases. Approximately 44% of the daily mortality was among persons aged 65 years and over.

PM10 and weather in Bangkok varied considerably during 1992-1997 (Table 2). The mean concentration of PM10 was 68 $\mu g/m^3$; it was higher than 150 $\mu g/m^3$ (US ambient 24-hour air quality standard) for a few days. Seasonal patterns were evident for PM10, visibility, mean temperature, and relative humidity (Fig 2).

Table 1
Descriptive statistics of daily mortality in Bangkok, 1992-1997.

Causes of death	Total deaths	Deaths per day	SD
All non-external causes	134,138	61.2	23.3
Cardiovascular	32,559	14.9	7.1
Respiratory	5,311	2.4	2.1
Other	96,268	44	21.0

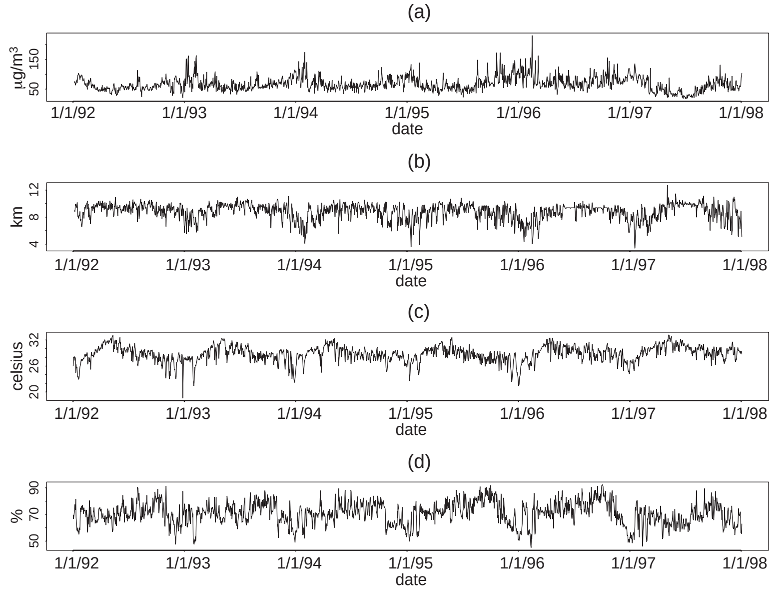

Fig 2–Time series plots: (a) PM10; (b) visibility; (c) temperature; (d) relative humidity, Bangkok, 1992-1997.

Basic model development

Table 3 shows the results of the development of predictive basic models for long-term trends and weather, before assessing whether PM10 made any significant additional contribution to the variation of daily mortality. Of these models, the best predictive basic model contains a nonparametrically smooth function of time, six indicator variables of time created for the problematic periods, indicator variables for day of week, and bivariate smooth function of same-day mean temperature and relative humidity, which represents the nonparametrically joint influence of these two terms on daily mortality (model W4 in Table 3). According to AIC values, this model fits the data better than models T1 to T3 and W1 and slightly better than model W3 (see models in Table 3).

Evaluating PM10 and visibility effects

We examined the individual impact of the index day as well as lags up to 3 days and 3-day and 5-day moving averages of PM10 and visibility. It was shown that 5-day moving average of PM10 and visibility was the most strongly associated with daily mortality from all non-external causes and was selected as the final model.

We performed partial autocorrelation function (PACF) plots of the final model residuals to assess possible serial correlation of the residuals, which is commonly found in time series data. There was only a slight serial correlation of the residuals at lag 1 and lag 2 of approximately r = 0.045; this minimal serial correlation should not have had a significant effect on the estimated standard error of the regression coefficients.

The approximate percent change in daily mortality for one interquartile range (30 µg/m^3) increase in PM10 and 95% confidence intervals are shown in Table 4. An interquartile range increment in PM10 was associated with a 2.3% (95% CI= 1.3, 3.3) increase in daily mortality from all non-external causes, with a 0.8% (95% CI= -0.9, 2.4) increase from cardiovascular diseases, with a 5.1% (95% CI =

Table 2
Distribution of air pollutant and weather in Bangkok,1992-1997.

