GASEOUS AND PARTICULATE EMISSIONS RELEASED TO THE ATMOSPHERE FROM VEGETATION FIRES

Joel S. Levine

Atmospheric Sciences Division
NASA Langley Research Center
Hampton, Virginia 23681-0001
USA

SUMMARY

During 1997 and 1998, relatively small-scale, human-initiated fires for land clearing and land use change developed into uncontrolled large-scale and devastating fires. These fires occurred in Southeast Asia, South and Central America, Africa, Europe, China, and the United States. These uncontrolled and widespread vegetation fires were a consequence of extreme drought conditions apparently brought about by the 1997 El Niño, one of the most severe on record. On a daily basis, these fires were reported on the front pages of the world's newspapers and on radio and television throughout the world. Internet websites described the daily, and in some cases, the hourly progress of these wildfires. To assess the health and environmental impacts of these fires, knowledge of the gaseous and particulate emissions produced in vegetation fires and released into the atmosphere is critical. The calculation of gaseous and particulate emissions from vegetation fires is outlined. This paper considers the gaseous and particulate species produced during vegetation fires and the procedures to calculate their source strengths.

Biomass burning, the burning of living and dead vegetation for land-clearing and land-use change, has been identified as a significant source of gases and particulates to the regional and global atmosphere (1-3). A variety of carbon and nitrogen species are released into the atmosphere during vegetation fires (Tables 1 and 2) (4). These tables give the amount of each compound expressed as the percentage of carbon (Table 1) and nitrogen (Table 2) in the vegetation.

The major gases produced during the biomass burning process listed in Tables 1 and 2 include many environmentally important gases, such as carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), oxides of nitrogen (NO_x = nitric oxides (NO) + nitrogen dioxide (NO_2)), and ammonia (NH_3). Carbon dioxide and methane are greenhouse gases, which trap earth-emitted infrared radiation and lead to global warming. Carbon monoxide, methane, and the oxides of nitrogen lead to the photochemical production of ozone (O_3) in the troposphere. In the troposphere, ozone is an irritant and harmful pollutant, and in some cases, is toxic to living systems. Nitric oxide leads to the chemical production of nitric acid (HNO_3) in the troposphere. Nitric acid is the fastest growing component of acidic precipitation. Ammonia is the only basic gaseous species that neutralizes the acidic nature of the troposphere. Particulate matter, small (usually about 10 micrometres or smaller) solid particles, such as smoke or soot particles, are also produced during the burning process and released into the atmosphere. These solid particles absorb and scatter incoming sunlight and hence impact the local, regional, and global climate. In addition, these particles (specifically, particulates 2.5 micrometres or smaller) can lead to various human respiratory and general health problems when inhaled. The gases and particulates produced during biomass burning lead to the formation of "smog." The word "smog" was coined as a combination of smoke and fog and is now used to describe any smoky or hazy pollution in the atmosphere.

The bulk of the world's biomass burning occurs in the tropics - in the tropical forests of South America and Southeast Asia and in the savannas of Africa and South America. The majority of biomass burning (perhaps as much as 90 per cent) is believed to be human-initiated, with natural fires triggered by atmospheric lightning only accounting for about 10 per cent of all fires (5).

Over the last few years, a series of books have documented much of our current understanding of biomass burning, including the remote sensing of fires, fire ecology, fire measurements and modelling, fire combustion, gaseous and particulate emissions from fires, the atmospheric transport of these emissions and the chemical and climatic impacts of burning. These volumes include: Goldammer (6), Levine (7), Crutzen and Goldammer (8), Goldammer and Furyaev (9), Levine (10), Levine (11), and van Wilgen et al (12). The topic of health impacts of biomass burning gaseous and particulate emissions is noticeably lacking in these volumes.

To assess both the health and environmental impacts of forest burning, the gaseous and particulate matter emissions produced during the fire and released into the atmosphere must be known. The expression for calculating total mass burned and the various gases and particulates produced, makes use of the following information: area burned, biomass burned, biomass loading, fire efficiency, and the various species emission ratios.

The calculation of gaseous and particulate emissions from vegetation fires

The gaseous emissions from vegetation fires can be calculated using an expression from Seiler and Crutzen (2):

$$M = A * B * E \quad \text{I}$$

where M = total mass of vegetation consumed by burning (tons), A = area burned (km^2), B = biomass loading ($tons/km^2$), and E = burning efficiency (dimensionless). Typical values for B and E for tropical vegetation are summarized in Table 3 (13). A global estimate of the total annual amount of biomass consumed during burning is given in Table 4 (5).

