

Chapter 13

Trends and Seasonal Variations of Climate, Air Quality, and Mortality in Three Major Cities in Taiwan

Mei-Hui Li

Abstract The interactions among climate change, air pollution, and human health are multiple and complex. Many epidemiological studies in Taiwan have consistently demonstrated the effects of short-term exposures to extreme weather events, particulate matter, and traffic-related air pollutants on a variety of health effects. However, these findings might not explain or predict overall seasonal mortality patterns to provide insights into the drivers of mortality acting on society levels for public health policy and practice. There are very limited studies on seasonality of weather, air pollution, and mortality in Taiwan. The objectives of this study are to evaluate if there are any changes in trends and seasonality of mortality in three major Taiwanese cities from 1991 to 2010 and examine its association with climatic condition and air pollution. Among these major Taiwanese cities, seasonal mortality patterns are similar in two subtropical cities, Taipei and Taichung, compared to another tropical city, Kaohsiung. Taipei had significantly increased trends in most monthly temperature variables and the number of hot days examined during 1991–2010 compared to the other two cities. Winter/summer ratios of mortality only showed a decreased trend in Taipei, but not in Taichung or Kaohsiung. Mean monthly ambient temperature was also found as the most optimal temperature variable for predicting all-cause monthly mortality at all three cities in this study. Seasonal mortality patterns in three cities were with higher levels of deaths from December to March. Trends in air quality are showing mixed patterns over the past two decades. SO₂, CO, and NO_x concentrations have decreased significantly and steadily, while O₃ has significantly increased in recent years. In three major Taiwanese cities, O₃ and PM₁₀ are major air pollutants of current concerns. The results of this study showed that monthly mean O₃, PM₁₀, and NO_x levels and monthly mortality were not closely related, but temperature-related variables were positively associated with monthly mortality among three major Taiwanese cities. Moreover, changes in other socioeconomic and demographic factors may also play a key role in determining seasonality mortality and morbidity and need to be considered in future studies.

M.-H. Li (✉)

Department of Geography, National Taiwan University, Taipei, Taiwan

e-mail: meihuili@ntu.edu.tw

Keywords Seasonal mortality patterns • Urbanization • Air pollution • Climate change

Introduction

The global urban population has exceeded rural population since 2014 (United Nations 2014). Urbanization is a process of intensive human activities in land use and economic development. Urbanization has numerous negative effects on air pollution worldwide, and urban areas are the significant emission sources of greenhouse gases due to concentrate industries, transportation, and households. The urban areas are also at great risk affected by climate change with increases in the frequency and intensity of heavy rainfalls, heat waves, and other extreme weather events (Lankao 2008; Romero-Lankao et al. 2012). Furthermore, air quality is strongly dependent on weather and is sensitive to climate change. Both climate change and air pollution are the most challenging global issues we face today. Many processes of urbanization contribute to climate change and air pollution such as combustion of fossil fuels and land use changes; therefore, cities have become research hotspots to understand the link between climate change and air pollution on human health.

Seasonal variations of mortality and disease in human society are well known. Proper assessment of seasonal mortality in a population is with important scientific and public health implications. While climate change may lead to alter seasonality of atmospheric condition, seasonal mortality patterns can be also influenced by these changes. Especially, air pollution and climate change can influence each other through complex interactions in the atmosphere and affect human health in different regions. There are many short-term effects or epidemiological studies on the relationships between air pollution and health or temperature and mortality in Taiwan. Several recent studies have already reported significant associations between daily temperature and daily mortality or cardiopulmonary diseases in Taiwanese cities (Liang et al. 2008, 2009; Lin et al. 2011, 2012, 2013a, b; Wang et al. 2012; Sung et al. 2013; Wang and Lin 2014). Moreover, there is growing evidence that particulate matter is responsible for mortality and cardiorespiratory diseases in Taiwanese cities (Tsai et al. 2010, 2014a, b, 2015; Chang et al. 2015a, b; Cheng et al. 2015; Wang and Lin 2015). However, these recent findings might not explain or predict overall seasonal mortality patterns. In fact, there are very limited studies on seasonality of weather, air pollution, and mortality in Taiwan.

The objectives of this study are to evaluate if there are any changes in trends and seasonality of weather, air pollution, and mortality in three Taiwanese cities from 1991 to 2010. First, the seasonal patterns of mortality, climate, and air quality are described in three major Taiwanese cities. Second, any changes in trends of mortality, climate, and air quality are examined in these three cities. Third, relationships between climate, air pollution, and mortality are investigated.

Methods

Study Area

Three metropolitans, Taipei, Taichung, and Kaohsiung, were selected for this study. Taipei is the largest and capital city of Taiwan at northern Taiwan. Kaohsiung is the second largest city and an industrial city located on the southwestern coast of Taiwan. Taichung is the third largest metropolitan area located in the west-central part of Taiwan. Table 13.1 shows some basic characteristics of these three cities. At the end of 2010, both Taichung and Kaohsiung cities were merged with Taichung and Kaohsiung counties to form large special municipalities, respectively. Therefore, monthly all-cause mortality, weather, and air quality data were analyzed from 1991 to 2010 for these three cities in this study.

Mortality Data

Monthly all-cause mortality data were retrieved online from the Ministry of Health and Welfare website during the period from 1991 to 2010 for Taipei, Taichung, and Kaohsiung. The seasonality index (100-Index) and winter/summer ratio were applied to assess seasonal mortality. A 100-Index was estimated by each month death relative to the average month death for each year and multiply it by 100. A winter/summer ratio was calculated as the number of winter deaths (December to March) divided by the number of summer deaths (June–September) for each year. On 21 September 1999, the Jiji earthquake occurred in central Taiwan, causing 87 and 112 deaths in Taipei and Taichung, respectively. Such deaths were excluded from calculating winter/summer ratio in Taipei and Taichung for 1999.

