THE STATUS OF AIR POLLUTANT PM10 FROM A HUMAN HEALTH PERSPECTIVE IN TAICHUNG CITY, TAIWAN

by

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ABSTRACT

The Status of Air Pollutant PM_{10} from A Human Health Perspective in
Taichung City, Taiwan

Su-Miao Lai

The association of air pollution with health effects has been studied for decades. Many researches have shown that ambient air pollution is associated with respiratory disease and cardiovascular diseases. The Central Taiwan Science Park (CTSP) established in Taichung City raised residents' attention in terms of potential health effects caused by increased air pollution. The aim of this study attempts to analyze the status of PM_{10}, one of the major air pollutants, in Taichung City, Taiwan and estimate the likelihood of health effects. This research examined air quality data from the air monitoring stations, obtained from Taiwan's EPA. Specifically, PM_{10} concentrations from two air monitoring stations in Taichung City, in proximity to the CTSP and one control air monitoring station in Taichung County were first examined through time-trend graphs, descriptive statistics. A student's t-test was conducted to compare PM_{10} levels between the two years prior CTSP construction and two years after, in order to investigate whether CTSP played a role in terms of PM_{10} levels. The results of this test showed that after CTSP was built there was a small but statistically significant increase in the average PM_{10} levels. To conclude, this study compares the current status of PM_{10} to other large cities and estimates the health risk of long-term exposure to air pollution.

Table of Contents

Table of Contents - Continue

List of Figures

List of Figures - Continue

List of Tables

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I also want to thank for the support and encouragement from my family, friends and former colleagues in Taiwan.

Chapter 1

Introduction

According to environmental history, we have known of two major smog incidents around the 1950s. One had occurred in Donora, Pennsylvania, USA, 1948. Twenty people died, approximately six hundred were hospitalized, and thousands more were affected in that particular environmental disaster. The other one happened in London, UK in 1952, which was known as a killer smog and caused approximately four thousands deaths. These deaths drew worldwide attention to the relationship between air pollution and public health effects. Since then, there has been much research in this field.

Over the past few decades, research on air pollution has shown that it has significant impact on human health mainly on the respiratory system but also some evidence shows cardiovascular effects as well. The data from hospitalized patients and clinic visiting patients have been adopted as health indicators of the impact of air pollution. Many studies in western countries have been carried out due to the growing interest in particulate matter (PM) among the types of air pollutants, especially in United States and Europe. The research was conducted with data from many cities with prospective study or cohort study design. Several prospective epidemiological studies have been preformed with large cohorts in many cities.

Air pollution has been a big issue in central Taiwan. Residents have complained about air pollution and have expressed concerns about health effects related to environmental factors. In recent years, the government built a Central Taiwan Science Park in the suburb area of Taichung city. It is important to evaluate the concentration of air pollution of the surrounding environment with the goal to prevent respiratory illness and to ensure the safety of community. The present study will analyze the air pollution data over a period of time including the time of the Park construction, obtained from the air monitoring stations established by Environment Protection Agency of Taiwan.

There are six criteria pollutants included in the National Ambient Air Quality Standards (NAAQS), Ozone (O_3), particulate matter (PM), NO, CO, SO_2 and lead. In this study, PM_{10} will be addressed as a pollutant indicator. The primary research question to be addressed in this paper is as follows: “What is the status of air pollutants, specifically PM_{10}, from a human health perspective in Taichung City, Taiwan?”

Chapter 2

Health Effects Literature Reviews

2.1 Air Pollution and Health Effects

To date, there are many studies have confirmed that there is an association between PM_{10} concentration and health effects, both at low-dose and high-exposure levels. The health impact of particulate matter pollution is shown in Figure 1. There are many literature sources that provide some evidence for health outcome. Some of the major studies are summarized below.

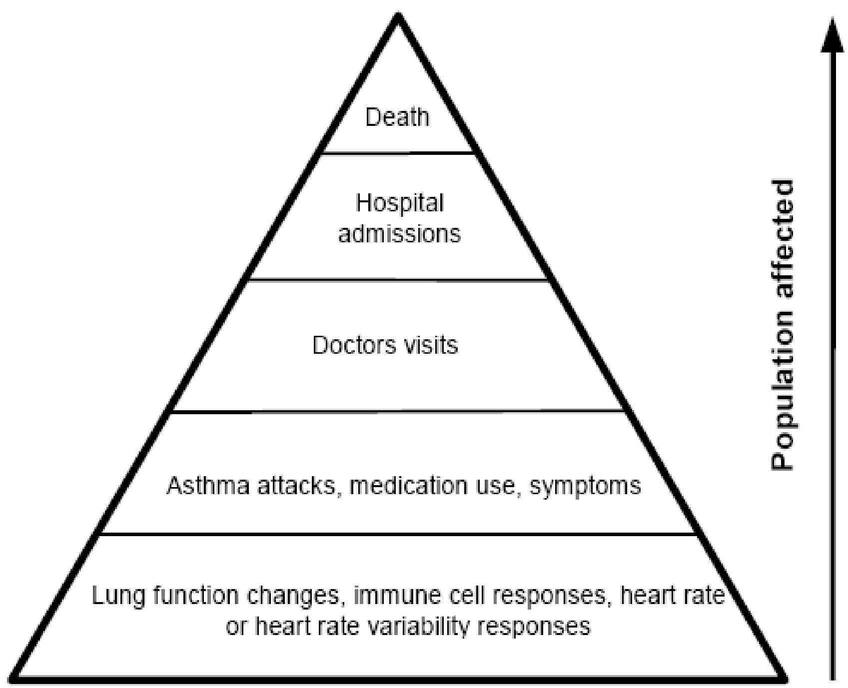

Figure 1 - Pyramid of the impact of particulate pollution (Ministry for the Environment, 2003)

2.1.1 Type of Air Pollution

According to the Clean Air Act (CAA), U.S. EPA selected six common air pollutants, which are known as criteria pollutions. They are particulate matter (PM), ozone (O_3), lead (Pb), carbon monoxide (CO), sulfur oxides (SO_2) and nitrogen oxides (NO and NO_2, together named NOx). PM is the term that describes a mixture of solid particles and liquid droplets found in the air. Different particles size has different health effects. $PM_{2.5}$ and PM_{10} are two major categories of particulate matter for which research has been done. PM2.5 is the particle with diameter less than 2.5 micrometers and PM_{10} is the particle with diameter less than 10 micrometers. In this study, PM_{10} is the pollutant of interest that will be investigated.

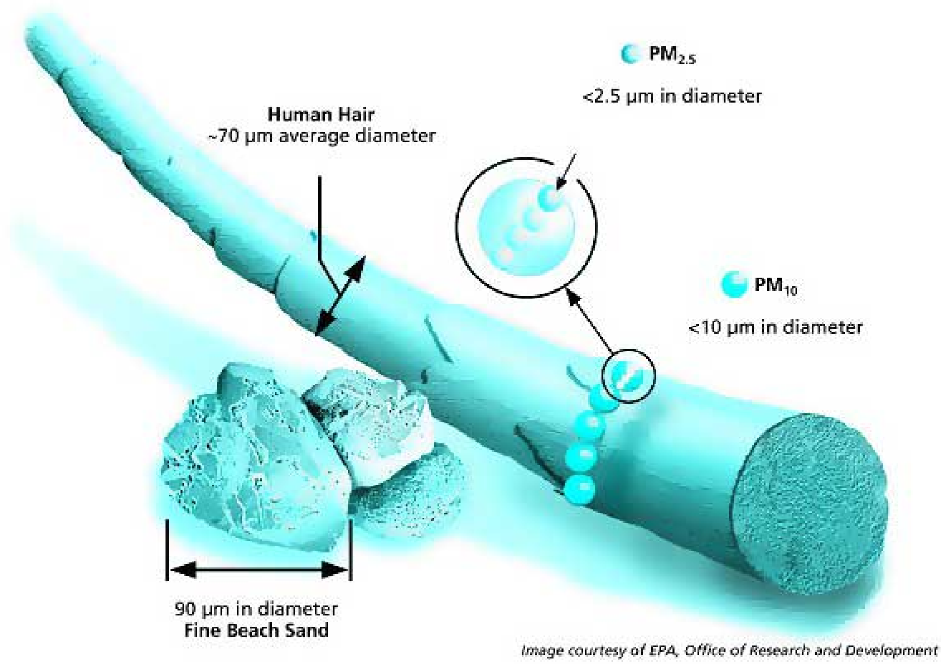

Figure 2 - Relative size of particulate matter pollutants (http://www.epa.gov/air/particlepollution/basic.html)

2.1.2 Physiology of Respiratory System

There are many particles in the air. Some sizes of particles are easy to inhale into the lung and cause health effects. The particles with diameter > 10μm usually precipitate within a short time and do not have high impact as health hazards, except for eye and upper respiratory irritation (nose, throat). The diameter of particles < 10μm are considered as particulate matter (PM_{10}). The main sources are traffic dust, vehicle, burning, industry and second pollutant from other air pollution. If the diameter is smaller, the chance of getting into the lung becomes bigger.

PM_{10} is particulate matter less than 10µm in aerodynamic diameter and $PM_{2.5}$ is particulate matter less than 2.5µm in aerodynamic diameter. General speaking, most the diameter of particles > 4.7µm will deposit on the nasal cavity and pharynx. The diameter of particles between 3.3µm and 4.7µm will deposit on trachea and bronchus. The diameter of particles between 2.1µm and 3.3µm will deposit on bronchiole. The diameter of particles between 1.1µm and 2.1µm will deposit on terminal bronchiole. The diameter of particles < 1.1µm will deposit on alveolar or alveoli. (EPA, Taiwan) Figure 3 illustrates the parts of the respiratory system.

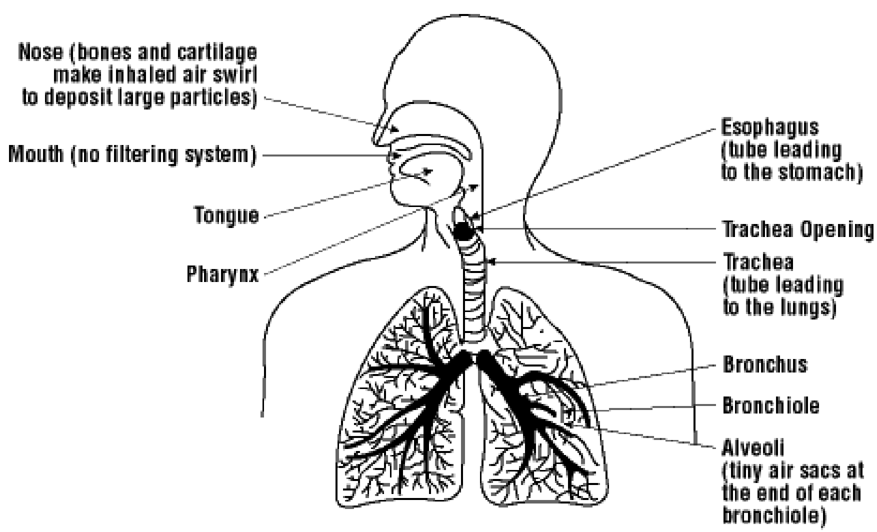

Figure 3 - The parts of the respiratory system (Canadian centre for Occupational and health Safety) (http://www.ccohs.ca/oshanswers/chemicals/how_do.html)

2.2 Studies of Human Health

Previous epidemiological studies have shown an association between the levels of ambient air pollutants and daily mortality ((Joel Schwartz, 1994; Klea Katsouyanni, et al., 2001), daily clinic and emergence room visits and hospitalization rate for respiratory disease and cardiovascular disease (B. Brunekreef & B. Forsberg, 2005; C. Arden Pope III, et al., 2004). Air pollutants had been found to contribute to both increased mortality and hospital admissions (Francesca Dominici, et al., 2006).

