Article

A Methodology of Health Effects Estimation from Air Pollution in Large Asian Cities

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Abstract: The increase of health effects caused by air pollution seems to be a growing concern in Asian cities with increasing motorization. This paper discusses methods of estimating the health effects of air pollution in large Asian cities. Due to the absence of statistical data in Asia, this paper carefully chooses the methodology using data of the Japanese compensation system. A basic idea of health effects will be captured from simple indicators, such as population and air quality, in a correlation model. This correlation model enables more estimation results of respiratory mortality caused by air pollution to be yielded than by using the relative model. The correlation model could be an alternative method to estimate mortality besides the relative risk model since the results of the correlation model are comparable with those of the relative model by city and by time series. The classification of respiratory diseases is not known from the statistical yearbooks in many countries. Estimation results could support policy decision-making with respect to public health in a cost-effective way.

1. Research Purpose

Mortality is probably the earliest health outcome to be investigated. In one of the first long-term exposure studies on air pollution—an analysis of large towns in England—researchers observed a strong correlation between smoke emissions and death caused by bronchitis [1,2]. This research is an attempt to use a very unique track record from the Pollution-related Health Damage Compensation and Prevention System (herein referred to as the compensation system) in Japan.

The issue of relative risk estimation is its procedure and the coefficients, due to a limited quantity of statistical data on deaths by cause at the city level in Asian countries. The research below shows how to estimate death caused by air pollution. The earliest cohort study focusing on air pollution, an epidemiology study covering 14–16 years, compared the risk of death in a previous cohort study of over 8000 adults in six cities in the US by using "relative risk models". Here is an example of relative risk. If people who smoke for a certain time are, on average, 15 times more likely to develop lung cancer than those who do not smoke. In this case, their relative risk is 15. After adjustment for smoking and other risk factors, the mortality rate in the most polluted city was higher than in the least polluted city [3]. The American Cancer Association (ACS) study in the US is the largest cohort study of long-term mortality caused by air pollution. The ACS study links data for approximately 500,000 adults with air pollution data. The results reveal that mortality of cardiopulmonary at 6%

increases with each 10 μg/m^3 elevation in fine particulate matter PM$_{2.5}$ [4]. Particulate matter (PM) represents a mixture of organic and inorganic substances. It covers a wide range of diameters. PM$_{2.5}$ is particulate matter with an aerodynamic diameter of <2.5 μm [5]. The Health Effect Institute (HEI) conducted a literature survey meta-analysis of short-term exposure. Epidemiologic research has provided estimates of the health effects from short-term exposure to air pollution in many Asian cities [6]. The World Health Organization (WHO) published estimated numbers of deaths caused by air pollution worldwide [7–9] based on the significant contributions from ACS study and Harvard six cities. Cohen et al. raised questions on the shape of the model and the applicability of the coefficients for other area [10]. Ostro describes a methodology how to apply for developing countries [9]. Vimercati et al. explained correlation between exposure of metals and biological monitoring data by controlling factors such as residential location, diet, lifestyle habits, etc., based on a questionnaire [11,12]. Nasari et al. examined shapes of estimation models between air pollution and mortality. They suggested a combined non-linear model by examining the results from US and Canada [13]. Anenberg et al. estimated PM$_{2.5}$ related health impact using a relative risk model. They concluded that adaptation of the stringent vehicle emission standard Euro 6 would eliminate real-world diesel related NOx emissions, avoiding PM$_{2.5}$ and ozone related premature deaths in 2040 [14].

This paper considers the methodology applied to health effect estimation caused by air pollution in large Asian cities using evidence of respiratory patients caused by air pollution from Japan. The estimated coefficient will be compared to the coefficient of the relative risk model in order to discuss the possibility of the application of the methodology in large Asian cities.

2. Relative Risk Model vs. Correlation Model

There are various causes of mortality due to respiratory disease. This section considers two models to determine the mortality rates of respiratory diseases caused by air pollution. Due to uncertainty in developing countries, alternative methods should be considered to yield mortality caused by air pollution in large cities.

Quantifying the magnitude of health effects from the compensation system in Japan, the mortality rate due to respiratory disease caused by air pollution is applied for two models: the relative risk model and the correlation model.

2.1. Relative Risk Model

According to the WHO, the relative risk is an indicator to show the strength of an association rather than risk difference because it indicates the relation to a magnitude of the baseline rates. The relative risk shows an assessment of the causal relationship. The concept of the relative risk represents a relative change in health effects between an affected group and a non-affected group. Equation (1) is a typical equation of the relative risk model [7–9]. Equation (1) means that relative risk can be specified as an exponential function by change of PM$_{2.5}$ *X* from PM$_{2.5}$ baseline *X$_0$* with a coefficient. Equation (2) is unfolded a log-linear function from Equation (1). A coefficient α of Equation (2) was obtained from Osaka data from 1974–1988 [15,16].