Climatological Data

Taipei (station no 466920), Taichung (station no 467490), and Kaohsiung (station no 467440) weather stations of the Central Weather Bureau (CWB) are located at urban centers with the most representative of the population's exposure in

Table 13.1 Characteristics of three Taiwanese cities

City	Area (km ²) ^a	Density in 2009 (persons/km ²) ^a	Topography	Climate
Taipei	271.8	9653	Taipei Basin	Subtropical monsoon
Taichung	161.9	6631	Taichung Basin	Subtropical monsoon
Kaohsiung	146.6	9948	Jianan Plain	Tropical monsoon

^aUrban and Regional Planning Statistics, 2010, from Department of National Spatial Planning and Development for National Development Council, R.O.C. (Taiwan)

these three cities (Fig. 13.1). The climatological data were extracted from these three CWB weather stations from 1991 to 2010, with the monthly data including mean daily ambient temperature, relative humidity, atmospheric pressure, rainfall, hours of sunshine, diurnal temperature range, maximum and minimum temperatures, etc.

Air Quality Data

Air quality monitoring stations were fully automated and provided daily readings of SO₂ (by ultraviolet fluorescence), PM₁₀ (by beta-ray absorption), NO₂ (by ultraviolet fluorescence), carbon monoxide (CO) (by nondispersive infrared photometry), and ozone (O₃) (by ultraviolet photometry) by the Taiwanese Environmental Protection Administration (EPA). Five, two, and six air quality monitoring stations in Taipei, Taichung, and Kaohsiung were selected to analyze average monthly data for SO₂, CO, PM₁₀, O₃, and NO_x from July of 1993 to December of 2010, respectively (Fig. 13.1). During the period of January 1991–June 1993, air pollution data only existed from one and three air quality monitoring stations in Taipei and Kaohsiung, respectively. There was no air quality data available for Taichung from January 1991 to June 1993. Therefore, air quality records between 1994 and 2010 were used for trend analysis in three cities.

Statistical Analysis

Because climate, air quality, and mortality data do not follow a normal distribution and can show seasonal changes within a year, nonparametric statistic methods are applied in all data analysis. Seasonal Mann-Kendall (MK) trend tests which defined each month as a “season” were used to assess monthly data change over 20 years. Classic MK trend test was also performed to assess and determine the presence of a trend on winter/summer ratios and annual mean metrological variables or air qualities. In this study, the magnitude of changes in metrological variables during the study period was determined by Sen’s estimator method (Sen 1968), while the statistical significance was analyzed through MK test by using the NIWA’s Time Trends and Equivalence software version 3.31 (Jowett 2012). Comparison of air qualities among three cities was determined by nonparametric Kruskal-Wallis test followed by Mann-Whitney test as post hoc test. The associations between mean monthly mortality and monthly temperature-related variables or air pollutant concentrations were evaluated by quadratic regression analysis. Pearson correlation coefficient was also used to estimate the correlation of monthly temperature-related variables or air pollutant concentrations with monthly mortality 100-Index.