The total mass of carbon [M(C)] released to the atmosphere during burning is related to M by the following expression

$M(C) = C * M$ (tons of carbon)....................................II

C is the mass percentage of carbon in burning biomass. For tropical vegetation, C=0.45 (5). The mass of CO_2 [$M(CO_2)$] released during the fire is related to M(C) by the following expression

$M(CO_2) = CE * M(C)$..**III**

The combustion efficiency (CE) is the fraction of carbon emitted as CO_2 relative to the total carbon compounds released during the fire. For tropical vegetation fires, CE = 0.90 (5).

Once the mass of CO_2 produced by burning is known, the mass of any other species, X_i [$M(X_i)$], produced by burning and released to the atmosphere can be calculated with knowledge of the CO_2-normalized species emission ratio [$ER(X_i)$]. The emission ratio is the ratio of the production of species X_i to the production of CO_2 in the fire. The mass of species X_i is related to the mass of CO_2 by the following expression

$M(X_i) = ER(X_i) * M(CO_2)$ (units of tons of element X_i)...**IV**

where X_i = CO, CH_4, NO_x, NH_3, O_3, etc. It is important to note that O_3 is not a direct product of biomass burning. However, O_3 is produced via photochemical reactions of CO, CH_4, and NO_x, all of which are produced directly by biomass burning. Hence, the mass of ozone resulting from biomass burning may be calculated by considering the ozone precursor gases produced by biomass burning. Values of CO_2 and CO_2-normalized gaseous species emission ratios for tropical forests are given in Table 5. The tropical forest fire emission ratios for gases in Table 5 are based on the measurements of Andreae (5), Andreae et al (14), and Blake et al (15). These emission measurements were obtained for burning tropical forests in South America. Emission ratios for tropical savanna fires are summarized in Table 6 (16). Sometimes, the emission of gases or particulates is represented by the "emission factor." The emission factor provides information on the quantity of gas or particulate produced as a function of the amount of biomass consumed by burning. The emission factor usually has units of grams of gas or particulate produced per kilogram of biomass consumed by fire.

To calculate the total particulate matter (TPM) released from vegetation fires, we use the following expression (17):

$$TPM = M * P \quad \text{..........} \quad V$$

where P is the emission factor, i.e., the conversion of biomass matter to particulate matter during burning. For tropical forest burning, C = 20 tons of TPM per kiloton of biomass consumed by fire (17).

Recent studies using forms of equations **I** to **V**, have estimated the gaseous and particulate emissions resulting from vegetation fires in various tropical regions, including Brazil (15), southern Africa (16,18), and Southeast Asia (19,20). An estimate of the annual production of gases and particulates resulting from burning in the African and global savannas is given in Table 7 (16) and an estimate for annual global production of gases and particulates is given in Table 8 (5). The values in this table are based on the amount of burned biomass given in Table 3 (13).

ACKNOWLEDGEMENTS

This research was funded by the Global Change Program of the US Environmental Protection Agency under Interagency Agreement DW 80936540-01-1 and the Director's Discretionary Fund of the NASA Langley Research Center.

REFERENCES

1. Crutzen PJ, Heidt LE, Krasnec JP, Pollock WH, Seiler W. Biomass burning as a source of atmospheric gases CO, H_2, N_2O, NO, CH_3Cl, COS. Nature, 1979; 282:253-6.

2. Seiler W, Crutzen PJ. Estimates of gross and net fluxes of carbon between the biosphere and the atmosphere from biomass burning. Climatic Change, 1980;2: 207-47.

3. Crutzen PJ, Andreae MO. Biomass burning in the tropics: impact on atmospheric chemistry and biogeochemical cycles. Science, 1990;250: 1679-87.

4. Lobert, JM, Scharffe, DH, Hao et al. Experimental evaluation of biomass burning emissions: nitrogen and carbon containing compounds. In: Levine JS (ed). Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications. The MIT Press, Cambridge, Massachusetts, 1991;289-304.

5. Andreae MO. Biomass burning: its history, use, and distribution and its impact on environmental quality and global climate. In: Levine JS (ed). Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications. The MIT Press, Cambridge, Massachusetts, 1991; 3-21.

6. Goldammer JG (ed). Fire in the Tropical Biota: Ecosystem Processes and Global Challenges. Springer-Verlag, Berlin, Germany, 1990.