Equations (3) and (4), are processes to get the number of deaths caused by air pollution in large Asian cities. Equation (3) estimates an attributable fraction which qualifies the impact of exposure above a theoretical minimum level [10]. Equation (4) yields the number of deaths by respiratory disease caused by air pollution from the attributable fraction multiplied by the total number of mortality of respiratory disease.

$$RR = \exp[\alpha(X - X_0)] \tag{1}$$

$$LnRR = \alpha M \tag{2}$$

$$\frac{RR - 1}{RR} = AF \tag{3}$$

$$AF \times TR = E \qquad (4)$$

RR: Relative risk

α: Coefficient of respiratory disease mortality of Osaka, 1974–1988;

X: Current annual mean of $PM_{2.5}$ ($\mu g/m^3$) (converted from PM_{10});

X_0: Baseline of $PM_{2.5}$ = 10 (Converted from the PM_{10} standard);

M: A change of air quality from the baseline $M = X - X_0$;

TR: Total respiratory disease mortality numbers in a city (per 1000 population);

E: Respiratory disease mortality numbers caused by air pollution in a city (per 1000 population);

AF: Attributable fraction (the ratio of respiratory disease mortality caused by air pollution).

2.2. Correlation Model

This research proposes a simple linear regression model to estimate death caused by air pollution for the following three reasons. First, a reliable track record of the compensation system yields statistically significant results with a linear model in the case of Japan. Second, the procedure of estimation by the correlation model is simpler than that of the relative risk model. The relative model requires estimating the respiratory/cardiovascular disease group including causes of air pollution and others (tobaccos etc.) from the population. The number of deaths caused by air pollution is estimated directly from population and air quality in the correlation model. Third, the correlation model can estimate more results than the relative risk model. Air pollution data is more available than that of the number of deaths caused by disease, in general [17–19].

The other method for determining mortality rates is to perform an estimation from a linear model of derived respiratory mortality. Applying many trial estimations, we thought that a linear model fits with a single factor better than a non-linear model with multiple explanatory factors. The pre-results indicate the possibility of an integrated model of "one fit for all". The number of deceased patients is divided by the number of the population. The correlation between the change in $PM_{2.5}$ from the baseline and the mortality per 1000 people is estimated. Equation (5) shows the direct correlation between the $PM_{2.5}$ baseline X_0 and the mortality of the same baseline, as in Equation (1) [17–19].

The coefficient of Equation (5) can be compared with that of Equation (2) from in Section 4 "Results". Applying for dataset of Table 1 and the coefficients of Table 2, the number of deaths from the correlation model was compared to the number of deaths from the relative risk model in Figures 1–3.

$$Y = \beta M \qquad (5)$$

Y: The number of deaths in the compensation system per 1000 population;

β: The coefficient of respiratory disease mortality.

3. Methodology of Data Verification

3.1. Health Effect Data—TR, E

This section describes data treatment on respiratory disease mortality. Respiratory disease mortality numbers caused by air pollution in a city (*E*, in Equation (4)) data was extracted from the compensation system. The data of the health effects caused by air pollution was available from the Pollution-related Health Damage Compensation Law (herein referred to as the compensation law). The compensation law was enacted in 1973 to provide prompt and fair compensation for victims. The law determined designated areas where health damage has occurred by air pollution. It certifies patients who were affected by the four pollution-related respiratory and circulatory diseases (pulmonary emphysema, asthmatic bronchitis, bronchial asthma, and chronic bronchitis). If patients with these four diseases in the certified areas satisfied certain other conditions (such as extended residence in the certified area, non-smoker status, or illness established by a medical doctor), they were considered as certified patients.

Welfare services were provided to facilitate the recovery by the compensation system from June 1974 in accordance with the compensation law. Local governments of the designated area published the total number of certified patients, mortality, recovered and newly-registered in an environmental white paper every year. We confirmed that the data of the compensation system is consistent by simple calculations.

Quantifying the magnitude of the impact of air pollution, Osaka data was selected for comparison because the whole of Osaka city was covered as a designated area while other certified areas did not cover the whole administrative district. The coefficients of Osaka city were applied for estimation of deaths caused by air pollution in large Asian cities. Since the amendment of the compensation system came into effect in 1988, the portion for the time span from 1974 to 1988 should be valid for the relative risk analysis because the system did not accept new registrations after 1988.