Variables	5%	25%	50%	75%	95%	Mean	SD
PM_{10} (µg/m^3)	34.6	50.1	64.1	80.7	111.5	68.0	23.9
Visibility (km)	6.5	8.2	9.1	9.6	10.2	8.8	1.2
Temperature (ºC)	25.4	27.8	28.9	30.0	31.6	28.8	1.8
Humidity (%)	56.0	65.5	71.0	76.5	84.0	70.8	8.4

Table 3
Basic model development for daily mortality from all non-external causes in Bangkok, 1992-1997.

Model	Covariates	AIC	Over-dispersion	Model degrees of freedom
Time				
T1	Smooth function of time (61.5 df)	3,573.9	1.57	62.5
T2	T1 + time 0 +time 1 +time 2 +time 3 + time 4 + time 5	2,975.8	1.31	68.6
T3	T2 + day of week	2,957.8	1.30	74.6
Weather				
W1	T3 + current day mean temperature	2,872.8	1.26	75.6
W2	W1 + current day relative humidity	2,864.7	1.25	76.6
W3	T3 + smooth mean temperature and smooth relative humidity (4.4 df)	2,837.1	1.24	79.0
W4[a]	T3 + bivariate smooth function of current day mean temperature and relative humidity (5.7 df)	2,833.8	1.24	80.3

[a]Best predictive basic model.

Table 4
Percent change in daily mortality per one interquartile range of PM10 (30 $\mu g/m^3$) in the final robust Poisson regression model[a], 1992-1997 Bangkok.

Age (yrs)	All non-external causes	Cardiovascular	Respiratory	Other
All ages	2.3	0.8	5.1	2.4
	(1.3, 3.3)[b]	(-0.9, 2.4)	(0.6, 9.6)	(1.3, 3.5)
55 - 64	1.5	-2.5	1.4	1.7
	(-0.8, 3.9)	(-6.3, 1.3)	(-11.3, 14.2)	(-1.1, 4.5)
65 - 74	4.2	2.9	2.8	5.6
	(2.0, 6.3)	(-0.7, 6.5)	(-9.5, 15.2)	(3.1, 8.1)
75 - >75	3.9	1.6	10.2	3.7
	(2.1, 5.6)	(-1.8, 5.0)	(-0.1, 20.5)	(1.8, 5.6)

[a]The final model included smooth function of time, dummy variable of time 0 - time 5, day of week, bivariate smooth function of mean temperature and relative humidity, and 5-day lagged moving average PM10 were used in the model for all causes, and other diseases, current day for cardiovascular, and 3-day moving average for respiratory diseases.
[b]Approximate 95% confidence intervals are given in parentheses.

0.6, 9.6) increase from respiratory diseases, and with a 2.4% (95% CI= 1.3, 3.5) increase from other diseases. Table 5 presents the approximate percent change in mortality for an interquartile range decrease in visibility (about 1.5 km) and 95% confidence intervals. An interquartile decrease in visibility was associated with a 1.3 % (95% CI = 0.4, 2.3) increase in daily mortality from all non-external causes, with a 1.7% (95% CI = 0.1, 3.2) increase from cardiovascular diseases, with a 8.1 % (95% CI = 4.1, 12.0) increase from respiratory diseases, and with a 1.5% (95% CI = 0.4, 2.6) increase from other diseases.

Fig 3 presents the estimated percent change in daily mortality and 95% confidence interval for all ages and subgroups of age for mortality from all non-external causes and each cause-specific category. Generally, the patterns of the influence of PM10 across age groups for each category of mortality were consistent with those for visibility. They were stronger for ages 65-74 years and 75 years and older than for persons aged 55-64 years, in which the estimated effects were very small and possibly negligible.

