

Vulnerability to Environmental Exposure in the Context of Air Pollution Changes and Daily Out-Patient Visits in Chiang Mai, Thailand

Nareerut Pudpong

Department of Public Health, Sirindhorn College of Public Health Chonburi, 29 Vachiraprakarn Road, Muang District, Chonburi Province, 20000 Thailand.

Abstract

Compared to the developed countries of North America and Europe, few studies have been conducted on the effects of air pollution on daily morbidity (hospital visits/admissions) in developing countries, particularly in Southeast Asia with its tropical climate. This study aims to identify those groups of people who are more susceptible to daily changes in air pollution in a developing, tropical country such as Thailand.

Generalised negative binomial regression was used to assess the short-term effects of air pollution (SO₂, NO₂, CO, O₃, PM₁₀, and PM_{2.5}) on daily outpatient visits (all-cause and respiratory: ICD-10 J00-J99) in Chiang Mai from 2002 to 2006, controlling for seasonality and potential confounders. Lag effects of exposure and modification by age, sex, and occupation were also examined. The results showed that the effects of SO₂ were higher than other pollutants (using wide CIs), with higher all-cause visits among the elderly (11.8% increase, 95% CI: -4.2 to 30.5), males (6.3% increase, 95% CI: -7.8 to 22.4), and manual workers (31.2% increase, 95% CI: 4.4 to 64.9) per 10ppb increase in SO₂. Despite no statistical significant difference being observed in morbidity risk between subgroups, the elderly seemed to be more vulnerable to daily changes in air pollution than other groups. It is recommended therefore that public health interventions be targeted at this group of people.

Key words: Vulnerability/ Air pollution/ Exposure/ Out-patient visits/ Chiang Mai/ Thailand

1. Introduction

Climate change is anticipated to pose increasing public health risks around the globe. Differences in population vulnerability are of particular concern due to growing evidence that climate change may lead to an increase in deaths and illnesses associated with air pollution variations, particularly in developing parts of the world with limited adaptive capacity (McMichael et al., 1998; Patz et al., 2005; Haines et al., 2006). Research evidence has suggested that age and sex may modify the relationships between environmental exposure and daily mortality and morbidity. While numerous studies indicate that the elderly appear to be the most susceptible to air pollution exposure (Schwartz, 1995; Delfino et al., 1998; Morgan et al., 1998; Spix et al., 1998; Wong et al., 1999; Atkinson et al., 2001; Hwong and Chan, 2002; Anderson

et al., 2003; Koken et al., 2003; Lee et al., 2003; Simpson et al., 2005; Barnett et al., 2006; Larrieu et al., 2007; Ulirsch et al., 2007), there is still no consistency in the role of sex in the association (Hong et al., 2002; Annesi-Maesano et al., 2003; Koken et al., 2003; Bateson and Schwartz, 2004; Granados-Canal et al., 2005; Luginaah et al., 2005; Medina-Ramon and Schwartz, 2008). In addition, socioeconomic (SES) factors may also play a crucial role on environmental related death and illness. Factors such as educational attainment and occupation could be a SES indicator reflecting the different impacts of environmental exposure on health (Schwartz, 2000; Jerrett et al., 2004; Ou et al., 2008; Wong, et al., 2008). To date, most research studies on air pollution effects have been conducted in developed countries, such as in the United States, Canada, and European countries (Schwartz, 1995; Spix

*Corresponding author

Email: nareerutp@yahoo.com

et al., 1998; Atkinson et al., 1999; Goldberg et al., 2000; Atkinson et al., 2001; Koken et al., 2003; Sunyer et al., 2003). There is much less evidence about population susceptibility to air pollution in developing countries, particularly in the Asian region with a tropical climate (Xu et al., 1995; Lee et al., 2003; Health Effects Institute, 2004; Buadong et al., 2009). This study aims to identify the groups of people who are more susceptible to daily changes in air pollution in a developing, tropical country, i.e., Thailand, by using a time-series approach in determining effect modification by age, sex, and occupation.

2. Methods

2.1 Study area and population

Muang district, the most urban area in Chiang Mai (the second largest province of Thailand), was chosen for the study. Chiang Mai is about 750 kilometres north of Bangkok (16 north of latitude, 99 east of longitude), with annual average temperature of 25.4 °C (min = 20.1 °C, max = 31.8 °C), humidity of 72%, and rainfall of 1,000-1,200 mm (Chiang Mai Provincial Operation Centre 2006). There are three seasons in Chiang Mai: winter (November-February), summer (March-May), and rainy (June-October) seasons. During the study period, in Muang district, there was a population density of 1,947.2/sq km (area = 152.4 sq km; population = 296,753 people) (Chiang Mai Provincial Operation Centre 2006).

2.2 Out-patient visit, air pollution, and meteorological data

Health outcomes were daily morbidity (out-patient visits) in Muang district from October 2002 to September 2006, which were obtained from the Chiang Mai provincial health office. There were 10 district health centres and 11 hospitals that had contributed to the health data. However, in each month,

there were different numbers of the health centres and hospitals contributing to the data during the study period. Daily records of out-patient visits by all causes and respiratory visits (ICD-10th, J00-J99) were used for the investigation. The data were stratified by age: children (0-14 years), adults (15-64 years) and the elderly (65 and over), sex: male and female, and occupation: unemployed, manual, and non-manual workers.