Mortality rates due to respiratory diseases between vital statistics of Japan and the compensation system were compared in order to determine the portion of deaths caused by air pollution because WHO and the vital statistics data above include not only disease caused by air pollution but also disease from other causes, such as tobacco. Below are common methods of how to treat data appropriately in the models.

Respiratory disease mortality numbers (*TR* in Equation (4)) data was extracted from the vital statistics of Japan at the city level. The total number of respiratory diseases included bronchitis, chronic obstructive pulmonary disease (COPD), pulmonary emphysema, and asthma, except for acute bronchitis in the vital statistics. They were comparable to the number of mortality cases in the compensation system. The total number of deaths due to respiratory disease in the vital statistics was lower than the number of deaths recorded in the compensation system. Some of the certified patients may pass away due to causes other than the certified respiratory diseases (bronchitis, COPD, pulmonary emphysema, and asthma).

First, we verified if categories are identical throughout the WHO [20] and vital statistics in Japan [21,22]. The data on Japan's vital statistics is categorized and reported to the WHO statistics according to ICD-10. The WHO follows the definition of the International Statistical Classification of Diseases (ICD). In 1995, ICD was updated from ICD-9 to ICD-10 in Japan. Along with the change, the rule concerning the death certificate for deceased persons was revised. Before 1995, "heart failure" was one of the main causes of death. Since 1995, a description of the direct cause of heart failure is required on the death certificate. COPD mortality rises from 1665 in ICD-9 to 1669 in ICD-10. The change of ICD affects the increase of COPD by 1.9% with respect to 2006 data. Regarding data of respiratory diseases in Asia, most of the countries follow ICD-10 at present. The implementation year of ICD-10 varies from 1995 to 2012. ICD categories of respiratory disease are J00–J99.

3.2. Air Pollutant X and X_0

Historically speaking, the relationship between NO_2 and health effects has been a representative indicator for the evaluation of health effects in Japan. However, Particulate matter (PM) values were applied for Equations (2) and (5) because many of the most recent studies on health effects caused by air pollution are with regard to PM. For air quality data, the annual averages were collected from white papers of Osaka city to estimate the coefficients from Equations (2) and (5). However, Suspended Particulate Matter (SPM) is widely monitored in Japan. The definition of SPM is considered particulates with aerodynamic ranging from below 0.01 μm to 100 μm in Europe and US. On the other hand, the definition of SPM is approximately PM_7 in Japan. According to reports of Ministry of Environment of Japan, SPM was converted into PM_{10} (particulate matter with an aerodynamic diameter of <10 μm) by multiplying 1.07 from a Japanese monitoring result in 1999. According to National Institute of Environmental Studies, the conversion factor was updated as 1.16 in 2012. We employed the conversion equation $PM_{10} = SPM \times 1.07$ for the monitoring data of 1974–1988 [23].

According to a survey by Ostro [9], RR is estimated from $PM_{2.5}$ rather than PM_{10}. The value of PM_{10} can be converted to $PM_{2.5}$ from available information. For many urban areas in developed countries, the $PM_{2.5}$ level is 0.50–0.65 of the PM_{10} level. Evidence from China shows that levels of 0.51–0.72 [24] and 0.5 [9] can be assumed. For the estimation of Equation (2), this analysis assumes that $PM_{2.5}$ is 0.5 of PM_{10}.

The existing level of $PM_{2.5}$ without man-made PM_{10} is assumed as 5–10 μg/m^3 according to Ostro [9]. Theoretically, the baseline level means the minimum level of exposure. Some studies treat the baseline level as the threshold. A maximum value 10 μg/m^3 for our estimation of mortality rates caused by air pollution in Bangkok was applied in our model.

The WHO refers to a target of avoidable death proposed by the European Unit Target Limit Value for 2010 of 20 μg/m^3 PM_{10} (0.5 × 20 μg/m^3 PM_{10} = 10 μg/m^3). The baseline level X_0 is assumed to be 10 μg/m^3 for the estimation of Equations (2) and (5).

