# Particulate air pollution (haze) due to the 1997 forest fires and effects on deaths in Malaysia

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**Abstract**

In 1997, uncontrolled widespread forest fires resulted in severe haze or smoke pollution in Malaysia. We aimed to determine associations between particulate air pollution and daily mortality in three cities during the haze period. We analysed daily hospital-based mortality data and air pollution data using Poisson regression methods. Mean daily particulate matter less than 10 microns ($PM_{10}$) levels reached 458µg/m$^3$, 852µg/m$^3$, and 148µg/m$^3$ in Kuala Lumpur, Kuching and Kota Bharu respectively. There were no significant associations between the haze period and non-trauma mortality for the three cities. In Kuala Lumpur there were associations between mean daily $PM_{10}$ and non-trauma deaths (RR = 1.04, 95%CI = 0.90-1.21) and cardiovascular deaths (RR = 1.24, 95%CI = 0.96-1.60), and between carbon monoxide and cardiovascular deaths (RR = 1.18, 95%CI = 0.94-1.46). In both Kuching and Kota Bharu, there were no significant associations between air pollutants and deaths except for between carbon monoxide and cardiovascular deaths in Kota Bharu (RR = 1.57, 95%CI = 1.06-2.32). In Kuala Lumpur we found only a weak, non-significant association between daily $PM_{10}$ levels and deaths. Although we did not find any associations between the peak haze period and mortality in any of the three cities, a real effect may have been obscured by methodological and data constraints. The findings have important implications for governments in terms of risk management and risk communication when particulate air pollution is due to forest fires or bushfires.

**Key words**: $PM_{10}$, air pollution, deaths, forest fires, haze, Poisson regression, time series analysis

## Introduction

Biomass air pollution or haze was first observed in Malaysia in the early 1960s. It was then generally mild and sporadic in nature. From the 1980s, haze has become a regular phenomenon in this nation. Although the haze was severe in 1990, 1991 and 1994, the worst haze in Malaysia's history was in September 1997 when uncontrolled widespread forest fires, mainly on the Indonesian islands of Sumatra and Borneo, resulted in severe smoke pollution. During this period, the entire country was almost covered with haze for a period of two months and the particulate air pollution levels in some areas were up to 15 times greater than usual levels.

The health effects of biomass smoke have been documented in the studies of fire-fighters in North America (Betchley *et al.*, 1997; Rothman *et al.*, 1991), women and children exposed to cooking fires in developing countries (Azizi & Henry, 1991; Perez-Padilla *et al.*, 1996) and communities with wood burning heaters (Larson & Koenig, 1994; Fairley, 1990; Lipsett *et al.*, 1997). Particulate matter is the most consistently elevated pollutant in haze episodes (Brauer, 1998). A series of epidemiological studies have highlighted the associations between particulate air pollution and increases in mortality (Schwartz, 1996; Schwartz & Dockery, 1992; Moolgavkar *et al.*, 1995; Anderson *et al.*, 1995; Katsouyanni *et al.*, 1997; Morgan *et al.*, 1998; Simpson *et al.*, 1997). There are few published studies on the effects of biomass particulate air pollution due to forest fires in South East Asia (Chew *et al.*, 1997; Hashim *et al.*, 1997, Emmanuel, 2000; Tan *et al.*, 2000).

We aimed to determine if there was any association between particulate air pollution due to biomass smoke and daily mortality in three cities in Malaysia during the period of haze.

## Materials and Methods

The study period was from 1 January 1997 to 31 December 1997 in three cities - Kuala Lumpur, Kuching and Kota Bharu. Kuala Lumpur and Kuching were most affected by the 1997 haze whilst Kota Bharu was the least affected. Kuala Lumpur is the largest city in Malaysia and close to the Indonesian island of Sumatra. It is highly urbanised with a population of about 1.3 million people. Kuching and Kota Bharu are smaller provincial cities. Kuching is located at the northern aspect of the island of Borneo whilst Kota Bharu is on the east coast of peninsular Malaysia and furthest away from the major sources of the biomass air pollution.

*Mortality data*

Through active surveillance, we obtained daily hospital-based mortality data for each of the three cities. One major hospital each in Kuala Lumpur and Kuching, and two hospitals in Kota Bharu were involved in the study. We categorised deaths into non-trauma, respiratory and cardiovascular deaths based on diagnoses recorded on death certificates.