Meteorological and air pollution data were provided by the Pollution Control Department (PCD), the centre for controlling the real-time monitoring stations in Thailand. Daily mean levels of meteorological variables (temperature, humidity, and rainfall), and of air pollution (SO₂, NO₂, CO, O₃, PM₁₀, and PM_{2.5}) were obtained from the two monitoring stations located within Muang district, one in the inner city and another one in suburban area (approximately 10 kilometres apart). The air pollution data were the average levels of both stations, while meteorological data from the inner city station with less missing information was used because there were no substantial differences in meteorological levels between the two stations.

2.3 Statistical analysis

Time-series regression methods were used to examine the relationships between daily morbidity and daily mean levels of pollutants in this study. A time series design generally aims to understand how explanatory variables influence health outcomes over time by using regression analysis for the investigation (Zeger et al., 2006). The time series method has been widely used to detect the short-term effects of air pollution on daily mortality and morbidity in many cities worldwide. The key advantage of this method is that the study population serves as its own control, and this, therefore, eliminates the influence of other

underlying risk factors (such as smoking) that may vary among subjects, but do not vary from day to day (Pope III and Schwartz, 1996).

Generalized negative binomial regression, allowing for overdispersion, was used to model relationships between air pollution and daily out-patient visits (McCullough and Nelder, 1989). The negative binomial model is in the following form:

$$\text{Log}[E(Y)] = \beta_0 + \beta_1 X_1 + \dots + \beta_p X_p$$

Where $E(Y)$ is the expected daily counts of out-patient visits, $X_1 \dots X_p$ are explanatory variable (predictors) of Y , and $\beta_1 \dots \beta_p$ are the regression coefficients for the predictors.

The core model was developed by using smooth function of time (b-splines for date) with 6 degrees of freedom (df)/year to control for long-term trends and seasonality. To account for between-month changes in health data contributors, indicator variables for months of the study (1-48) were incorporated into the model. To account for days of the week and holiday effects, indicator variables of days of the week, public holidays, and two long holiday periods: international new year (30 Dec-2 Jan) and Thai new year (13-16 Apr) were incorporated into the model. Because influenza epidemics may confound the findings in time-series studies as they may be more prevalent during cold period (O'Neill et al., 2005), the period comprising daily out-patient visits by respiratory disease above the 99th centile of the total respiratory visits was used as an influenza indicator in this study.

To account for delayed effects of exposure, lag effects up to 4 days for air pollution were examined. To control for

confounding by meteorology, natural cubic splines (3df) of temperature, humidity and rainfall were incorporated into the model to allow for any non-linear relationships. To check for model fit, residual and Partial Autocorrelation Function (PACF) plots were created when adding a new variable to the model. Autoregressive terms at any significant orders were also added when necessary.

The results were reported as a percentage increase in the risk of out-patient visits associated with a 10-unit increase in a pollutant (except CO, one unit increase). To address the issue of collinearity, which is one common problem in epidemiological studies due to the difficulty in determining the actual, single contribution of an exposure on health outcomes because of the fact that there are several air pollutants in the air (Greenland, 1993; Morgenstern and Thomas, 1993), the two pollutant model was also developed for the three pollutants (SO₂, O₃, and NO₂) that exhibited higher effects based on single pollutant models in the present study. For the stratified analyses by age, sex and occupation, tests for interactions between subgroups were undertaken.

3. Results

Table 1 shows the daily out-patient visits by the studied characteristics (age, sex, and occupation) for all-cause and respiratory visits during the study period. As can be seen, adult people held the majority of out-patient visits. Male people visited hospital slightly higher than female people. Unemployed people were about one in four of the total visit (excluding children and the elderly).

Table 1 Daily out-patient visits by age, sex, and occupation in Chiang Mai (Oct. 2002 to Sep. 2006)

Variable	Respiratory (J00-J99)	All-cause
Age (year)		
0-14	40.2%	13.1%
15-64	49.1%	67.1%
≥ 65	10.1%	19.3%
Missing	0.6%	0.6%
Sex		
Male	46.6%	42.5%
Female	52.9%	56.8%
Missing	0.5%	0.8%
Occupation*		
Unemployed	19.0%	25.2%
Non-manual	24.3%	21.6%
Manual	3.8%	6.8%
Unknown	2.8%	17.2%
Total count	139, 256	1,398,369

*Excluding children (0-14) and the elderly (≥ 65).

Table 2 presents the summary statistics of daily air pollution and meteorological variables in Muang district, Chiang Mai, during the study period. Levels of all pollutants were generally well below the National

Ambient Air Quality Standard (The Pollution Control Department, 2005), except only PM₁₀, which occasionally exceeded the 24-hour recommended standard of 120µg/m³ (there is no standard levels for PM_{2.5}).

Table 2 Summary statistics of daily air pollution and meteorological variables in Chiang Mai (Oct. 2002 to Sep. 2006)

Variables	obs (day)	% missing	mean	SD	Percentiles				
					min	25	50	75	max
SO ₂ (ppb)	1408	3.63	1.33	1.3	0	0.69	1.13	1.8	20.41
NO ₂ (ppb)	1408	3.63	12.29	6.38	0.9	7.7	10.45	15.49	42.7
CO (ppm)	1412	3.35	0.66	0.36	0	0.4	0.65	0.89	2.74
O ₃ (ppb)	1421	2.74	17.6	8.2	1.14	11.13	16.15	22.83	52.0
PM ₁₀ (µg/m ³)	1397	4.38	53.9	39.2	10.54	27.82	31.91	67.13	269.9
PM _{2.5} * (µg/m ³)	830	43.19	31.25	22.65	5.96	16.99	27.02	37.08	223.83
Temperature (°C)	1387	5.06	26.69	2.64	19.73	25.10	27.02	28.52	33.33
Relative humidity (%)	1362	6.78	70.85	14.32	31.11	62.33	71.52	81.78	99.79
Rain (mm/hr)	1371	6.16	0.13	0.42	0	0	0	0.03	5.32

*Data on PM_{2.5} were available from April 2004.