3.3. The Number of Results Expected from the Two Models

A total of 31 cities were selected as the analysis area (Table 1). These comprise mostly capital cities or cities where the dataset was available. The necessary data items for calculation are as follows: population, air quality $PM_{2.5}$ (*X*; data converted from PM_{10}/SPM) and cause of death for respiratory disease (*TR*; data from death statistics) [25–71]. The dataset was rated by three categories: three data items available (population/air quality/cause of death, at least 10 years), two data items available, and only one item of data availability. Bangkok, Beijing, Colombo, Hong Kong, Shanghai, and Singapore enabled a comparison of the results of the two models because of the availability of the three data items in the time series more than 10 years. A column "km^2/monitoring site" means areas covered by one monitoring site of air quality in order to assess representativeness of air quality data. Areas covered per monitoring site of air quality in Bangkok, Beijing, Hong Kong, Shanghai and Singapore are 143, 73, 100, 81 and 140 km^2. Information of monitoring site in Colombo could not be found from related documents.

Table 1. City data availability and the surface area per monitoring site [25–71].

No.	Rate	City	Urban Population	TSP/PM2.5/PM10	Cause of Death for Respiratory Disease (J00–J99)	km^2/ Monitoring Site
1	△	Bangalore	1990, 1995, 1996, 2000, 2001, 2005	1995, 1999–2007, 2012, 2013	NA	89
2	○	Bangkok	1990, 1995–2014	1990, 1995–2013	1995, 1996, 2000, 2011, 2013	143
3	○	Beijing	1990, 1995–2014	1990, 1995, 1999–2014	1995–2014	73
4	△	Chongqing	1995–2014	1997–2014	NA	37
5	○	Colombo	1995–2014	1998–2012	1995, 2003–2006, 2009	NA
6	△	Dalian	1995, 1998, 2000–2014	2003–2008, 2012	NA	26
7	△	Delhi	1990, 1995–2005	1990, 1995–2007	NA	66
8	×	Dhaka	1995, 1997–2005	1997–2007	NA	581
9	△	Guangzhou	1995–2014	1995, 1998–2014	NA	81
10	△	Hanoi	1995, 1999–2014	1996, 1998–2003	NA	117
11	△	Ho Chi Minh City	1995, 1998–2008, 2010–2012	1995–2007	NA	210
12	○	Hong Kong	1995–2014	1995–2014	1995–2014	100

Table 1. *Cont.*

No.	Rate	City	Urban Population	TSP/PM2.5/PM10	Cause of Death for Respiratory Disease (J00–J99)	km^2/ Monitoring Site
13	△	Jakarta	1995, 1998–2006, 2010, 2013–2014	1990, 1995, 1999–2003, 2007, 2009	NA	111
14	×	Karachi	1990, 1998	1990, 2000, 2001, 2003	NA	14,091
15	×	Kathmandu	1995, 2000, 2001, 2005	2003–2007	NA	25
16	△	Kuala Lumpur	1995, 1996, 1998–2012	1995–2007, 2010, 2012, 2013	NA	77
17	△	Manila	2000, 2005–2007	1990, 1995–2007	1996–1999	53
18	△	Mumbai	1990, 1995, 2000, 2001, 2005	1995–2007	NA	NA
19	×	Okinawa Naha-City	NA	NA	NA	40
20	△	Phnom Penh	1995, 1998–2006, 2008, 2013	1995, 2001, 2002	NA	21
21	△	Qingdao	1996–2012	NA	NA	45
22	△	Seoul	1995, 2000, 2005, 2007	1990, 1995–2005, 2007	NA	30
23	○	Shanghai	1990, 1995–2014	1990, 1995–2014	1990, 1995–2008, 2010–2014	81
24	△	Shenyang	1995, 1998, 2000–2007, 2010–2012	2003–2007	1998	22
25	△	Shenzen	1995–2014	1996–2014	1996–1998	NA
26	○	Singapore	1990, 1995–2014	1990, 1995–2014	1995–2014	140
27	×	Taipei	1995, 2000, 2002–2005, 2007	1995–2008	NA	NA
28	×	Ulaanbaater	1995, 2000–2006	2008	NA	588
29	×	Vientiane	1995, 1998, 2000–2006, 2014, 2015	2002–2004, 2007, 2008	NA	NA
30	△	Yangon	1995, 1998, 2000–2010, 2014	2007	1990, 1995, 1998–2007, 2010–2013	518
31	×	Yokohama	1995–1999	NA	NA	16

○: three items of data available (population/air quality/cause of death by respiratory diseases) at least 10 years; △: two data items available out of the three items; *X*: only one item of data available; NA: no answer.