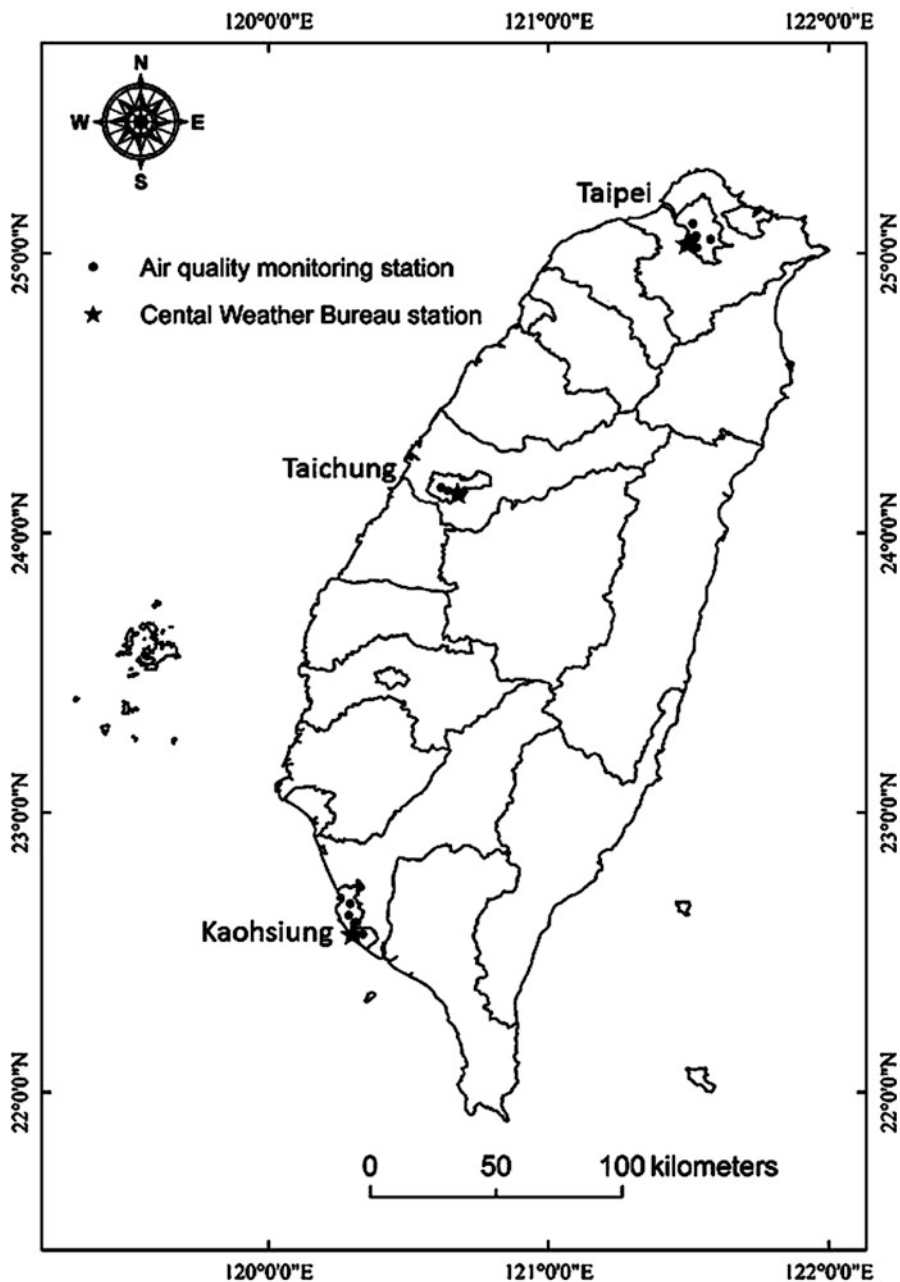


Fig. 13.1 The locations of weather and air quality monitoring stations in three major cities in Taiwan

Results

Seasonal Variations of All-Cause Mortality

Except winter/summer ratio of 2002 in Kaohsiung which was less than 1, all-cause mortality was higher in the winter (December to March) than in the other seasons at three cities during 1991–2010 (Fig. 13.2). Winter/summer ratios of mortality in Taipei showed a decreased trend ($P = 0.041$) from 1991 to 2010 as examined by MK test. No significant trend was observed for Taichung ($P = 0.256$) or Kaohsiung ($P = 0.230$) during the same period. The mean winter/summer ratio of 1.08 in Kaohsiung was the lowest among three cities with a range of 0.962–1.166. On the other hand, the mean winter/summer ratios in Taipei and Taichung were 1.13, but the mean winter/summer ratio in Taichung was with the highest variation ranging from 1.006 to 1.312.

Overall seasonal mortality (100-Index) patterns in three cities were with generally higher levels of deaths from December to March (Fig. 13.3). Mortality in July was also slightly higher than monthly average mortality in Kaohsiung, but not in Taipei or Taichung (Fig. 13.3). The 100-Index of Taipei ($P = 0.048$) and Taichung ($P = 0.015$) in March exhibited a decreased trend during a 20-year period as determined by MK trend tests. Furthermore, the 100-Index of Kaohsiung in August ($P = 0.041$), September ($P = 0.025$), and December ($P = 0.01$) all showed increased trends during a 20-year period.

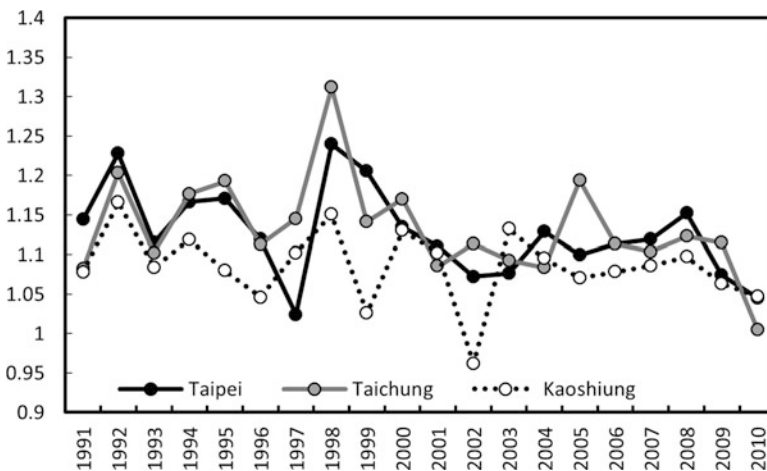


Fig. 13.2 Winter/summer ratios of mortality in three Taiwanese cities from 1991 to 2010 (Mortality data were retrieved from the Ministry of Health and Welfare of Taiwan)