7. Levine JS (ed). Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications. The MIT Press, Cambridge, Massachusetts, 1991.

8. Crutzen PJ, Goldammer JG (eds). Fire in the Environment: The Ecological, Atmospheric, and Climatic Importance of Vegetation Fires. John Wiley and Sons, Chicester, England, 1993.

9. Goldammer JG, Furyaev VV (eds). Fire in Ecosystems of Boreal Eurasia. Kluwer Academic Publishers, Dordrecht, The Netherlands, 1996.

10. Levine JS (ed). Biomass Burning and Global Change: Remote Sensing, Modeling and Inventory Development, and Biomass Burning in Africa. The MIT Press, Cambridge, Massachusetts, 1996.

11. Levine JS (ed). Biomass Burning and Global Change: Biomass Burning in South America, Southeast Asia, and Temperate and Boreal Ecosystems, and the Oil Fires of Kuwait. The MIT Press, Cambridge, Massachusetts, 1996.

12. van Wilgen BW, Andreae MO, Goldammer JG, Lindesay JA (eds). Fire in Southern African Savannas: Ecological and Atmospheric Perspectives. Witwatersrand University Press, Johannesburg, South Africa, 1997.

13. Scholes RG, Kendall J, Justice CO. The quantity of biomass burned in southern Africa. Journal of Geophysical Research, 1996;101: 23667-76.

14. Andreae MO, Browell EV, Garstang M, et al. Biomass burning emission and associated haze layers over Amazonia. Journal of Geophysical Research, 1988;93: 1509-27.

15. Blake NJ, Blake DR, B Sive C, et al. Biomass burning emissions and vertical distribution of atmospheric methyl halides and other reduced carbon gases in the South Atlantic Region. Journal of Geophysical Research, 1996;101: 24,151-64.

16. Andreae MO, Atlas E, Cachier H, et al. Trace gas and aerosol emissions from savanna fires. In: Levine JS (ed). Biomass Burning and Global Change, Volume 1. The MIT Press, Inc., Cambridge, Massachusetts, 1996;278-95.

17. Ward DE. Factors influencing the emissions of gases and particulate matter from biomass burning. In: Goldammer JG (ed). Fire in the Tropical Biota: Ecosystem Processes and Global Challenges. Springer-Verlag, Berlin, Ecological Studies, 1990;84: 418-36.

aerosol particles due to vegetation burning in southern hemisphere Africa. Journal of Geophysical Research, 1996;101:23,667-82.

19. Levine, JS. The 1997 fires in Kalimantan and Sumatra, Indonesia: gaseous and particulate emissions. Geophysical Research Letters, 1999;26:815-8.

20. Levine JS, Bobbe T, Ray N, Singh A, Witt RG. Wildland Fires and the Environment: A Global Synthesis. United Nations Environmental Program, Nairobi, Kenya, UNEP/DEIAEW/TR.99-1,1999.

21. Brown S, Gaston G. Estimates of biomass density for tropical forests. In: Levine JS (ed). Biomass Burning and Global Change, Volume 1. The MIT Press, Cambridge, Massachusetts, 1996;133-9.

Table 1
Carbon and gases produced during biomass burning (4)

Compound	Mean emission factor relative to the fuel C (%)
Carbon dioxide (CO_2)	82.58
Carbon monoxide (CO)	5.73
Methane (CH_4)	0.424
Ethane (CH_3CH_3)	0.061
Ethene ($CH_2=CH_2$)	0.123
Ethine (CH=CH)	0.056
Propane (C_3H_8)	0.019
Propene (C_3H_6)	0.066
n--butane (C_4H_{10})	0.005
2-butene (cis) (C_4H_8)	0.004
2-butene (trans) (C_4H_8)	0.005
i-butene, i-butene (C_4H_8 + C_4H_8)	0.033
1,3-butadiene(C_4H_6)	0.021
n-pentane (C_3H_{12})	0.007
Isoprene (C_5H_8)	0.008
Benzene (C_6H_6)	0.064
Toluene (C_7H_8)	0.037
m-, p-xylene (C_8H_{10})	0.011
o-xylene (C_8H_{10})	0.006
Methyl chloride (CH_3Cl)	0.010
NMHC (As C) (C_2 to C_8)	1.18
Ash (As C)	5.00
Total Sum C	94.92 (including ash)

Table 2
Nitrogen gases produced during biomass burning (4)