4. Results

4.1. Overall Comparison

Table 2 represents the estimation results of the coefficient for Equation (2) of the relative model and (5) of the correlation model. The models yielded statistically significant results. In Table 1, coefficient of α is estimated from the data for Osaka from 1974 to 1988 in Equation (2). The coefficient α is estimated as 0.0291 for four pollution-related respiratory and circulatory diseases from long-term exposure of PM$_{2.5}$. T value is 16.30. For reference, this is 3.25 times larger than the result of Pope et al. (0.0089) for cardiopulmonary mortality from long-term PM$_{2.5}$ exposure [9]. The difference of estimation results may indicate different definitions of respiratory disease (WHO: J30–J99 [20], Japan: only four diseases,

J40–J47) and other factors. β is estimated from the data for Osaka from 1974 to 1988 in Equation (5). The coefficient of correlation model is 0.0062. T value is 4.31. These coefficients are applied for the estimation of mortality caused by air pollution in large Asian cities.

Table 2. Results of coefficient estimation.

Items of Results	Equation (2) α	Equation (5) β
Coefficient	0.0291 (16.30)	0.0062 (4.31)
Adjusted R2	0.856	0.499
The number of observations	10	15

( ): *t* value.

Figure 1 shows the result comparison from the relative risk model and the correlation model. A clustering around a line drawn line at a 45 degree angle indicates that the results of the correlation model are close to the results of the relative risk model. The results of Beijing, Bangkok, Colombo, Hong Kong, Shanghai, and Singapore from the two models were available. The values of Beijing seemed to be outliers. The values of Shanghai were relatively higher than the others in Figure 1. Figure 2 shows the results of Colombo, Hong Kong, Singapore, and Bangkok.
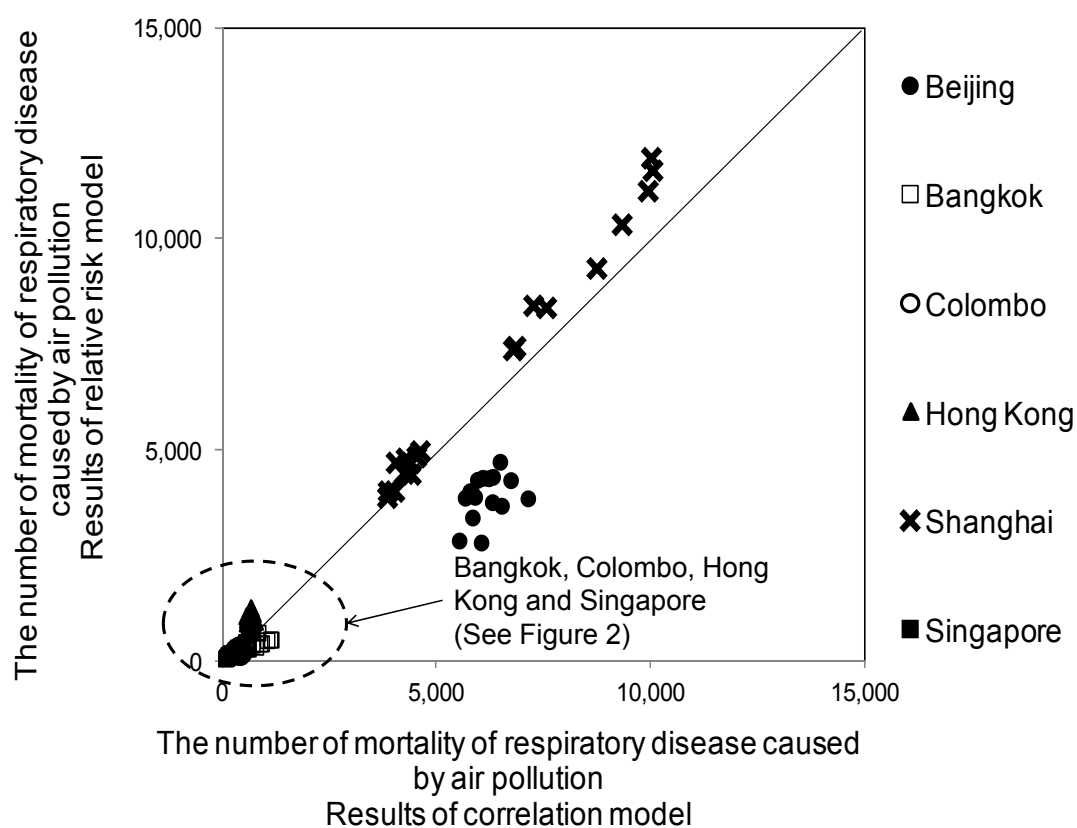