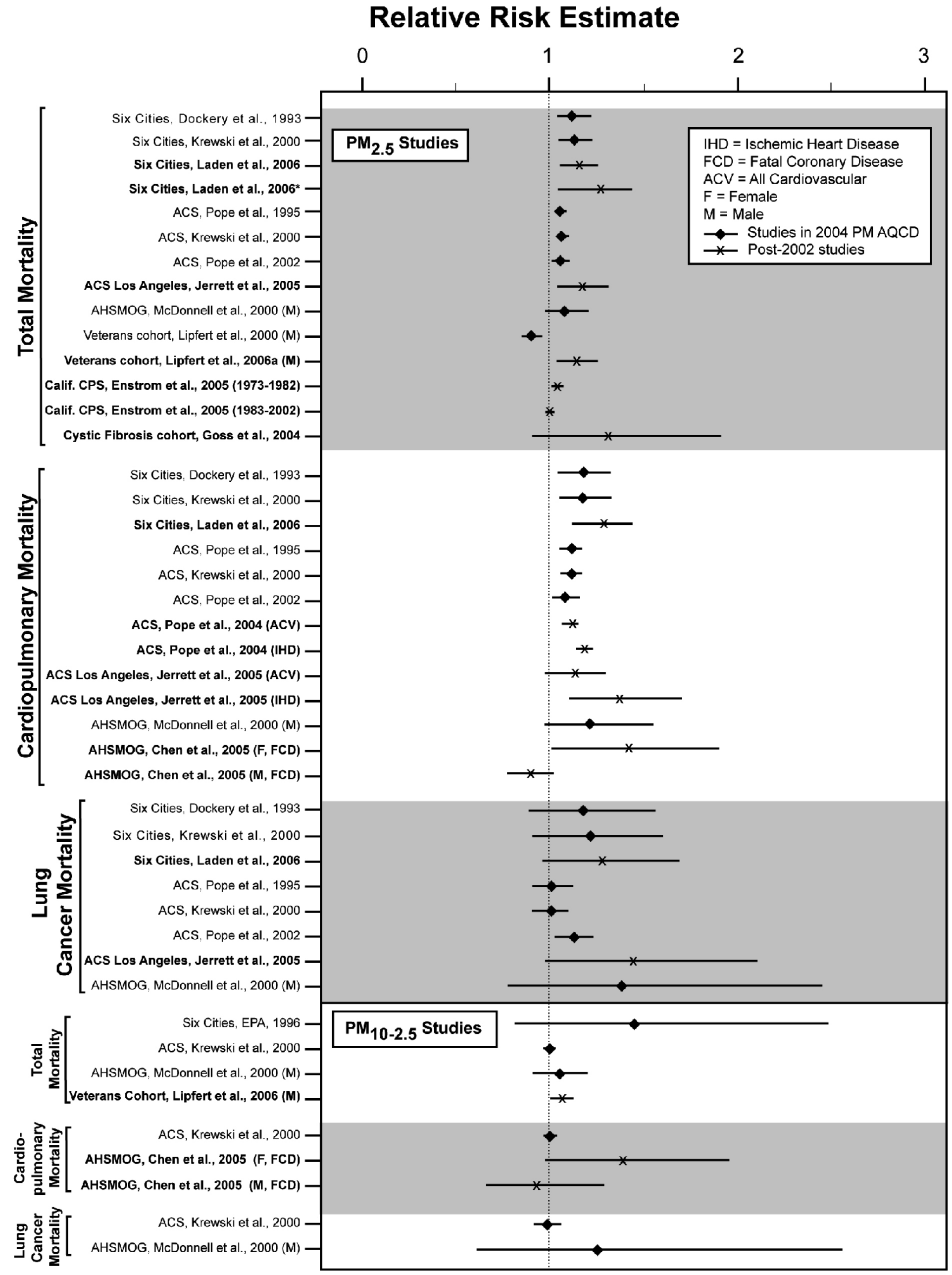

Figure 4 - Relative risk estimates (and 95% confidence intervals) for associations between long-term exposure to PM (per 10 PM10–2.5) and mortality. *Note the second result presented for Laden et al. (2006) is for the intervention study results (U.S. EPA, 2006a).

2.2.1 North America studies

The Harvard six cities study (SCS) (Moolgavkar, Dockery, & Pope, 1994) and American Cancer Society (ACS) Study (Pope, et al., 1995) have been particularly influential in contributing insights into particulate matter research as the leading studies. Both studies indicate particulate matter is associated with chronic health effects, such as cardiovascular, respiratory, and mortality (Pope, et al., 1995). Besides these two studies, many studies estimate relative risk for associations between long-term exposure to PM and mortality (Figure 4).

2.2.2 Europe studies

Air Pollution and Health: A European Approach (APHEA 2 project) (N. Kunzli, et al., 2000) investigated short-term health effects of particles in eight European cities. The study provides the evidence that particulate concentrations in European cities are associated with increased numbers of hospital admissions for respiratory diseases.

A collaborative study titled "Air Pollution and Health: A Combined European and North American Approach" shows the results of multicity time-series data on the effect of air pollution on respiratory disease. The study includes data from the European APHEA and the U.S. NMMAPS (National Morbidity, Mortality and Air Pollution Study) projects, as well as Canadian data (Evangelia Samoli, et al., 2008). This study found the health risk estimates of PM_{10} are similar in Europe and United States, but higher in Canada. Also, the risk for older age population is higher.

A cohort study conducted in the Netherlands found long-tern exposure to traffic-related air pollution may shorten life expectancy (Gerard Hoek, Bert Brunkreef, Sandra Goldbohm, Pual Fischer, & Piet A van den Brandt, 2002). Health and exposure data among 10 European cities were available for 2001 and 2002 (Ferran Ballester, et al., 2008) (Table 1).

Table 1 - European cities, demographic and environmental data (Ferran Ballester, et al., 2008)

City	Mortality and demographic data				PM10	
	Year of the data	**Annual deaths, 30 years and over**	**Population, 30 years and over**	**Mortality rate, 30 years and over (x1000)**	**Measurement method**	**PM10 measured levels (annual average, $\mu g/m^3$)**
Athens	2001	28407	2023945	14.04	β-attenuation	52.1
Barcelona	2002	16385	1033376	15.86	gravimetric	39.7
Budapest	2001	24291	1137019	21.36	TSP, β-ray	22.2
Hamburg	2001	17651	1176425	15.00	TEOM, β-absorption	19.1
Lisbon	2002	17895	1215742	14.72	β-attenuation	28.8
London	2001	54576	4166772	13.10	TEOM	13.1
Madrid	2002	25692	1952919	13.16	β-attenuation	33.3
Paris	2001	42983	3664892	11.73	TEOM	22.4
Rome	2001	21439	1754427	12.22	β-gauge monitor	47.3
Vienna	2002	16652	1052083	15.83	gravimetric	30.0

2.2.3 New Zealand studies

Two epidemiological studies addressed the relationship between particulate matter and health in New Zealand (Ministry for the Environment, 2003). One is the mortality impact of PM_{10} concentration and temperature (Simon Hales, Clare Salmond, G. Ian Town, Tord Kjellstrom, & Alistair Woodward, 1999), which is not like previous studies because it shows no relationship between deaths from cardiovascular disease and PM_{10} concentration. The other study indicated an increase in respiratory hospital admission and cardiac admissions with increased air pollution (J.A. McGowan, P.N. Hider, E. Chacko, & G.I. Town, 2002).

2.2.4 Asia studies

Unlike other countries, Asian countries do not have many studies of human health associations with ambient particulate matter. There are only a few studies that have addressed the association of exposure to PM10 and health outcomes and all are single-city studies in Asia. However, there are data showing that Asia has higher air pollution than western countries. The level of air pollution may be higher because most of the Asian countries are still developing and have fewer if any restrictions on environmental emissions. To date, there are many cities that still suffer from very high PM10 level in Asia (e.g. cities in China and India). China and India have been rapidly developing countries for the last two decades. Public health has been threatened by industry pollution in many ways, in addition to air pollution. Some western studies (e.g. APHEA) have served as a resource of methodology to help Asian countries to get on board with similar efforts to study air pollution health effects. Public Health and Air Pollution in Asia (PAPA) is an ongoing project based on APHEA (Evangelia Samoli, et al., 2008).

PAPA is a project supported through HEI (Health Effects Institute) for understanding the effects of air pollution on human health in Asia. Seven countries participated in this project, China, India, Malaysia, Philippines, Indonesia, Korea, and Vietnam. This project lasted four years from 2002 to 2006. It reviewed all of existing studies of air pollution and health outcomes in Asia, conducted new high quality studies in representative cities on health effects of air pollution, and provided local scientists more scientific and technical capacity (http://www.cleanairnet.org/caiasia/1412/article-48844.html).

An HEI report titled "The Health Effects of outdoor Air Pollution in Developing Countries of Asia: A literature Review" (Health Effects Institute, 2004) presents the epidemiological research of health effects associated with ambient air pollution in Asia from 1980 to 2003, with a total of 138 papers published in peer-reviewed literatures. Those studies were conducted in 9 countries, China, Taiwan, South Korea, Japan, India, Thailand, Malaysia, Singapore and Indonesia.

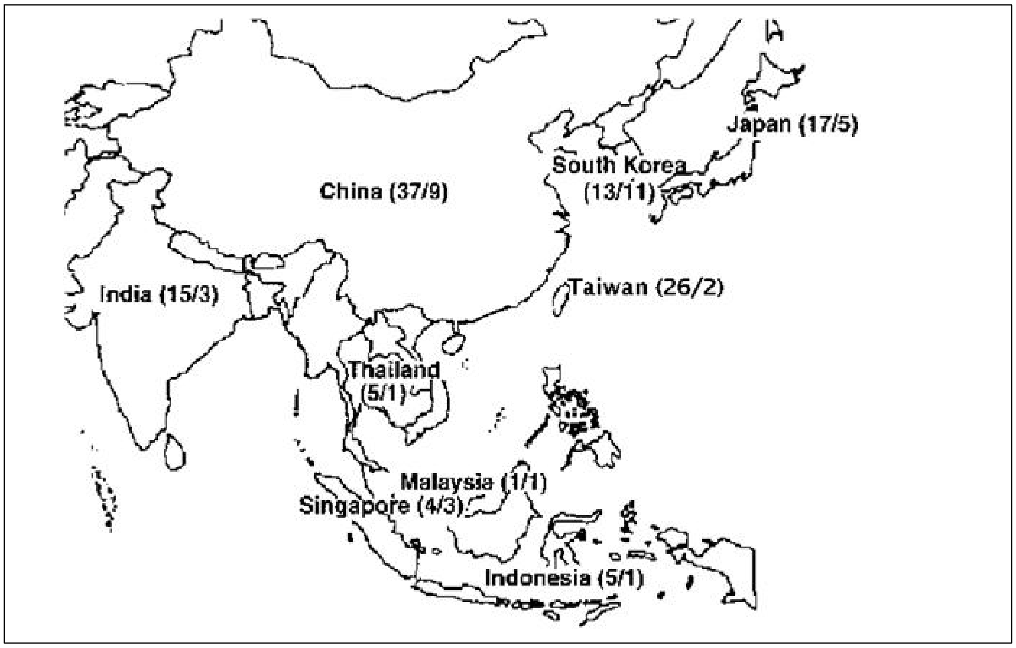

Figure 5 - Epidemiologic studies of air pollution in Asia published from 1980 to 2003. Numbers in parentheses are total studies/time-series studies conducted. (HEI Special Report 15 Executive Summary, Health Effects of Outdoor Air Pollution in Developing Countries of Asia, 2004)

2.2.5 Taiwan Studies

Like other Asian countries, Taiwan used to be a developing country and has very high concentration of PM level. It contributes a lot of research related to the association particulate matter with health effects. However, even though Taiwan is not a member of PAPA, it should be included in the global public health perspective. Taiwan has carried out short-term research to provide detailed information about the impact of air pollution on the Taiwanese population.