Compound	Mean emission factor relative to the fuel N (%)
Nitrogen oxides (NO_x)	13.55
Ammonia (NH_3)	4.15
Hydrogen cyanide (HCN)	2.64
Acetonitrile (CH_3CN)	1.00
Cyanogen (NCCN) (As N)	0.023
Acrylonitrile (CH_2CHCN)	0.135
Propionitrile (CH_3CH_2CN)	0.071
Nitrous oxide (N_2O)	0.072
Methylamine (CH_3NH_2)	0.047
Dimetylamine ($(CH_3)_2NH$)	0.030
Ethylamine ($CH_3CH_2NH_2$)	0.005
Trimethylamine ($(CH_3)N$)	0.02
2-methyl-1-butylamine ($C_5H_{11}NH_2$)	0.04
n-pentylamine (n-$C_5H_{11}NH_2$)	0.137
Nitrates (70% HNO_3)	1.10
Ash (As N)	9.94
Total sum N (As N)	33.66 (Including ash)
Molecular nitrogen (N_2)	21.60
Higher HC and particles	20

Table 3
Biomass load range and burning efficiency in tropical ecosystems (13)

Vegetation type	Biomass load range (tons/km^2)	Burning efficiency
Tropical rainforests(21)	5000-55000	0.20
Evergreen forests	5000-10000	0.30
Plantations	500-10000	0.40
Dry forests	3000-7000	0.40
Fynbos	2000-4500	0.50
Wetlands	340-1000	0.70
Fertile grasslands	150-500	0.96
Forest/savanna mosaic	150-500	0.45
Infertile savannas	150-500	0.95
Fertile savannas	150-500	0.95
Infertile grasslands	150-350	0.96
Shrublands	50-200	0.95

Estimates of annual amounts of global biomass burning and the resulting release of carbon to the atmosphere (5)

Source	Biomass burned (Tg dm/yr)	Carbon released (TgC/yr)
Savanna	3690	1660
Agricultural waste	2020	910
Fuel wood	1430	640
Tropical forests	1260	570
Temperate/boreal forests	280	130
World total	8680	3910

Table 5
Typical emission ratios for tropical forest fires

Species	Tropical forest fires
CO_2	90.00%
CO	8.5%
CH_4	0.32%
NO_x	0.21%
NH_3	0.09%
O_3	0.48%
TPM[a]	20 ton/kiloton(20)

a - Total particulate matter emission ratios are in units of tons/kiloton (tons of total particulate matter/kiloton of biomass or peat material) consumed by fire.

Table 6
Typical emission ratios for tropical savanna fires (16)

Species	Tropical savanna fires
CO	6.2%
CH_4	0.4%
NMHC	0.6%
H_2	1.0%
NO_x	0.28%
N_2O	0.009%
NH_3	0.15
SO_2	0.025%
COS	0.001%
CH_3Cl	0.095%
CH_3Br	0.00083%
CH_3I	0.00026%
TPM	10 ton/kiloton

Table 7
Emissions from the African savanna and the global savanna (16)
(Units are Tg species/year; 1 Tg = 10^{12} grams = 10^6 metric tonnes)

Species	Global savanna	African savanna
CO_2	3280	6070
CO	130	240
CH_4	5	9
NMHC	6	11
H_2	1.5	2.8
NO_x	6	11
N_2O	0.30	0.56
NH_3	2	3.7
SO_2	1.2	2.2
COS	0.4	0.7
CH_3Cl	0.22	0.41
CH_3Br	0.004	0.007
CH_3I	0.002	0.004
TPM	20	37
PM2.5	10	19
CCN[1]	2.4×10^{27}	4.5×10^{27}

[1] cloud condensation nuclei (CCN) in units of CCN per kilogram of dry matter.

Table 8
Comparison of annual global emissions from biomass burning with emissions from all sources (including biomass burning) (5)

Species	Biomass burning (Tg element/yr)	All sources (Tg element/yr)	Biomass burning (%)
CO_2 (gross)[a]	3500	8700	40
CO_2 (net)[b]	1800	7000	26
CO	350	1100	32
CH_4	38	380	10
NMHC[c]	24	100	24
N_2O	0.8	13	6
NO_x	8.5	40	21
NH_3	5.3	44	12
Sulphur	2.8	150	2
COS	0.09	1.4	6
CH_3Cl	0.51	2.3	22
H_2	19	75	25
Tropospheric O_3	420	1100	38
TPM[d]	104	1530	7
POC[e]	69	180	39
EC[f]	19	<22	>86

a. Biomass burning plus fossil fuel burning.
b. Deforestation plus fossil fuel burning.
c. Nonmethane hydrocarbons (excluding isoprene and terpenes).
d. Total particulate matter (Tg/yr).
e. Particulate organic matter (including elemental carbon).
f. Elemental (black-soot) carbon.

