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Abstract

We investigated the cardiorespiratory health effects of smoke exposure from the 1997 Southeast Asian Forest Fires among persons who were hospitalized in the region of Kuching, Malaysia. We selected admissions to seven hospitals in the Kuching region from a database of all hospital admissions in the state of Sarawak during January 1, 1995 and December 31, 1998. For several cardiorespiratory disease classifications we used Holt-Winters time-series analyses to determine whether the total number of monthly hospitalizations during the forest fire period (August 1 to October 31, 1997), or post-fire period (November 1, 1997 to December 31, 1997) exceeded forecasted estimates established from a historical baseline period of January 1, 1995 to July 31, 1997. We also identified age-specific cohorts of persons whose members were admitted for specific cardiorespiratory problems during January 1 to July 31 of each year (1995–1997). We compared Kaplan-Meier survival curves of time to first readmission for the 1997 cohorts (exposed to the forest fire smoke) with the survival curves for the 1995 and 1996 cohorts (not exposed, pre-fire cohorts). The time-series analyses indicated that statistically significant fire-related increases were observed in respiratory hospitalizations, specifically those for chronic obstructive pulmonary disease (COPD) and asthma. The survival analyses indicated that persons over age 65 years with previous hospital admissions for any cause ($\chi^2_{1df} = 5.98$, $p = 0.015$), any cardiorespiratory disease ($\chi^2_{1df} = 5.3$, $p = 0.02$), any respiratory disease ($\chi^2_{1df} = 7.8$, $p = 0.005$), or COPD ($\chi^2_{1df} = 3.9$, $p = 0.047$), were significantly more likely to be rehospitalized during the follow-up period in 1997 than during the follow-up periods in the pre-fire years of 1995 or 1996. The survival functions of the exposed cohorts resumed similar trajectories to unexposed cohorts during the post-fire period of November 1, 1997 to December 31, 1998. Communities exposed to forest fire smoke during the Southeast Asian forest fires of 1997 experienced short-term increases in cardiorespiratory hospitalizations. When an air quality emergency is anticipated, persons over age 65 with histories of respiratory hospitalizations should be preidentified from existing hospitalization records and given priority access to interventions. © 2005 Elsevier GmbH. All rights reserved.

Keywords: Forest fires; Air pollution; Respiratory health; Asthma; COPD

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Introduction

In 1997, uncontrolled forest fires burned in the Indonesian states of Kalimantan and Sumatra. The fires, in combination with a severe drought, produced a regional air pollution episode that affected Malaysia, Singapore, Thailand, Brunei and the Philippines. During a continuous two-month period, an estimated 20 million people were exposed to ambient concentrations of particulate matter (PM₁₀) that exceeded the US EPA's 24 h National Ambient Air Quality Standard of 150 µg/m³ (Brauer et al., 2001). On September 22, 1997, 24-h PM₁₀ concentrations peaked at 852 µg/m³ in Kuching, the capital of the state of Sarawak, Malaysia. This peak concentration exceeded the US EPA's 24-h hazardous level of 500 µg/m³.

As population expansion into wildland environments continues, human exposures to forest fire smoke are likely to increase (US Centers for Disease Control and Prevention, 2002, 2001, 1999; Ward, 1999). A limited number of epidemiologic investigations suggest that population exposures to wood smoke are associated with increased self-reporting of respiratory symptoms (US Centers for Disease Control and Prevention, 2002; Larson and Koenig, 1994; Shusterman et al., 1993) and increased emergency department admissions for chronic obstructive pulmonary disease (COPD), bronchitis, asthma, and chest pain (US Centers for Disease Control and Prevention, 2001, 1999; Mott et al., 2002; Duclos et al., 1990). However, these health endpoints are influenced by individual perceptions and decisions to seek medical care. Thus they are somewhat subjective and can increase with the psychosomatic stress that is often associated with air pollution emergencies. Population densities of exposed communities have not commonly been large enough to produce sample sizes sufficient to assess epidemiologic relationships between poor air quality and more objective and severe indicators of morbidity such as hospitalizations for cardiorespiratory problems (US Centers for Disease Control and Prevention, 2001).

When dispensing intervention resources into smoke-exposed communities, public health professionals tend to assume that older persons, and persons with COPD, are most susceptible to the adverse health effects of forest fire smoke exposure (Mott et al., 2002). However, an assessment of cardiorespiratory health effects in cohorts of exposed and unexposed persons of different ages and disease histories has not been undertaken. The systematic identification of those most susceptible to forest fire smoke exposures remains necessary for the development of science-based recommendations for public outreach and targeted intervention.

In this study we investigate the cardiorespiratory health effects of the 1997 Southeast Asian forest fires among persons who were hospitalized at any of seven

hospitals in the region of Kuching, Malaysia between January 1, 1995 and December 31, 1998. Specifically, this study has three objectives:

1. To determine whether there was an increase in total hospitalizations, cardiovascular hospitalizations, and respiratory hospitalizations during the months of the forest fires in 1997 relative to the non-fire years of 1995 and 1996, adjusting for seasonal variation in admissions.
2. To assess whether cohorts of persons with previous hospital admissions for cardiorespiratory diseases were more likely to be readmitted for the same condition during the forest fires of 1997 than during the same months during pre-fire years of 1995 and 1996.
3. To assess the duration of any longer term post-fire health effects (in the form of longer term increases in re-hospitalization rates among persons with a history of disease) in cohorts of persons exposed to the forest fire smoke.