The association between air pollution and asthma is known world-wide. Asthma is characterized by a combination of inflammatory process and bronchial constriction that prevents the person from taking a deep enough breath. During the past several years, asthma has become a severe health issue and a public health challenge in Taiwan. Asthma prevalence in Taiwan was found to be 1.34%, 5.04% and 5.82% in 1974, 1985 and 1990, respectively (KH Hsieh & JJ Shen, 1988). Traffic-related air pollutants have been associated with asthma in school children (B-F Hwang, Y-L Lee, Y-C Lin, J J K Jaakkola, & Y L Guo, 2005; N. Kunzli, et al., 2000) .

Another study from Taiwan showed evidence of an association between PM10 and mortality from respiratory and cardiovascular disease among elderly people during the winter season (Wen-Miin Liang, Hsing-Yu Wei, & Hsien-Wen Kuo, 2009).

Chapter 3

Air Pollution in Taichung City, Taiwan

Air pollution has been raising serious public health concerns in Taiwan for several years, particularly with regards to respiratory illness, such as childhood asthma (B-F Hwang, et al., 2005). The association between ambient air pollution and health effects should be addressed in terms of public health. It has become a significant public health issue. Also, it is important to understand the current trends of air pollution in Taiwan and the projections to future pollution levels in light of new industry development and population increases. Excess health effects from increased air pollution would result in increased hospital visits that would greatly burden the national health care system budget. This study will be focused on the PM_{10} concentration in Taichung City and its associated health effects.

3.1 Geography

Taiwan is an island located in East Asia and has an area of 35,801 km^2 (13,822.8 sq mi). Given the small area and large population, the air pollution issue becomes more serious.

Figure 6 - The location of Taiwan in Asia (http://www.jccp.or.jp/english/country/img/asia_taiwan_map.gif)

Taichung city is a third largest city in Taiwan and is located in the Taichung Basin. The city is located just north of the 24° latitude and about 120.5° east longitude. Taichung city is composed of eight executive districts (Figure 8). In this study, the data collected are from three air monitoring stations located in Si-Tun District, West District and the southern boundary of South District.

Figure 7 - The location of Taichung City in Taiwan (commons.wikimedia.org)

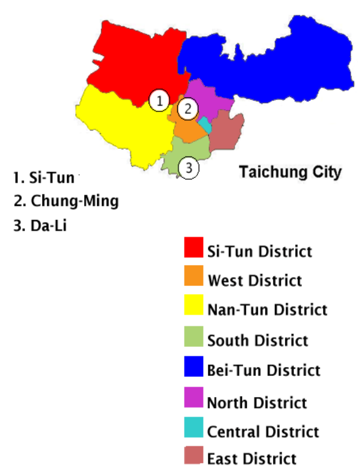

Figure 8 - The eight districts and three Taiwan EPA air monitoring stations in Taichung City

3.2 Climate

According to weather statistics, Taichung city’s annual average temperature is 23℃ (73°F), annual average rainfall is about 1,708 mm, and the average humidity is 80%. Taichung city usually has South-East and North-West wind in the summer and North and North-East wind in the spring, fall and winter (Source: Taichung Weather Station, Central Weather Bureau; data collected period: 1897-1995).

3.3 Demographics

The population in Taichung is now just over one million (January. 2009 = 1,066,843). The ratio of male and female is 95.31 (male/female*100). Population density is 6,524 persons per square kilometers.

3.4 Activities in Taichung City

Taichung City is the third largest city in Taiwan. The economy has been growing tremendously. Since its location is in the center of Taiwan, Taichung City has become an important transit center in Taiwan. Lately, Taichung Port has become a major port for airplanes and ships between Taiwan and China following some transportation policy changes. Also, many manufactures have moved into the area for work related to the Central Taiwan Science Park (CTSP) (Figure 9) and got involved in the construction that started since 2003. These activities have stimulated economic growth and development. On the other hand, they may be contributing to increased air pollution and impact on Taichung City residents’ health.

Figure 9 - Central Taiwan Science Park (Image from http://www.ctsp.gov.tw/)

An additional big concern in Central Taiwan is the Taichung coal-fired power plant. It's located in the area of Taichung port and generates the most electricity in the summer. According to a survey of CARMA (Carbon Monitoring for Action), Taichung coal-fired power plant had been ranked first in the world in terms of CO_2 emissions. It emitted 39,700,000 tons CO_2 and generated 39,200,000 MWh energy and 2,022 intensity presently (Data from CARMA (www.CARMA.org)).

Figure 10 - Taichung coal-fired power plant (image from http://tpctcps.myweb.hinet.net/)

3.5 Air Monitoring Stations

The air monitoring station in Da-Li monitors SO_2, CO, O_3, PM_{10}, NOx (NO, NO_2), spell this out before you abbreviate: THC, NMHC, CH_4, $PM_{2.5}$, CO_2. The monitor machine is established in a residential area. Da-Li station is located on the third floor of Da-Li City Hall. The average height of surrounding buildings is about 20 meters. To the North is Da-Li Elementary school. There is no building or structure in the area that could influence the accuracy of the data. In Figure 11 the panel number 5 shows the air monitoring machine. Panel numbers 1, 2, 3, 4, 6, 7, 8, and 9 show the surrounding environment.

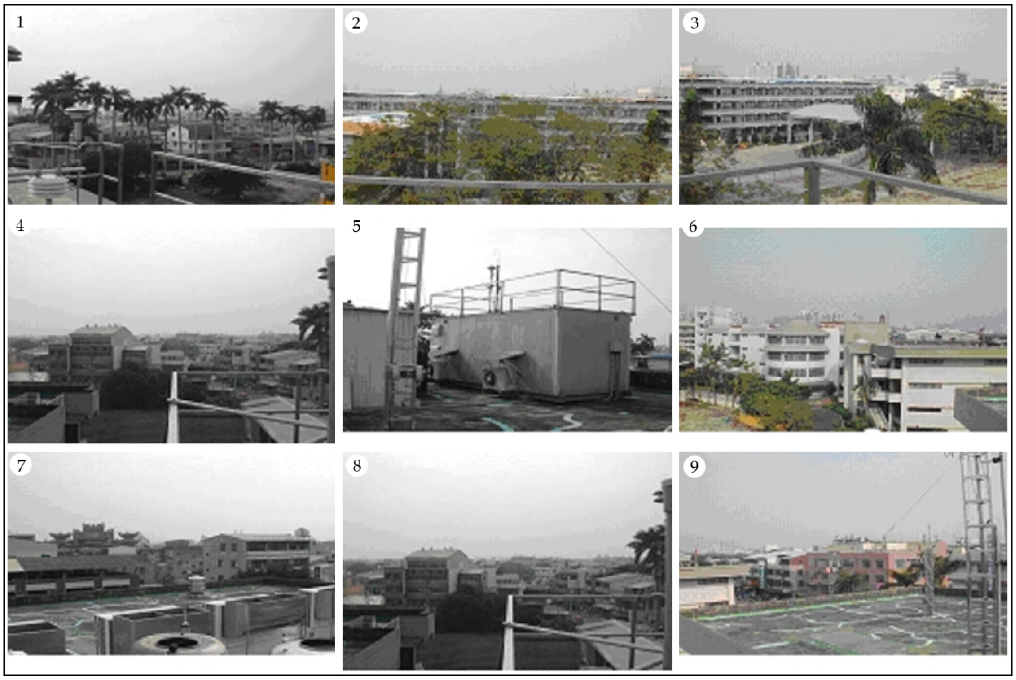

Figure 11 - Da-Li air monitoring station (EPA)

The Chung-Ming air monitor station is located on the third floor of Chung-Ming Elementary School. To the east, about 100 meters, is the Chung-Ming South Road that is 5 meters wide. To the south, about 150 meters, is the Chung-Kang Road that is 35 meters width. The traffic load is heavy because of these two roads. In Figure 12 the panel 5 shows the air monitoring machine. Number 1, 2, 3, 4, 6, 7, 8, and 9 of pictures are the surrounding environment.

Figure 12 - Chung-Ming air monitoring station (EPA)

Si-Tun station is in rural. It is located on the second floor of the administration building at National Taichung School for The Deaf. There are new school building constructions in front of building, farms in school's backyard, and northwest is Taichung Industry Park. Also, this station is about one kilometer away from waste water treatment plant. Si-Tun station monitors SO_2, CO, O_3, PM_{10}, NOx, NO, NO_2, THC, NMHC, CH_4. In Figure 13 the panel 5 shows air monitoring machine. Panel 1, 2, 3, 4, 6, 7, 8, and 9 of pictures are the surrounding environment.

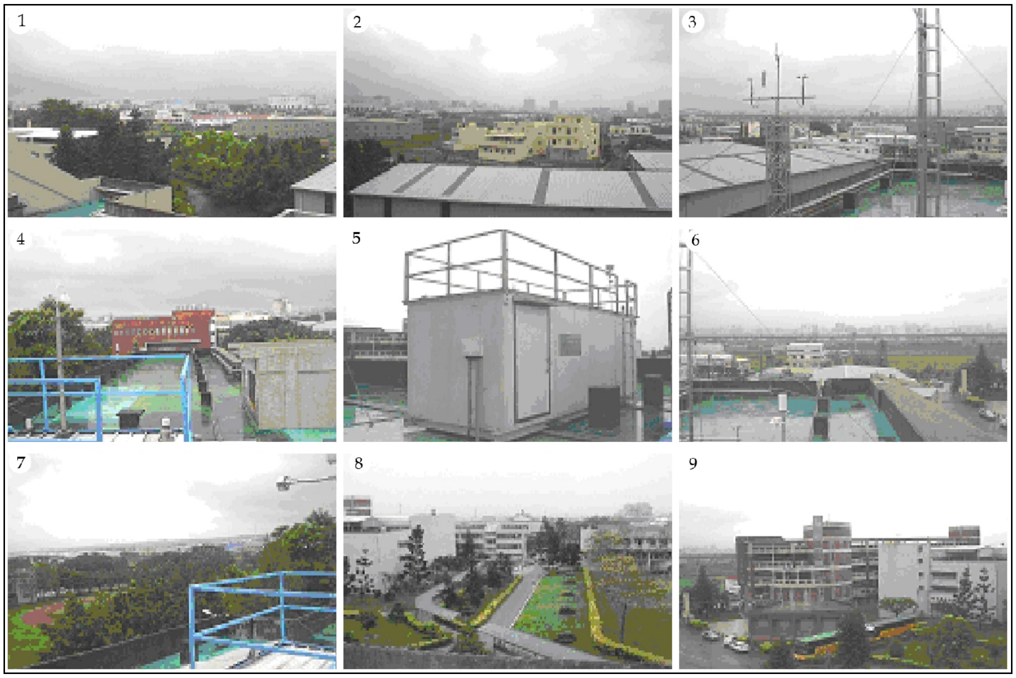

Figure 13 - Si-Tun air monitoring station (EPA)

3.6 Air Quality Regulation

In the United States, The Clean Air Act (CAA) was launched in 1990. It has been improving air quality in the states since then. In 2001, the Canadian federal government also declared PM_{10} as a toxic substance under the Canadian Environmental Protection Act (CEPA). The European Union also has standards for air pollutant criteria. Table 2 and Table 3 give a comparison of PM_{10} standard in some western and Asian countries.

Table 2 - Comparison of PM_{10} standards in western countries

Pollution	Averaging ($\mu g/m^3$)	U.S.	California	Mexico	Canada	E.U.
PM_{10}	1 day (24-h)	150	50	150	50	50
	1 year	—	20	50	—	40

— No value

Table 3 - Comparison of PM_{10} standards in Asia count

Pollution	Averaging (μg/m^3)	Japan	Korea	India	China	Hong Kong	Taiwan
PM_{10}	1 day (24-h)	100	<100	100	150	180	125
	1 year	—	<70	60	100	55	65

— No value

3.7 Central Taiwan Science Park

Compared to Taipei (first big city) and Kaohsiung (second big city), Taichung has less population and pollution. However, in recent years the Taiwan government intends to develop a plan for Taichung as a third business/industry city. Many city plans have been undergoing, and the Central Taiwan Science Park has the most impact in terms of growth.