*Air quality and meteorological data*

We obtained mean daily concentrations of particulate matter less than 10 microns ($PM_{10}$), sulphur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), ozone ($O_3$) and carbon monoxide (CO) from the Department of Environment. Kota Bharu and Kuching each had only one continuous air quality monitoring station whereas for Kuala Lumpur the air quality data were averaged across two monitoring stations. Monitoring instruments and protocols were those approved by the United States EPA (Tong, 1999). The Malaysian Meteorological Services provided daily meteorological data.

*Statistical analysis*

Data for each city were analysed separately. We used Poisson regression methods to determine associations between air pollution and deaths for both single and multi-pollutant models (Schwartz, 1996; Morgan *et al.*, 1998; Simpson *et al.*, 1997). We developed a basic Poisson regression model with daily non-trauma deaths as the dependent variable. Initial model building consisted of controlling for temperature, relative humidity, seasonal and long term time trends. Regression diagnostics were performed to check the model fit.

Once the basic model had been developed, air pollution variables were entered into the model. We examined the effects of lagging air pollution levels and of cumulative exposures. Cumulative exposures were calculated by averaging the current day and previous days air pollutant concentrations.

We also created indicator variables for the period (12 September 1997 to 28 September 1997) when the $PM_{10}$ levels were highest (forest fire period). This 17-day period had the highest $PM_{10}$ concentrations (daily mean $PM_{10}$ concentrations in Kuala Lumpur were greater than 200ug/m$^3$ on all 17 days). This time period also captured the main peak $PM_{10}$ concentrations for Kota Bharu and Kuching. A control period corresponding to the forest fire period was also identified (control period: 12 April 1997 to 28 April 1997). This allowed us to compare deaths between the forest fire and control periods.

Interaction terms between $PM_{10}$ and the forest fire period were not significant and were excluded from all analyses. There was no evidence of autocorrelation among the residuals (partial correlation coefficient for lag 1: Kuala Lumpur = -0.03; Kota Bharu = 0.002; Kuching = -0.07).

All regression models controlled for day of study, month, day of the week, mean temperature, mean relative humidity, daily rainfall and the forest fire period. Associations are expressed as relative risks (RR) and 95% confidence intervals (95%CI) for death for an increase in the relevant air pollutant from the 10th to the 90th percentile. Analyses were conducted using SAS statistical software (SAS Institute Inc. 1989).

**Results**

*Air pollution data*

Table 1 summarises the air pollution and death data. Only $PM_{10}$ and $O_3$ exceeded the Recommended Malaysian Guidelines (RMG) ($PM_{10}$: 42 days and 30 days for Kuala Lumpur and Kuching respectively; $O_3$: 49 and 6 days for Kuala Lumpur and Kuching respectively).

Mean daily $PM_{10}$ levels in Kuala Lumpur and Kuching started to increase in May, peaked in September and decreased in November 1997 (Figures 1a-1c). In Kuala Lumpur there was a five-fold increase in $PM_{10}$ levels, a 15-fold increase in Kuching and a three-fold increase in Kota Bharu. Maximum mean daily $PM_{10}$ levels reached 458μg/m$^3$, 852μg/m$^3$, and 148μg/m$^3$ in

Kuala Lumpur, Kuching and Kota Bharu respectively.

There was a consistent rise in $SO_2$ level from July to October in Kuching but it was below the RMG of 0.04 ppm. Kuala Lumpur had higher CO levels throughout the year compared to the other two cities but in none of the three cities did the CO concentrations exceed the RMG.

For Kuala Lumpur, there were weak to moderate positive correlations between $PM_{10}$ and $O_3$ (r = 0.28), $NO_2$ (r = 0.40), $SO_2$ (r = 0.41) and CO (r = 0.62). In Kota Bharu, there were moderate to strong correlations between $PM_{10}$ and $O_3$, $NO_2$ and CO. In Kuching, weak to moderate to strong correlations were present among all the air pollution variables (except between $PM_{10}$ and CO (r = 0.92)).