Hospitalization data provided by the Sarawak Health Department provided a unique opportunity to undertake this investigation as: (a) the population density of exposed persons was sufficient to permit cohort analyses of hospitalizations, and (b) the absence of significant industrial pollution permitted an independent assessment of the health effects of forest fire smoke exposure (Sastry, 2002).

Materials and methods

Data source

Hospitalizations were selected from a database of all public hospital admissions that occurred in the state of Sarawak, Malaysia between January 1, 1995 and December 31, 1998. Analyses were limited to hospitalizations that occurred in the Kuching region, the area of Sarawak where air quality was most continuously monitored during the 1997 forest fires. The hospitals included in these analyses were Sarawak General Hospital, Lundu District Hospital, Bau District Hospital, Serian District Hospital, Sri Aman Divisional Hospital, Saratok District Hospital and Betong District Hospital. Transfers between hospitals, admissions to a leprosarium and a mental hospital, and normal deliveries (ICD-9-CM 650) were excluded from the admissions data set. Staff of the Sarawak Health Department also manually searched the national death registry to determine deaths from any cause during the four-year study period that occurred to persons ages 40 and older who were hospitalized with COPD.

Case definitions

Any hospital admission with a primary discharge diagnosis inclusive of ICD-9-CM codes 390 to 519 was classified as a cardiorespiratory admission. Respiratory admissions were a subset of those admissions with a primary discharge diagnosis inclusive of ICD-9-CM codes 460 to 519. Within the respiratory admissions, COPD admissions were those with a primary discharge diagnosis inclusive of ICD-9-CM codes 490 to 496, and asthma admissions included a primary discharge diagnosis of ICD-9-CM 493. Circulatory admissions were a subset of cardiorespiratory admissions with a primary discharge diagnosis inclusive of ICD-9-CM codes 390 to 459. Within the circulatory admissions, admissions for Ischemic Heart Disease (IHD) included a primary discharge diagnosis inclusive of ICD-9-CM 410 to 414 (Table 1).

Descriptive analyses

We calculated the frequency and percent of total hospitalizations that occurred during January 1, 1995 through December 31, 1998 by age categories (0–18, 19–39, 40–64, and 65+), sex, and race-ethnicity (Chinese, Malay, Sarawak Native, and other) within disease classification (all causes, cardiorespiratory, respiratory, circulatory, COPD, asthma, and IHD). We then calculated the frequency and percent of total hospitalizations that occurred during August 1 through October 31 by disease classification within age separately for the years 1995, 1996, 1997 and 1998. This allowed us to compare the relative distribution of hospitalizations that occurred during the forest fire period of August 1 through October 31, 1997 to the distribution of hospitalizations that occurred during the same months of the non-fire years of 1995, 1996 and 1998.

Time-series analyses

Time-series analyses were used to determine if the total number of monthly hospitalizations that occurred during the fire period (August 1 through October 31, 1997), or post-fire period (November 1, 1997 through December 31, 1997) exceeded forecasting estimates established from a historical baseline period of January 1, 1995 through July 31, 1997. We used the Holt-Winters method of exponential smoothing to adjust for trend and monthly seasonal components. This method applies a locally weighted least squares approach to performing a trend and seasonal residual decomposition of a time series (Holt, 1957; Winters, 1960). The time-series analyses, which made use of Holt-Winters additive models, were systematically undertaken for each age

category within disease classification using the FORECAST procedure in Statistical Analysis Software version 8 (SAS Institute, Cary N.C.). Observed hospitalizations during the fire and post-fire periods were compared to 95% prediction intervals surrounding forecasted estimates based on the historical baseline period.

Survival analyses of hospital re-admissions during the fire period

The hospitalization data were provided as encounter-level admissions data. We unduplicated the data using a linkage code comprised of patient name, age, sex, and race/ethnicity in order to track repeat admissions occurring to the same person over time. The data were then anonymized.

For each disease classification, we identified separate age-specific cohorts (<18, 19–39, 40–64, 65+) of persons whose members were admitted for that condition during January 1 through July 31 of each year, 1995 through 1997. Members of each of these yearly cohorts were then followed until first re-admission for the same condition during the second half of the year (August 1 through to December 31) 1995–1997 (Fig. 1). We compared Kaplan-Meier survival curves of time to first readmission for the 1997 cohorts (exposed to the forest fire smoke) to the survival curves for the 1995 and 1996 cohorts (not exposed, pre-fire cohorts). The primary outcome of interest was the percent of persons in each cohort who were readmitted during the follow-up period.

Deaths occurring in hospitals could be determined from the admissions data. However we were only able to link deaths occurring outside of the hospitals to persons over age 40 with COPD and/or asthma. For this reason, survival curves for persons over 40 with COPD or asthma reflect time to re-admission or death from any cause, where survival curves for all other cohorts reflect time to readmission only.