The CTSP was planned to increase economic growth in Central Taiwan area. The CTSP Preparation Plan was approved by Executive Yuan on September 23, 2002 and broke ground on July 28, 2003. At the same time, firms started to move in and build the Park's facilities. CTSP includes six business types, which are precision machinery, optoelectronics, integrated circuits, biotechnology, communications, and computer accessories. Since the CTSP intends to be a big cluster of high technology business in central Taiwan, pollution concerns have been raising among the public, particularly for local residents.

Chapter 4

Methods

4.1 PM_{10} Measuring Technology

The Environmental Protection Agency (EPA) in Taiwan has three air quality monitoring stations (Figure 8) in Taichung area. They are located in Da-Li (Figure 11), Chung-Ming (Figure 12), and Si-Tun (Figure 13). These monitoring stations are fully automated and provide readings of PM_{10} levels using a technology called beta-ray absorption. The Figure 14 illustrates the Beta Attenuation Principle.

Beta-ray Absorption monitors can efficiently analyze the concentration of the particles in the air, and automatically and continually monitor particles in a long period of time. The principle of the design of beta-ray absorption monitors is to calculate the concentration of particles systematically based on the difference of radiant intensity on filter paper. The air sample from the atmosphere gets into the system by an air pump. Before the air enters the analytical system, the air goes through a sampling system. This system includes a sampling door for the collected air, filter to determine the size of particles, such as PM_{10} or $PM_{2.5}$, and heater equipment to eliminate water interaction.

When air sampling goes into the system, it goes through a specific material filter paper which will collect the particle in the air. There is an equipment that contains radioactive elements, such as Carbon-14, that emit electrons during the nuclear decay of these radioactive elements. When the radiation goes through the filter paper it loses intensity and it is counted on an acceptor to calculate radiation paused intensity.

The radiation intensity will be measured on the filter paper before and after collecting the particles. By doing so, we can recognize the difference. The difference of intensity reflects the ratio of the particulate matter. Thus, the system can calculate the concentration of PM_{10} or $PM_{2.5}$ in the air.

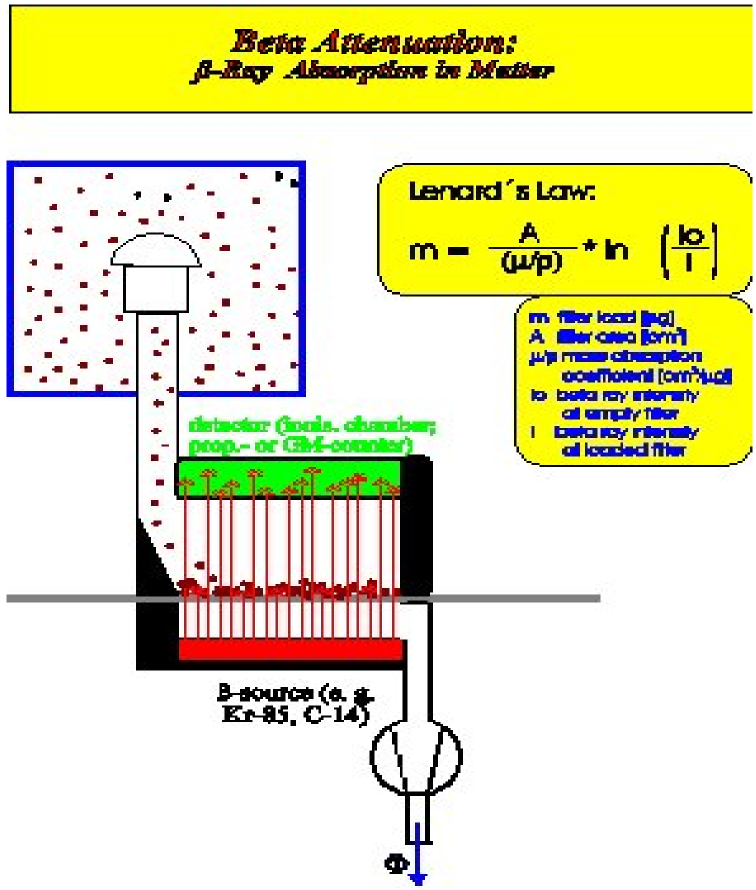

Figure 14 - Beta attenuation principle
(http://www.esmonline.de/andersen/product/group6/betaa.htm).

4.2 Data Sources

EPA in Taiwan has 123 regular air monitoring stations around the nation. They are used to measure basic air pollution criteria. In Taichung city, there are three stations, which are Da-Li station, Chung-Ming station and Si-Tun station.

For the purposes of this study, the data of PM_{10} concentration in Da-Li, Chung-Ming and Si-Tun stations were collected for fourteen years, from 1994 to 2007. These data were accessible and downloaded from the EPA air monitoring database.

Weather data, such as average annual temperature, average annual humidity and precipitation were collected from Taichung Weather Station, Central Weather Bureau. Population data were collected from Taichung City Hall.

Health effect data were provided by Department of Health, Executive Department, Taiwan. The data include mortality rate of lung cancer and cardiovascular disease and respiratory disease. Health effects from literature reviews will be used as well.

4.3 Data Analysis

I used SPSS Statistics 17.0 software package and Microsoft Excel to conduct statistical analysis. First descriptive statistics of PM_{10}, temperature, humidity and precipitation were computed.

The establishment of the CTSP 2003 drew the public's attention because of the concern that it would lead to increased air pollution in Taichung City area. To find out whether the CTSP had an impact on PM_{10} levels, annual average levels of PM_{10} before and after 2003, the year that the CTSP was established, were compared using a student t-test for two independent means. Time trends graphs were prepared to observe the trend of PM_{10} levels over time for the 14 years of study.

There are several possible factors that are associated with PM_{10} as shown in previous research, such as temperature (Cizao Ren, Gial M. Williams, & Shilu Tong, 2006; Cizao Ren & Shilu Tong, 2006; Steven Roberts, 2004), humidity (Wen-Chao Ho, et al., 2007) and traffic (Joachim Heinrich & Heinz-Erich Wichmann, 2004). In order to clarify the relative contribution of these factors, they were used as explanatory variables in a multiple regression analysis, with PM_{10} levels as the dependent variable.

In addition to the above, a regression analysis was performed to analyze the relationship between PM_{10} and some environmental factors which are temperature, humidity, precipitation and population. The annual PM_{10} value and seasonal PM_{10} value of three air monitoring stations are also presented.

After presenting the status of PM_{10} in Taichung City over time, I looked at the resident's health conditions. Time trends graphs were prepared to observe the trend of PM_{10} levels over time during the same time period for which air monitoring data were collected. I also prepared graphs of health conditions over the same time period for which air monitoring data were collected. The diseases with the top ten mortality rates show the primary health outcomes of Taichung City. I will estimate the impact of health effect based on current PM_{10} levels and statistical information of their relationship from other published studies.

Chapter 5

Results

5.1 Time Trend Comparisons of Air Pollutants in Two Air Monitoring Stations in Taichung City

To get a general idea about air pollutants in Taichung City, I compiled data from Taiwanese EPA air monitoring database to present annual average values of five pollutants, which are NO_2, NO, SO_2, PM_{10}, and O_3 from 1994 to 2007. In Taichung City, there are two air monitoring stations in Chung-Ming (Table 4) and Si-Tun (Table 5) that monitor and represent air quality.

Table 4 presents the average concentrations of NO_2, NO, SO_2, PM_{10} and O_3 from 1994 to 2007 at the Chung-Ming station. Table 5 presents the average concentrations of NO_2, NO SO2, PM_{10} and O_3 from 1994 to 2007 at the Si-Tun station.

Table 4 - Annual Average concentrations of five air pollutants at the Chung-Ming Station

						Air Pollutants
Chung-Ming	Year	NO_2(ppb)	NO(ppb)	SO_2(ppb)	PM10(μg/m_3)	O_3(ppb)
	1994	36.17	19.30	6.48	81.72	19.35
	1995	30.17	15.96	5.80	74.21	21.41
	1996	28.36	13.64	4.88	65.95	26.88
	1997	32.87	17.07	5.16	69.36	20.58
	1998	29.28	16.09	3.35	60.01	17.82
	1999	29.44	13.85	3.51	67.07	19.55
	2000	29.80	14.38	3.26	64.57	21.04
	2001	30.08	12.72	2.88	59.83	21.94
	2002	27.55	10.63	3.09	62.37	24.80
	2003	25.42	9.45	3.24	62.64	26.86
	2004	25.82	8.89	3.34	66.29	21.91
	2005	22.10	10.15	3.47	64.16	23.70
	2006	23.25	9.34	3.24	59.60	23.40
	2007	22.86	8.00	3.39	58.12	25.10

Table 5 - Annual Average concentrations of five air pollutants at the Si-Tun Station

					Air Pollutants	
Si-Tun	Year	NO_2(ppb)	NO(ppb)	SO_2(ppb)	PM_{10}($\mu g/m^3$)	O_3(ppb)
	1994	24.68	12.56	5.78	60.05	22.47
	1995	21.09	10.25	4.88	61.04	20.85
	1996	22.05	10.54	4.98	60.32	23.04
	1997	23.40	12.74	4.70	63.43	21.99
	1998	22.14	12.65	3.75	54.73	15.24
	1999	19.90	10.91	3.19	66.24	19.32
	2000	21.49	12.96	2.73	72.68	21.84
	2001	19.98	10.46	2.57	66.42	22.53
	2002	19.00	11.10	2.64	62.87	25.64
	2003	17.33	17.96	2.97	63.20	27.27
	2004	20.57	7.07	3.15	74.07	28.66
	2005	17.65	6.85	3.77	71.70	27.84
	2006	18.27	6.77	3.70	60.44	28.15
	2007	18.10	6.13	3.44	59.70	29.18

Among five pollutants in Taichung City, the trend of O_3 (Figure 15) levels are increasing in both Chung-Ming station and Su-Tun station. According to the measurements from the Si-Tun station, the O_3 levels were relatively stable from 1994 to 1997, decreased from 1997 to 1998 and have been increasing from 1999 to 2007. During the period of 1996 to 1998 and 2003 to 2004, the O_3 levels in Chung-Ming station decreased, otherwise increased.

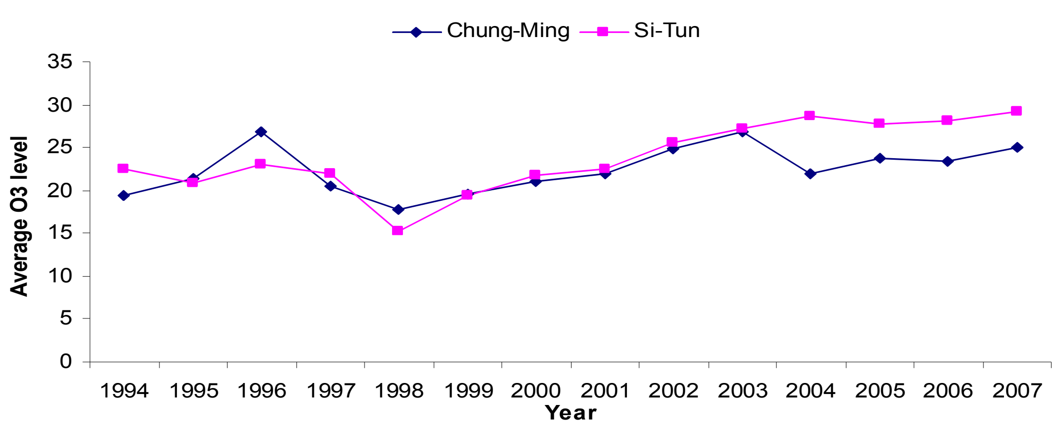

Figure 15 - O_3 levels in Chung-Ming and Si-Tun station 1994-2007

According to PM_{10} measurements in Chung-Ming station and Si-Tun station (Figure 16), PM_{10} concentration was decreasing from 1994 to 1998 and did not change a lot from 1999 to 2007. The trend of PM_{10} in Si- Tun did not have much change from 1994 to 2007.