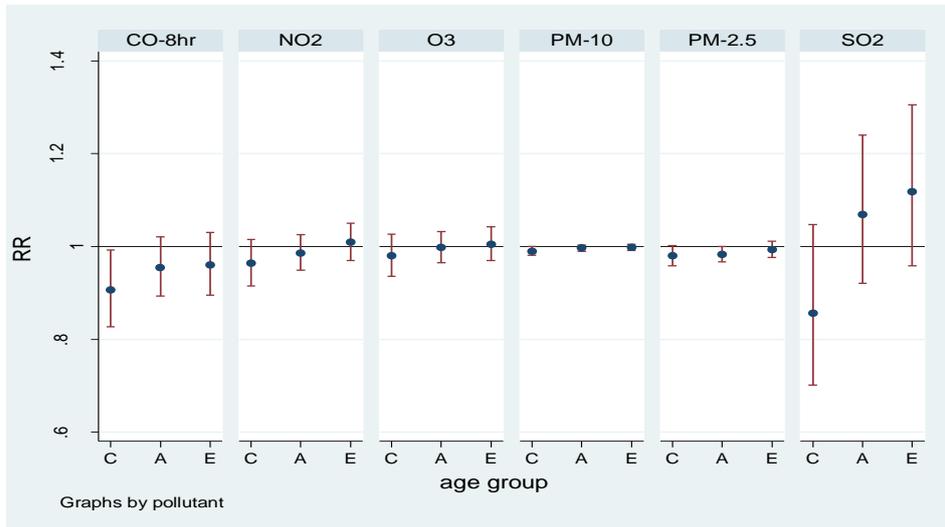
Figure 1 shows the risk estimates of out-patient visits from single, pollutant, distributed lag model (0-4 days) for each 10 unit increase of a pollutant (one unit increase for CO) in different age groups studied during the study period. As shown in the figure, SO₂ exhibited larger estimated effects compared to other pollutants (though imprecise). Overall, air pollution effects (on either all-cause or respiratory visits) were found to be higher

among the elderly than other age groups, but there were no statistically significant differences between subgroups based on the test for interactions (result not shown). However, when looking at the effects by sex and occupation illustrated in figure 2 and 3, there was no consistency of air pollution effects across the pollutants for sex and occupation, although the larger estimated effects were observed in males and manual workers (for SO₂ in

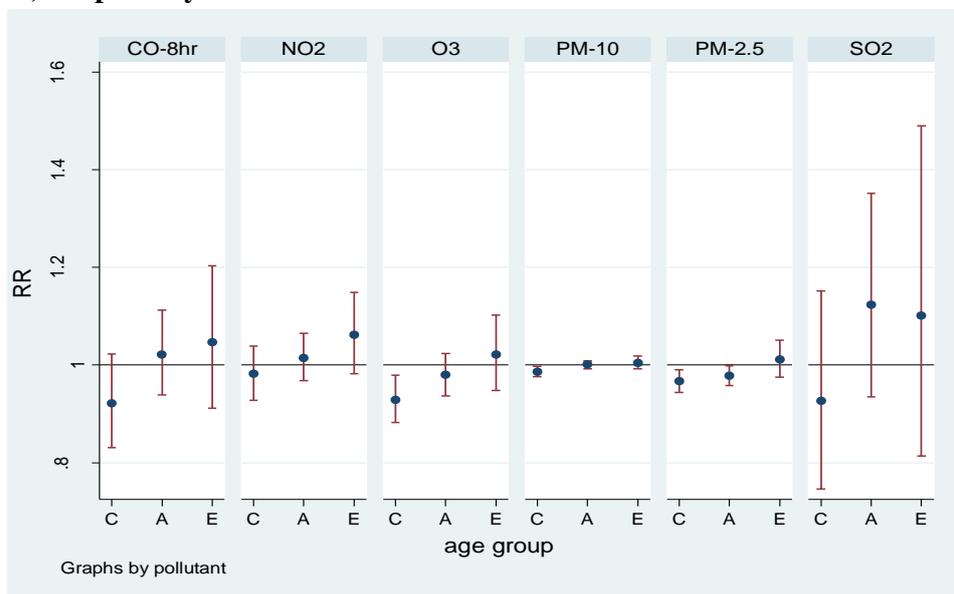
particular). There were no dramatic changes in the effects of the three selected pollutants (SO₂, O₃, and NO₂) obtained from the two-pollutant models compared

to those obtained from the single pollutant models, and therefore the results were not shown.

