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Article

Association of Human Mortality with Air Pollution of Hong Kong

Ka-In Hoi, Ding-Bian Zhang, Kai-Meng Mok and Ka-Veng Yuen *

Department of Civil and Environmental Engineering, University of Macau, Av. Padre Tomás Pereira Taipa, Macau SAR 999078, China; E-Mails: kihoi@umac.mo (K.-I.H.); u5419940@anu.edu.au (D.-B.Z.); KMMOK@umac.mo (K.-M.M.)

* Author to whom correspondence should be addressed; E-Mail: kvyuen@umac.mo; Tel.: +853-8397-4960; Fax: +853-2883-8314.

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Abstract: In this study, we attempted to investigate the general statistical association of air pollution with the cardiovascular and respiratory mortality of the elderly in Hong Kong. Based on six years of measurements including the major air pollutant concentrations (PM_{10}, SO_2, NO, NO_2, O_3, CO), ambient temperature, and mortality (respiratory, cardiovascular) between 2005 and 2010, correlation analysis was carried out in annual, monthly and weekly time scales. From an annual perspective, it was found that the air pollution species may pose a constant effect on the respiratory and the cardiovascular mortality during the studied period since the elderly mortality rates and the air pollution annual concentrations show obvious constant trends. From a monthly time scale, it was found that NO_2 and CO have high positive cross correlation with the respiratory mortality of the following 1 to 2 months. In addition, PM_{10} and CO also have similar delayed influence on the cardiovascular mortality. Among these four pollutants, only CO was found to exhibit high statistical association in the weekly time scale and it is most related to the cardiovascular mortality of the week after next. Therefore, it was concluded that the effect of air pollution on the elderly mortality of Hong Kong should be cumulative. This study implies that the establishment of weekly or monthly air quality indices is necessary for health implications.

Keywords: air pollution; cardiovascular mortality; Hong Kong; respiratory mortality

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1. Introduction

Hong Kong, a well-known mega-city worldwide, has experienced alarming air pollution since the last two decades. This situation is threatening due to its well-known association with the human mortality, especially for the elderly [1–5]. In view of this, many studies were carried out to model their relationship in Hong Kong so that more accurate limit values of air quality standards or indices could be established to protect this fragile group [6–9]. However, these studies mainly focused on investigating the short-term effects of air pollution on the daily mortality. In fact, previous study showed that the smoothed daily averaged pollutant concentration of Hong Kong has weak correlation with the instantaneous daily mortality but achieve a better relation with the time lag ranging from 19 to 93 days for different pollutants [10]. Therefore, it is believed that more chronic air pollution exposure may also accelerate the human mortality due to its accumulation in human bodies. Therefore, the present study attempted to address this issue by investigating the general statistical correlations of the main air pollution species of Hong Kong with the elderly mortality rates of different (annual, monthly and weekly) time scales. In the following section, the air pollution and mortality data used in this study are briefly introduced.

2. Data

2.1. Air Pollution and Meteorological Data

To provide public information of the current and historical air quality conditions, the Hong Kong Environmental Protection Department (HKEPD) established an automatic air quality monitoring network that acquires continuous measurements of hourly PM_{10}, SO_2, NO, NO_2, CO and O_3 concentrations since 1999. There are 11 general monitoring stations and 3 roadside stations distributed in the main districts of Hong Kong. The spatial distribution of these stations can be found in [11]. In the present study, hourly concentrations of these air quality species measured at all monitoring stations between 2005 and 2010 were adopted from the database of HKEPD. Data prior to 2005 were not used in order to avoid the effect of large-scale epidemics (e.g., SARS) in the mortality data. As mentioned above, the present study aims to quantify the overall correlation of air pollution and mortality in different time scales. Therefore, the spatial averaged concentration was obtained from all hourly station measurements as the measure of the overall air pollution situation. Meanwhile, the weekly, monthly, and annual averages of the spatial averaged concentration history were chosen as the characteristic indicators to reflect different extents of chronic pollution exposure.

Apart from the air pollutant concentrations, the local meteorological conditions, especially the ambient air temperature, has been demonstrated to link with the human mortality of Hong Kong [12]. Therefore, this major cofounding variable of human mortality was also included in the analysis. The daily time history of the spatial averaged air temperature (2005–2010) of Hong Kong meteorological monitoring network was obtained as the raw data from the database of the Hong Kong Observatory. In addition, weekly, monthly, and annual averages of the spatial averaged temperature were computed and chosen as the characteristic meteorological indicators of elderly mortality.

2.2. Mortality Data

The daily counts of non-accidental mortality of elderly (age > 65) between 2005 and 2010 were obtained from the Census and Statistics Department of Hong Kong (HKCSD). Within this non-accidental mortality group, two subsets (Respiratory and Cardiovascular mortality) that are particularly linked with air pollution were extracted for analysis. The cause of mortality here is classified according to the 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10). Apart from the cause of mortality, these data are also classified geographically according to the place of residence, which is represented by the Tertiary Planning Unit (TPU). The whole territory of Hong Kong is divided into 289 TPUs by the Planning Department of Hong Kong and the corresponding locations can be referred to [13]. From these raw data, the mortality rates of the studied groups were estimated to account for the gradual expansion of population size in Hong Kong. Based on these settings, the correlation analysis of the major air pollution indicators, the cofounding ambient temperature and the elderly mortality rates in Hong Kong is presented below.