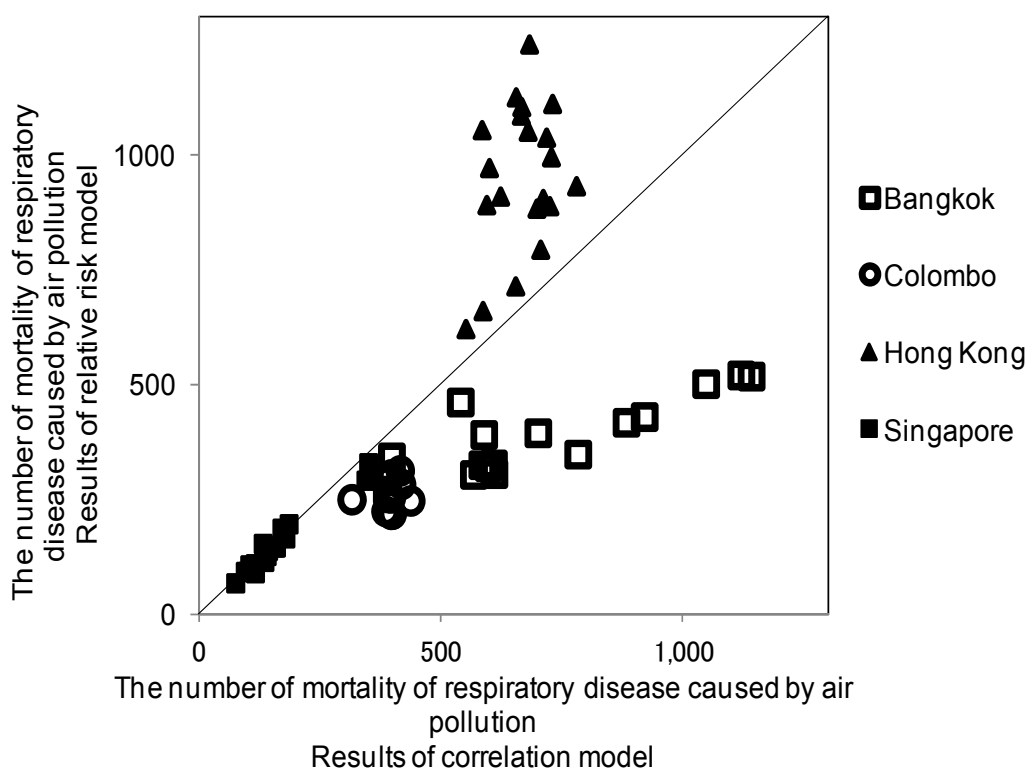**Figure 1.** Overall comparison of the results from the two models.

Figure 2. Overall comparison of the results from the two models (Bangkok, Colombo, Hong Kong, and Singapore).

4.2. Comparison by City and by Time Series

Figure 3 shows the results by city and by time series. The correlation model estimated 323 values while the relative model yielded 154 values. The number of outcomes from the correlation model is double from that of the relative risk model. One hundred fifty four values out of 323 were compared in Figure 3. The total number of deaths estimated from the correlation model for 10 cities was 22,713; this amounts to 18 deaths per 100,000 people in 2012.

The correlation model results of Bangkok, Beijing, and Colombo were overestimated by the relative risk model. The results of the correlation model in Hong Kong were underestimated by the relative risk. The results of the correlation model in Shanghai and Singapore are estimated as those of the relative model. The differences of the results between these two models might be affected from uncertain factors such as socio-economic factors. Accessibility of hospitals, availability to medicine, health insurance systems, etc., may affect the behavior of how to recover from the diseases. In the long-term, the number of potential patients may influence the data of vital statistics. The number of deaths from traffic accidents can be compared with the deaths caused by air pollution for reference.