1a) All-cause visits



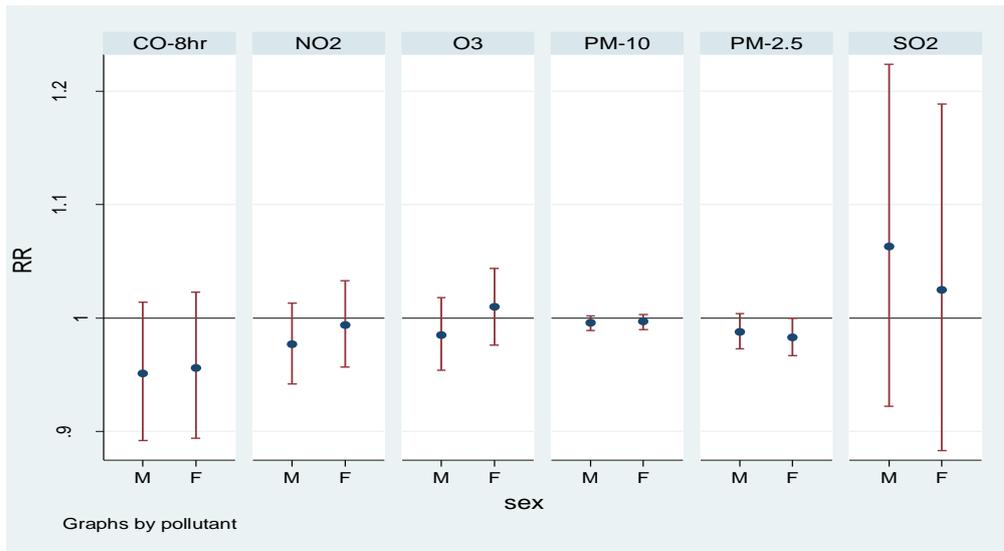
1b) Respiratory visits



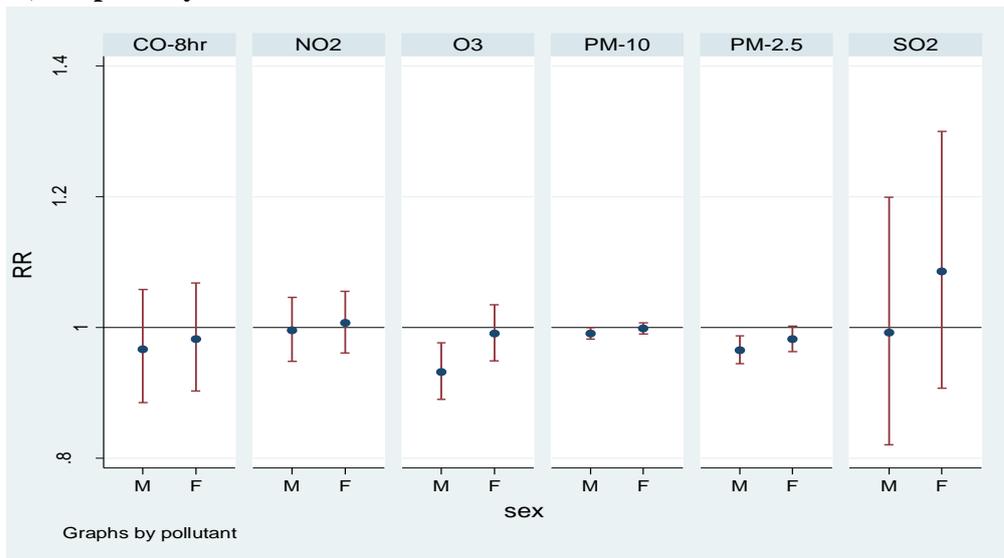
Note: C = Children (0-14 year), A = Adult (15-64 year), E = Elderly (≥ 65year).

Figure 1 Risk estimates for single pollutant, distributed lag models (0-4 days) for a 10-unit increase of a pollutant (one unit increase for CO) on daily out-patient visits in different age groups in Chiang Mai (Oct. 2002 to Sep.2006).