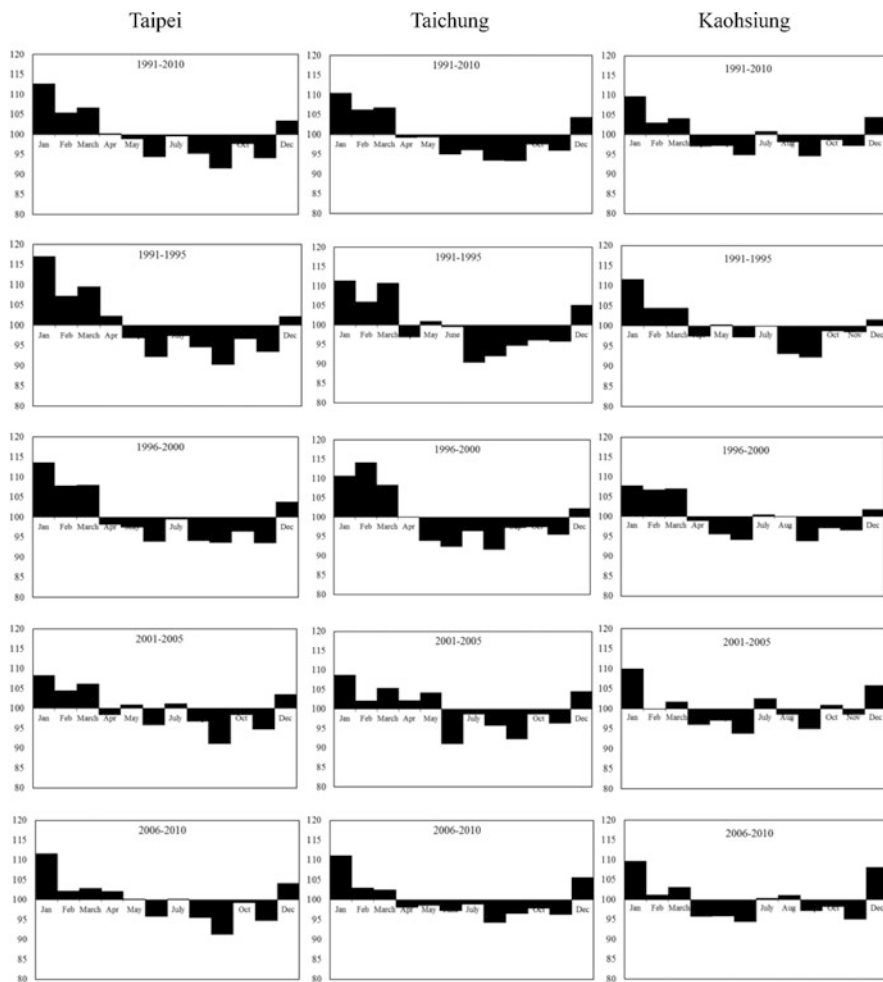


Fig. 13.3 Seasonality in mortality in three Taiwanese cities during the period 1991–2010 and every 5-year period (Mortality data were retrieved from the Ministry of Health and Welfare of Taiwan)

Trend and Seasonal Changes of Climatic Conditions

Taipei, Taichung, and Kaohsiung weather stations demonstrated significantly positive trends with a Sen slope value averaging 0.044, 0.020, and 0.020 °C/year in mean monthly temperature over 20 years, respectively (Table 13.2). Three weather stations also showed increased trends in monthly maximum relative humidity and mean minimum temperature (Table 13.2). Maximum temperature-related variables in Taipei and Kaohsiung displayed increased trends, but showed no changes in Taichung between 1991 and 2010 (Table 13.2). Monthly mean diurnal temperature

Table 13.2 Summary of different climatic trends determined by using the seasonal Mann-Kendall test and Sen’s slope methods during the period 1991–2010 in three major Taiwanese cities

Variable	N	Taipei		N	Taichung		N	Kaohsiung	
		Monthly M-K test P	Sen slope		Monthly M-K test P	Sen slope		Monthly M-K test P	Sen slope
PP01	240	0.667	0.412	237	0.099	0.600	237	0.800	0.015
PS01	240	0.245	0.017	240	0.029	-0.036	240	0.001	-0.050
RH01	240	0.902	0.000	240	0.061	0.000	240	0.783	0.000
RH02	240	0.300	0.071	240	0.792	0.000	240	0.125	-0.111
RH04	137	0.000	5.500	137	0.000	5.588	137	0.000	5.500
SS01	240	0.085	0.659	240	0.772	-0.104	240	0.000	1.801
SS02	240	0.075	0.200	240	0.888	-0.017	240	0.000	0.490
TX01	240	0.000	0.044	240	0.029	0.020	240	0.021	0.020
TX02	240	0.000	0.044	240	0.342	0.007	240	0.077	0.020
TX04	240	0.000	0.055	240	0.077	0.020	240	0.000	0.006
TX06	240	0.007	0.050	240	0.036	0.033	240	0.352	0.012
TX08	240	0.000	0.060	240	0.632	0.000	240	0.000	0.050
TX09	240	0.000	0.043	240	0.000	0.033	240	0.030	0.018
TX10	240	0.029	0.014	240	0.005	-0.019	240	0.001	0.018
TX11	240	0.319	0.014	240	0.006	-0.036	240	0.017	0.025
DY03	240	0.018	0.000	240	0.879	0.000	240	0.001	0.000
DY04	240	0.007	0.000	240	0.519	0.000	240	0.523	0.000
DY05	240	0.972	0.000	240	0.945	0.000	240	0.924	0.000

The bold values represent the significant trend at the 5% level
PP01 precipitation (mm), *PS01* mean station pressure (hPa), *RH01* mean relative humidity (%), *RH02* minimum relative humidity (%), *RH04* maximum relative humidity (%), *SS01* sunshine duration (hour), *SS02* rate of sunshine (%), *TX01* mean ambient temperature (°C), *TX02* dew point temperature (°C), *TX04* absolute maximum temperature (°C), *TX06* absolute minimum temperature (°C), *TX08* mean maximum temperature (°C), *TX09* mean minimum temperature (°C), *TX10* mean diurnal temperature range (°C), *TX11* maximum diurnal temperature range (°C), *DY03* number of days with maximum temperature ≥ 30 °C, *DY04* number of days with maximum temperature ≥ 35 °C, *DY05* number of days with minimum temperature ≤ 10 °C

range showed significantly increased trends in Taipei and Kaohsiung, but a significantly decreased trend in Taichung. Taipei had significantly increased trends in most monthly temperature variables and the number of hot days examined during 1991–2010 compared to the other two cities (Table 13.2).