The number of deaths caused by air pollution seems to exceed that of traffic accident in Bangkok, Beijing, Hong Kong and Shanghai. The number of deaths caused by air pollution seems to as same as that of traffic accident in Singapore. The number of deaths by traffic accidents seems to exceed that of air pollution in Colombo.
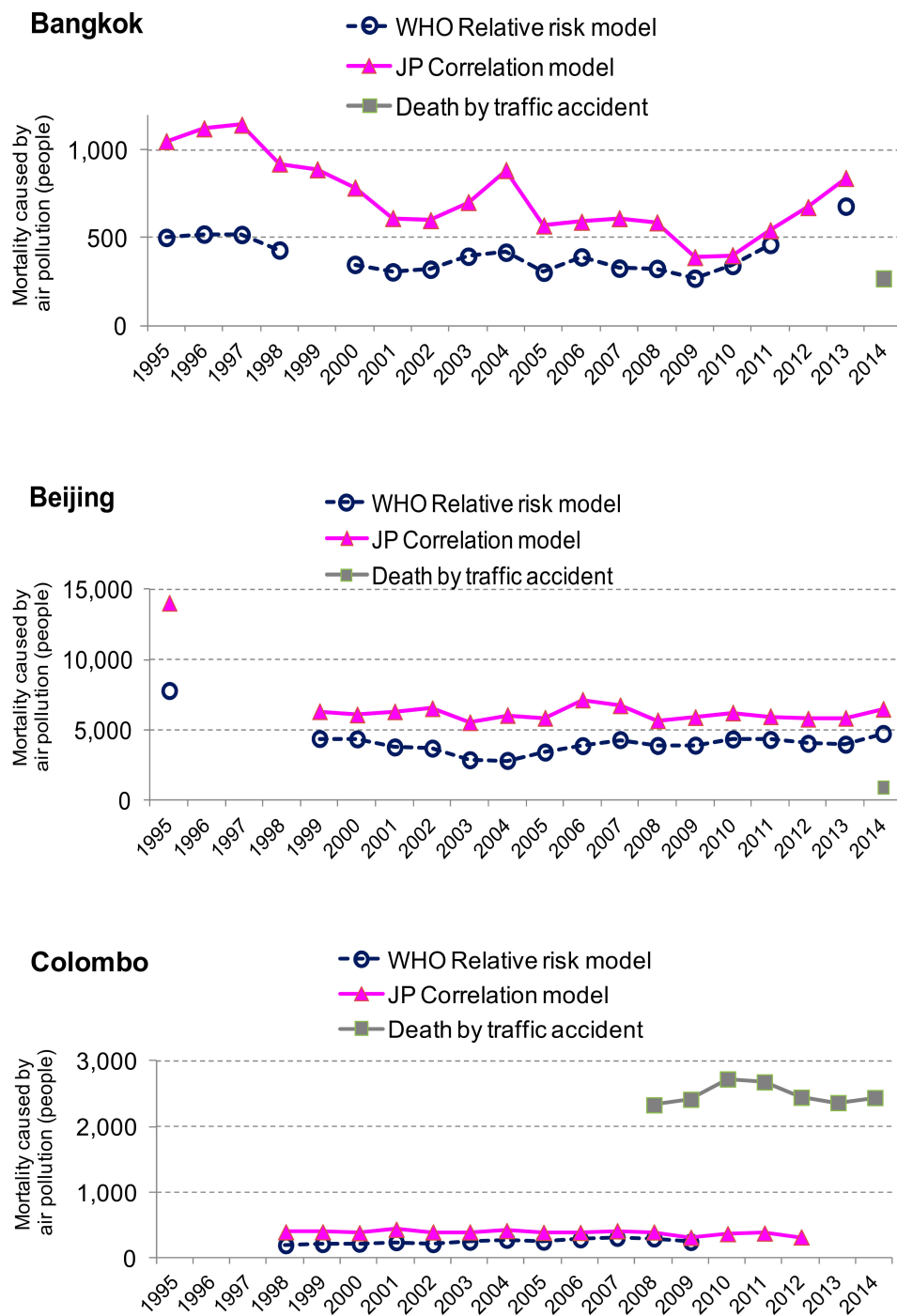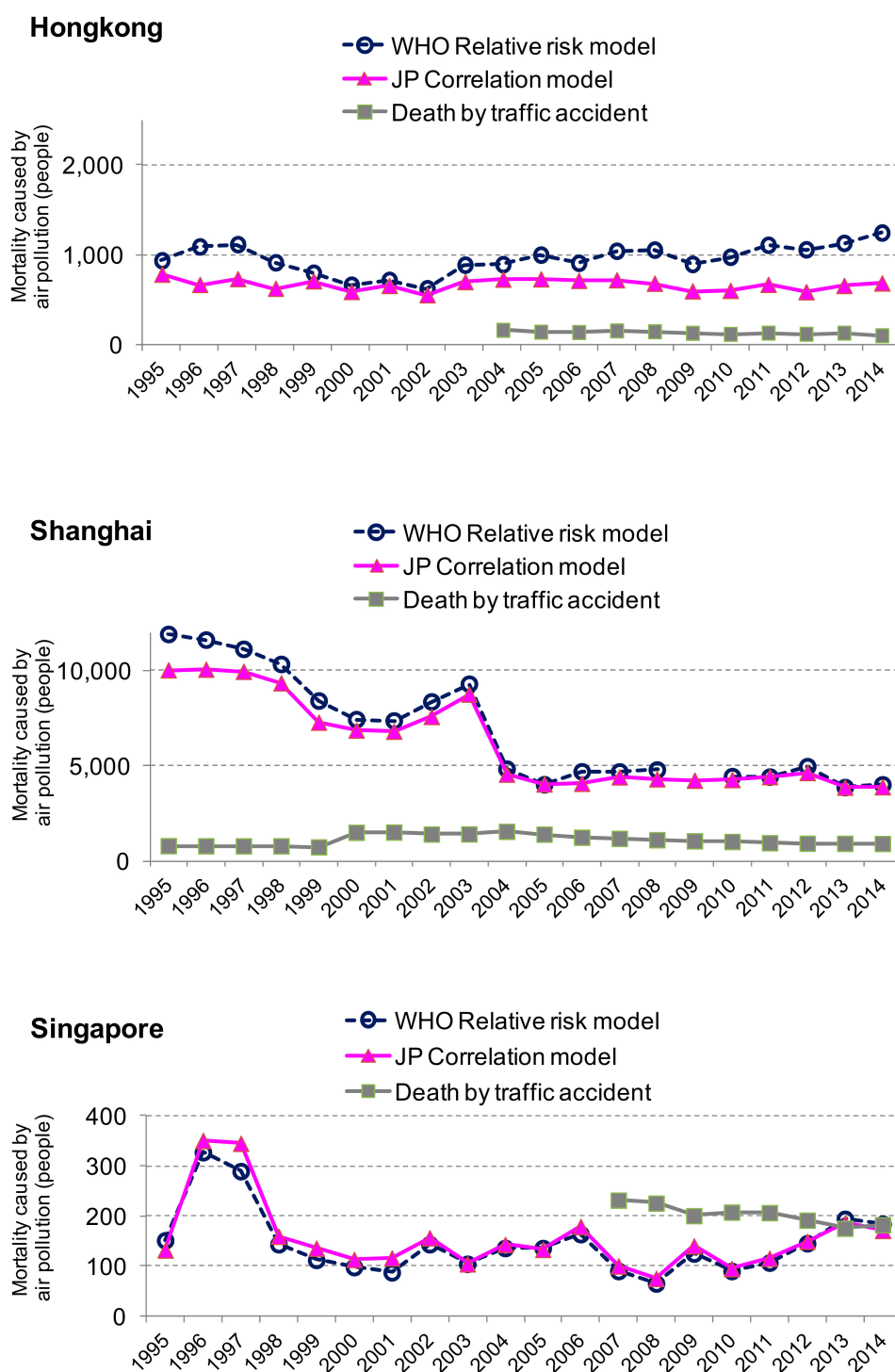
Figure 3. *Cont.*