2a) All-cause visits



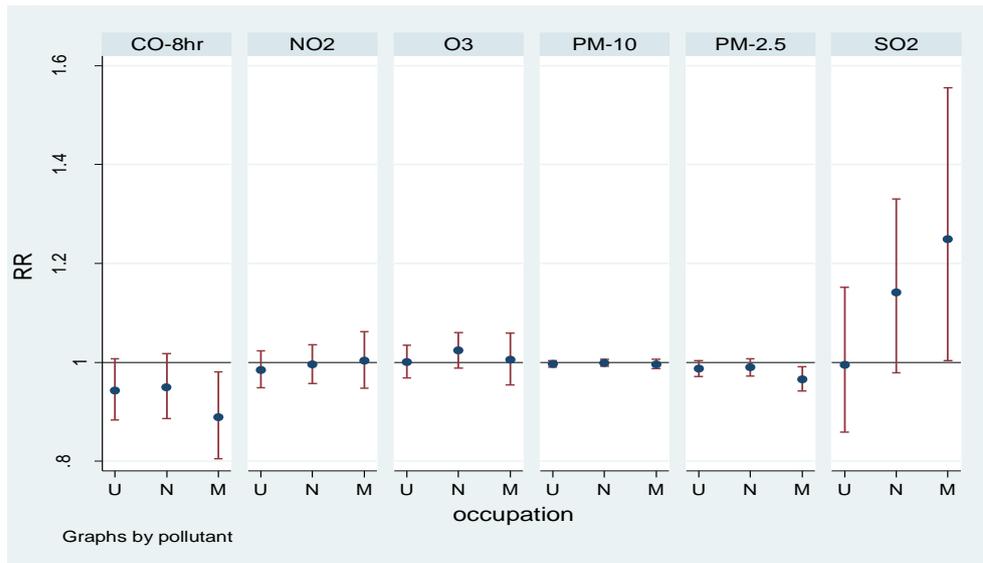
2b) Respiratory visits



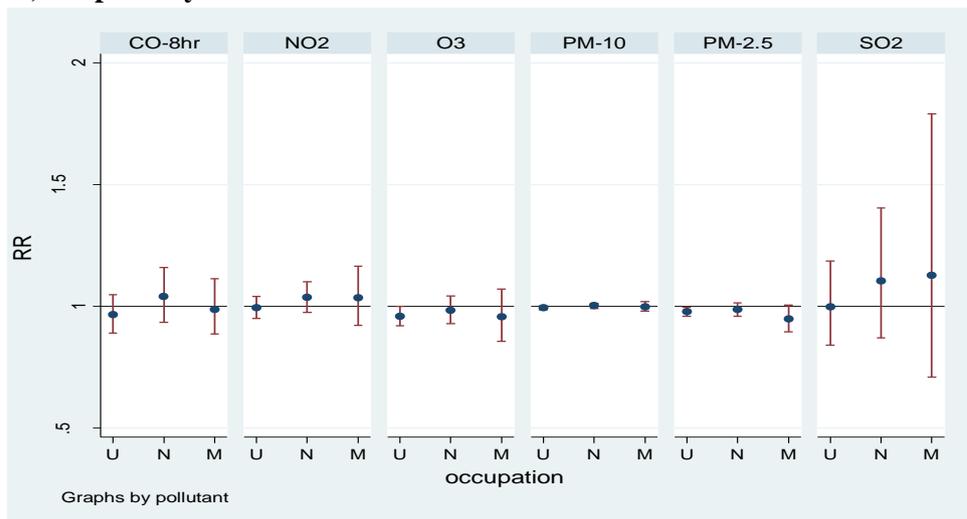
Note: M = male, F = female.

Figure 2 Risk estimates for single pollutant, distributed lag models (0-4 days) for a 10-unit increase of a pollutant (one unit increase for CO) on daily out-patient visits in different sex groups in Chiang Mai (Oct. 2002 to Sep.2006).

3a) All-cause visits



3b) Respiratory visits



Note: U = unemployed people, N = non-manual workers, M = manual workers.

Figure 3 Risk estimates for single pollutant, distributed lag models (0-4 days) for a 10-unit increase of a pollutant (one unit increase for CO) on daily out-patient visits in different occupation groups in Chiang Mai (Oct. 2002 to Sep.2006).

4. Discussion

In the present study, there were no statistically significant effects of air pollution on daily morbidity (out-patient visits) in Chiang Mai. However, air pollution effects were found to be higher among the elderly people than other people.

4.1 Air pollution effects

Among all studied pollutants, SO₂ exhibited the largest positive estimated effects on the out-patient visits, though not statistically significant. SO₂ is a chemical compound produced by fuel combustion and is usually found more prevalent in industrial areas. Although there is no major industry in Chiang Mai, SO₂ may be emitted as a by product of the

production processes of small factories around the city (e.g. agricultural, transportation, and food factories). The study found that there were notably larger effect sizes of SO₂ on daily all-cause and respiratory visits compared to other pollutants. The finding of large estimated effects of SO₂ is in agreement with several time series studies of air pollution in Asia (Health Effects Institute, 2004). For example, in Beijing, it was found that an increase in non-surgery out-patient visits of 20.2% was significantly associated with an increase in SO₂ levels (6 µg/m³ - 106 µg/m³) (Xu et al., 1995). In Seoul, a rise of hospital admissions for ischemic heart disease in the elderly of 32.0% (95% CI, 8.0% to 62.0%) associated with an interquartile increase in SO₂ (4.4 ppb) was observed (Lee et al., 2003). The effect sizes of SO₂ found in this study were relatively larger than those found in Europe and America (Schwartz, 1995; Spix et al., 1998; Atkinson et al., 1999; Koken et al., 2003; Sunyer et al., 2003). For example, the APHEA (Air Pollution and Health - A European Approach) study in West European cities found a 6.0% (95% CI, 1.0% to 11.0%) increase in respiratory admissions in the elderly (≥ 65 year) for each 50 µg/m³ increase in SO₂ levels (Spix et al., 1998). A study in Denver, USA, observed a 9% increase in a risk of hospital admissions for dysrhythmias associated with a 25-75th percentile change in SO₂ levels (3.8 - 7.2 ppb) (Koken et al., 2003).

The failure to detect the effects of PM₁₀ and PM_{2.5} in this study was not expected since particulate matter is the pollutant that shows consistent evidence of adverse health effects worldwide, even at low levels. Time series studies conducted in America (the National Mortality and Morbidity Air Pollution Study; NMMPS), Europe (APHEA), and Canada have shown consistent evidence of acute effects of particulate matter on daily mortality and morbidity (Goldberg

et al., 2000; Samet et al., 2000; Atkinson et al., 2001). The review of time series studies in Asia and the recent publication of the Public Health and Air Pollution in Asia (PAPA) project have also confirmed adverse effects of PM₁₀ on both mortality and morbidity in several Asian countries (Health Effects Institute, 2004; Health Effects Institute, 2008). Moreover, another recent study in Bangkok demonstrated a positive effect of PM₁₀ on hospital visits for cardiovascular diseases (CVDs) among the elderly (≥ 65 years) (Buadong, Jinsart et al. 2009). However, the failure to establish positive associations between particulate matter and health outcomes has occasionally occurred in some places. For example, a study in Denver, U.S.A., did not find any association between particulate matter and hospitalization for any CVDs (Koken et al., 2003). Another study in the UK also found inconsistent associations between particulate matters (PM_{2.5-10}) and hospital admissions, and even found several large negative associations (Anderson et al., 2001).