Survival analyses of hospital re-admissions during the post-fire period

We also evaluated the longer term effects of forest fire smoke exposure on cohort hospital readmission rates. For each disease classification, we identified unexposed age-specific cohorts of persons whose members were admitted for that condition during January 1 through July 31 of 1995. Members of these cohorts then followed until first re-admission for the same condition during a 17 month follow-up period of August 1, 1995 through December 31, 1996. The 17-month Kaplan-Meier survival curves for these unexposed cohorts were then compared to those of exposed cohorts who were enrolled during January 1 through July 31 of 1997 and followed until first re-admission for the same condition

Table 1. Frequency (percent of total) hospitalizations occurring in the Kuching region during 1995–1998 by age, sex and race/ethnicity

	0–18	19–39	40–64	65+	Male	Female	Chinese	Malay	Sarawak native	Other	Total
All causes	63,484 (33.4)	61,558 (32.4)	42,848 (22.6)	22,126 (11.6)	89,441 (47.1)	100,575 (52.9)	40,663 (21.4)	63,509 (33.4)	80,605 (42.4)	5239 (2.8)	190,016 (100.0)
Cardiorespiratory (ICD-9-CM 390–519)	11,083 (5.8)	3947 (2.1)	10,269 (5.4)	8292 (4.4)	18,756 (9.9)	14,835 (7.8)	7431 (3.9)	10,759 (5.7)	14,743 (7.8)	658 (0.3)	33,591 (17.7)
Circulatory (ICD-9- CM 390–459)	533 (0.2)	1528 (0.8)	6305 (3.3)	4737 (2.5)	7055 (3.7)	6048 (3.2)	4232 (2.2)	3806 (2.0)	4765 (2.5)	300 (0.2)	13,103 (6.9)
IHD (ICD-9-CM 410– 414)	22 (0.0)	168 (0.1)	1489 (0.8)	1046 (0.5)	1816 (1.0)	909 (0.4)	1008 (0.5)	942 (0.5)	681 (0.4)	94 (0.0)	2725 (1.4)
Respiratory (ICD-9- CM 460–519)	10,550 (5.6)	2419 (1.3)	3964 (2.1)	3555 (1.8)	11,701 (6.2)	8787 (4.6)	3199 (1.6)	6953 (3.7)	9978 (5.3)	358 (0.2)	20,488 (10.8)
COPD (ICD-9-CM 490–496)	2965 (1.6)	1345 (0.7)	2824 (1.5)	2682 (1.4)	5613 (3.0)	4203 (2.2)	1703 (0.9)	3397 (1.8)	4541 (2.4)	175 (0.1)	9816 (5.2)
Asthma (ICD-9-CM 493)	2899 (1.6)	1197 (0.6)	1234 (0.6)	228 (0.1)	2900 (1.5)	2658 (1.4)	916 (0.5)	2260 (1.2)	2268 (1.2)	114 (0.0)	5558 (2.9)

*Total hospitalizations by year in the Kuching region were 46,061 in 1995; 49,976 in 1996; 48,721 in 1997; and 45,258 in 1998; Cardiorespiratory hospitalizations by year in the Kuching region were 7731 in 1995; 8982 in 1996; 9023 in 1997; and 7855 in 1998.

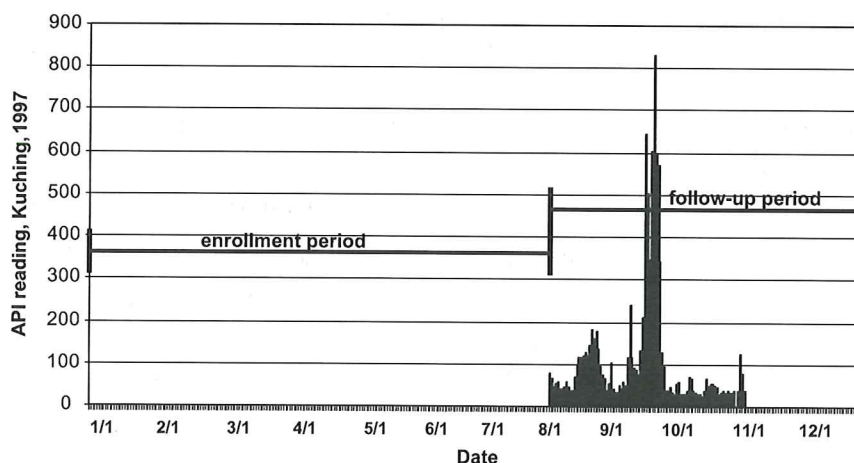


Fig. 1. Air pollution index (API) readings in Kuching, 1997 and their relationship to selection of cohort enrollment and follow-up periods.

during August 1, 1997 through December 31, 1998. All survival analyses were undertaken using the LIFETEST procedure in Statistical Analysis Software version 8, and statistical significance was assessed using log-rank χ^2 tests with a priori significance levels set at $p < 0.05$.