Figure 3. Comparison by city and by time series.

5. Conclusions and Further Improvements

A basic idea of health effects was captured from simple indicators, such as population and air quality in the correlation model based on the track record of the Japanese compensation system. Based on empirical findings from data in Osaka, mortality due to respiratory diseases are calculated for large Asian cities. It discusses the validity of the correlation model measurements by comparing with the relative risk model.

The correlation model doubled estimated results of respiratory mortality caused by air pollution more than by using the relative model because of data availability. There are some improvements for data reliability (air quality, population, definition of mortality caused by respiratory disease etc.), but the correlation model could be one of the alternative methods to estimate mortality besides the relative risk model.

The results are comparable to those of the relative risk model as long as the data quality is reliable. Political implications could prepare public health policy in advance, which will be cost effective. Governments could implement preventive measures against air pollution in developing countries, referring the level of deaths caused by traffic accidents.

Several improvement points are observed for the next step of the correlation model.

- This "one fit for all" model should be adjusted by local conditions. Mortality rates will be influenced by the availability of medical treatments/medical care systems in Asia. The correlation model should include indicators of these medical facilities.
- The application of the Japanese coefficients for Asia could be improved. The coefficient β should be estimated from all of Japan to increase accuracy. The definition of respiratory disease mortality in statistical yearbooks from each country should be verified.
- Due to uncertainty, factors which affect the results should be identified as a next step.

Abbreviations

The following abbreviations are used in this manuscript:

Compensation system	Pollution-related Health Damage Compensation and Prevention System
COPD	Chronic obstructive pulmonary disease
GBD	Global Burden of Disease
ICD	International statistical Classification of Disease
NO_2	Nitrogen Dioxide
PM	Particulate Matter According to the US EPA, particulate matter includes PM_{10} and $PM_{2.5}$
SO_2	Sulphur dioxide
SPM	Suspended Particulate Matter
TSP	Total Suspended Matter
USEPA	Environmental Protection Agency in the USA
WHO	World Health Organization

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