In this study, the inability to capture the positive effects of PM₁₀ and PM_{2.5} is difficult to explain. There was no reason to think that the unusual results were due to the statistical techniques since most techniques used in the study were adopted from those previously employed by several studies, such as the APHEA project, which were acknowledged to be reasonably robust (Katsouyanni et al., 2001). The behavioural adaptation of the local population might be a possible explanation. A smoke haze usually occurs in the northern part of Thailand in recent years, particularly during the dry season (February-March). It mainly originates from traditional agricultural burning, forest fires and wood-fired cooking in the local area of the northern provinces of Thailand (including Chiang Mai), and neighbouring countries (e.g. Laos and Myanmar). As a consequence, the

warning system to prevent adverse health effects of the haze, which has been implemented (including health education e.g. wearing mask, staying in the home when there is dense smog), may have increased awareness among the Chiang Mai population. This may have reduced the impacts of particulate matter in the city due to the fact that particle is the fine product of the dust in the air (that people learn to avoid being exposed to).

4.2 Effect modification

Air pollution effects were found to be stronger among elderly than other age groups (though there were no statistically significant differences between subgroups). This corresponds to many previous studies either in Europe or America (Schwartz, 1995; Delfino et al., 1998; Spix et al., 1998; Atkinson et al., 2001; Anderson et al., 2003; Koken et al., 2003; Larrieu et al., 2007; Ulirsch et al., 2007) or in Asia Pacific region (Morgan et al., 1998; Wong et al., 1999; Hwong and Chan, 2002; Lee et al., 2003; Simpson et al., 2005; Barnett et al., 2006), which indicated that the elderly people are particularly vulnerable to air pollution. The susceptibility to air pollution among older people may be due to the general deterioration of their physiological functions, especially the heart and lung. Compared to younger people, older people are prone to have higher frequencies of both pre-existing pulmonary diseases and clinically severe infections of respiratory diseases (Delfino et al., 1998). Moreover, older people also have a higher risk of suffering from air pollution effects due to a decline of antioxidant defences (Kelly et al., 2003).

There was neither consistency nor statistically significant evidence of air pollution effects across sex and occupation groups in this study. According to the literature, the role of sex differences in environmental exposure-related health outcomes remains unclear. Some studies showed stronger estimated effects of air

pollution in females compared to males (Hong et al., 2002; Annesi-Maesano et al., 2003; Bateson and Schwartz 2004; Luginaah et al., 2005; Medina-Ramon and Schwartz, 2008), whereas others found a higher risk in males than in females (Koken et al., 2003; Granados-Canal et al., 2005).

The finding of stronger air pollution effects (SO₂) in manual workers may be explained by relatively higher exposure to outdoor air pollution compared to other groups. In this study, the manual workers were blue-collar workers and those who worked outdoors (e.g. farmers, gardeners, and construction labourers). Therefore, this group was more likely to be exposed to outdoor air pollution than other occupational groups, resulting in the stronger estimated effects among them. In addition, it might also be possible that the manual workers in this population represented the low SES groups, which were more susceptible to air pollution as suggested by previous studies (Jerrett et al., 2004; Ou et al., 2008; Wong et al., 2008).

4.3 Limitations

Health records in the present study were the records of both elective and emergency visits and it was unable to distinguish between the two. Furthermore, unlike mortality, morbidity outcomes may be influenced by several factors (such as perceived need of individuals as well as their health care seeking behaviours, and availability of health care services and transportations), which could influence a patient's decision in visiting a hospital. Therefore, any true effects of air pollution in the study may be distorted and/or attenuated by these factors.

Misclassification of outcomes was a second issue in this study because health data were derived from several health centres and hospitals. Thus, variability of disease diagnoses across data contributors may have some impact on the study results. However, due to the use of broad

categories of diseases and the reasonable assumption that their diagnostic practices would have not varied greatly overtime, there should not be an enormous impact of this misclassification on the study results.

Because of using exposure data from fixed monitoring stations, not personal measurements, measurement error of exposure is a third issue of concern in this study. It is well known that this error would cause a bias to the null (Armstrong 1998). Thus, this impact may lead to an underestimation of air pollution effects in the present study.

5. Conclusions

In conclusion, the study suggests that there was little evidence of air pollution effects on daily morbidity in Chiang Mai. Despite no statistically significant differences between subgroups studied, the elderly seemed to be more vulnerable to air pollution than others. Thus, preventive measures and public health interventions should have been introduced and targeted to this group of people.

6. Acknowledgements

I would like to express my gratitude to the collaboration from the Chiang Mai Provincial Health Office and the Pollution Control Department for data provision in the present study.