*Death data*

Daily deaths for the three cities are presented in Table 1. We estimated that 75% of all deaths in Kuala Lumpur, 47% in Kuching and 63% in Kota Bharu were certified in the study hospitals.

Generally, there were fewer mean daily deaths experienced during the forest fire period compared to the control period (Table 2). The control period did not experience any unusual climatic patterns or disease outbreaks that would have increased the number of deaths for that period.

*Single pollutant models*

There were no significant associations between $PM_{10}$ and the forest fire periods for non-trauma mortality for the three cities (Kuala Lumpur: RR = 1.11, 95%CI = 0.77-1.60; Kuching: RR = 0.61, 95%CI = 0.29-1.26; Kota Bharu: RR=0.85, 95%CI = 0.54-1.32).

Table 3 presents the beta-coefficients and RRs for non-trauma, respiratory and cardiovascular deaths due to same day air pollution from single pollutant Poisson regression models for each of the three cities.

In Kuala Lumpur, an increase in mean daily $PM_{10}$ concentration was associated with a slightly increased risk for non-trauma deaths (RR = 1.04 for 107ug/m$^3$ increase in $PM_{10}$). When the forest fire period was excluded from the model, the associations between $PM_{10}$ and non-trauma mortality was slightly stronger but was still not statistically significant (RR = 1.07, 95%CI = 0.94-1.21).

There was a stronger association between $PM_{10}$ and cardiovascular deaths (RR = 1.24, 95%CI = 0.96-1.60). The associations between $O_3$, $NO_2$ and CO and deaths were strongest for cardiovascular deaths, and especially between CO and cardiovascular deaths (RR = 1.18, 95%CI = 0.94-1.46).

Compared to lagged values of $PM_{10}$ (up to five lag days), lag 3 $PM_{10}$ had the strongest association with non-trauma deaths. The RR for lags ranged from 0.96 for lag 4 to 1.08 for lag 3. Four day cumulative exposure showed the strongest association with non-trauma deaths (RR = 1.14, 95%CI = 0.95-1.37). None of the associations between lagged and cumulative $PM_{10}$ and non-trauma deaths were significant.

There was no consistency in the association between $PM_{10}$ and respiratory deaths categorised into four age groups (Table 4). The risk for respiratory deaths was highest in the <5 year age group. For cardiovascular deaths, the RR was greater than one for all four age groups, and highest in the <5 year age group (RR = 1.47, 95%CI = 0.23-9.40).

In Kuching, the RR for non-trauma, respiratory and cardiovascular deaths and $PM_{10}$ were generally less than one (Table 3) and not statistically significant. In Kota Bharu, only the association between CO and cardiovascular deaths was significant (RR = 1.57, 95%CI = 1.06-2.32). Most of the RRs were greater than one, and the largest associations were with cardiovascular deaths.

**Discussion**

The smoke haze from uncontrolled forest fires that enveloped many South East Asian countries in the latter half of 1997 was the most severe and prolonged particulate air pollution episode experienced in the history of these countries. In this study we focussed on the effects of forest fires $PM_{10}$ on deaths in Kuala Lumpur, the largest city in Malaysia.

In Kuala Lumpur, we found near significant associations between both daily $PM_{10}$ and CO levels and cardiovascular deaths. There was also a slightly increased risk for non-trauma deaths due to $PM_{10}$. In Kuching, where the baseline air pollution was less than in Kuala Lumpur, but which experienced higher peaks of particulate pollution during the haze period, there were no positive associations between $PM_1$ levels mortality. In Kota Bharu, there was a significant

**Table 1. Summary statistics for mean daily air pollutants and daily deaths for Kuala Lumpur, Kuching and Kota Bharu, 1997**

