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Association Between Daily Mortality And Weather In Hong Kong

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Abstract

Background: Weather variables are believed to have influence on human health and this climate/weather-mortality/morbidity relationship has been a public health concern for centuries. However, the weather-mortality association has not received much attention in Hong Kong. Objectives: The present study attempted to investigate the association between weather and daily mortality from all causes of death, circulatory and respiratory diseases in Hong Kong from 1995 to 2005. Methods: Generalized additive models (GAM) using a cubic smoothing spline to control seasonal and long-term trends of mortality data were employed. Multiple-day lag effects of weather variables on mortality were also examined. Results: Temperature was found to be a major factor causing deaths from circulatory and respiratory diseases, but not deaths from all causes. The younger age groups (age <65) had shorter time lags for mortality than the elderly (age older age group ≥65) who were also more susceptible to weather stress.

INTRODUCTION

The awareness of the impacts of weather/climate on health has a long history since Hippocrates, who related meteorological changes to health [1]. An understanding of the nature of the effects of weather conditions on health is essential for optimal health protection. Thus this weather-health association has become a public health concern. Recently, in the light of global climate change, influence of weather on mortality/morbidity has received increasing attention.

The most extensively studied weather-health relationship is the association between temperature and mortality. Nonlinear relations (U, J or V shaped) of temperature and mortality are observed [2,3,4,5,6,7,8]. Apart from temperature, other weather variables, such as humidity, barometric pressure and rainfall, are also found to be related to mortality [4,9,10,11,12]. Nonetheless, the combined impact of weather variables on mortality is less widely examined.

Further, there is often a lag between mortality/morbidity and weather conditions in addition to the immediate impact of weather on health, because the effects of weather parameters can occur after some delay. However, this lag structure between weather and mortality has not been widely investigated. The objectives of the present study are to assess the weather-mortality relationship and to explore the lag effects of weather on daily mortality in Hong Kong, a sub-tropical city. Results of the study can provide better understanding of weather-mortality association and useful information to help formulate public health policies, particularly preventive measures.

DATA AND METHODS

DATA

Hong Kong, located at the southeastern coast of China, has an area of 1104 km^2 and a population of 7 million. The city features a sub-tropical climate with a hot and humid summer (May to August) and a mild winter (December-February). In summer, the mean monthly temperature ranges from 25.8°C (in May) to 28.4°C (in August) with high mean monthly relative humidity of over 80%. The mean daily summer maximum temperatures often exceed 31°C. In winter, the mean monthly temperature is around 16°C-18°C with a mean monthly relative humidity of 73%. Temperatures in the urban areas can occasionally drop below 10°C after the passage of a cold front. The average annual rainfall is 2382 mm with a summer maximum [13].

Daily mortality numbers, covering all deaths reported in Hong Kong, for the period from 1995 to 2005 were obtained from the Hong Kong Census and Statistics Department that is a government agency in charge of the provision of adequate and reliable statistics. Mortality data were coded according to the 9 th International Classification of Diseases (ICD-9). Since 2001, the classification of causes of death is based on the 10 th Revision of the International Classification of Diseases (ICD-10) instead of ICD-9. For this analysis, daily mortality counts from all causes (ICD-9: 001-999; ICD-10: A00-T98), circulatory diseases (ICD-9: 390-459; ICD-10: I00-I99) and its subsets cerebrovascular disease (CVD; ICD-9: 430-438; ICD-10: I60-I69) and ischaemic heart disease (IHD; ICD-9: 410-414; ICD-10: I20-I25) were selected. In addition daily mortality from respiratory diseases (ICD-9: 460-519; ICD-10: J00-J99) were chosen. The daily mortality counts of these selected causes were further divided into gender and arbitrary age groups ≤24 (infant, child, adolescence and young adult), 25-44 (adult), 45-64 (middle age) and ≥65 (elderly).

It is suggested that there are associations between various weather variables and mortality. Weather variables including daily maximum temperature (max temp), minimum temperature (min temp), dew point temperature (dewpt), barometric pressure (pressure), cloud cover as an estimate of solar radiation (cloud) and wind speed (wind) were selected for this analysis. Daily meteorological data for the study period that were measured at the Hong Kong Observatory Station were obtained from the Hong Kong Observatory.

STATISTICAL METHODS

Counts of daily deaths were assumed to be Poisson random variables. The weather-mortality relation was examined by using the generalized additive models (GAMs), with extending Poisson regression to assess the nonlinear effects of weather variables [14]. The GAMs allow independent variables having a non-linear effect on the predicted outcome to be modeled using non-parametric smoothing functions such as splines. A cubic smoothing spline, that was also employed to remove seasonal and long-term patterns of mortality data, was used in the present study.