7. References

- Anderson, H.R., Atkinson, R.W., Bremner S.A., and Marston, L. 2003. "Particulate air pollution and hospital admissions for cardiorespiratory diseases: are the elderly at greater risk?" **European Respiratory Journal** 40(Supplement): 39s-46s.
- Anderson, H.R., Bremner, S.A., Atkinson, R.W., Harrison, R.M., and Walters S. 2001. "Particulate matter and daily mortality and hospital admissions in the west midlands conurbation of the United Kingdom: associations with fine and coarse particles, black smoke and sulphate." **Occupational and Environmental Medicine** 58(8): 504-510.
- Annesi-Maesano, I., Agabiti, N., Pistelli, R., Couilliot, M.-F., and Forastiere F. 2003. "Subpopulations at increased risk of adverse health outcomes from air pollution." **European Respiratory Journal** 21(Suppl. 40): 57s-63s.
- Armstrong, B.G. 1998. "Effect of measurement error on epidemiological studies of environmental and occupational exposures." **Occup Environ Med** 55(10): 651-656.
- Atkinson, R.W., Anderson, H.R., Sunyer, J., Ayres, J., Baccini, M., Vonk, J.M., Boumghar, A., and other. 2001. "Acute effects of particulate air pollution on respiratory admissions: results from APHEA 2 project. Air Pollution and Health: a European Approach." **American Journal of Respiratory and Critical Care Medicine** 164(10 Pt 1): 1860-1866.
- Atkinson, R.W., Bremner, S.A., Anderson, H.R., Strachan, D.P., Bland, J.M., and De Leon, A.P. 1999. "Short-term associations between emergency hospital admissions for respiratory and cardiovascular disease and outdoor air pollution in London." **Archives of Environmental Health** 54(6): 398-411.
- Barnett, A.G., Williams, G.M., Schwartz, J., Best, T.L., Neller, A.H., Petroeschovsky, A.L. 2006. "The effects of air pollution on hospitalizations for cardiovascular disease in elderly people in Australian and new zealand cities."

- Environmental Health Perspectives** 114(7): 1018-1023.
- Bateson, T.F. and Schwartz, J. 2004. "Who is sensitive to the effects of particulate air pollution on mortality? A case-crossover analysis of effect modifiers." **Epidemiology** 15(2): 143-149.
- Buadong, D., Jinsart, W., Funatagawa, I., Karita K., and Yano, E. 2009. "Association between PM10 and O3 levels and hospital visits for cardiovascular diseases in Bangkok, Thailand." **Journal of Epidemiology** 19(4): 182-188.
- Chiang Mai Provincial Operation Centre 2006. **General information of Chiang Mai Province**. Chiang Mai, Chiang Mai Provincial Operation Centre.
- Delfino, R.J., Murphy-Moulton, A.M., and Becklake, M.R. 1998. "Emergency room visits for respiratory illnesses among the elderly in Montreal: association with low level ozone exposure." **Environmental Research** 76(2): 67-77.
- Goldberg, M.S., Bailar, J.C.3rd, Burnett, R.T., Brook, J.R., Tamblyn, R., Bonvalot, Y. 2000. "Identifying subgroups of the general population that may be susceptible to short-term increases in particulate air pollution: a time-series study in Montreal, Quebec." **Research Report Health Effect Institute** (97): 7-113; discussion 115-120.
- Granados-Canal, D.J., Chardon, B., Lefranc, A., and Gremy, I. 2005. "Air pollution and respiratory hospital admissions in greater Paris: exploring sex differences." **Archives of Environmental and Occupational Health** 60(6): 307-313.
- Greenland, S. 1993. "Basic problems in interaction assessment." **Environmental Health Perspectives** 101 Suppl 4: 59-66.
- Haines, A., Kovats, R.S., Campbell-Lendrum, D., and Corvalan, C. 2006. "Climate change and human health: impacts, vulnerability and public health." **Public Health** 120(7): 585-596.
- Health Effects Institute. 2004. **Health Effects of Outdoor Air Pollution in Developing Countries of Asia: A Literature Review, Special report 15**. Boston.
- Health Effects Institute. 2008. **Public health and air pollution in Asia (PAPA): Key results from Bangkok, Hong Kong, Shanghai, and Wuhan. Communication 13**. Boston, MA.
- Hong, Y.C., Lee, J.T., Kim, H., Ha, E.H., Schwartz, J., and Christiani, D.C. 2002. "Effects of air pollutants on acute stroke mortality." **Environmental Health Perspectives** 110 (2): 187-191.
- Hwong, J. S. and C. C. Chan 2002. "Effects of air pollution on daily clinic visits for lower respiratory tract illness." **American Journal of Epidemiology** 155(1): 1-10.
- Jerrett, M., Burnett, R.T., Brook, J., Kanaroglou, P., Giovis, C., Finkelstein, N. 2004. "Do socioeconomic characteristics modify the short term association between air pollution and mortality? Evidence from a zonal time series in Hamilton, Canada." **Journal of Epidemiology and Community Health** 58(1): 31-40.
- Katsouyanni, K., Touloumi, G., Samoli, E., Gryparis, A., Le Tertre, A., Monopoli, Y. 2001. "Confounding and effect modification in the short-term effects of ambient particles on total mortality: results from 29 European cities within the APHEA2 project." **Epidemiology** 12(5): 521-531.
- Kelly, F.J., Dunster, C., and Mudway, I. 2003. "Air pollution and the elderly: oxidant/antioxidant issues