| | Kuala Lumpur | Kuching | Kota Bharu |
|---|---|---|---|
| **$PM_{10}$ (ug/m$^3$)** | | | |
| Mean±SD* | 100.3±60.51 | 71.9±104.68 | 39.1±19.77 |
| Median | 83.5 | 41.0 | 34.0 |
| Range | 25-458 | 14-852 | 13-148 |
| **$O_3$ (ppm)** | | | |
| Mean±SD | 0.058±0.025 | 0.03±0.013 | 0.031±0.009 |
| Median | 0.055 | 0.026 | 0.031 |
| Range | 0.002-0.145 | 0.007-0.073 | 0-0.052 |
| **$NO_2$ (ppm)** | | | |
| Mean±SD | 0.060±0.022 | 0.021±0.007 | 0.016±0.0067 |
| Median | 0.061 | 0.019 | 0.015 |
| Range | 0.008-0.129 | 0.006-0.043 | 0-0.036 |
| **CO (ppm)** | | | |
| Mean±SD | 2.8±1.01 | 1.14±0.99 | 1.19±0.485 |
| Median | 2.72 | 0.86 | 1.11 |
| Range | 0.46-6.58 | 0.19-7.06 | 0.34-2.98 |
| **$SO_2$ (ppm)** | | | |
| Mean±SD | 0.004±0.002 | 0.006±0.003 | 0.004±0.002 |
| Median | 0.003 | 0.006 | 0.004 |
| Range | 0-0.013 | 0-0.018 | 0.001-0.013 |
| **Temperature (°C)** | | | |
| Mean±SD | 27.8±0.94 | 26.5±1.06 | 27.2±1.12 |
| Median | 27.7 | 26.5 | 27.3 |
| Range | 25.530.1 | 23.7-29.3 | 24.1-30.1 |
| **Relative humidity (%)** | | | |
| Mean±SD | 78.3±5.24 | 84.8±5.10 | 83.1±5.13 |
| Median | 78.7 | 84.9 | 82.7 |
| Range | 63.3-89.7 | 66.3-96.4 | 52.5-98.4 |
| **Rainfall (mm)** | | | |
| Mean±SD | 8.02±14.5 | 8.5±15.70 | 6.4±17.15 |
| Median | 0.7 | 0.5 | 0 |
| Range | 0-103.3 | 0-96.3 | 0-169.8 |
| **All cause deaths** | | | |
| Total | 4514 | 843 | 1359 |
| Mean±SD | 12.4±4.0 | 2.3±1.6 | 3.7±2.1 |
| **Non-trauma deaths** | | | |
| Total | 3380 | 793 | 1235 |
| Mean±SD | 9.6±3.4 | 2.3±1.6 | 3.4±2.0 |
| **Cardiovascular deaths** | | | |
| Total | 1025 | 220 | 352 |
| Mean±SD | 2.8±1.8 | 0.6±0.8 | 1.0±1.1 |
| **Respiratory deaths** | | | |
| Total | 372 | 135 | 118 |
| Mean±SD | 1.0±1.0 | 0.4±0.6 | 0.3±0.6 |

*SD = standard deviation

**Table 2. Mean daily $PM_{10}$ levels and number of non-trauma, respiratory and cardiovascular deaths for the forest fire and control periods[a] Kuala Lumpur, Kota Bharu and Kuching, 1997**

| | Daily $PM_{10}$ levels (ug/m3) | | Daily non-trauma deaths | | Daily respiratory deaths | | Daily cardiovascular deaths | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD* | Mean | SD | Mean | SD | Mean | SD |
| **Kuala Lumpur** | | | | | | | | |
| Forest fire period | 312.8 | 73.4 | 9.1 | 3.3 | 1.0 | 1.2 | 2.5 | 2.0 |
| Control period | 63.1 | 14.5 | 9.6 | 3.2 | 0.9 | 0.9 | 3.5 | 2.0 |
| **Kuching** | | | | | | | | |
| Forest fire period | 409.8 | 259.6 | 1.9 | 1.7 | 0.2 | 0.4 | 0.8 | 0.9 |
| Control period | 32.7 | 7.7 | 2.4 | 1.4 | 0.3 | 0.6 | 0.8 | 0.8 |
| **Kota Bharu** | | | | | | | | |
| Forest fire period | 84.7 | 30.2 | 3.1 | 2.0 | 0.3 | 0.5 | 0.8 | 1.3 |
| Control period | 31.2 | 9.2 | 3.5 | 1.4 | 0.5 | 0.6 | 0.9 | 0.8 |

[a]See Methods for definitions of forest fire and control periods; * SD = standard deviation