The Unbiased Risk Estimator (UBRE) was used to select the best model and degree of smoothness for the non-linear components [15]. The UBRE allows the selections of covariates and smoothing parameter of the spline function at the same time. The lowest value of UBRE indicates the most appropriate model [16]. The adjusted r^2 (coefficient of determination) values were used to determine the goodness of the model fit. The UBRE is a very convenient choice from a computation point of view and is readily available in most statistical software. Backward selection was employed to choose the weather variables in the models.

Weather conditions can affect mortality not only on the current day but also several preceding days [5]. In exploring the delayed effects of weather on mortality, multiple-day lags ranging from 0 to 14 days before death were examined. The best models with lag structures were again selected by the UBRE.

In addition, various GAMs were run to investigate the associations between weather variables and daily deaths by gender and age groups. All analyses were conducted using R statistical software and the significant level was set at 0.05.

RESULTS

For study period from 1995 to 2005 (4018 days), a total of 369,896 deaths (56.23% male; 43.77% female) from all causes were recorded. The total numbers of deaths from circulatory, CVD, IHD and respiratory diseases were 98,883 (50.55% male; 49.45% female), 36,202 (48.17% male; 49.45% female), 37809 (54.84% male; 45.16% female) and 66,899 (58.14% male; 41.86% female) respectively. Among all the death counts, over 75-90% of the deaths from all causes (75.76%), circulatory diseases (85.26%), CVD (85.48%), IHD (78.81%) and respiratory diseases (90.75%) were aged ≥65. Table 1 shows the summary statistics of the mortality and meteorological data used in this study.

Figure 1

Table 1. Summary statistics of daily death counts and weather parameters in 1995-2005 (4018 days)

	Mean	SD	Minimum	Maximum
All Causes				
Total death	92.06	14.82	50	159
Male	51.77	9.42	26	91
Female	40.29	8.29	16	77
Age ≤24	1.63	1.36	0	12
Age 25-44	4.89	2.30	0	24
Age 45-64	15.74	4.06	5	34
Age ≥65	69.74	13.70	32	134
Circulatory				
Total death	24.61	6.79	6	56
Male	12.44	4.20	1	32
Female	12.17	4.00	1	30
Age ≤24	0.10	0.30	0	4
Age 25-44	0.54	0.75	0	6
Age 45-64	2.97	1.81	0	11
Age ≥65	21.00	6.30	3	50
CVD				
Total death	9.01	3.33	0	23
Male	4.34	2.00	0	16
Female	4.67	2.00	0	15
Age ≤24	0.00	0.10	0	2
Age 25-44	0.19	0.43	0	3
Age 45-64	1.10	1.07	0	7
Age ≥65	7.70	3.10	0	22
IHD				
Total death	9.41	3.62	0	29
Male	5.16	2.00	0	17
Female	4.25	2.00	0	15
Age ≤24	0.00	0.10	0	1
Age 25-44	0.13	0.36	0	3
Age 45-64	1.04	1.07	0	6
Age ≥65	7.40	4.00	0	25
Respiratory				
Total death	16.65	5.39	3	41
Male	9.68	4.00	1	27
Female	6.97	3.00	0	23
Age ≤24	0.10	0.30	0	3
Age 25-44	0.21	0.47	0	4
Age 45-64	1.20	1.15	0	9
Age ≥65	15.00	5.10	3	38
Weather parameters				
Maximum temperature (°C)	25.72	5.21	8.40	35.40
Minimum temperature (°C)	21.66	5.01	5.80	29.40
Dew point temperature (°C)	19.20	5.86	-8.10	26.80
Wind speed (ms^{-1})	2.79	1.19	0.40	9.80
Barometric pressure (hPa)	1012.80	6.43	986.50	1030.70
Cloud cover (%)	68.11	25.52	0.00	100.00

On the basis of UBRE criterion, the best models for weather effects on mortality counts of selected causes of death are presented in Table 2.

Figure 2

Table 2. Models for weather effects on daily mortality (significant level=0.05).