Results

Descriptive analyses

There were 190,016 hospitalizations for any cause in the region of Kuching, Malaysia during the period of 1995 to 1998. Of these hospitalizations, 20,488 (10.8%) were for respiratory problems, 13,103 (6.9%) were for circulatory problems, 9816 (5.2%) were for COPD and 5558 (2.9%) were for asthma. The total number of hospitalizations was also evenly distributed across years (46,061 hospitalizations in 1995; 49,796 in 1996; 48,721 in 1997; and 45,258 in 1998) (Table 1).

Over 40% (80,605) of the hospitalizations during 1995–1998 occurred to natives of Sarawak, 33% (63,509) occurred to persons of mainland Malay descent, and 21% (40,663) to persons of Chinese descent. Thirty-four percent (64,974) of the hospitalizations were admissions of persons aged 40 years and older, although the distribution of hospitalizations by age varied considerably with disease classification (Table 1).

Among persons of all ages, the total number of hospitalizations for any cause was modestly elevated (by 8%) during the forest fire period of August 1 through October 31, 1997 (12,663 hospitalizations) relative to the average number of hospitalizations that occurred during the same months in 1995, 1996, or 1998 (an average of 11,761 hospitalizations, Table 2). There was a larger

fire-related impact on the observed number of hospitalizations that were due to respiratory problems. This became more apparent with the increasing age of the patient. In the 19–39, 40–64 and 65+ age categories, respiratory and specifically COPD hospitalizations increased during the fire period of 1997. Among persons aged 40–64 there were 226 hospitalizations for COPD during the fire period, and an average of 151 hospitalizations during the same time periods in 1995, 1996 and 1998 (a relative fire-related increase of 50%). An increase of 42% in COPD hospitalizations was also observed among persons aged 65 years and older (208 hospitalizations during the fire period and an average of 146 hospitalizations during the same months in 1995, 1996 and 1998). An 83% increase in asthma hospitalizations was observed in the 40–64 year age group in 1997 (115 hospitalizations) relative to the average of the non-fire years (an average of 63 hospitalizations per year during 1995, 1996 and 1998). A 22% increase in asthma hospitalizations was observed in the 19–39 year age group (Table 2).

Time-series analyses

Table 3 presents a summary of findings from the time-series analyses. The results of the time-series analyses suggest that fire-related increases in hospitalizations were more evident for respiratory admissions than for circulatory admissions. Among persons of all ages, asthma admissions were significantly elevated during the month of October 1997 relative to seasonally adjusted forecasted estimates that were established using a 31-month baseline period of January 1, 1995 through July 31, 1997 (Table 3). The statistically significant increase in asthma admissions was most notable among persons

Table 2. Frequency (percent of total within age category) of hospitalizations occurring in the Kuching region during August–October 1997 (the fire period) in comparison to the months of August–October, 1995, 1996 and 1998 (non-fire periods) by disease classification within age group

	August–October, 1995	August–October, 1996	August–October, 1997	August–October, 1998
<i>All ages</i>				
All causes	11,554 (100.0)	12,618 (100.0)	12,663 (100.0)	11,110 (100.0)
Cardiorespiratory	1782 (15.4)	2075 (16.4)	2185 (17.3)	1713 (15.4)
Circulatory	776 (6.7)	905 (7.2)	909 (7.2)	691 (6.2)
IHD	132 (1.1)	172 (1.4)	203 (1.6)	152 (1.4)
Respiratory	1006 (8.7)	1,170 (9.3)	1,276 (10.1)	1022 (9.2)
COPD	525 (4.5)	617 (4.9)	757 (6.0)	545 (4.9)
Asthma	303 (2.6)	351 (2.8)	439 (3.5)	325 (2.9)
<i>Ages 0–18</i>				
All causes	3724 (100.0)	4165 (100.0)	4236 (100.0)	3590 (100.0)
Cardiorespiratory	530 (14.2)	583 (14.0)	569 (13.4)	510 (14.2)
Circulatory	32 (0.9)	42 (1.0)	34 (0.8)	17 (0.5)
IHD	4 (0.1)	2 (0.0)	1 (0.0)	1 (0.0)
Respiratory	498 (13.4)	541 (13.0)	535 (12.6)	493 (13.7)
COPD	182 (4.9)	186 (4.5)	217 (5.1)	187 (5.2)
Asthma	177 (4.8)	185 (4.4)	216 (5.1)	183 (5.1)
<i>Ages 19–39</i>				
All causes	3962 (100.0)	4303 (100.0)	4077 (100.0)	3588 (100.0)
Cardiorespiratory	231 (5.8)	263 (6.1)	281 (6.9)	213 (5.9)
Circulatory	91 (2.3)	88 (2.0)	105 (2.6)	89 (2.5)
IHD	10 (0.3)	12 (0.3)	12 (0.3)	12 (0.3)
Respiratory	140 (3.5)	175 (4.1)	176 (4.3)	124 (3.5)
COPD	71 (1.8)	93 (2.1)	106 (2.6)	77 (2.1)
Asthma	64 (1.6)	81 (1.9)	95 (2.3)	89 (2.0)
<i>Ages 40–64</i>				
All causes	2633 (100.0)	2725 (100.0)	2816 (100.0)	2640 (100.0)
Cardiorespiratory	590 (22.4)	659 (24.2)	737 (26.2)	614 (19.5)
Circulatory	396 (15.0)	422 (15.5)	435 (15.4)	322 (11.4)
IHD	74 (2.8)	82 (3.0)	114 (4.0)	66 (2.5)
Respiratory	194 (7.4)	237 (8.7)	302 (10.7)	212 (8.0)
COPD	136 (5.2)	168 (6.2)	226 (8.0)	148 (5.6)
Asthma	53 (2.0)	70 (2.6)	115 (4.1)	66 (2.1)
<i>Ages 65+</i>				
All causes	1235 (100.0)	1425 (100.0)	1534 (100.0)	1292 (100.0)
Cardiorespiratory	431 (34.9)	570 (40.0)	598 (39.0)	476 (36.8)
Circulatory	257 (20.8)	353 (24.8)	335 (21.8)	283 (21.9)
IHD	44 (3.6)	76 (5.3)	76 (5.0)	72 (5.6)
Respiratory	174 (14.1)	217 (15.2)	263 (17.1)	193 (14.9)
COPD	136 (11.0)	170 (11.9)	208 (13.6)	133 (10.3)
Asthma	9 (0.7)	15 (1.1)	13 (0.8)	13 (1.0)