**Table 3. Beta coefficients and relative risks associated with an increase in pollutant concentration from the 10th to 90th percentile from single pollutant Poisson regression models for Kuala Lumpur, Kuching and Kota Bharu, 1997**

| | Non-trauma deaths | | Respiratory deaths | | Cardiovascular deaths | |
|---|---|---|---|---|---|---|
| | Beta (SE)* | RR (95%CI) | Beta (SE) | RR (95%CI) | Beta (SE) | RR (95%CI) |
| **Kuala Lumpur** | | | | | | |
| $PM_{10}$ | 0.0004 | 1.04 | -0.0025 | 0.76 | 0.0020 | 1.24 |
| (107µg/m$^3$)** | (0.0007) | (0.90-1.21) | (0.0020) | (0.50-1.16) | (0.0012) | (0.96-1.60) |
| $O_3$ | -0.1095 | 0.99 | -0.4143 | 0.97 | 0.7963 | 1.05 |
| (0.067ppm) | (0.9359) | (0.88-1.22) | (2.5514) | (0.70-1.36) | (1.6305) | (0.85-1.31) |
| $NO_2$ | -1.2504 | 0.93 | -6.1173 | 0.71 | 0.3651 | 1.02 |
| (0.057ppm) | (1.2360) | (0.81-1.07) | (3.3622) | (0.48-1.03) | (2.1779) | (0.80-1.30) |
| CO | -0.0095 | 0.97 | -0.0397 | 0.90 | 0.0606 | 1.18 |
| (2.68ppm) | (0.0244) | (0.86-1.11) | (0.0671) | (0.63-1.28) | (0.0417) | (0.94-1.46) |
| **Kuching** | | | | | | |
| $PM_{10}$ | -0.0007 | 0.97 | -0.0001 | 0.99 | -0.0021 | 0.80 |
| (105µg/m$^3$) | (0.0007) | (0.84-1.12) | (0.0017) | (0.70-1.40) | (0.0014) | (0.60-1.07) |
| $O_3$ | 3.8220 | 1.13 | -12.4191 | 0.68 | -5.9776 | 0.83 |
| (0.031ppm) | (4.9387) | (0.83-1.52) | (11.2765) | (0.34-1.35) | (8.92830) | (0.48-1.43) |
| $NO_2$ | -2.2101 | 0.96 | 4.5649 | 1.08 | -21.2484 | 0.70 |
| (0.017ppm) | (7.0855) | (0.76-1.22) | (15.4961) | (0.64-1.81) | (12.5849) | (0.46-1.06) |
| CO | 0.0354 | 1.05 | -0.0035 | 0.99 | -0.2098 | 0.73 |
| (1.49ppm) | (0.0754) | (0.85-1.31) | (0.1797) | (0.56-1.59) | (0.1370) | (0.50-1.12) |
| $SO_2$ | -1.1177 | 0.99 | -8.6679 | 0.94 | -41.9874 | 0.75 |
| (0.007ppm) | (16.7499) | (0.79-1.25) | (38.1960) | (0.56-1.59) | (29.7883) | (0.50-1.12) |
| **Kota Bharu** | | | | | | |
| $PM_{10}$ | -0.0004 | 0.98 | -0.0007 | 0.97 | 0.0047 | 1.20 |
| (39µg/m$^3$) | (0.0023) | (0.83-1.17) | (0.0073) | (0.56-1.70) | (0.0045) | (0.85-1.69) |
| $O_3$ | 0.5065 | 1.01 | -11.0407 | 0.79 | -2.5868 | 0.95 |
| (0.021ppm) | (4.2466) | (0.85-1.20) | (14.0489) | (0.44-1.41) | (8.5586) | (0.67-1.35) |
| $NO_2$ | 6..6696 | 1.11 | -9.1995 | 0.87 | 9.8674 | 1.16 |
| (0.015ppm) | (5.7861) | (0.93-1.31) | (19.1719) | (0.50-1.53) | (11.6620) | (0.82-1.63) |
| CO | 0.1272 | 1.17 | 0.2388 | 1.34 | 0.3701 | 1.57 |
| (1.22ppm) | (0.0866) | (0.95-1.44) | (0.2861) | (0.68-2.65) | (0.1628) | (1.06-2.32) |
| $SO_2$ | 12.1549 | 1.04 | -96.9639 | 0.75 | 32.9156 | 1.10 |
| (0.003ppm) | (24.9769) | (0.90-1.20) | (89.5702) | (0.44-1.27) | (51.7153) | (0.81-1.50) |