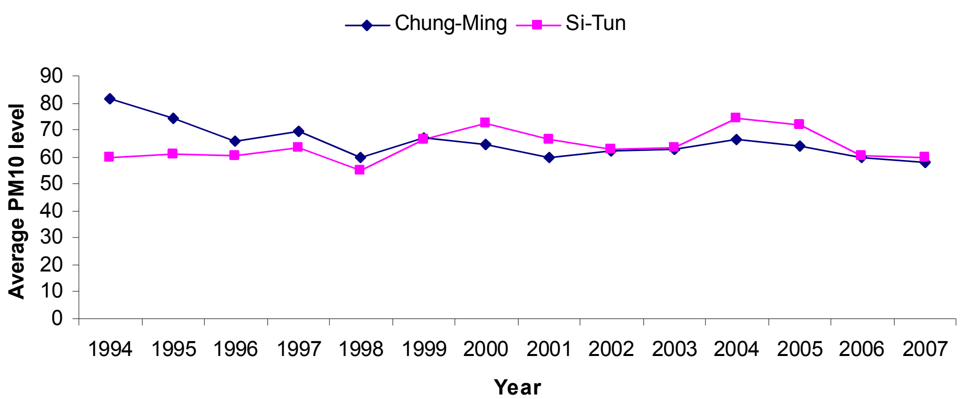

Figure 16 - PM_{10} levels in Chung-Ming and Si-Tun station 1994-2007

According to NO_2 measurements in Chung-Ming station and Si-Tun station (Figure 17), the trend of NO_2 concentration has been decreasing. Also, Chung-Ming station has reported consistently higher NO_2 concentration than Si-Tun station from 1994 to 2007.

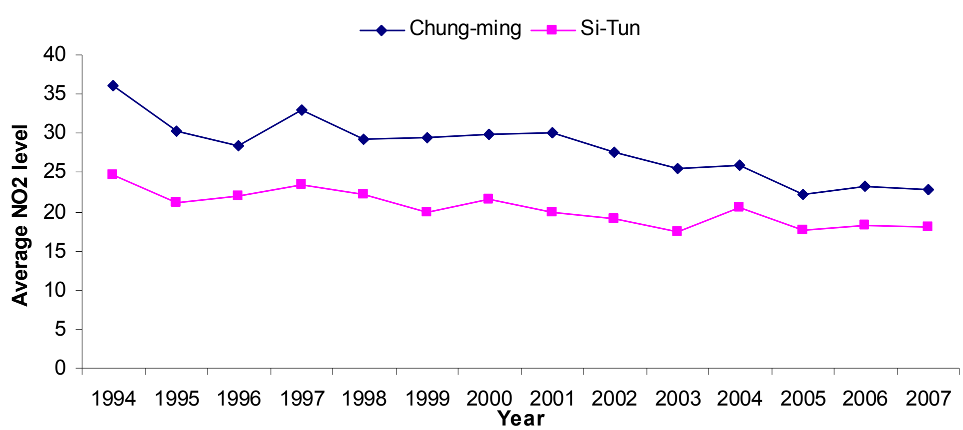

Figure 17 - NO_2 levels in Chung-Ming and Si-Tun station 1994-2007

The SO_2 levels reported from Chung-Ming and Si-Tun stations were close each year (Figure 18). It appears that SO_2 levels in both stations decreased from 1994 to 1998 and SO_2 levels have very slightly changed between 1999 and 2007.

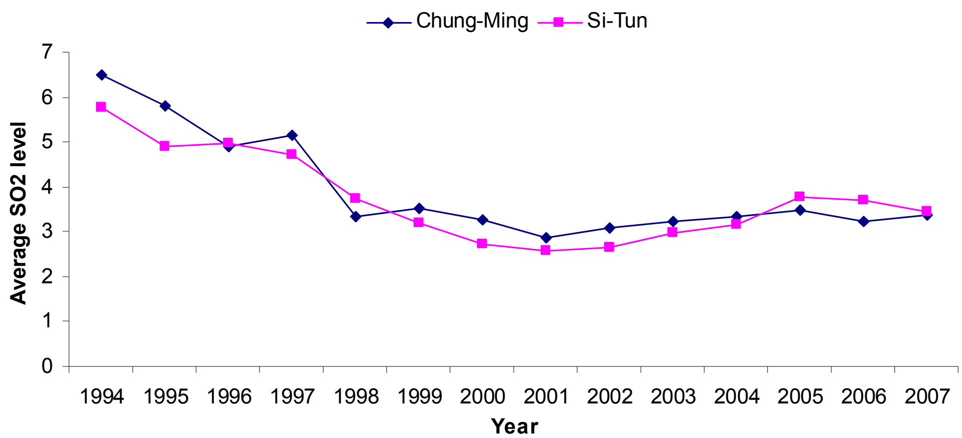

Figure 18 - SO_2 levels in Chung-Ming and Si-Tun station 1994-2007

Figure 19 shows that in general the Chung-Ming station has reported higher NO levels than Si-Tun station with the exception of the years 2002 when the NO level at Si-Tun station was equal or slight higher than Chung-Ming and particularly in 2003 when the NO level measured at Si-Tun peaked at much higher level than Chung-Ming station. Overall, the trend of NO recorded has been steadily decreasing over time.

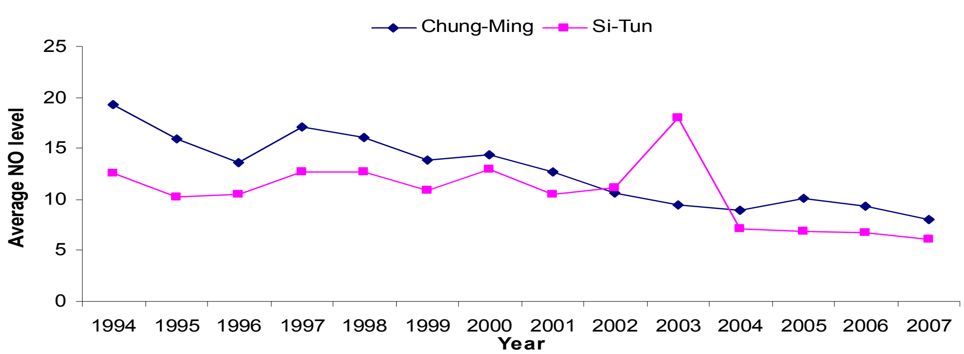

Figure 19 - NO levels in Chung-Ming and Si-Tun station 1994-2007

The sources of these air pollutants may be common among some of them, and this may result in similar changes in their levels. In order to see whether there is a relationship among them, I compared the correlation of air pollutants in both air monitoring stations in 2007. The results for Chung-Ming station showed that the relationship among air pollutants, while statistically significant, was moderate in strength besides the relationship of NO_2 and O_3 that was very low. The levels of PM_{10} were positively correlated with NO (r=0.30), NO_2 (r=0.66), SO_2 (r=0.71) and O_3 (r=0.42) (Table 6). The levels of NO were positively correlated with NO_2 (r=0.65), and SO_2 (r=0.23). The correlation of NO and O_3 was negative (r=-0.34). The correlation between NO_2 and SO_2 (r=0.51) was positive. SO_2 and O_3 were weakly but positively correlated (r=0.26).

Table 6 - Five pollutants correlation at the Chung-Ming station in 2007

	PM10	NO	NO2	SO2	O3
PM10	1	0.30**	0.66**	0.71**	0.42**
NO		1	0.65**	0.23**	-0.34**
NO2			1	0.51**	0.03
SO2				1	0.26**

** Correlation is significant at the 0.01 level (2-tailed).

Similar relationships among air pollutants were shown for the results from Si-Tun station. While statistically significant, the correlations were moderate in strength with the exception of the non-significant relationship of NO_2 and O_3. The levels of PM_{10} were positively correlated with NO (r=0.27), NO_2 (r=0.62), SO_2 (r=0.53) and O_3 (r=0.35) (Table 7). The levels of NO were positively correlated with NO_2 (r=0.66) and SO2 (r=0.26). The correlation of NO and O_3 was negative (r= -0.36). The correlation between NO_2 and SO_2 (r=0.47) is positive. SO_2 and O_3 are positively correlated (r=0.07).

Table 7 - Five pollutants correlation at the Si-Tun station in 2007

	PM10	NO	NO2	SO2	O3
PM10	1	0.27**	0.62**	0.53**	0.35**
NO		1	0.66**	0.26**	-0.36**
NO2			1	0.51**	0.06
SO2				1	0.07**

** Correlation is significant at the 0.01 level (2-tailed).

The air pollutant levels between Chung-Ming and Si-Tun stations showed significant positive correlations (Table 8). PM_{10} levels (r=0.63) between the Chung-Ming and Si-Tun stations are more strongly correlated than O_3(r=0.48), NO(r=0.39), NO_2(r=0.43) and SO_2 (r=0.26).

Table 8 - Pearson correlation coefficients between Chung-Ming station and Si-Tun station

PM_{10}	0.63**
O_3	0.48**
SO_2	0.43**
NO	0.39**
NO_2	0.43**

** Correlation is significant at the 0.01 level (2-tailed).

5.2 Comparisons for PM_{10} Concentration between Seasons and Air Monitoring Stations

One of the difficulties with describing the air pollution in any location is the accurate representation of the peaks of air pollution and the number of times that the levels exceed air quality standards. This information may be lost if levels are averaged over the entire year and it is not easily seen if only the average levels of each pollutant are reported. I analyzed the air monitoring data on PM_{10} and I compared the levels to the EPA PM_{10} 24 hour (24-h) standard. Besides the data of Chung-Ming station and Si-Tun station, I added the data from Da-Li station as a control. Da-Li station is located in a rural area in the border of Taichung City and is not close to Chung-Ming and Si-Tun stations. I found that the three air monitoring stations had different situations with regards to the incidence of daily PM_{10} level being above the 24-h standard (125µg/m^3). The data from the Da-Li station show that the number of days when PM_{10} levels were above the PM_{10} standard decreased from 1994 to 2002, started to increase from 2003 to 2005 and after 2005 the days decreased again to 2007 (Figure 20). The annual average concentration also had the same trend.

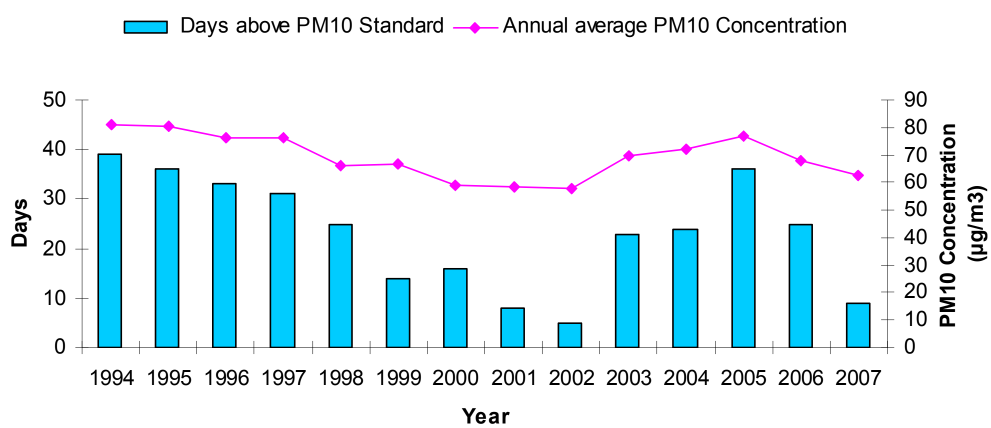

Figure 20 - 1994-2007 Da-Li station PM_{10} concentration

Figure 21 shows that the annual average PM_{10} value in Chung-Ming station ranged between 60µg/m3 and 80µg/m3. Before 2000 Chung-Ming station recorded more days with PM_{10} levels above the 24-h standard (125µg/m3). After 2000 the days above standard decreased with the exception of the year 2004. This year follows the start of the Science Park construction and may indicate a temporary increase in pollution that didn't continue after completion of construction.