in the 40–64 year age category, where increases in hospitalizations beyond the 95% prediction intervals of the forecasted estimates were apparent during all three months of the forest fire period (Table 3 and Fig. 2).

A similar pattern was observed for COPD admissions. Fire-related increases in COPD hospitalizations were most evident in the 40–64 year age category, where significant increases were observed during August and September 1997 (Table 3). The overall impact of the

forest fire on all respiratory hospitalizations closely mirrored its effects on COPD (Table 3).

Survival analyses

Table 4 presents the findings from the survival analyses of hospital re-admissions during the fire period. Persons over age 65 with previous hospital admissions

Table 3. Summary of significant findings from time series analyses: months between August and December, 1997. Holt-Winters' tests indicated that observed hospitalizations exceeded upper-bound 95% prediction intervals (PI) surrounding forecasted hospitalizations

	0–18			19–39			40–64			65 +			All ages	
	Month and year	Observed hosps.	95% PI	Month and year	Observed hosps.	95% PI	Month and year	Observed hosps.	95% PI	Month and year	Observed hosps.	95% PI	Month and year	Observed hosps.
All causes	n.s.			n.s.			n.s.			n.s.			n.s.	
Cardiorespiratory	n.s.			8/97	109	51.5–91.5	n.s.			n.s.			n.s.	
Circulatory	n.s.			n.s.			n.s.			n.s.			n.s.	
IHD	n.s.			8/97	6	–0.5–5.7	n.s.			n.s.			n.s.	
Respiratory	n.s.			8/97	69	28.1–67.9	8/97	110	57.1–99.0	n.s.			n.s.	
							9/97	107	57.0–99.2					
COPD w/asthma	n.s.			n.s.			8/97	79	37.7–74.5	n.s.			8/97	255
							9/97	82	36.0–73.0					
Asthma	n.s.			8/97	34	2.9–32.2	8/97	42	10.4–34.8	n.s.			10/97	184
							9/97	41	5.9–31.3					
							10/97	32	5.9–30.6					

Note: "n.s." indicates that the count of hospitalizations did not exceed forecasted 95% prediction limits for any month between 8/1997 and 12/1997. Forecasted time-series trends were established using the baseline period of January 1995 to July of 1997. hosps. = hospitalizations.

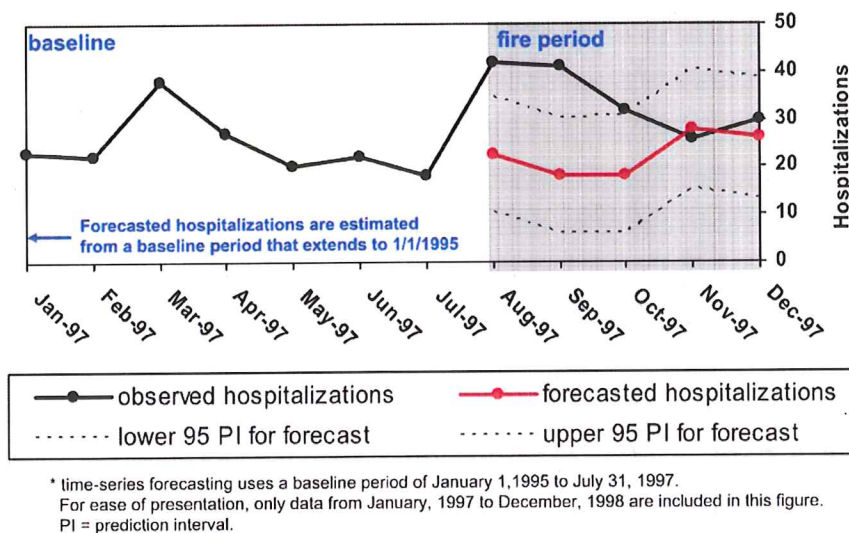


Fig. 2. Time series analyses: Comparison of observed and forecasted hospitalizations from August 1 to December 31, 1997 using the Holt-Winters' forecasting method*—asthma hospitalizations, ages 40–64.