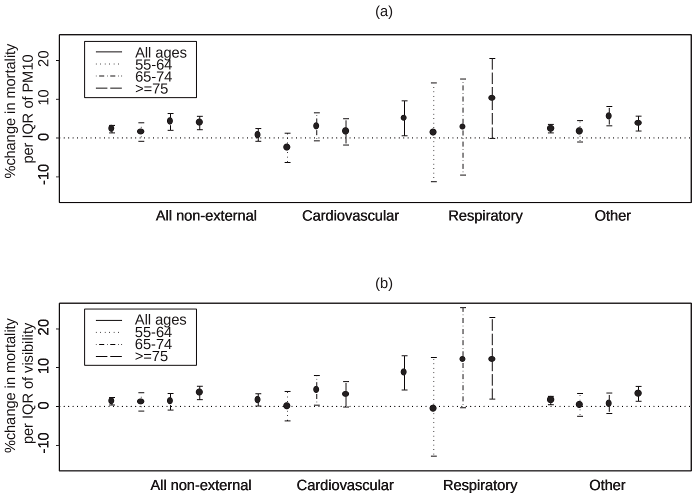

Fig 3–Percent change in daily mortality and approximated 95 % confidence interval associated with: (a) a one interquartile range increase of PM10 (30 μg/m^3); (b) with a one interquartile decrease of visibility (1.5 km), for each mortality category in Bangkok, 1992-1997.

Because causes other than cardiovascular and respiratory diseases were responsible for about two-thirds of all non-external causes, we further assessed the association of PM10 and visibility, with mortality from other diseases by subcategorizing these diseases into 'senility' (ICD9 797) plus unknown causes (ICD9 799), and a remaining disease group (34%). Fig 4 shows the estimated effects and 95% confidence intervals across the age groups of the two subgroups. When deaths caused by senility and unknown causes were excluded from the mortality caused by other diseases, the effects of PM10 and visibility on mortality from all other remaining diseases for all ages were no longer observed,

Table 5

Percent change in daily mortality per one interquartile range decrease of visibility (about 1.5 km) in the final robust Poisson regression model[a] of each cause of death category, Bangkok, 1992-1997.

Age (yrs)	All non-external causes	Cardiovascular	Respiratory	Other
All ages	1.3	1.7	8.1	1.5
	(0.4, 2.3)[b]	(0.1, 3.2)	(4.1, 12.0)	(0.4, 2.6)
55 - 64	1.1	0.04	-0.6	0.4
	(-1.2, 3.5)	(-3.8, 3.8)	(-14.0, 11.6)	(-2.6, 3.3)
65 - 74	1.2	4.0	11.2	0.8
	(-0.9, 3.3)	(0.4, 7.6)	(-0.3, 21.8)	(-1.9, 3.4)
75 - >75	3.4	3.0	11.2	3.2
	(1.7, 5.0)	(-0.1, 6.2)	(1.9, 19.9)	(1.3, 5.0)

[a]The final model included smooth function of time, dummy variable of time 0 - time 5, day of week, bivariate smooth function of mean temperature and relative humidity, and 5-day lagged moving average visibility were used in the model for all non-external causes, and other diseases, current day for cardiovascular, and 3-day moving average for respiratory diseases.

[b]Approximate 95% confidence intervals are given in parentheses.

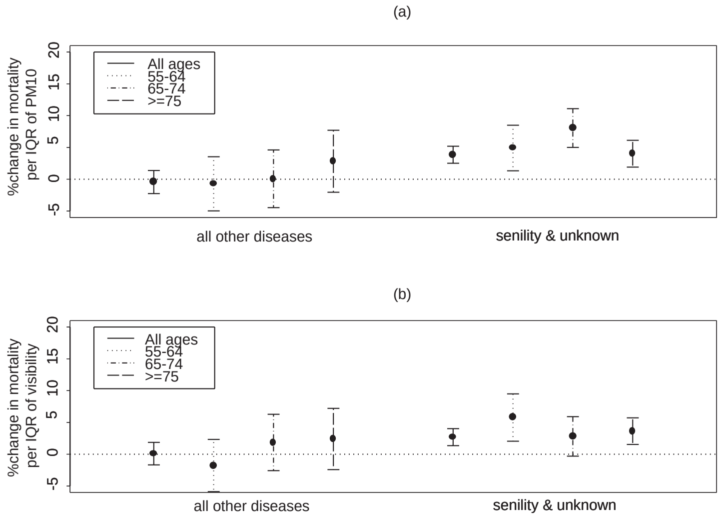

Fig 4–Percent change in daily mortality and approximated 95 % confidence interval associated with: (a) a one interquartile range increase of PM10 (30 μg/m^3); (b) with a one interquartile decrease of visibility (1.5 km), for other diseases in Bangkok, 1992-1997.

but stronger and significant associations were observed for each age group of mortality from the senility and unknown causes combined group.