SE = standard error; **Range between the 10th and 90th percentile for the particular air pollutant

**Table 4. Beta coefficients and relative risks associated with different age groups for an increase in $PM_{10}$ concentration from the 10th to 90th percentile from single pollutant Poisson regression models for Kuala Lumpur, 1997***

| Age group (years) | Respiratory deaths | | Cardiovascular deaths | |
|---|---|---|---|---|
| | Beta (SE)** | RR (95% CI) | Beta (SE) | RR (95% CI) |
| <5 | 0.0028 (0.0053) | 1.35 (0.44-4.13) | 0.0036 (0.0088) | 1.47 (0.23-9.40) |
| >65 | -0.0001 (0.0034) | 1.01 (0.49-2.07) | 0.0009 (0.0020) | 1.10 (0.72-1.68) |
| <5 and >65 | 0.0002 (0.0027) | 1.02 (0.58-1.80) | 0.0009 (0.0020) | 1.10 (0.72-1.68) |
| 5-65 | -0.0050 (0.0028) | 0.58 (0.32-1.05) | 0.0027 (0.0015) | 1.34 (0.97-1.83) |

*$PM_{10}$ increased by 98ug/$m_3$ (from 10th to 90th percentile); **Beta-coefficient (standard error)

association only between CO levels and cardiovascular deaths.

Despite the associations between $PM_{10}$ concentrations and daily non-trauma mortality, we could not demonstrate any associations between the peak haze period and increased non-trauma, respiratory or cardiovascular mortality in any of the three cities. In Kuala Lumpur there was a non-significant 11% increase in non-trauma deaths due to the haze period independent of the effects of particulate pollution. When $PM_{10}$ was excluded from the model, the peak haze period was associated with a greater, but still non-significant, increase in non-trauma deaths (17% increase, data not shown).

Although there is some published literature on the associations between forest fires and morbidity (Betchley *et al*., 1997; Rothman *et al*., 1991; Smith *et al*., 1996; Duclos *et al*., 1990; Chew *et al*., 1995), there is little published literature on particulate pollution due to forest fires and deaths. In view of numerous studies supporting an association between urban particulate air pollution and increased mortality, we expected associated increases in deaths due to forest fire particulate pollution. However, we were not able to demonstrate such a relationship in our study. In Singapore, in a time series analysis, Emmanuel (2000) also did not find any significant associations between the 1997 haze and mortality.

There may be a number of reasons why we did not find associations between haze and deaths. We conducted a time series analysis with small numbers of daily deaths and a very short time series. Although we controlled for seasonal trends in our analyses, we may not have had a long enough time series to control for long term cyclical variations. Furthermore, the small number of daily deaths meant that we also might not have had the power to detect small associations between particulate matter and deaths during the forest fire period. The possibility of a type two error remains high.

At the time of the haze, the population was urged to stay indoors and not to engage in strenuous physical activities if they had any chronic medical condition especially respiratory or cardiovascular disease. Many residents in the worst affected regions also wore face-masks to filter the haze pollution. It is a matter for conjecture as to how effective these measures might have been in reducing personal exposure to particulate pollution and subsequent deaths.

Kuala Lumpur generally has moderately high $PM_{10}$ levels (daily mean of 82 $\mu g/m^3$ excluding the forest fire period). In our 12 month time series study for Kuala Lumpur we found a 4% increased risk in non-trauma deaths and 24% increase in cardiovascular deaths for a 107 $\mu g/m^3$ increase in $PM_{10}$ concentration. Our results for the magnitude of the association between non-trauma deaths and $PM_{10}$ are smaller than those reported in other studies (Morgan *et al*., 1998; Simpson *et al*., 1997; Dockery & Pope, 1994).

We did not find increased RRs for the association between $PM_{10}$ concentration and non-trauma deaths for the other two cities. This may be explained by the fact that compared to Kuala Lumpur, both Kuching and Kota Bharu generally experienced lower mean levels of particulate pollution throughout 1997; both these cities had smaller number of deaths and a larger proportion of daily deaths were not certified and therefore the causes of deaths were not available to us.