for any cause, any cardiorespiratory disease, any respiratory disease, or COPD, were significantly more likely to be re-hospitalized during the follow-up period in 1997 than during the follow-up periods in the pre-fire years of 1995 or 1996. When considering hospitalizations due to any cause, 11.2% of persons over age 65 were re-admitted during the follow-up period in 1997, and an average of 9.4% were re-admitted during the control periods in the pre-fire years of 1995 and 1996 (χ^2 , 1df = 5.98, $p = 0.015$). When considering respiratory hospitalizations, 12.9% of persons over age 65 were re-admitted during the follow-up period in 1997, and an average of 8.0% were re-admitted during the control periods in 1995 and 1996 (χ^2 , 1df = 7.80, $p = 0.005$) (Table 4 and Fig. 3). Persons over age 65 with previous admissions for COPD were more likely to be re-hospitalized for COPD, or to die from any cause, during the follow-up period in 1997 (14.0% were re-admitted or died during follow-up, χ^2 , 1df = 3.9, $p = 0.047$) than during the control periods in the pre-fire years of 1995 and 1996 (an average of 9.7% were re-admitted or died during follow-up in the pre-fire years) (Table 4). For each of these disease classifications, the steeper decline in the trajectory of the 1997 survival curve among persons aged 65 and older only began once the Kuching Air Quality Index reached concentrations equivalent to exceedences of the US Environmental Protection Agency's (USEPA) National Ambient Air Quality Standards. With the exception of circulatory re-admissions among persons aged 19–39 (where sample sizes were very small), no significant increases in hospital re-admissions rates were observed in cohorts of persons younger than age 65.

We assessed the longer-term effects of smoke exposure by comparing the 17 months survival functions

of exposed cohorts enrolled during January 1 through July 31 of 1997 to unexposed cohorts enrolled during January 1 through July 31 of 1995. No significant long-term differences in survival functions were observed. Although statistically significant increases in readmission rates were observed in cohorts of persons aged 65 and older during the forest fire, the survival functions of the exposed cohorts resumed similar trajectories to unexposed cohorts during the post-fire period of November 1, 1997 through December 31, 1998 (Fig. 4).

Discussion

These findings demonstrate that many communities exposed to forest fire smoke during the Southeast Asian forest fires of 1997 experienced short-term increases in cardiorespiratory hospitalizations. Significant increases in respiratory hospitalizations, particularly those due to asthma, were observed in the 19–39 and 40–64 age categories. Survival analyses indicated that persons over age 65 with prior hospitalizations for respiratory diseases were significantly more likely than others to be re-hospitalized for their conditions during the forest fire. However the impact of smoke exposure on this population appeared to be limited to the period during which the forest fires were burning, as long term assessments of re-hospitalization rates indicated that the survival functions of exposed cohorts resumed trajectories similar to unexposed cohorts during the 17 months following the end of the forest fires. Cohorts defined as exposed to the forest fire smoke only began to demonstrate increases in hospital re-admission rates relative to unexposed cohorts once the Kuching Air

Table 4. Summary of results from survival analyses: log-rank χ^2 tests (1df) comparing the survival of the 1997 (smoke exposed) cohorts to pooled survival results of the 1995 and 1996 (non-exposed) cohorts