- worth consideration." **European Respiratory Journal** 40 (Suppl.): 70s-75s.
- Koken, P.J., Piver, W.T., Ye, F., Elixhauser, A.L., Olsen M., and Portier, C.J. 2003. "Temperature, air pollution, and hospitalization for cardiovascular diseases among elderly people in Denver." **Environ Health Perspect** 111(10): 1312-1317.
- Larrieu, S., Jusot, J.F., Blanchard, M., Prouvost, H.C., Declercq, P., Fabre, L. 2007. "Short term effects of air pollution on hospitalizations for cardiovascular diseases in eight French cities: the PSAS program." **Science of the Total Environment** 387(1-3): 105-112.
- Lee, J.T., Kim, H., Cho, Y.S. Hong, Y.C., Ha, E.H. and Park, H. 2003. "Air pollution and hospital admissions for ischemic heart diseases among individuals 64+ years of age residing in Seoul, Korea." **Archives of Environmental Health** 58(10): 617-623.
- Luginaah, I.N., Fung, K.Y., Gorey, K.M., Webster, G., and Wills, C. 2005. "Association of Ambient Air Pollution with Respiratory Hospitalization in a Government-Designated "Area of Concern": The Case of Windsor, Ontario." **Environ Health Perspect** 113(3): 290-296.
- McCullough, P. and Nelder, J.A. 1989. **Generalized Linear Models**. London, CHAPMAN & HALL/CRC.
- McMichael, A.J., Patz, J., and Kovats, R.S. 1998. "Impacts of global environmental change on future health and health care in tropical countries." **British Medical Bulletin** 54(2): 475-488.
- Medina-Ramon, M. and Schwartz, J. 2008. "Who is more vulnerable to die from ozone air pollution?" **Epidemiology** 19(5): 672-679.
- Morgan, G., Corbett, S., and Wlodarczyk, J. 1998. "Air pollution and hospital admissions in Sydney, Australia, 1990 to 1994." **Am J Public Health** 88(12): 1761-1766.
- Morgenstern, H. and Thomas, D. 1993. "Principles of study design in environmental epidemiology." **Environ Health Perspect** 101 Suppl 4: 23-38.
- O'Neill, M.S., Hajat, S., Zanobetti, A., Ramirez-Aguilar, M., and Schwartz, J. 2005. "Impact of control for air pollution and respiratory epidemics on the estimated associations of temperature and daily mortality." **Int J Biometeorol** 50(2): 121-129.
- Ou, C.Q., Hedley, A.J., Chung, R.Y., Thach, T.Q., Chau, Y.K., Chan, K.P. 2008. "Socioeconomic disparities in air pollution-associated mortality." **Environ Res** 107(2): 237-244.
- Patz, J.A., Campbell-Lendrum, D., Holloway, T., and Foley, J.A. 2005. "Impact of regional climate change on human health." **Nature** 438(7066): 310-317.
- Pope III, C.A. and Schwartz, J. 1996. "Time series for the analysis of pulmonary health data." **American Journal of Respiratory and Critical Care Medicine** 154(6 Pt 2): S229-233.
- Samet, J.M., Zeger, S.L. Dominici, F., Curriero, F., Coursac, I., Dockery, D.W., Schwartz, J. 2000. "The National Morbidity, Mortality, and Air Pollution Study. Part II: Morbidity and mortality from air pollution in the United States." **Res Rep Health Eff Inst** 94(Pt 2): 5-70; discussion 71-79.
- Schwartz, J. 1995. "Short term fluctuations in air pollution and hospital admissions of the elderly for respiratory disease." **Thorax** 50(5): 531-538.
- Schwartz, J. 2000. "Assessing confounding, effect modification, and thresholds in the association between ambient

- particles and daily deaths." **Environ Health Perspect** 108(6): 563-568.
- Simpson, R., Williams, G., Petroschevsky, A., Best, T., Morgan, G., Denison, L. 2005. "The short-term effects of air pollution on hospital admissions in four Australian cities." **Australian and New Zealand Journal of Public Health** 29(3): 213-221.
- Spix, C., Anderson, H.R., Schwartz, J., Vigotti, M.A., LeTertre, A., Vonk, J.M. 1998. "Short-term effects of air pollution on hospital admissions of respiratory diseases in Europe: a quantitative summary of APHEA study results. Air Pollution and Health: a European Approach." **Arch Environ Health** 53(1): 54-64.
- Sunyer, J., Atkinson, R., Ballester, F., Le Tertre, A., Ayres, J.G., Forastiere, F. 2003. "Respiratory effects of sulphur dioxide: a hierarchical multicity analysis in the APHEA 2 study." **Occup Environ Med** 60(8): e2.
- The Pollution Control Department. 2005. "Daily ambient air quality report." Retrieved February 21, 2005, from <http://www.pcd.go.th>.
- Ulirsch, G.V., Ball, L.M., Kaye, W.C., Shy, M., Lee, C.V., Crawford-Brown, D. 2007. "Effect of particulate matter air pollution on hospital admissions and medical visits for lung and heart disease in two southeast Idaho cities." **Journal of Exposure Science and Environmental Epidemiology** 17(5): 478-487.
- Wong, C. M., Ou, C.Q., Chan, K.P., Chau, Y.K., Thach, T.Q., Yang, L., Chung, R.Y. 2008. "The effects of air pollution on mortality in socially deprived urban areas in Hong Kong, China." **Environ Health Perspect** 116(9): 1189-1194.
- Wong, T.W., Lau, T.S., Yu, T.S., Neller, A., Wong, S.L., Tam, W. 1999. "Air pollution and hospital admissions for respiratory and cardiovascular diseases in Hong Kong." **Occup Environ Med** 56(10): 679-683.
- Xu, X., Dockery, D.W., Christiani, D.C., Li and Huang, B.H. 1995. "Association of air pollution with hospital outpatient visits in Beijing." **Arch Environ Health** 50(3): 214-220.
- Zeger, S.L., Irizarry, R., and Peng, R.D. 2006. "On time series analysis of public health and biomedical data." **Annual Review of Public Health** 27: 57-79.