For each city, we only captured about 50%-75% of all deaths. The causes of deaths in those who were not certified may have been quite different from those deaths that were certified. However, the urgency of the situation, lack of resources and the fact that Malaysia lacks a centralised electronic death registry meant that we were unable to overcome issues of selection bias. Selection bias was minimised for Kuala Lumpur where at least 75% of all deaths were certified.

In the single pollutant models for Kuala Lumpur, we also found that an increase in CO levels of about 3ppm was associated with an 18% increase in cardiovascular mortality. As expected, we found moderate to strong correlations between $PM_{10}$ and CO concentrations and when we included $PM_{10}$ in the model, the association between CO and cardiovascular deaths was weaker (RR = 1.11; data not shown). For non-trauma deaths, we found a 3% decrease in deaths for a 3ppm increase in CO, unlike the small increases in risks to that previously reported (Kinney *et al.*, 1993; Burnett *et al.*, 1998; Saldiva *et al.*, 1995). However, in Kota Bharu, we found a significant increase in RR for CO and cardiovascular deaths (the only significant finding in the study). In view of the many comparisons made in this study, this could represent a chance finding.

In summary, we were not able to demonstrate that the episode of particulate matter air pollution due to forest fires (or haze) was associated with a significant increase in non-trauma, respiratory or cardiovascular mortality in Malaysia. However, it should be borne in mind that no apparent impact on deaths does not rule out other significant health impacts. The small number of daily deaths and the lack of a longer time series may be the reasons why we were unable to detect this association. However, in keeping with other international published studies, we found that $PM_{10}$ and CO were associated with increases in non-trauma and cardiovascular deaths. The results of this study have important implications in terms of risk management and risk communication for the governments and peoples of South East Asian nations, especially as it appears that haze will be a recurrent problem in these countries in the foreseeable future.

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**Figure 1a. Daily PM10 concentrations and non-trauma deaths for Kuala Lumpur, January-December 1997**