BASIC FACTS - DETERMINING DOWNWIND EXPOSURES AND THEIR ASSOCIATED HEALTH EFFECTS, ASSESSMENT OF HEALTH EFFECTS IN PRACTICE: A CASE STUDY IN THE 1997 FOREST FIRES IN INDONESIA

Osamu Kunii

Bureau of International Cooperation
International Medical Center of Japan
Ministry of Health and Welfare, Japan

INTRODUCTION

The dry conditions in Southeast Asia resulting from the 1997 El Niño Southern Oscillation climate phenomenon together with land clearing practices caused the second largest forest fires in Indonesia in this century. Since June 1997, more than 1,500 fires had consumed over 300,000 hectares mainly in Kalimantan and Sumatra islands, and generated intense smoke, which had affected neighbouring countries for several months and triggered secondary disasters like airbus and tanker collisions.

By September 1997, 2 haze-related deaths, some 32,000 suffering from respiratory problems, 2 million affected by haze were reported in Indonesia. In addition, a drought, which was harshest in 50 years, and related epidemics of cholera or dysentery caused over 260 deaths in Irian Jaya. However, no detailed data and information was available to explain public health impacts of the haze and to consider further countermeasures for prevention and protection of general population from the haze.

For providing advice and finding further assistance needs, the Japanese government dispatched public health experts to Indonesia in

September 1997. In this paper, I would like to illustrate the results of air quality measurements and an assessment of health effects in the 1997 forest fires of Indonesia, and review downwind exposures and their associated health effects in previous forest fires in the world.

METHODS

Air quality

The size distribution of particulate matter, carbon monoxide (CO) and carbon dioxide (CO_2) were measured in 8 sites between Jakarta, which was little affected by haze, and Jambi in Sumatra, which was seriously affected. The size distribution of particulates was measured with light scattering particle analyzer (RION KM-07).

Sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), particulate matters less than 10 microns in diameter (PM_{10}), CO, CO_2 were measured in three sites of Jambi. SO_2, NO_2 and O_3 were measured by the methods of Parazosanilin, Saltzmann and KI. PM10 was measured with a low volume air sampler. Inorganic ions, such as chlorite (Cl^-), nitrate (NO_3^-), sulfate (SO_4^{2-}) and ammonium (NH_4^+) were analyzed with ion chromatography using particulate samples collected with the high volume air sampler. From airborne particulate matter samples collected with the high air volume sampler, the polycyclic aromatic hydrocarbon (PAH) fractions, which are known carcinogens, were also analysed by the high performance liquid chromatography (HPLC)/spectrophotometric/ computer system.

Health effects and perception and behaviour

A total of 543 persons in six sites (an elementary school, a secondary high school, a high school, a nursing home, a local government office and a village) were interviewed. In the questionnaire, the following information was gathered: whether symptoms developed or worsened after the occurrence of haze, their severity, past history of respiratory or heart diseases, perception about the haze, shortage of drinking water/food, and preventive behaviours.

In addition, among the respondents, 88 persons with respiratory symptoms were physically examined which included auscultation for abnormal respiratory sounds and clinical signs of conjunctivitis. These subjects were also given a respiratory function test by spirometry.

RESULTS

Air pollution

The concentration of particulate matter 0.3-5.0 μm in size was observed to increase gradually as the measurement site became closer to the heavily affected area, while the concentration of particulate matter over 5.0 μm showed little increase (Figure 1). CO and CO_2 concentrations were also increased in the affected sites; with slight increase typical of urban air pollution in Jakarta (Figure 2).

The major air pollutant of the haze in Indonesia was particulate matter which far exceeded the 'hazardous' level and the maximum value of 500 in the Pollutant Standards Index (PSI) (Table 1). The concentration of 1864 $\mu g/m^3$ was over 10 times higher than that in Jakarta, and about 8 times higher than the maximum level of PM_{10} in the 1987 forest fire disaster in California, which consumed more than 2.4 million hectares (1). CO also showed considerably high concentrations at the 'very unhealthful' level of PSI, but SO_2, NO_2 and O_3 were in the 'good' or 'moderate' range.