The average diurnal temperature range from Taipei weather station observations is larger during summer (May–August) than during other months (Fig. 13.4). In contrast, the average diurnal temperature ranges from Taichung and Kaohsiung weather stations are larger during winter (December–March) than during other months (Fig. 13.4). The sunshine duration and rate of sunshine in Kaohsiung displayed positive trends during the 20-year period, but not in Taipei or Taichung.

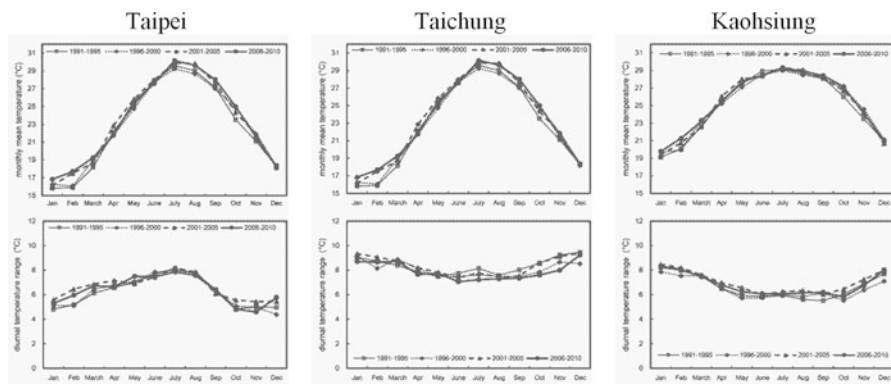


Fig. 13.4 Seasonality in mean temperature and diurnal temperature range in three weather stations at three cities during each 5-year period from 1991 to 2010 (The climatological data were obtained from Central Weather Bureau)

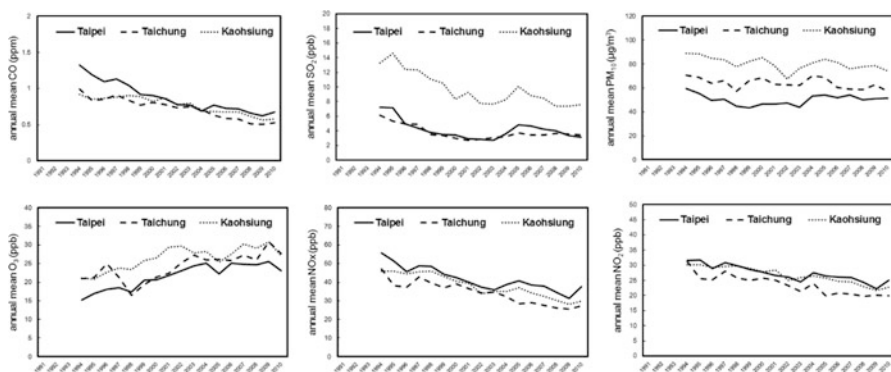


Fig. 13.5 Annual mean concentrations of air pollutants in three major Taiwanese cities during 1994–2010 (Air quality data were obtained from Taiwanese EPA)

Interestingly, the mean station pressure in Taichung and Kaohsiung showed negative trends during 1991 to 2010 (Table 13.2).

Trend and Seasonal Changes of Air Qualities

Based on the results of seasonal M-K trend tests, trends of all air quality parameters were significantly changed in all three cities with p values less than 0.01 during the study period 1994–2010. Trends in air quality are showing mixed patterns over the past two decades. SO₂, CO, and NO_x concentrations have decreased significantly and steadily, while O₃ has significantly increased in recent years (Fig. 13.5). On the

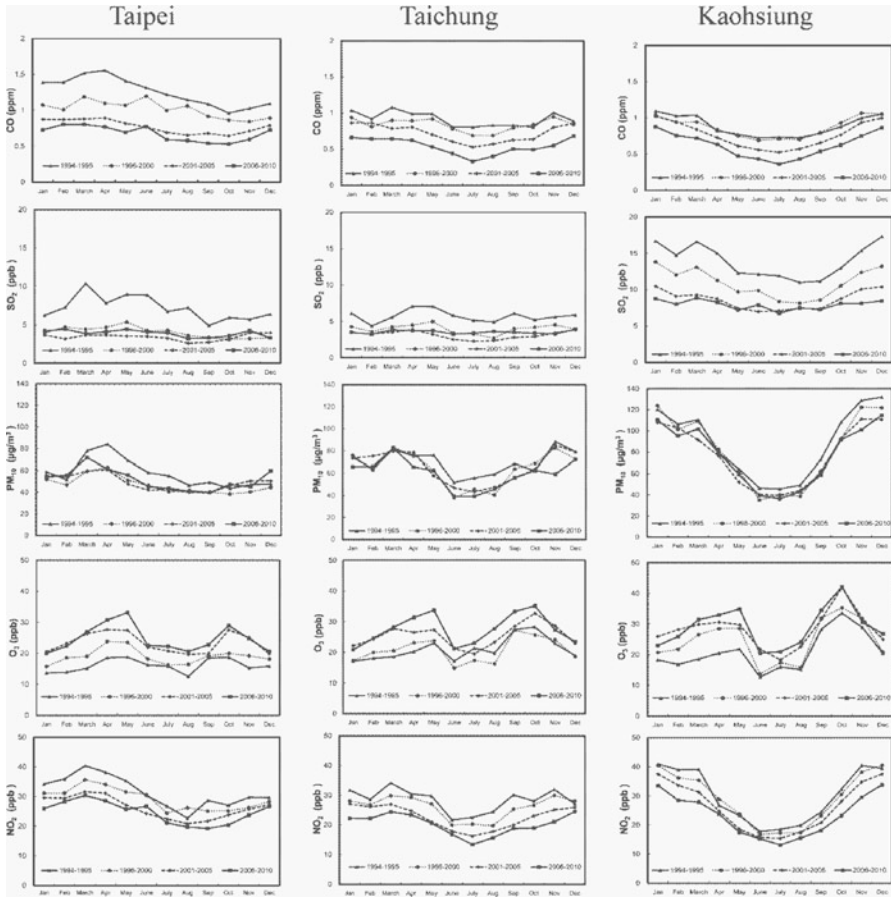


Fig. 13.6 Monthly variation of air qualities in three major Taiwanese cities, 1994–2010 (Air quality data were obtained from Taiwanese EPA)