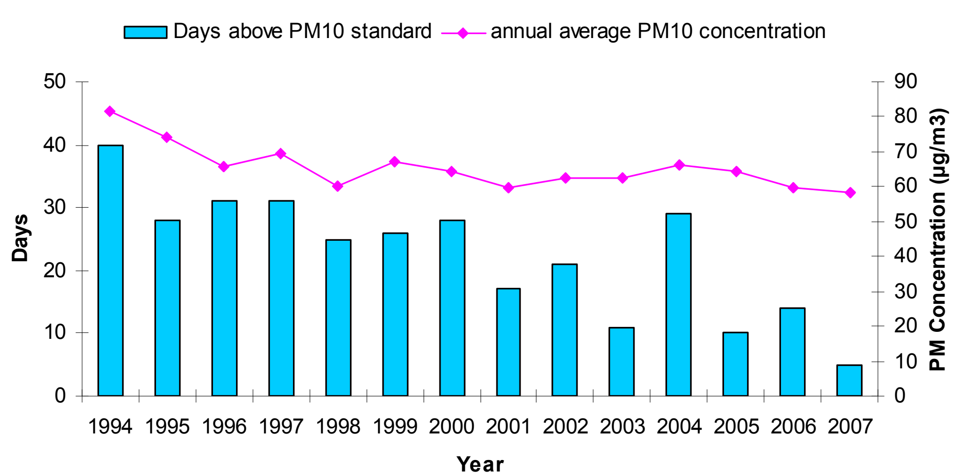

Figure 21 - 1994-2007 Chung-Ming station PM_{10} concentration

In contrast, the records from Si-Tun station show fewer days of PM_{10} above standard before 2000, but more days in 2000. After 2000, the days above PM_{10} standard decreased until 2004 and increased in 2005 (Figure 22). Just as with the Da-Li station, after 2005 the days exceeding the 24-h standard decreased again to 2007. The annual average PM_{10} concentration was between 55µg/m^3 and 75µg/m^3 from 1994 to 2007. Pollution recorded in 2004 at both stations was higher although it was also high in 2005 at the Si-Tun station. It appears that each station is influenced by different sources of PM_{10}. The reason for the high PM_{10} levels recorded at the Si-Tun station in 2000 is not clear.

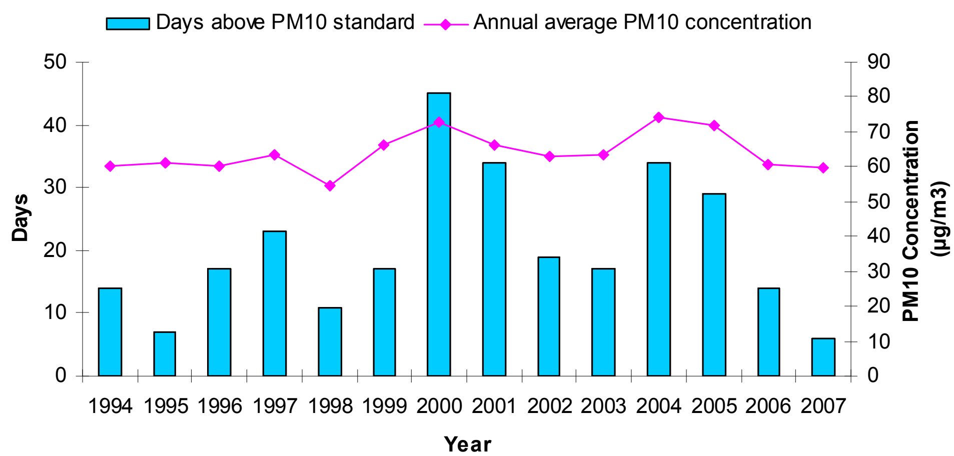

Figure 22 - 1994-2007 Si-Tun station PM_{10} concentration

I used one-way ANOVA to analyze the average PM_{10} among three air monitoring stations from 1994 to 2007. To satisfy the requirement of normal distribution of the data before using ANOVA, I had to transform PM_{10} data into $\ln(PM_{10})$ to meet the normality criterion. The homogeneity of variances test show unequal variance ($p=0.005$). Post-hoc test under unequal variance showed the average PM10 measured in Dali was significantly higher from that in Chung-Ming ($p<0.000$) and in Si-Tun ($p<0.000$).

Air pollution is likely affected by the seasonal weather patterns. Besides looking at annual average of PM_{10}, I integrated the daily PM_{10} into four seasons and considered the trend of seasonal PM_{10} average. March, April and May are determined as spring. June, July and August are determined as summer. September, October and November are determined as fall. December, January and February are determined as winter. Figure 23, Figure 24 and Figure 25 show that the average PM_{10} levels appear to be lower in the summer compared to spring, fall and winter according to measurements from all three air monitoring stations.

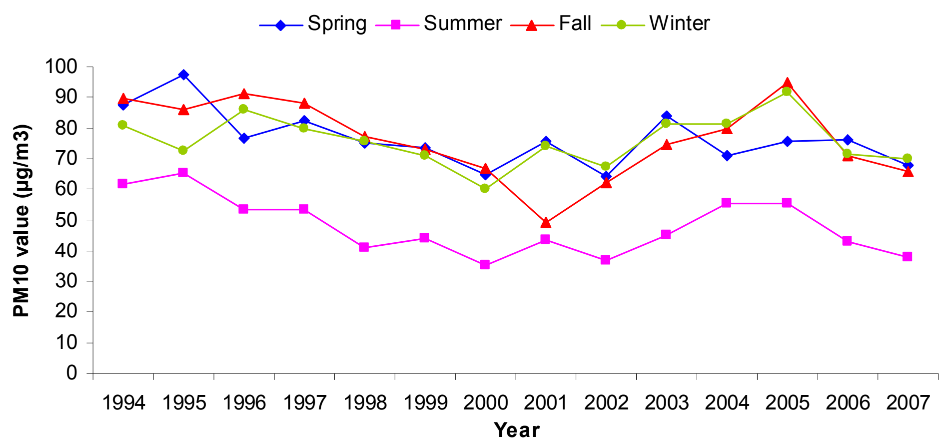

Figure 23 - Seasonal PM_{10} levels in Da-Li station

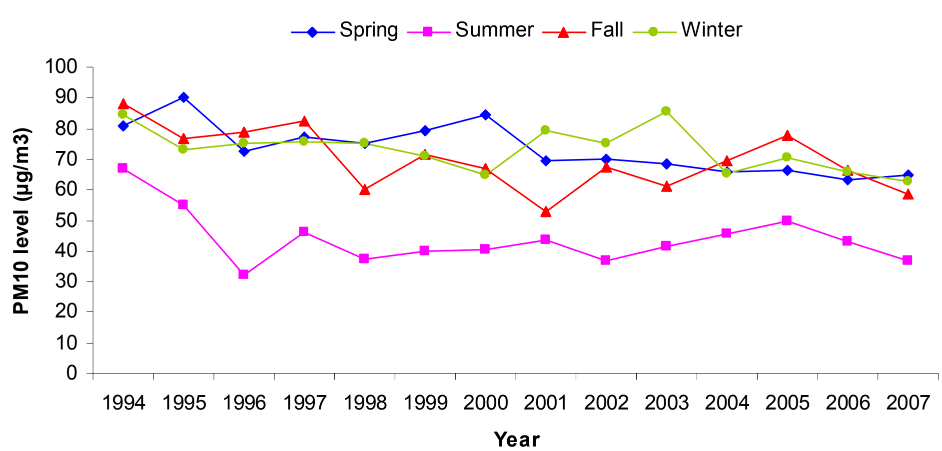

Figure 24 - Seasonal PM_{10} levels in Chung-Ming station

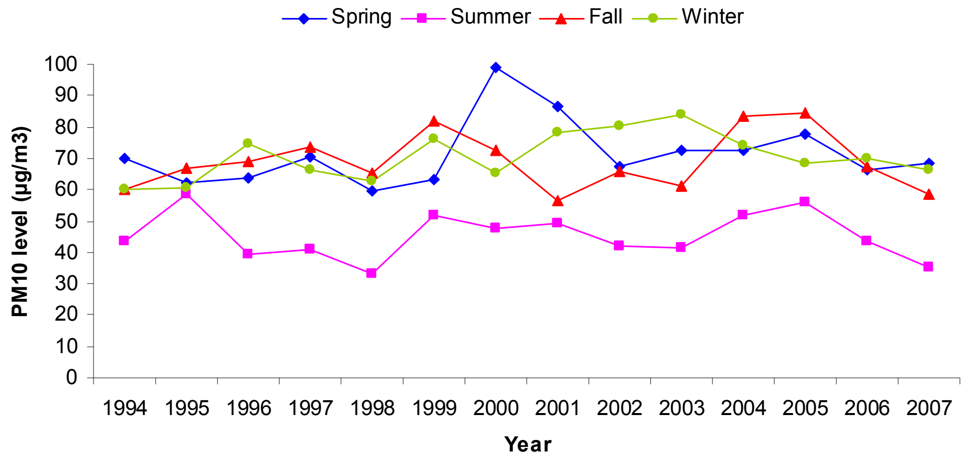

Figure 25 - Seasonal PM_{10} levels in Si-Tun station

The average PM_{10} values in spring for all three stations ranged between 59.4µg/m^3 and 99µg/m^3 (Figure 26); in summer between 32.3µg/m^3 and 66.8µg/m^3 (Figure 27); in fall between 49µg/m^3 and 94.8µg/m^3 (Figure 28) and in winter between 60µg/m^3 and 91.7µg/m^3 (Figure 29). Among all three of the air monitoring stations, the seasonal average PM_{10} levels indicated that summers had consistently lower PM_{10} levels.