Table 2 shows the concentration of inorganic ions in the suspended particulates. The concentration of SO_4^{2-} was 5-10 times higher than that in Tokyo, while Cl^- and NO_3^- were almost at the same level and NH_4^+ was slightly less. The concentrations of the 5-7 ring polycyclic aromatic hydrocarbons (PAHs) in the affected area were 6 to 14 times higher than those in the unaffected area, which showed almost proportional value to the particle concentration. The levels of 4-ring PAHs in Jambi were 40 - 60 times higher than those measured in Jakarta (Table 3).

Health effects

We collected data on the reported cases with pneumonia, bronchial asthma and conjunctivitis from central and local health authorities. Only statistics on outpatients with pneumonia were reported to the central government. In Central Kalimantan, which was one of the areas most heavily hit by the haze during the six-month period, the number of hospitalized cases with pneumonia in September was 33 times higher than that in the previous 12 months (Figure 3).

In Jambi, reported outpatient cases with pneumonia and asthma increased by 1.5 times in September. In a health centre of Jambi, serious cases which needed to be referred to higher level medical facilities increased by 20 per cent in September. In a district hospital of Jambi, cases admitted for bronchitis, acute laryngitis and bronchiectasis increased by 1.6, 8.0 and 3.9 times, respectively.

Out of 539 respondents, 532 (98.7 per cent) developed or became worse with some kinds of symptoms. Of these, 491 (91.1 per cent) had respiratory symptoms. The symptoms developed were considered mild, but all of the respondents had more than one symptom and 85.9 per cent had over 10 symptoms (Table 4). About 30 per cent developed fever which was suspected to be due to infection. For physical and economic reasons, some respondents with serious symptoms did not seek medical care. Respondents 16 to 59 years of age reported a significantly higher rate of symptoms than the other age groups. However, those over 60 years of age had a higher proportion of moderate and severe symptoms, and reported the worst health condition (Table 5). Those with a past history of asthma, bronchitis and heart disease also had a higher rate of symptom manifestations.

During physical examination, conjunctivitis was seen in 33.3 per cent of respondents, wheezing in 8.9 per cent, and other abnormal respiratory sounds in 2.9 per cent. Lung function tests showed that constrictive lung disorder, measured as vital capacity (VC) <80 per cent, and obstructive lung disorder, measured as forced expiratory volume in 1 second (FEV_1) <70 per cent, were seen in 67.4 per cent and 26.9 per cent, respectively (Figure 4).

Regarding perception of haze, 83.3 per cent felt threatened by the haze, and 60.5 per cent wanted to evacuate to safer places. Young respondents were more worried about their future and contemplating moving out of the area affected by the haze.

Of the respondents, 13.7 per cent always put on a protective mask when going out, while 10.9 per cent never and 13.0 per cent seldom did. Young respondents reported lower rate of using a mask.

DISCUSSIONS

The chemical composition of the smoke haze caused by forest fires is determined by the biota and material that are being burnt (2). Incomplete combustion of cellulosic materials in a forest fire produces air pollutants, such as particulate matter, CO_2, CO, NO_x, O_3, SO_2 and over 20 species of hydrocarbons (2, 3). Our study confirmed the findings of other investigations that particulate matter, especially inhalable or respirable particulate matter, is the major air pollutant. Carbon oxide and PAHs are also compounds of concern.

Typical urban air pollution also consists of particulate matter and gaseous compounds. Among them, PM_{10} or much finer $PM_{2.5}$ has been reported to be significantly associated with several indicators of acute health effect, such as mortality (4, 5), hospital admissions (4 - 6), emergency visits (7, 8), physical/functional limitation (9), symptom manifestations (10) and lung function (11, 12). A number of reports also illustrate the association between other typical urban air pollutants and adverse health effects (13 - 15). In contrast, epidemiological studies on the health effects of forest fire smoke are limited. An increase in emergency room visits of asthmatic patients was shown in two studies in California: one on an urban warehouse fire (16) and the other on bushfire (1). Studies of the 1991 urban wildfire in California (17) and the 1994 Sydney bushfires (18) demonstrated little or no increase in emergency room visits for asthma. Several studies on occupational exposures of firefighters to forest/wildland fire showed relatively mild and reversible respiratory health effects (19 - 21). Although we did not conduct an epidemiological study on emergency visits this time, there was evidence of increases in outpatient visits for pneumonia as well as asthma. Hospital admissions for respiratory symptoms were also increased in the affected area. However, due to unreliability of available data and lack of access of local people to medical facilities, outpatient visits and hospital admissions may not represent the real public health impact of the haze. Therefore, we conducted a survey on the health effects of the general population and found that almost all the people developed some kinds of symptoms after the haze, and over 90 per cent had respiratory problems. The survey indicates an extremely strong association between biomass smoke exposure and acute adverse health effects.