	Ages 0–18			Ages 19–39		
	Cohort	% with event between 8/1–12/31 of cohort year	χ^2 (1 df), <i>p</i> -value	Cohort	% with event between 8/1–12/31 of cohort year	χ^2 (1 df), <i>p</i> -value
All causes	97	276/8697 = 3.2%	0.08, <i>p</i> = 0.77	97	331/7999 = 4.1%	0.58, <i>p</i> = 0.45
	95+96	573/17,694 = 3.2%		95+96	624/15,878 = 3.9%	
Cardiorespiratory	97	58/1902 = 3.0%	0.43, <i>p</i> = 0.51	97	26/547 = 4.8%	0.00, <i>p</i> = 0.99
	95+96	119/3519 = 3.4%		95+96	49/1037 = 4.7%	
Circulatory	97	3/82 = 3.7%	0.31, <i>p</i> = 0.58	97	11/198 = 5.6%	4.09, <i>p</i> = 0.04
	95+96	3/128 = 2.3%		95+96	9/386 = 2.3%	
IHD	97	0/5 = 0.0%	1.00, <i>p</i> = 0.32	97	0/24 = 0.0%	0.49, <i>p</i> = 0.49
	95+96	1/5 = 20.0%		95+96	1/50 = 2.0%	
Respiratory	97	53/1820 = 2.9%	0.77, <i>p</i> = 0.38	97	15/353 = 4.2%	1.13, <i>p</i> = 0.29
	95+96	114/3392 = 3.4%		95+96	38/654 = 5.8%	
COPD	97	25/502 = 5.0%	0.45, <i>p</i> = 0.50	97	12/209 = 5.7%	1.5, <i>p</i> = 0.22
	95+96	45/769 = 5.9%		95+96	31/363 = 8.5%	
Asthma	97	25/487 = 5.1%	0.43, <i>p</i> = 0.51	97	8/185 = 4.3%	3.49, <i>p</i> = 0.06
	95+96	45/749 = 6.0%		95+96	29/331 = 8.8%	
	Ages 40–64			Ages 65+		
All causes	97	396/5153 = 7.7%	0.50, <i>p</i> = 0.48	97	281/2515 = 11.2%	5.98, <i>p</i> = 0.015
	95+96	802/10,023 = 8.0%		95+96	474/5050 = 9.4%	
Cardiorespiratory	97	106/1268 = 8.4%	0.41, <i>p</i> = 0.52	97	124/992 = 12.5%	5.3, <i>p</i> = 0.02
	95+96	214/2384 = 9.0%		95+96	180/1860 = 9.7%	
Circulatory	97	58/807 = 7.2%	0.52, <i>p</i> = 0.47	97	109/1360 = 8.0%	0.21, <i>p</i> = 0.64
	95+96	120/1494 = 8.0%		95+96	215/2547 = 8.4%	
IHD	97	15/212 = 7.1%	0.01, <i>p</i> = 0.91	97	11/125 = 8.8%	0.13, <i>p</i> = 0.71
	95+96	25/340 = 7.4%		95+96	17/222 = 7.7%	
Respiratory	97	42/483 = 8.7%	0.00, <i>p</i> = 0.99	97	58/448 = 12.9%	7.8, <i>p</i> = 0.005
	95+96	80/927 = 8.6%		95+96	67/836 = 8.0%	
COPD	97	39/332 = 11.7%	0.26, <i>p</i> = 0.60	97	49/349 = 14.0%	3.9, <i>p</i> = 0.047
	95+96	69/649 = 10.6%		95+96	61/628 = 9.7%	
Asthma	97	17/149 = 11.4%	0.09, <i>p</i> = 0.77	97	5/35 = 14.3%	2.07, <i>p</i> = 0.15
	95+96	30/288 = 10.4%		95+96	4/69 = 5.8%	

*Survival analysis includes all-cause mortality data that was merged with hospitalization data for use as a censoring variable.

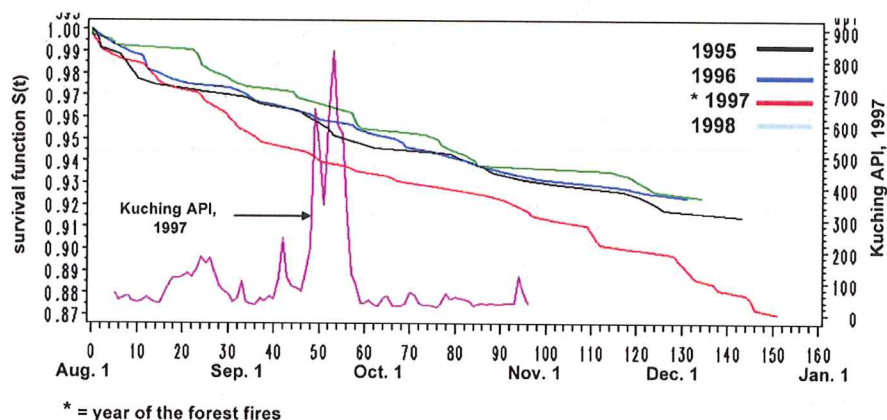


Fig. 3. Kaplan-Meier survival curves of time to hospital re-admission during follow-up, respiratory admissions (ICD-9 460-519), persons ≥ 65 years of age.

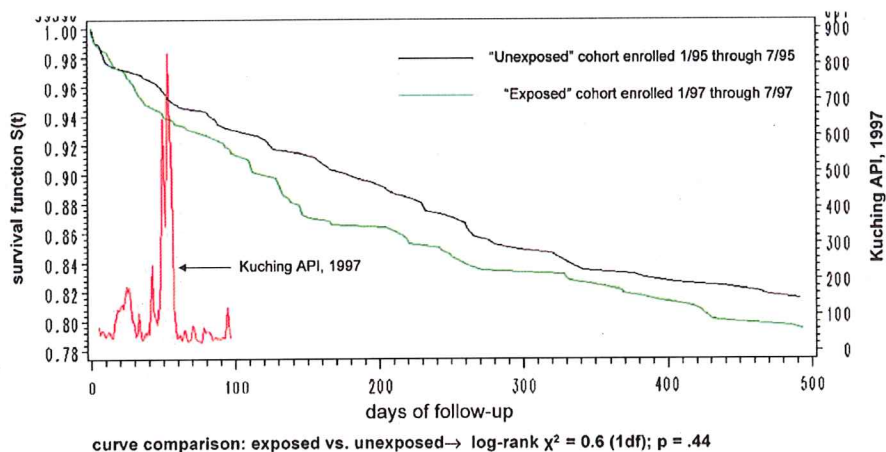


Fig. 4. Kaplan-Meier survival curves of time to hospital re-admission during extended follow-up, respiratory admissions, persons ≥ 65 years of age.