DISCUSSION

We found that increasing PM10 and decreasing visibility levels in Bangkok (1992-1997) were associated with increasing daily mortality from all non-external causes, cardiovascular, respiratory, and other diseases, having adjusted for smooth function of time, indicator variables of time at problematic periods in the temporal pattern of mortality, day of week, and bivariate smooth function of mean temperature and relative humidity. The association was stronger for respiratory diseases than for cardiovascular and other diseases and was stronger for persons aged ≥65 years than for those in the the younger age group. The influence of PM10 on mortality from respiratory and cardiovascular diseases was somewhat less than that of visibility; the influences were comparable for other diseases. The influence of PM10 was consistent with that found in Amsterdam (Verhoeff *et al*, 1996), Santiago (Ostro *et al*, 1996), and the Harvard Six Cities Study (Schwartz *et al*, 1996). The consistent findings from many locations, where climate and other unknown risk factors may differ suggest that findings of the present study are unlikely to be spurious, supporting the likelihood of a causal association between particles and mortality.

The association between PM10 and daily mortality in Bangkok was reported recently by Ostro *et al* (1999), who cited a 10 % increase in daily mortality from all non-external causes, a 16% increase from cardiovascular diseases, and a 30% increase from respiratory diseases for a 100 μg/m^3 increase in PM10. In the present study, an 8 % (approx) increase in daily mortality from all non-external causes, a 3% increase from cardiovascular diseases, and a 17% from increase respiratory diseases for a 100 μg/m^3 increase in PM10 were found. A possible explanation for the weaker associations found in the present analysis is that mortality data gathered during a longer time period (1992-1997), and used a multi-site mean PM10, whereas Ostro *et al* (1999) used one monitoring site for estimating PM10 exposure.

This study demonstrated that temperature and relative humidity were highly significant predictors of daily mortality in Bangkok; they were not linearly associated. More importantly, the study has shown that bivariate smooth function of temperature and relative humidity fit the Bangkok mortality data better than separate linear or non-linear terms of these variables. This issue was not addressed in the previous analysis of the Bangkok data (Ostro *et al*, 1999). To ensure the consistency of evidence drawn from the Bangkok data, we limited our analysis to the same period of time used in the Ostro analysis, *ie*, January 1, 1992 to November 30, 1995, and reproduced the final model of Ostro *et al* (1999) using the same variables as shown in their report. The linear and nonlinear effects of temperature and relative humidity were examined. We found that the model with bivariate smooth function of temperature and relative humidity (AIC = 1,828) was a better fit with the Bangkok data than the models with linear and separate smoothed terms of temperature and relative humidity (AIC = 1,935 and 1,895 respectively).

We found that mortality from senility and unknown causes accounted for approximately 66 % of mortality from diseases other than cardiovascular and respiratory disease; of these deaths, 53 % were among those aged 65 years and older. It is possible that some of mortality from cardiovascular diseases may have been wrongly attributed to these causes of deaths, especially when the deaths occurred suddenly and outside hospitals, thus influencing the association between PM10 and mortality from other diseases. This hypothesis was supported by the results when excluding senility and unknown causes from other diseases, *ie*, the association became nonsignificant and the influence reduced significantly, but the strong association between PM10 and mortality from senility and unknown causes was observed (Fig 4a). Similar evidence was observed for the association between visibility and mortality from other diseases (Fig 4b).

In this study, 33% of daily PM10 concentrations were estimated from visibility using a regression model. Of these, 7% were based on the visibility with high humidity (> 76.5%), and these may have been overestimated because the predictive regression model was based on visibility with low humidity (≤ 76.5%). However, the regression coefficients did not change when excluding all or only 7% of the visibility-based estimated PM10 from this analysis; this suggested that there should be no objection to imputing PM10 using visibility-based estimated PM10.