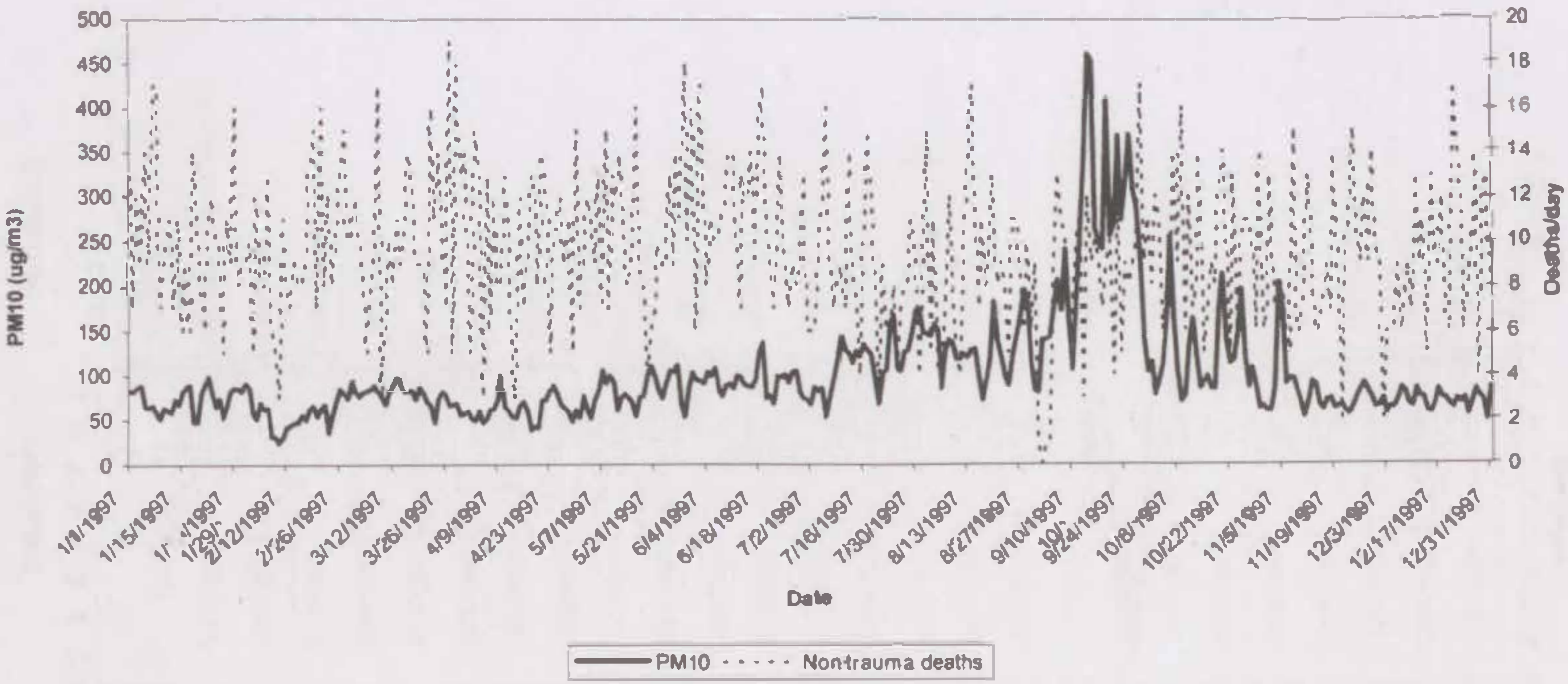

**Figure 1b. Daily PM10 concentrations and non-trauma deaths for Kuching, January-December 1997**

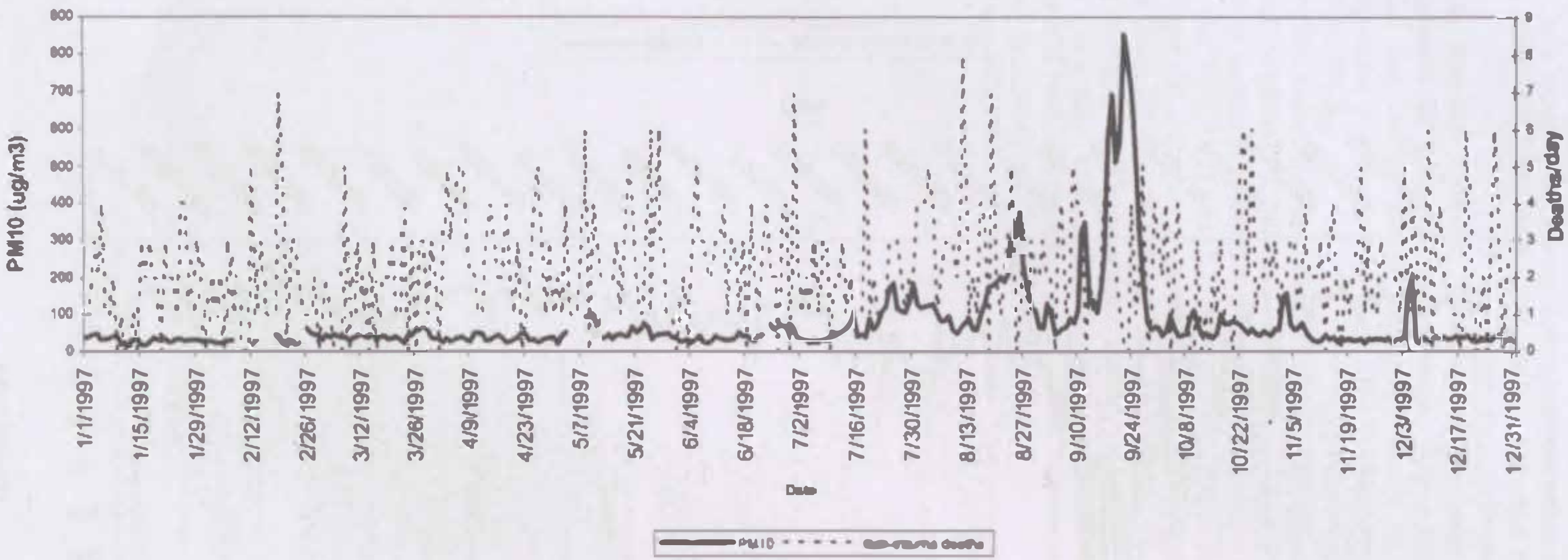

Figure 1c. Daily PM10 concentrations and non-trauma deaths for Kota Bharu, January-December 1997