other hand, traffic-related air pollutants, such as NO_2 and PM_{10} , have been kept constant over the past decade (Fig. 13.5). Overall, O_3 and PM_{10} are major air pollutants of current concerns in three major Taiwanese cities. Among three cities, the concentrations of SO_2 , O_3 , and PM_{10} in Kaohsiung were higher than those in Taipei and Taichung ($P < 0.001$). The levels of CO and NO_x in Taipei were higher than those in Taichung and Kaohsiung. The levels of NO_2 in Taichung were lower than those in Taipei and Kaohsiung (Fig. 13.5). The O_3 levels showed two peaks in May and October in all three cities, respectively (Fig. 13.6). The concentrations of CO , PM_{10} , and NO_2 showed a seasonal pattern with a peak in winter (January and December) in Kaohsiung, but not in Taipei or Taichung (Fig. 13.6).

Associations Between Climate, Air Pollution, and Mortality

Figures 13.7 and 13.8 present the monthly mortality 100-Index in relation to the monthly temperature-related variables and air pollutant concentrations in these three cities during the study period. Mean ambient temperature was found to be the most effective temperature variable among the temperature-related variables for predicting all-cause mortality 100-Index in all three cities (Fig. 13.7). Quadratic regression analysis in association with air pollutant concentrations and monthly mortality was not statistically significant in all three cities, and regression equations were not shown in Fig. 13.8. By calculating Pearson correlation coefficients, mean monthly O₃ concentrations showed no significant correlation with the monthly mortality at three cities (Fig. 13.8). In contrast, mean monthly PM₁₀ and NO_x concentrations showed significant correlation with the monthly mortality 100-Index at three cities ($P < 0.01$). Interestingly, monthly mean diurnal temperature range was negatively correlated with the monthly mortality 100-Index at Taipei ($r = -0.266$; $P < 0.001$), but was positively correlated with 100-Index at both Taichung ($r = 0.318$; $P < 0.001$) and Kaohsiung ($r = 0.538$; $P < 0.001$).

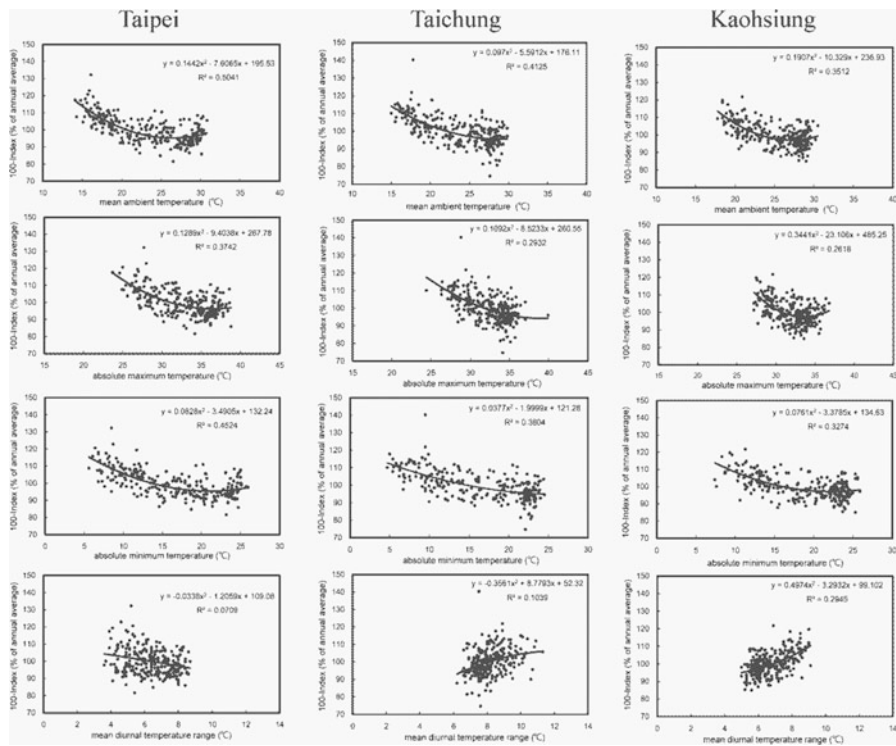


Fig. 13.7 Monthly mortality 100-Index in relation to the monthly temperature-related variables in three major Taiwanese cities during 1991–2010