Causes of death	Explanatory variables					Adj r^2	Lagged day
All causes							
Total death	-cloud	-dewpt	+pressure			0.540	7
Male	-cloud	-dewpt				0.374	5
Female	-cloud	-dewpt	-wind			0.387	7
Age ≤24	+cloud	-dewpt	-wind	+pressure	+min temp	0.088	1
Age 25-44	-cloud	+dewpt	-wind	+pressure	-min temp	0.031	0
Age 45-64	-dewpt	+pressure				0.036	6
Age ≥65	-cloud	-dewpt	-max temp			0.608	10
Circulatory							
Total death	-dewpt	-min temp				0.462	11
Male	-dewpt	-max temp				0.283	13
Female	+max temp	-min temp	+pressure			0.316	8
Age ≤24	N/A					—	—
Age 25-44	-min temp	-pressure				0.005	0
Age 45-64	+cloud	-dewpt	+pressure			0.069	6
Age ≥65	-dewpt	-min temp				0.471	9
CVD							
Total death	-dewpt	-min temp				0.183	10
Male	-dewpt	-min temp	+pressure	+wind		0.087	7
Female	-cloud	-wind				0.103	0
Age ≤24	N/A					—	—
Age 25-44	-pressure					0.008	0
Age 45-64	+pressure					0.036	4
Age ≥65	-dewpt	-min temp				0.192	11
IHD							
Total death	-dewpt					0.287	7
Male	-dewpt	-min temp	-pressure			0.168	7
Female	+pressure					0.157	0
Age ≤24	N/A					—	—
Age 25-44	-pressure					0.003	0
Age 45-64	-cloud	+pressure	-min temp			0.018	1
Age ≥65	-dewpt	+max temp				0.280	0
Respiratory							
Total death	-cloud	-dewpt				0.392	11
Male	-cloud					0.280	2
Female	-cloud	+max temp				0.208	0
Age ≤24	+max temp	-min temp				0.012	0
Age 25-44	+max temp	-min temp				0.045	5
Age 45-64	-cloud	+pressure				0.082	2
Age ≥65	-cloud	-pressure	+max temp			0.379	0

For mortality from all causes, significant negative relationship between cloud cover and dew point temperature and positive relationship between barometric pressure and total daily deaths was observed. The contributing weather variables affecting female mortality were slightly different from those of male mortality. In addition to cloud cover and dew point temperature, wind speed was included in the female model.

Dew point temperature and temperature had the most influential impacts on circulatory mortality. Wind speed was discovered to be associated only with gender-specific CVD mortality. Barometric pressure was also found to relate to gender-specific deaths.

Cloud cover and temperatures were associated with respiratory deaths. Positive relationship of maximum temperature and respiratory deaths was found in females only, showing that they were more sensitive to temperature than males.

The evaluation of weather impacts on mortality for various age group revealed that no association was found for age ≤24 for circulatory diseases. The weather-mortality relationship was discovered to be weak in age groups 25-44 and 45-64 (Adj r^2 ranged from 0.003 to 0.082). Temperature and dew point temperature were the major weather variables contributing to deaths for age group ≥65. Much stronger weather-mortality association was also detected in the elderly (Adj r^2 ranged from 0.192 to 0.608), who were more weather responsive.

The lagged weather effects on daily deaths varied from 7 to 11 days for total deaths of the selected causes. For both circulatory and respiratory mortality, weather conditions had a more delayed effects on males than females. No consistent patterns of lagged weather effects on age-specific deaths were observed. The most delayed weather effect on age ≥65 mortality was from CVD. However, weather conditions had direct impact on age ≥65 deaths from IHD and respiratory diseases.

DISCUSSION

The finding that negative association of cloud cover and dew point temperature and positive correlation of pressure with deaths from all causes is different from that of many previous studies, in which temperature was the most prominent weather variable. Further, this result is also dissimilar from the study in Birmingham, Alabama, where no weather variables were significantly related to total mortality [17]. However, it concurs with the study in Brisbane, where relative humidity was inversely associated with total deaths [18]. The exclusion of temperatures in the models suggests that the majority of population have acclimatized the hot, sultry summers and the mild winters in the subtropics. It is also claimed that better housing standards, such as having air conditioning and heating systems in homes, lessens the influence of temperature on health [19]. Air conditioning is widely available in most homes in Hong Kong and thus the effect of temperature is minimized.

In addition to cloud cover and dew point temperature, wind speed was also negatively related to female deaths from all causes. Clear sky and low humidity occur when the sub-tropical high pressure and the winter monsoon affect Hong Kong inducing hot and cold weather conditions in summer and winter respectively. Higher wind speed can be beneficial for alleviating thermal stress in summer but it can be detrimental for aggravating cold stress in winter. The inclusion of these weather variables in the female model indicates that they were more sensitive to the combined weather effects; and may plausibly be explained by the gender difference in thermoregulation.

In cold exposure, due to about 20% smaller body mass than males, women have less thermal inertia but greater vascular constriction in both superficial and deep arteries, resulting in cooler skin temperature [20,21]. In addition, their maximum heat production is 2/3 that of males [22]. The less capability of producing maximum heat and extreme vasoconstriction make women have more vulnerable in the cold.