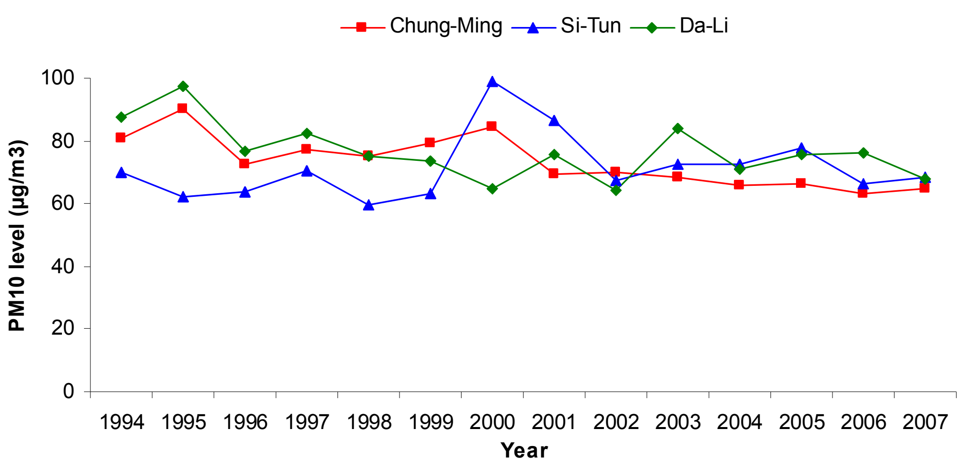

Figure 26 - Spring PM_{10} levels in three air monitoring stations

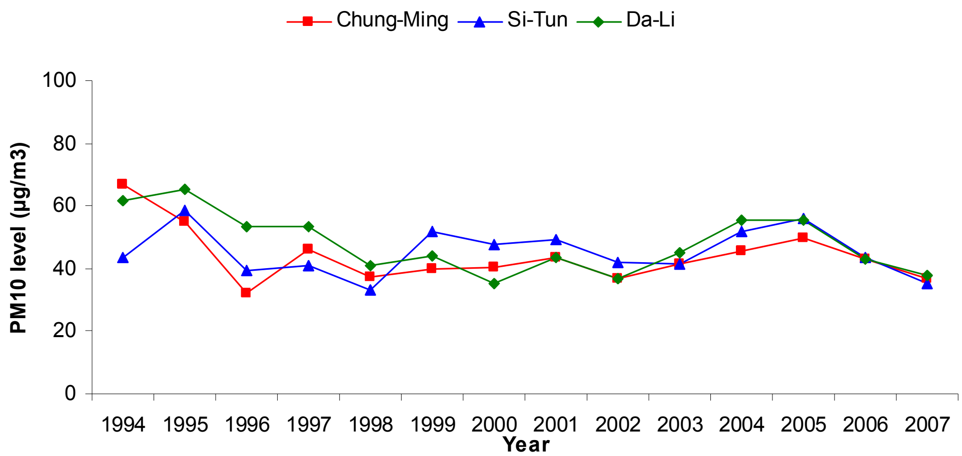

Figure 27 - Summer PM_{10} levels in three air monitoring stations

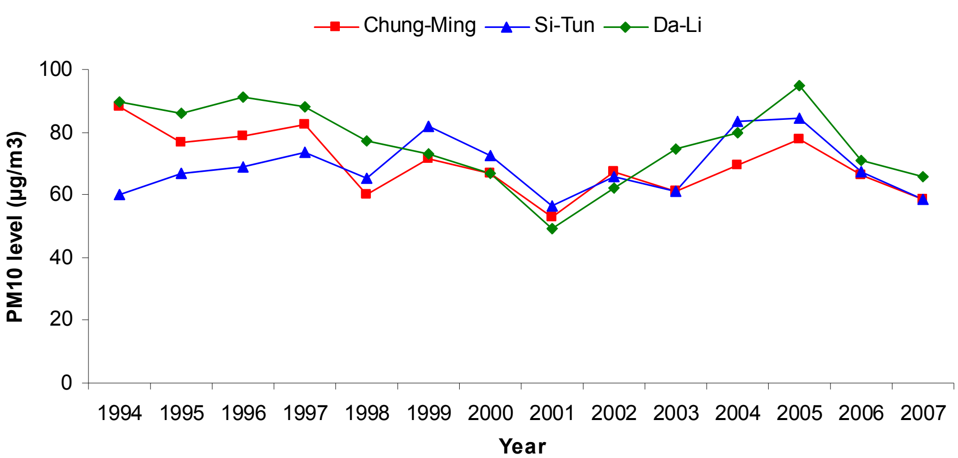

Figure 28 - Fall PM_{10} levels in three air monitoring stations

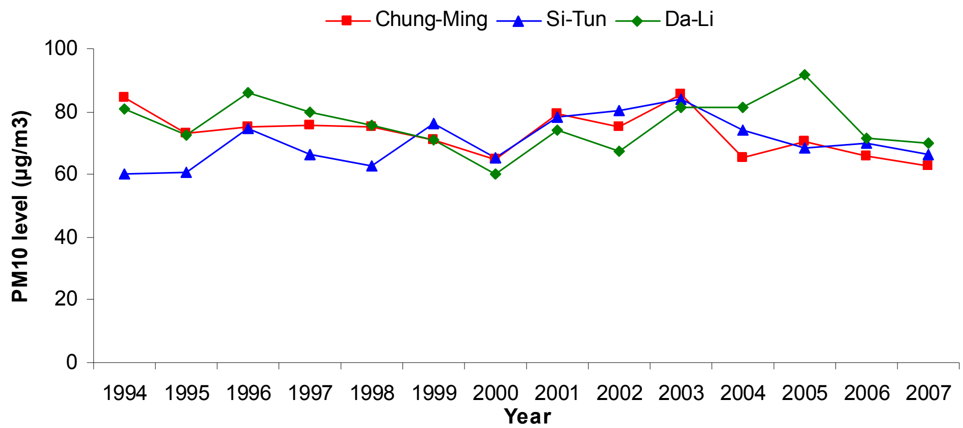

Figure 29 - Winter PM_{10} levels in three air monitoring stations

While the average PM_{10} levels present a summarized picture of this air pollutant, a more complete description must include the full range of PM_{10} measurements. Figure 30 shows the frequencies of a range of PM_{10} levels between seasons and air monitoring stations. It appears that the PM_{10} levels present a moderate right skew and similar distribution among spring, fall and winter in the period from 1994 to 2007, but a more pronounced skewed distribution to the right in the summers.

Also, the range of PM_{10} distribution was from 0µg/m^3 to 400µg/m^3. This indicates that residents had higher exposure on those high PM_{10} level days, substantially higher than the standard.

The Frequency of PM10 levels bwtween Seasons and Air monitoring Stations

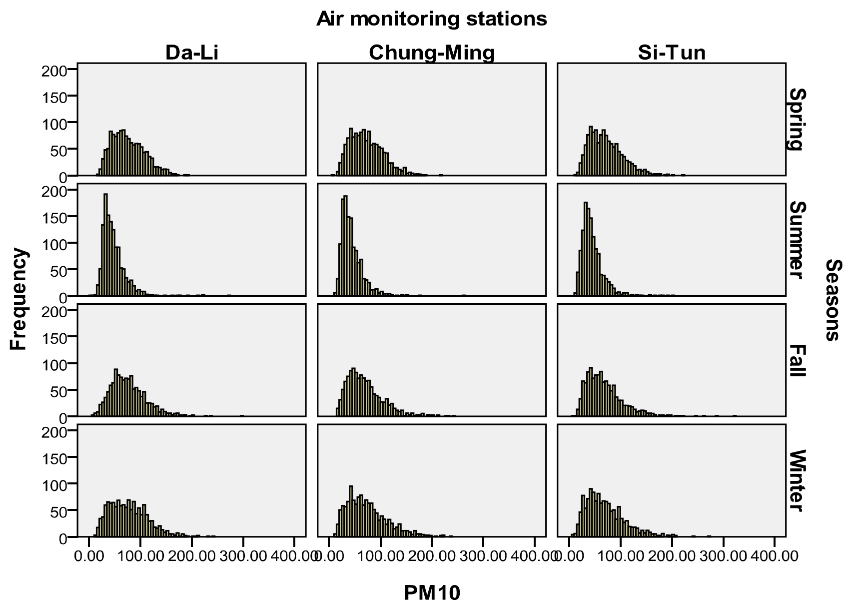

Figure 30 - PM_{10} Frequency between seasons and air monitoring stations

5.3 Comparison for PM_{10} Concentrations before and after the CTSP

The construction of the CTSP has attracted residents' attention and raised their concerns in terms of increasing air pollution in the surrounding area. I conducted t-test to see if there is a statistically significant difference on PM_{10} between before and after the Central Taiwan Science Park was built. I employed monitoring data on daily PM_{10} levels for the twenty-four months before and twenty-four months after the CTSP construction began. The data were obtained from the Si-Tun station because this is the closest to the location of the CTSP and reflects the air quality of that area.

Since the CTSP construction began in July 2003, the daily PM_{10} value between July 2001 and June 2003 will be used as a variable for before the CTSP was built. The daily PM_{10} value between July 2003 and June 2005 will be used as variable for during and shortly after the CTSP construction. The hypothesis is that daily PM_{10} levels have had a significant increase after the CTSP construction began. After removing the null data, I had 696 PM_{10} daily observations before the CTSP construction started and 725 PM_{10} daily observations during and after the CTSP construction phase (Table 9). The t-test for two sample means was preformed. The average PM_{10} level before the CTSP built was 63.42μg/m^3 with standard deviation 33.84 μg/m^3. The average PM_{10} level after CTSP built was 68.16μg/m^3 with a Standard deviation 37.09μg/m^3. The result suggested that PM_{10} levels are significantly higher after the CTSP was built (t= -2.52, p=0.012, CI=(-1.04, -8.44)).

Table 9 - Descriptive Statistics about PM_{10} before and after CTSP

		N	Mean	Std.Dev	Std. error
PM_{10} (μg/m3)	Before CTSP	696	63.42	33.84	1.28
	After CTSP	725	68.16	37.09	1.38

Since it appears that the PM_{10} levels were higher on average following CTSP construction and that health effects are more pronounced on days of peak pollution when the standard is exceeded, I used t-test method to see if there was a difference in the number of days exceeding the standard before and after the CTSP. I organized the data as two groups. One group included the number of days exceeding the standard in each month for 24 months before CTSP was built (total of 43 days). The other group included the number of days exceeding the standard in each month for 24 months after CTSP was built (total of 52 days). Then a two samples t-test method was conducted. The result revealed that there was no statistically significant difference in the number of days exceeding the PM_{10} standard between before and after CTSP was built (p=0.65).

5.4 Multiple Regression Model for PM_{10}

Many studies indicated that temperature, population, precipitation and humidity could be factors that affect ambient PM_{10} levels. In this study, Multiple Linear Regression (MLR) will be preformed to analyze the relationship between PM_{10} levels and temperature, population, precipitation and humidity in Taichung City from 1994 to 2007. Table 10 presents the descriptive statistics for temperature, population, precipitation, humidity, PM_{10}.

Table 10 - Descriptive Statistics of PM10 parameter in the multiple regression model

	N	Min.	Max.	Mean	Std.
Annual average temperature (F)	14	73.2	75.7	74.49	0.66
Annual average humidity (%)	14	72.4	77.1	74.7	1.66
Annual average rainfall (mm)	14	930.6	2574.5	1859.13	474.92
Population (persons)	14	832654	1055898	959466.7	73320.5
Annual average PM10 level (μg/m^3)	14	60.1	74.3	66.3	4.716

Temperature, population, precipitation and humidity are the independent variables, and PM_{10} is the dependent variable. In order to conduct multiple regression method, all of the variables should be quantitative variables and data should satisfy all of assumptions, which are linearity, normality and homoscedasticity. From examination of the Residuals Plots, it is indicated that the assumptions of linearity, normality and homoscedasticity are satisfied. Also, in the scatter plot matrix of each independent variable with the dependent variable, linearity and normality are confirmed.

There is no missing data and no outliers. The χ^2 critical value is 18.47 (df=4) at α=0.001. All of the cases with MAH_1 are less than 18.47. Thus, we do not need to eliminate any case.

After all assumptions are fulfilled, I conduct a multiple linear regression to investigate if I can use temperature, population, precipitation and humidity to predict PM_{10} in Taiwan City. The model shows a statistically significant prediction of PM_{10} in Taiwan City at the 5% significance level (R^2=0.641, F (4,9) = 4.022, p=0.039).

In the coefficients table, each parameter is tested for the hypothesis that it has no relationship with the PM_{10} levels or that its coefficient is equal to zero. The t-values and p-values provide the results of testing the null hypothesis for each parameter. Because none of the p-values is <.05, we can not rejected the null hypothesis that they are equal to zero and therefore the coefficients do not provide any evidence that there is linear relationship between each independent variable and PM_{10}. In other words, the coefficients for temperature (-4.622), humidity (-0.011), precipitation (0.001) and population (-1.92×10^{-5}) are not significantly different from 0 ($p>0.001$). Even though the overall model is valid and it is statistically significant for the set of parameters, each parameter is not significantly associated with PM_{10} levels. This model accounts for 64.1% of variance on the PM_{10}. Tolerance for all variables is greater than 0.1, so multicollinearity is not a problem in this study.

The regression equation in natural units is

$$PM_{10} = 428.84 - 4.62 Temperature - 0.01 Humidity + 0.001 Percipitation - 1.92 \times 10^{-5} Population$$

Indeed, the interpretation of the coefficients would not describe the relationships in a meaningful way. The coefficient of temperature is -4.622. So, for every increase of one unit on temperature, the PM_{10} is predicted to be lower by 4.622. The coefficient of humidity is -0.011. So, for every increase of one unit on humidity, PM_{10} is predicted to be lower by 0.011. The coefficient of precipitation is 0.001. So, for every increase of one unit on precipitation, PM_{10} is predicted to be higher by 0.001. The coefficient of population is -1.92×10^{-5}. So, for every increase of one unit on population, PM_{10} is predicted to be lower by 1.92×10^{-5}.