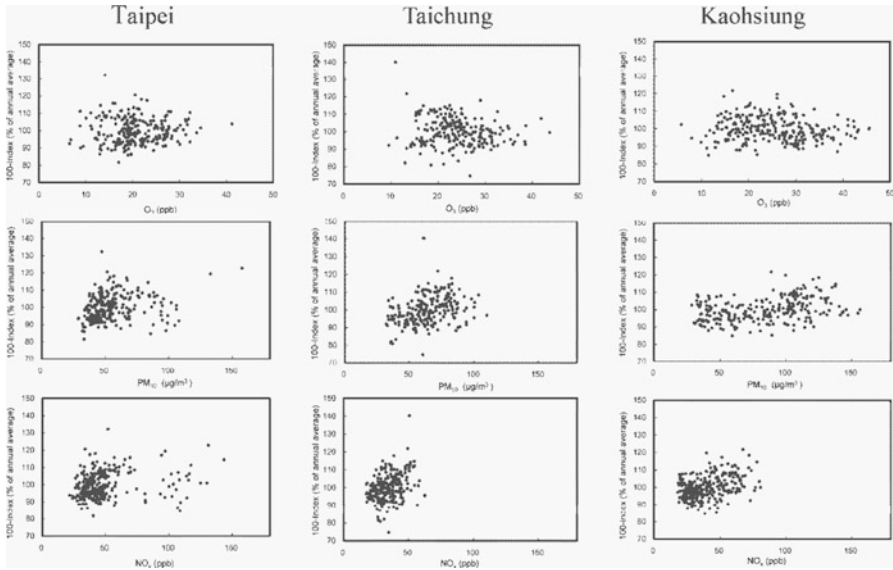


Fig. 13.8 Monthly mortality 100-Index in relation to the monthly mean O_3 , PM_{10} , and NO_x in three major Taiwanese cities during 1994–2010

Discussion

Among these major Taiwanese cities, seasonal mortality patterns are similar in two subtropical cities, Taipei and Taichung, compared to another tropical city, Kaohsiung.

Overall, seasonality index of mortality in three cities showed decreasing amplitude of seasonal variations during the past 20 years. Winter/summer ratios of mortality only showed a statistically significant decreased trend in Taipei, but not in Taichung or Kaohsiung. Monthly analyses showed that 100-Index of two subtropical cities, Taipei and Taichung, in March exhibited a significantly decreased trend. On the other hand, the 100-Index of Kaohsiung, a tropical city, in August, September, and December showed significantly increased trends during a 20-year period. Taipei is the most densely populated city in Taiwan and had significantly increased trends in most monthly temperature variables and the number of hot days examined during 1991–2010 compared to the other two cities. Ambient temperature was suggested as the most optimal temperature variable among high-temperature indices for predicting all-cause daily mortality in Taiwan (Lin et al. 2012). Similar results were also found for all-cause monthly mortality at all three cities in this study.

Air pollutants did not show to be a good predictor for monthly mortality 100-Index for all three cities. In Taiwan, ambient air quality has improved in the last two decades. However, there is a large body of evidence suggesting that

exposure to air pollution, even at the current levels, leads to adverse health effects. In Kaohsiung, higher levels of ambient air pollutants increase the risk of hospital admissions for cardiovascular diseases (Chang et al. 2015a), respiratory diseases (Tsai et al. 2014b; Cheng et al. 2015), and daily mortality for all causes (Tsai and Yang 2014; Tsai et al. 2015). In Taipei, particulate matter and traffic-related air pollutants, CO, O₃, and NO_x, were positively associated with increased risk of hospital admissions for cardiovascular diseases (Yang 2008; Chiu et al. 2013), asthma (Chan et al. 2009), respiratory diseases (Yu and Chien 2016), emergency room visits for stroke in the warm seasons (Chen et al. 2014), and daily mortality for all causes (Tsai et al. 2014a). On the other hand, many epidemiological studies showed that air pollution level and daily mortality lack a strong association either in Taipei or Kaohsiung (Tsai et al. 2003; Yang et al. 2004; Tseng et al. 2015). The result of this study also showed that monthly mean O₃, PM₁₀, and NO_x levels and monthly mortality were not closely related at these three cities.

In conclusion, monthly mean temperature-related variables, but not monthly mean air qualities, are positively associated with monthly mortality among three major Taiwanese cities. Moreover, the changes in other socioeconomic and demographic factors may also play a key role in determining seasonality mortality and morbidity and shall be considered in future studies.

References

- Chan TC, Chen ML, Lin IF, Lee CH, Chiang PH, Wang DW, Chuang JH (2009) Spatiotemporal analysis of air pollution and asthma patient visits in Taipei, Taiwan. *Int J Health Geogr* 8(1):1
- Chang CC, Chen PS, Yang CY (2015a) Short-term effects of fine particulate air pollution on hospital admissions for cardiovascular diseases: a case-crossover study in a tropical city. *J Toxicol Environ Health A* 78(4):267–277
- Chang CC, Chiu HF, Yang CY (2015b) Fine particulate air pollution and outpatient department visits for headache in Taipei, Taiwan. *J Toxicol Environ Health A* 78(8):506–515
- Chen SY, Lin YL, Chang WT, Lee CT, Chan CC (2014) Increasing emergency room visits for stroke by elevated levels of fine particulate constituents. *Sci Total Environ* 473:446–450
- Cheng MH, Chiu HF, Yang CY (2015) Coarse particulate air pollution associated with increased risk of hospital admissions for respiratory diseases in a tropical city, Kaohsiung, Taiwan. *Int J Environ Res Public Health* 12(10):13053–13068
- Chiu HF, Peng CY, Wu TN, Yang CY (2013) Short-term effects of fine particulate air pollution on ischemic heart disease hospitalizations in Taipei: a case-crossover study. *Aerosol Air Qual Res* 13:1563–1569
- Jowett I (2012) Time trends and equivalence software, version 3.31
- Lankao PR (2008) Urban areas and climate change: review of current issues and trends – issues paper for the 2011 global report on human settlements, 101p. http://www.Ral.Ucar.Edu/staff/prlankao/GRHS_2011_IssuesPaperfinal.Pdf. Accessed 18 August 2016
- Liang WM, Liu WP, Chou SY, Kuo HW (2008) Ambient temperature and emergency room admissions for acute coronary syndrome in Taiwan. *Int J Biometeorol* 52(3):223–229
- Liang WM, Liu WP, Kuo HW (2009) Diurnal temperature range and emergency room admissions for chronic obstructive pulmonary disease in Taiwan. *Int J Biometeorol* 53(1):17–23