3. Analysis and Discussion

3.1. Annual Time Scale

Table 1 shows the annual information of the elderly cardiovascular (CVD) mortality rate, the respiratory (RES) mortality rate, the mass concentrations of the major pollutants, namely the sulfur dioxide (SO_2), the respirable particulates (PM_{10}), the nitrogen dioxide (NO_2), the nitrogen oxide (NO), the ground-level ozone (O_3) and the temperature (T) between 2005 and 2010. In addition, the coefficient of variation (σ/μ) is calculated to indicate the inter-annual variability of each variable within the study period. In this table, it is noted that the CVD and RES mortality rates possess a virtually constant trend. This is reflected by both small σ/μ ratios; implying that their influencing environmental factors may also exhibit similar trends during this period. Examining the σ/μ ratios of the air pollution variables and the ambient temperature, it was found that those ratios, which are mostly less than 10% except for SO_2, also indicate minor long-term variation throughout this period. This is consistent with the previous implication. Therefore, both of the air pollution parameters and the ambient temperature may pose a constant annual effect on the elderly CVD and RES mortality rates of Hong Kong.

Table 1. Annual statistics of elderly mortality, major pollutant concentration and temperature of Hong Kong.

	CVD	RES	SO_2 (μg/m^3)	PM_{10} (μg/m^3)	NO_2 (μg/m^3)	NO (μg/m^3)	O_3 (μg/m^3)	CO (mg/m^3)	T (°C)
2005	0.0105	0.0079	21.7	59.1	60.8	163.7	91.6	0.53	23.3
2006	0.0097	0.0072	21.8	58.6	62.2	166.3	85.8	0.54	23.5
2007	0.0100	0.0079	21.3	59.3	62.3	159.0	92.4	0.57	23.7
2008	0.0102	0.0077	20.9	54.9	62.6	157.5	87.1	0.59	23.1
2009	0.0097	0.0081	14.0	49.7	62.6	144.4	75.4	0.64	23.6
2010	0.0095	0.0085	11.6	48.5	65.9	150.9	85.2	0.59	23.3
σ/μ (%)	3.73	5.63	24.54	8.86	2.70	5.21	7.08	6.75	0.93

3.2. Monthly Time Scale

Table 2 shows the Pearson cross-correlation of the monthly mortality, the major pollutant concentrations and the temperature between 2005 and 2010. Each cell of the table consists of the cross-correlation (value outside the parenthesis) between the variable $X_{i,t}$ from the *i*th row in the *t*th month and the other variable $X_{j,t+\tau}$ from the *j*th column in the (t + τ)th month, where i,j = 1,…,9 and τ is the time difference in months between two observed variables. The adjacent parenthesis contains the time difference of the observed variable pair which shows the highest absolute correlation among all possible integers in $\tau \in [-6,6]$. In this table, the possible range of cross-correlation for any two variables is between −1 to 1. Therefore, the variable pair is said to be highly/weakly correlated here with the threshold of the absolute cross-correlation being 0.5. Based on this criterion, the most plausible parameter linking with CVD or RES mortality (highlighted values in bold) is identified for each time difference among the highly correlated variable pairs.

Within the highlighted variable pairs, it is first noted that the CVD mortality rate is positively correlated with the RES mortality rate. These two variables have a very high cross correlation of 0.83 with zero lag; meaning that both should vary at the same pace. In addition, both variables are negatively correlated with temperature with zero time lag. Therefore, it is expected that both types of mortality should possess similar seasonal cycle with high mortality rates observed during winter and low mortality rates occurring in summer. Apart from this apparent relationship with the ambient temperature, it was found that both types of mortality are associated statistically with certain air pollutants. For the monthly CVD mortality, it is related to NO (Cross-correlation: 0.73, τ = 0), CO (Cross-correlation: 0.73, τ = −1), PM_{10} (Cross-correlation: 0.63, τ = −2), and O_3 (Cross-correlation: 0.54, τ = −3). It is noted that all values of τ are non-positive, meaning that the change of CVD mortality was generally preceded by changes in the pollutant concentrations. Although this cannot give direct implication of causality, it is suspected that high dosage of those air pollution species in a given month may accumulate in this fragile group. Meanwhile, this cummulative exposure may weaken their health status and lead to the association of higher monthly CVD mortality rates a few months later. However, it is noticed that the ambient temperature T is also highly correlated with NO (Cross-correlation: −0.74, τ = 0) and O_3 (Cross-correlation: −0.49, τ = 3). More importantly, the identified time lags are the same as those for the variable pairs of (CVD and NO) as well as (CVD and O_3). This implies the correlation of CVD mortality with these two pollution species may be due to the cofounding effect of temperature. As for the RES mortality, it has relatively stronger correlation with NO_2 (Cross-correlation: 0.56, τ = −2) and CO (Cross-correlation: 0.59, τ = −1). Although the ambient temperature T is also highly correlated with NO_2 (Cross-correlation: −0.75, τ = 1), the identified time difference is different from that of the variable pair (RES and NO_2). Therefore, this further confirmed the influence of NO_2 on the RES mortality.