Quality Index reached concentrations equivalent to exceedences of the USEPA's National Ambient Air Quality Standards. This finding strengthens our assertion that forest fire smoke exposure was the primary etiologic influence on the health effects observed.

This study also included some limitations. Data on deaths occurring out of the hospitals were only available for persons over age 40 who were hospitalized with COPD. As a result, for younger cohorts or those with other conditions, we were unable to distinguish between persons that had died and persons that were censored without a hospital readmission during the follow-up period. The impact of this limitation would likely be negligible in younger, healthier, age categories, but may have led to conservative estimates of the smoke-related impact on older persons with relatively severe health conditions such as IHD. Air pollution data were unavailable for many areas of Malaysia, and our study was therefore limited to the region of Kuching, where exposure could be most confidently estimated. We were also unable to assess changes in community cigarette smoking over time. To the extent that there was an increase in community smoking behaviors during the time of the fires, this could have been an unmeasured confounding influence on the cardiorespiratory outcomes. Finally, because we were uncertain of the precise catchment areas of the hospitals included in this investigation, we could not confidently select population data for use as a denominator in rate calculations. However we were able to compare hospital re-admission rates within specified cohorts of individuals over time.

These limitations notwithstanding, the results of this investigation have several implications for public health professionals who are considering interventions to prevent respiratory health effects during acute air pollution emergencies. Persons over age 65 with recent

admission histories for cardiorespiratory problems are most susceptible to adverse health effects associated with forest fire smoke exposure. When an air quality emergency is anticipated, these persons should be pre-identified from existing hospitalization records and given priority access to possible interventions including:

- (1) *Evacuation opportunities.* Difficulties in predicting the intensity and duration of a community smoke exposure may make evacuation to avoid smoke (as opposed to fire) an unattractive option for many members of the non-susceptible general population (Mott et al., 2002). However, if driving hazards associated with poor visibility can be avoided, evacuation to reduce smoke exposure may be a helpful protective measure for sensitive groups.
- (2) *Clean air sanctuaries.* In non-air conditioned homes over 80% of outdoor combustion-source particulates may penetrate indoors (Suh et al., 1992). Public buildings that are tightly sealed, include air conditioning, and have installed air filtration or purification systems may therefore provide community residents with an important opportunity to avoid particulate exposures.
- (3) *Medication/oxygen dispensaries.* Additional access to prescription and OTC medications can be established at emergency shelters and clean air sanctuaries through arrangements with local pharmacies. This approach was undertaken during forest fires in the United States in 2002 (US Centers for Disease Control and Prevention, 2002). Susceptible persons should also be routinely contacted throughout the fire season in order to assure that they have adequate access to any needed medications and/or oxygen supplies. During a forest fire in 1998, public health professionals in California, USA, undertook

this strategy to target and protect susceptible persons in their community (Mott et al., 2002).

- (4) *Portable air cleaners.* While expensive, properly maintained portable high efficiency particulate air (HEPA) cleaners can reduce indoor fine particle concentrations, and have been distributed to smoke-exposed communities with some evidence of a public health benefit (Mott et al., 2002). However, any air cleaner recommended for use in a community should be labeled with a Clean Air Delivery Rate (CADR) that indicates the maximum effective room size in which it may be used.

Although persons over age 65 may be most susceptible to health effects associated with smoke exposure, these findings also demonstrate modest fire-related increases in hospitalizations among younger persons without a known history of cardiorespiratory diseases. Broader interventions such as mask dissemination and the release of public service announcements (PSAs) to reduce smoke exposure in the general community have previously been implemented but require further evaluation. Only respirator masks (e.g. HEPA masks) can filter the fine particulate in smoke. However, these masks are commonly worn inconsistently, with an inadequate face seal, and do not reduce exposure to dangerous gases such as carbon monoxide. Even when worn properly, face masks may also increase airflow resistance which may be dangerous to those with cardiopulmonary diseases. As face masks appear to be an intervention that may offer a false sense of security and possibly encourage outdoor exposure when it is unnecessary (Mott et al., 2002), they should not be disseminated to the general public without further validation of their efficacy and effectiveness.

However, a variety of media outlets can be used immediately before and during forest fires to provide updated information on current air quality, emergency contact numbers, the types of people who may be most susceptible to health effects, and potential protective actions that can be undertaken. A critical role of the media is to increase intervention utilization by raising public awareness of the location of clean air sanctuaries, evacuation opportunities, and the existence of additional medication/oxygen dispensaries. In this regard, targeting PSAs to the most vulnerable population of persons over age 65 would likely maximize their impact. When smoke exposure appears imminent, hospital administrators should also consider increasing the relative presence of respiratory staff and supplies in an anticipation of an increased burden of hospitalizations. However, the scientific basis for recommending these and other community intervention strategies must be

strengthened through community trials of intervention effectiveness. This would be aided by the validation of biologic markers of forest fire smoke exposure that can then be used to more sensitively assess the complex relationship between ambient air pollution concentrations and individual exposures.

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