In the heat, females have more blood pooled to the periphery [23] causing their skin temperature 0.5 ^{o} -1.2^{o}C higher than that of males [24,25]. Women also have lower sweating rate than men; and thus they store more body heat to initiate sweating for evaporative cooling. In order to maintain the core-to-skin heat transfer, greater cardiovascular exertion is required [21]. This increasing cardiac output makes females more susceptible in hot conditions.

Temperature, dew point temperature and barometric pressure were the contributing factors to deaths from circulatory diseases. This finding is comparable with many previous studies. Temperature, dew point temperature, wind and pressure were correlated with IHD mortality in Birmingham UK [26]. Cardiovascular death was detected to escalate as humidity and pressure increased and a U shaped temperature relationship was discovered in Taiwan [27,28]. Some studies revealed that pressure was the major weather variable causing circulatory deaths [10,11,29]. However, Woo et al. [30] found no significant correlation between temperature and stroke incidence.

Temperature is believed to affect blood pressure and blood viscosity [3,31]. Blood pressure increases with lower temperature although higher temperature may increase nocturnal levels [32]. Low temperature also increases blood viscosity and heart rate [3] and may trigger circulatory diseases. Barometric pressure changes also lead to increased risk of subarachnoid haemorrhage onset and the mechanism is unclear. It is believed that change in pressure might be associated with the change in inflammatory mediators [29], and changes in intra-aneurysmal or transaneurysmal pressure would influence the risk of rupture [10,33].

Temperature and cloud cover were related to deaths from respiratory diseases. The inverse cloud cover association in the present study was different from the previous one conducted by Yan [34]. In addition to temperature, humidity was found to be negatively associated with respiratory mortality in Birmingham, Alabama [17] and with respiratory infection in Athens, Greece [35]. Weak weather-respiratory mortality association was discovered in Taiwan [28].

In general, cold temperature can trigger respiratory diseases. Broncho-constriction, that may increase susceptibility of pulmonary infection, may be induced by breathing in cold air. It is also suggested that increased mortality was connected with cold weather because of elevated occurrence of influenza and other respiratory infections [36].

In heat exposure, blood is forced into the periphery to promote heat loss; and thus blood pressure increases because blood vessels near the body core are constricted [21]. In addition, blood viscosity and cholesterol level also escalate with high temperatures [37]; and these increases will interact with atrial fibrillation provoking blood clot. Pulmonary vascular resistance and hyperventilation develop [38] and precipitate respiratory distress.

The inclusion of maximum temperature and less cloudiness in the female model of respiratory deaths denotes that females are more sensitive to hot sunny conditions. This finding corresponds to previous studies that female mortality is higher in hot weather [39,40,41,42]. In addition to the gender differences in thermoregulatory responses to the heat, the lower tolerance time in the heat in women than men due to excessive body heat storage [43] contributes to the greater female susceptibility of respiratory disease.

The strong weather-mortality associations in age group ≥65 ascertain that the elderly are more susceptible to weather stress. This evident weather-mortality relationship is due to the failure of homeostatic defense mechanism with advancing age, which in turn would provoke circulatory, respiratory or other diseases [27]. For the lagged weather effects, the younger age groups (age less than 65) had shorter time lags for mortality from all causes and circulatory diseases. A plausible explanation is that younger people are more exposed to stressful weather because of physical activities or working outdoors [44].

CONCLUSION

This study evaluated the weather-mortality relationship in Hong Kong. It is apparent that weather has an imperative effect on mortality. The elderly are more susceptible to the influence of weather. Results of the present study are consistent with some previous findings, but also contradict other findings. The conflicting findings, which are understandable, are mainly owing to the diverse weather variables included in various studies. This can also imply that the influence of weather on mortality/morbidity is not well understood.

This study has some limitations. The findings of the current study cannot be generalized to other locations because the weather data used were from a fixed site instead of individual exposure. Thus, there may be possible bias on exposure measurement.

Without considering seasonality and controlling confounding effects of air pollution is another limitation. Air pollution effects on mortality are noted to be augmented at higher temperature [45,46]. Further, meteorological changes are also related to morbidity/mortality. Diurnal temperature range is found having an influence on mortality [47,48]. Future research in weather-morbidity/mortality association analyses should include changes of weather variables, traditional meteorological parameters, lagged weather effects and air pollution impacts. With better understanding of health responses to weather conditions (including direct, changing and lagged weather impacts) and air pollution (both direct and lagged impacts), better health services and policies could be formulated, such as warning of stressful weather and air pollution episode to susceptible population, better management of medical or hospital resources.

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