3.3. Weekly Time Scale

Based on the monthly correlation analysis in Table 2, it was found that some of the air pollution species (CO, PM_{10}, NO_2) have high statisical associations with RES and CVD elderly mortality rates. Now the next interesting part is to examine if these identified species have more short-term interaction with the elderly mortality. Table 3 shows similar cross-correlation of the weekly mortality, the ambient temperature and the concentrations of CO, PM_{10} and NO_2. Again, both mortality rates vary almost at the same pace and are negatively correlated with temperature. As for the air pollution species, only CO was still found to have cumulative effect on the CVD weekly mortality (Cross-correlation: 0.62, $\tau = -2$) and this relationship was further confirmed by the different time difference corresponding to the variable pair of the CVD mortality and the ambient temperature (Cross-correlation: −0.83, $\tau = -1$). On the contrary, weak cross-correlation of other species with the CVD or RES mortality implied those pollutants need more chronic exposure to trigger the adverse health effects of the elderly.

Table 2. Cross-correlation of monthly mortality, major pollutant concentrations and temperature with the associated time lag (in months) shown in parenthesis.

	CVD	**RES**	**SO_2 (μg/m^3)**	**PM_{10} (μg/m^3)**	**NO_2 (μg/m^3)**	**NO (μg/m^3)**	**O_3 (μg/m^3)**	**CO (mg/m^3)**	***T* (°C)**
CVD	1(0)	0.83(0)	0.23(0)	**0.63(−2)**	0.55(0)	**0.73(0)**	**0.54(−3)**	**0.73(−1)**	**−0.86(0)**
RES		1(0)	−0.11(0)	0.49(−2)	**0.56(−2)**	0.5(−1)	0.48(−3)	**0.59(−1)**	**−0.71(0)**
SO_2			1(0)	0.32(0)	−0.17(6)	0.48(0)	−0.23(−6)	0.26(−6)	−0.09(4)
PM_{10}				1(0)	0.87(0)	0.56(2)	0.63(0)	0.77(0)	−0.73(1)
NO_2					1(0)	0.6(0)	0.62(0)	0.77(0)	−0.75(1)
NO						1(0)	0.46(−3)	0.76(0)	−0.74(0)
O_3							1(0)	−0.47(−5)	−0.49(3)
CO								1(0)	−0.83(0)
T									1(0)

Table 3. Cross-correlation of weekly mortality, major pollutant concentrations and temperature with the associated time lag (in weeks) shown in parenthesis.

	CVD	**RES**	**CO (mg/m^3)**	**PM_{10} (μg/m^3)**	**NO_2 (μg/m^3)**	***T* (°C)**
CVD	1(0)	**0.74(1)**	**0.62(−2)**	0.39(0)	0.50(0)	**−0.83(−1)**
RES		1(0)	0.47(−4)	0.21(−4)	0.37(−4)	**−0.67(−1)**
CO			1(0)	0.64(0)	0.67(0)	−0.74(0)
PM_{10}				1(0)	0.80(0)	−0.55(4)
NO_2					1(0)	−0.6(−1)
T						1(0)

4. Conclusions

In this study, the association of CVD and RES mortality of Hong Kong with other environmental factors including the major air pollutants of Hong Kong and the ambient temperature was investigated for different (annual, monthly, and weekly) time scales. Between 2005 and 2011, it was found that there was a virtually constant trend in the annual mortality rate of Hong Kong and the other environmental factors. Since the studied time span is short for an annual perspective, it can only be concluded that those environmental factors might have imposed some constant effect on the elderly mortality. As for the monthly time scale, it was found that both mortality rates exhibit apparent seasonal behavior indicated by the obvious negative correlation with the ambient temperature. On the other hand, it was found that the CVD mortality is highly correlated with CO and PM_{10} and the RES mortality is highly correlated with CO and NO_2. More importantly, the concentrations of those pollutants in the previous 1–3 months were found to have the highest absolute cross-correlation with the CVD/RES mortality rate. Therefore, it was suspected that high dosage of those identified pollutants in a given month may accumulate in the elderly and deteriorate substantially their health conditions. This leads to the increased mortality rates a few months later. For weekly time scale, the ambient temperature is still an important covariate of both mortality rates. As for the air pollution counterpart, only CO was found to be highly correlated with the weekly CVD mortality rate. This implies other major air pollutants may require more chronic exposure to trigger their health effects. Based on these findings, subsequent establishment of weekly and monthly air quality indices is suggested and more detailed research to quantify these threshold values with regression models [6–9,14–15] is called for. Apart from that, further research of $PM_{2.5}$ and RES/CVD mortality is suggested in future study to demonstrate the effect of fine particle exposure on the human mortality of Hong Kong.

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Author Contributions

The technical part of this work was performed by D.-B. and K.-I. under the supervision of K.-M. and K.-V. The subsequent writing of the paper was contributed by the joint effort of all authors.

Conflicts of Interest

The authors declare no conflict of interest.

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