- Lin YK, Ho TJ, Wang YC (2011) Mortality risk associated with temperature and prolonged temperature extremes in elderly populations in Taiwan. *Environ Res* 111(8):1156–1163
- Lin YK, Chang CK, Li MH, Wu YC, Wang YC (2012) High-temperature indices associated with mortality and outpatient visits: characterizing the association with elevated temperature. *Sci Total Environ* 427:41–49
- Lin YK, Chang CK, Wang YC, Ho TJ (2013a) Acute and prolonged adverse effects of temperature on mortality from cardiovascular diseases. *PLoS One* 8(12):e82678
- Lin YK, Chang CK, Chang SC, Chen PS, Lin C, Wang YC (2013b) Temperature, nitrogen dioxide, circulating respiratory viruses and acute upper respiratory infections among children in Taipei, Taiwan: a population-based study. *Environ Res* 120:109–118
- Romero-Lankao P, Qin H, Dickinson K (2012) Urban vulnerability to temperature-related hazards: a meta-analysis and meta-knowledge approach. *Glob Environ Chang* 22(3):670–683
- Sen PK (1968) Estimates of the regression coefficient based on Kendall's tau. *J Am Stat Assoc* 63:1379–1389
- Sung TI, Wu PC, Lung SC, Lin CY, Chen MJ, Su HJ (2013) Relationship between heat index and mortality of 6 major cities in Taiwan. *Sci Total Environ* 442:275–281
- Tsai S, Yang CY (2014) Fine particulate air pollution and hospital admissions for pneumonia in a subtropical city: Taipei, Taiwan. *J Toxicol Environ Health A* 77(4):192–201
- Tsai SS, Huang CH, Goggins W, Wu TN, Yang CY (2003) Relationship between air pollution and daily mortality in a tropical city: Kaohsiung, Taiwan. *J Toxicol Environ Health A* 66(17):1341–1349
- Tsai DH, Wang JL, Chuang KJ, Chan CC (2010) Traffic-related air pollution and cardiovascular mortality in central Taiwan. *Sci Total Environ* 408(8):1818–1823
- Tsai SS, Chang CC, Liou SH, Yang CY (2014a) The effects of fine particulate air pollution on daily mortality: a case-crossover study in a subtropical city, Taipei, Taiwan. *Int J Environ Res Public Health* 11(5):5081–5093
- Tsai SS, Chiu HF, Liou SH, Yang CY (2014b) Short-term effects of fine particulate air pollution on hospital admissions for respiratory diseases: a case-crossover study in a tropical city. *J Toxicol Environ Health A* 77(18):1091–1101
- Tsai SS, Weng YH, Chiu YW, Yang CY (2015) Short-term effect of coarse particles on daily mortality rate in a tropical city, Kaohsiung, Taiwan. *J Toxicol Environ Health A* 78(23–24):1409–1420
- Tseng E, Ho WC, Lin MH, Cheng TJ, Chen PC, Lin HH (2015) Chronic exposure to particulate matter and risk of cardiovascular mortality: cohort study from Taiwan. *BMC Public Health* 15(1):1
- United Nations (2014) World urbanization prospects: the 2014 revision, highlights, department of economic and social affairs, population division, New York, (ST/ESA/SER.A/352)
- Wang YC, Lin YK (2014) Association between temperature and emergency room visits for cardiorespiratory diseases, metabolic syndrome-related diseases, and accidents in metropolitan Taipei. *PLoS One* 9(6):e99599
- Wang YC, Lin YK (2015) Mortality associated with particulate concentration and Asian dust storms in Metropolitan Taipei. *Atmos Environ* 117:32–40
- Wang YC, Lin YK, Chuang CY, Li MH, Chou CH, Liao CH, Sung FC (2012) Associating emergency room visits with first and prolonged extreme temperature event in Taiwan: a population-based cohort study. *Sci Total Environ* 416:97–104
- Yang CY (2008) Air pollution and hospital admissions for congestive heart failure in a subtropical city: Taipei, Taiwan. *J Toxicol Environ Health A* 71(16):1085–1090
- Yang CY, Chang CC, Chuang HY, Tsai SS, Wu TN, Ho CK (2004) Relationship between air pollution and daily mortality in a subtropical city: Taipei, Taiwan. *Environ Int* 30:519–523
- Yu HL, Chien LC (2016) Short-term population-based non-linear concentration–response associations between fine particulate matter and respiratory diseases in Taipei (Taiwan): a spatio-temporal analysis. *J Expo Sci Environ Epidemiol* 26(2):197–206

Mei-Hui Li is a professor in the department of Geography at National Taiwan University. She received her Ph.D. degree from the University of Illinois at Urbana-Champaign. Her research interests extend across a wide range of environmental problems, with a particular focus on how anthropogenic activities affect the environment and human health. Her current work includes the development of biomarkers and bioindicators to monitor aquatic ecosystems, as well as how environmental change impacts ecosystem services and human health.