There was no epidemiological study on mortality of air pollution from forest fires. In air pollution episodes from fossil fuel combustion, a number of studies indicated that PM_{10} or $PM_{2.5}$ is significantly associated with overall and disease-specific mortality (4, 5, 22 - 24). Several reviews of these studies suggest that there is a dose-response relationship between PM_{10} and mortality (22). Most of the studies indicate that a 10 μgm^3 change in PM_{10} is associated with a 1.0 - 1.6 percent change in mortality (23, 24). A meta-analysis suggests that a 10 $\mu g/m^3$ change in PM_{10} is associated with a 3.4 per cent and a 1.4 per cent change in respiratory and cardiovascular mortality, respectively (23). WHO presented a methodology for estimating the total number of expected cases of premature mortality resulting from acute exposure to PM_{10} (25). It is uncertain whether the calculation of the mortality effects derived from epidemiological data of typical urban air pollution can be applied to cases of biomass smoke. However, if we assume it can be applied, the expected death cases can be estimated using the following formula:

Expected death cases = r/(1+r) x (current mortality rate) x (exposed population) where r is the additional risk associated with the current level of particles relative to the standard; and r is calculated by:

$$r = (\text{estimated percent effect of } PM_{10} \text{ per } \mu g/m^3) \times (1/100) \times (\text{change in } PM_{10})$$

Using 7.5 per 1000 (the crude mortality rate in Indonesia for the period 1990-1995) as the current mortality, 12 million as the exposed population (26), 422 $\mu g/m^3$ as the change in PM_{10} [based on the one-month average PM_{10} concentration of 565 $\mu g/m^3$ measured by Environmental

Management Center in Indonesia (27) minus the standard level of 143 $\mu g/m^3$], the number of expected death cases is 0.52/1.52 x (7.5/1000) x 12,000,000 = 30,789. [r = (0.123 x (1/100) x 422) = 0.52].

This figure might be overestimated since the calculation used the one-month average of PM_{10} in October-November during the haze episode instead of the annual average which is not available. Although 527 deaths were reported in eight haze-affected provinces of Indonesia from September to November 1997 (27), the precise number of the haze-related deaths was unknown because of poor documentation, misclassification or miscoding of the cause of death. Increased mortality from air pollution seems to be attributable to cardiovascular as well as respiratory causes (25, 28) and is dependent on the vulnerable population groups such as children, the elderly and those with respiratory/cardiovascular disease. However, it is not certain whether biomass smoke has the same mechanism of action and impact on the vulnerable groups and the general population as in the case of urban air pollution.

From a number of studies on particulate matter, there is no evidence that airborne particles from different combustion sources have different impacts on health. Therefore, it is not expected that biomass smoke particulate would be less harmful than that originated from fossil fuel combustion. However, the excess deaths may be different for particulate matter generated from fossil fuel combustion and biomass burning. There may be two reasons for this. One is that the chemistry of respirable particles produced by forest fires differs from that of typical urban particulate pollution. The other is that it might be difficult to attribute adverse health effects to a single pollutant in light of the complexity and variability of the mixture of air pollution to which people are exposed. The high intercorrelation between the pollutants makes it difficult to assess the health effect of one single pollutant. There are many reports that the concentration of other pollutants like ozone were more strongly related to mortality (29). The technical feasibility and scientific validity of implicating a single pollutant in such a complex mixture of air pollution to the health effects requires careful consideration and further research.