Decreased visibility indicates an increase in airborne fine particle concentrations because visibility has been known to be negatively correlated with fine particles and used to estimate fine particle concentration in the literature (Ozkaynak *et al*, 1985; Delfino *et al*, 1994; Abbey *et al*, 1995). As a result, the observed association between visibility and mortality is hypothesized to reflect the influence of fine particles on daily mortality rather than the influence of visibility itself on daily mortality. Fine particles can penetrate deeply into the periphery of the lung where their clearance is difficult, leading to ill-health (Lay *et al*, 1994; Pinkerton *et al*, 1995); there is no biologically plausible ill-health that may be caused by impaired visibility and that may add to non-external causes of death.

Generally, the results of the PM10/mortality and visibility/mortality analyses were comparable in terms of direction and magnitude of the associations across cause-specific mortality categories and subgroups of ages as well as the lag structure effects. The consistency of the two analyses suggests the feasibility of using visibility as a surrogate marker of fine particles when assessing the influence of fine particles on daily mortality and other heath endpoints. A strength of this study was the employment of the same approaches in data analysis, and in using the same data sets for response and covariates in the regression models for both the PM10 and visibility analyses, making it possible to compare appropriately the results of the two analyses.

In these analyses, control for a range of potential confounders such as SO_2 (sulfur dioxide), NO_2 (nitrogen dioxide), and O_3 (ozone) was not possible because of a lack of data on these pollutants. As a result, the observed associations may have been somewhat confounded. However, this confounding is expected to be minor because the evidence from previous studies suggests that the association between airborne particles and mortality was independent of SO_2 and O_3: in studies in Detroit, Philadelphia, Steubenville, St Louis, and eastern Tennessee, the effect of SO_2 on the relationship between particulate matter and mortality was examined, and none of the results was confounded by SO_2 (Schwartz, 1991; 1992a,b; Dockery *et al*, 1992). More importantly, the Utah Valley and Santa Clara studies were undertaken in locations where SO_2 concentrations were extremely low or negligible, but particle concentrations were relatively high (Fairley, 1990; Pope *et al*, 1992). The agreement of these two studies with the other studies regarding the positive association between particles and mortality suggests that SO_2 was unlikely to confound the association. The potential action of O_3 on the relationship between particulate matter and mortality is inconclusive. The impact of ozone on daily mortality was observed in Mexico city (Borja-Aburto *et al*, 1997), but not in Detroit, St Louis, and eastern Tennessee (Schwartz, 1991; Dockery *et al*, 1992). However, the risk estimate could have been overestimated by the inadequate control of NO_2 during analyses; its relationship with daily mortality has been documented in a recent study in Los Angeles (Kinney and Ozkaynak, 1991).

It is possible that the association observed could be confounded by indoor air pollution if its levels are associated with outdoor air pollution. However, this association is unlikely because houses and hospitals in Bangkok are not sealed tightly because of the warm weather and a general lack of air conditioning. As a result, the indoor and the outdoor air pollution levels may not be much different; outdoor measurements may be a better representation of personal exposure in Bangkok than in many cities with colder climates.

The high variations of air pollution levels presented in Bangkok as well as the large number of deaths per day increased the statistical power in detecting the influence of air particulate exposures. More interestingly, the probable lack of difference between indoor and outdoor air pollution in Bangkok can be considered as a strength when compared with other studies conducted in colder climates.

Conclusion

In summary, this study shows the independent influence of PM10 on daily mortality in Bangkok. The findings are consistent with those of studies conducted in cities in the US and Europe, where the climates differ from that of Bangkok. This provides further support that the association between PM10 and daily mortality is causal. More importantly, there is very little knowledge about the adverse health impact of air pollution in developing countries with tropical climates where environmental conditions are greatly different from those of developed countries. The results of this study enhance the understanding of the influence of air pollution on health and may reflect conditions in other developing countries with similar climates and air pollution. Future research to confirm these findings, using complete mortality and air pollution data, is suggested.

This study demonstrates that visibility was inversely associated with daily mortality from non-external causes in Bangkok from 1992-1997. The consistency of these findings with the PM10/mortality association suggests the possibility of using visibility as a surrogate marker of fine particles when investigation mortality and other health endpoints, thereby facilitating studies of the influence of particles on health endpoints when data on particulate mass are lacking. However, the application of these findings is best suited to settings in which the major sources of airborne particle pollution are combustion processes, which produce fine airborne particles. Future research will be needed to confirm this finding in other locations and in Bangkok when data on PM2.5 become available.

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