The forest fire episode of 1997 also resulted in high concentrations of sulfate (SO_4^{2-}). While sulfate, per se, is an unlikely causal factor for pollution-related mortality or morbidity, it is often closely correlated with variations in the strong acid component of ambient particulate matter (H^+) and concentrations of $PM_{2.5}$ which are more likely causal factors (30). Sulfate has been demonstrated to be a useful surrogate for ambient $PM_{2.5}$ and H^+ in epidemiological studies and as an index of PM exposure in ambient air quality guidelines and standards. In addition, the haze contained considerably high concentrations of CO. Evidence from seven large cities in the USA showed that high concentrations of CO were associated with increased hospital admissions for congestive heart failure among elderly people (31). And high concentrations of CO were also associated with increased plasma viscosity, which may lead to a rise in such hospital admissions. Little is known about the biological mechanisms linking ambient air pollution with exacerbation of cardiovascular diseases, but Seaton et al (32) postulated that inflammation in the peripheral airways caused by air pollutants might increase the coagulability of the blood, and thereby lead to an increased number of deaths.

There is limited evidence on the long-term health effects of typical industrial air pollution as well as biomass generated air pollution. As large populations were exposed for a long duration to intense biomass air pollutants, especially inhalable/respirable particulate matter and carcinogen from the forest fire episode in Indonesia, further studies are needed to evaluate long-term health effects.

REFERENCES

1. Duclos P, Sanderson LM, Lipsett M. The 1987 forest fire disaster in California: assessment of emergency room visits. Arch Environ Health 1990; 45: 53-8.

2. Chung YS. On the forest fires and the analysis of air quality data and total atmospheric ozone. Atmosph Environ 1984; 18: 2153-7.

3. Sandberg DV, Pickford SG, Darley EF. Emission from slash burning and the influence of flame retardant chemicals. J Air Pollut Control Assoc 1975; 25: 278-81.

4. Wordley J. Walters S. Ayres JG. Short term variations in hospital admissions and mortality and particulate air pollution. Occupat Environ Med 1997;54:108-16.

5. Thurston GD. A critical review of PM_{10}-mortality time-series studies. J Expos Analy Envir Epidem. 1996; 6:3-21.

6. Pope CA III. Respiratory hospital admissions associated with PM_{10} pollution in Utah, Salt Lake and Cache Valleys. Arch Environ Health, 1991; 46: 90-7.

7. Golsmith JR, Griffith H, et al. Emergency room admissions, meteorological variables and air pollutants: a path analysis. Am J Epidemiol 1983; 118: 759-79.

8. Samet JM, Bishop Y, et al.. The relationship between air pollution and emergency room visits in an industrial community. J Air Pollut Control Assoc, 1981; 31: 236-40.

9. Ostro BD. Air pollution and morbidity revisited: a specification test. J Environ Econ Manage, 1987; 14: 87-98.

10. Ostro BD, Lipsett ML, et al. Asthmatic response to airborne acid aerosols. Am J Public Health, 1991; 81: 694-702.

11. Ackermann-Liebrich U, Leuenberger P, et al. Lung function and long term exposure to air pollutants in Switzerland. Study on Air Pollution and Lung Diseases in Adults (SAPALDIA) Team. Am J Respir Crit Care Med 1997;155:122-9.

12. Scarlett JF. Abbott KJ, et al. Acute effects of summer air pollution on respiratory function in primary school children in southern England. Thorax. 1996; 51:1109-14.

13 Delfino RJ. Murphy-Moulton AM, et al. Effects of air pollution on emergency room visits for respiratory illnesses in Montreal, Quebec. Am J Respir Crit Care Med 1997;155:568-76.

14. Dockery DW. Cunningham J, et al. Health effects of acid aerosols on North American children: respiratory symptoms. Environ Health Perspect 1996;104:500-5.

15. Bates DV. Adverse health impacts of air pollution continuing problems. Scand J Work Environ Health. 1995;21:405-11.

16. Lipsett M, Waller K, et al. The respiratory health impact of a large urban fire. Am J Public Health 1994; 84: 434-8.

17. Schusterman D, Kaplan JZ, Canabarro C. Immediate health effects of an urban wildfire. West J Med 1993; 158: 133-8.

18. Smith MA. Jalaludin B, et al. Asthma presentations to emergency departments in western Sydney during the January 1994 bushfires. Int J Epidemiol 1996; 25:1227-36.

19. Rothman, N, Ford, DP, et al. Pulmonary function and respiratory symptoms in wildland firefighters J Occup Med 1991;33:1163-7.

20. Betchley C, Koenig JQ, et al. Pulmonary function and respiratory symptoms in forest firefighters. Am J Indust Med 1997;31:503-9.

21. Liu, D, Tager IB, et al. The effect of smoke inhalation on lung function and airway responsiveness in wildland fire fighters. Am Rev Respir Dis 1992;146:1469-73.