This indicates that these parameters are not enough by themselves to predict PM_{10}, as expected, and that other important factors that affect PM_{10} levels, such as sources of PM_{10} must be included. Unfortunately, no related data were available. However, there is some correlation between the parameters used and PM_{10}.

The correlation coefficient of annual average temperature with annual PM_{10} level is -0.756, indicating a strong correlation. The correlation coefficients of annual average humidity, annual average precipitation and population with annual PM_{10} level are 0.075, 0.018 and -0.515, respectively. This indicates that annual average humidity, annual average precipitation and population have little correlation with annual PM_{10} level.

5.5 Public Health - Current Situation in Taichung City

Figure 31 presents the top 12 diseases in Taichung City that have high mortality. Approximately 131.96 deaths per 100,000 persons were cancer patients, 36.93 deaths per 100,000 persons were cerebrovascular disease patients, 35.55 deaths per 100,000 persons were heart disease patients, and 4.37 deaths per 100,000 persons were related to bronchitis, chronic and unspecified, emphysema and asthma.

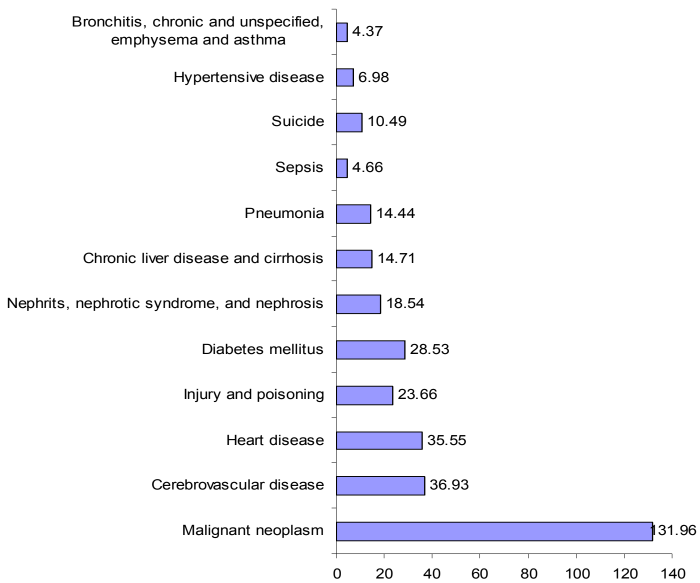

Figure 31 - Top 12 mortality rates of diseases (per 100,000 persons) in Taichung City 2001-2007

From 2001 to 2007, cancer prevalence rate was highest among the morality rates of diseases. After stratifying the data, Figure 32 shows lung cancer had highest death rate in the malignant neoplasm category, followed closely by liver cancer. Figure 33 shows that lung cancer death rate slightly increases from 2001 to 2007.

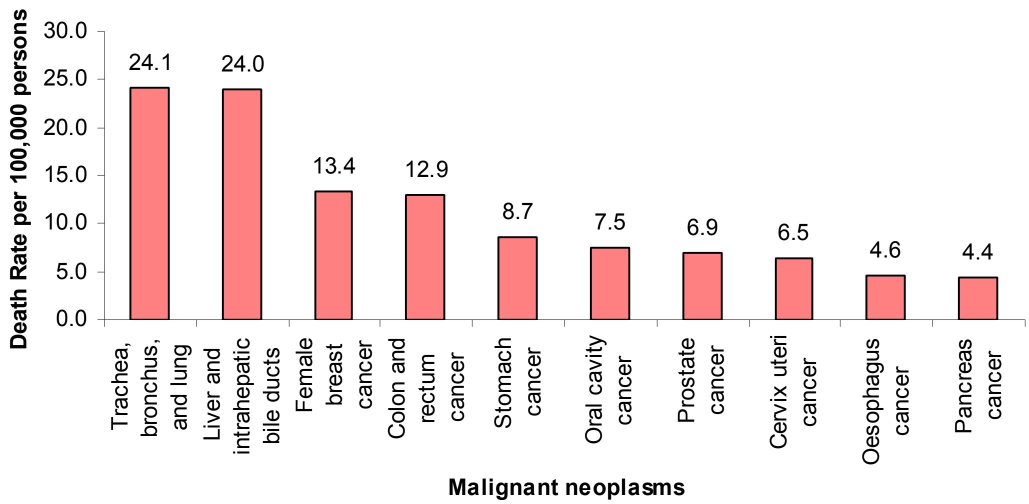

Figure 32 - Average death rate of cancer in Taichung City 2001-2007

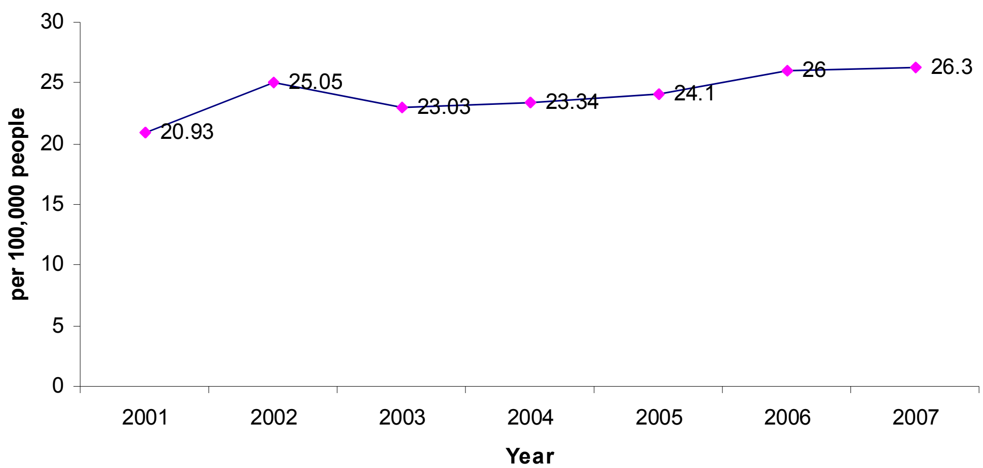

Figure 33 - Lung cancer death rates in Taichung City 2001-2007

As shown in the Figure 34, cerebrovascular disease declined from 2001 to 2004 and increased slightly from 2004 to 2007. The mortality rate of heart disease also showed an overall increasing trend with more variation. The mortality rate of the category including bronchitis, chronic and unspecified, emphysema and asthma was observed much less than the other two diseases associated with PM_{10}.

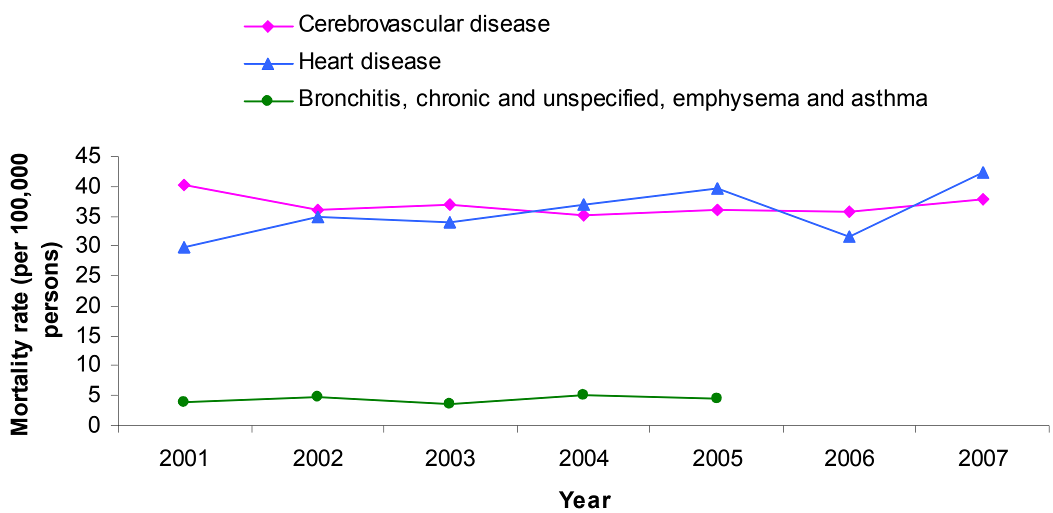

Figure 34 - Mortality rate of disease associated with PM_{10}

Chapter 6

Discussion and Conclusion

6.1 Review of Research Findings

6.1.1 Interpretation for the Results

There are many research studies on air pollution and its associated health effects over the world. Epidemiology-based health outcomes were used to quantify the effect of air pollution (Kunzli et al., 2000). However, it is difficult to measure precisely how air pollution impacts human health. Even if we measure the pollutants concentration in a certain area, many uncertainties still exist regarding the health effects impact for the residents. Air pollution existing in the air could be transported anywhere, depending on the wind direction. This study used two air monitoring stations in Taichung City to address the air pollution levels in the area and one air monitoring station in the Taichung County as a control. The results suggested the levels of pollutants in both Chung-Ming and Si-Tun were positively correlated and statistically significant. It shows air pollution levels in both Chung-Ming and Si-Tun were consistent.

The associations of particulates with daily mortality have been reported at lower concentration in locations which were humid and had high air pollution in cold weather (J. Schneider & A. Marcus, 1990). The extreme temperature is associated with cardiovascular mobility/mortality (Rupa Basu & Jonathan M. Samet, 2002). I found PM_{10} concentration in the cold weather appeared higher PM_{10} concentration in Taichung City. Wong et al. (T W Wong, W S Tam, T S Yu, & A H Wong, 2002) found that several pollutants had a statistically significant impact on daily mortality in the cool weather. Liang et al. (2009) had found the evidence of an association between PM_{10} and mortality from respiratory and cardiovascular diseases, especially among elderly people during the winter. However, there are many studies have addressed that temperature might be the confounder (Klea Katsouyanni, et al., 2001) or modify (Cizao Ren, et al., 2006; M. Stafoggia, J. Schwartz, F. Forastiere, C. A. Perucci, & Group, 2008) the association between PM_{10} and mortality. Other studies however, found little evidence for an interaction between ambient particulate matter and temperature on mortality (Samet, 1998; Roberts, 2004). Data on the health outcomes associated with ambient air pollutants were not available for this study. The relationship between PM_{10} and mortality in this study has not been addressed. However, based on the literature, the PM_{10} levels in Taichung City are higher than other cities and could be a factor for increasing respiratory diseases and heart diseases.

Five air pollutants in both Chung-Ming and Si-Tun have a strong positive correlation. The CTSP seems to play a role for increasing PM_{10} levels in Taichung City. The CTSP construction started in July 2003. I examined the levels of PM_{10} over time and I showed that in 2004 both Chung-Ming and Si-Tun stations recorded more days with PM_{10} levels above the standard. Si-Tun station had higher daily PM_{10} concentration than Chung-Ming station. This may be explained by the fact that Si-Tun station is located in the same district as the CTSP and had more impact from the CTSP during the time of construction.

Although the multiple linear regression model significantly predict PM_{10} with population, annual average temperature, annual average humidity and annual average precipitation (R^2=0.641, F (4,9) = 4.022, p=0.039), the coefficients of factors are too small to explain the relationship. This lack of strength can be explained because I used annual average value of temperature, humidity, precipitation and PM_{10} value not daily values.

Even before the CTSP was established, a coal-fired power plant in Taichung City has been running since 1998. This might explain the reason why Taichung City has high PM_{10} levels. More energy demand might happen because of the CTSP operation and development. Ambient air quality regulation should follow to address this issue.

6.1.2 Comparing Results in term of Health Effects in other Countries

Although this research did not study the association of PM_{10} levels and health effects directly, the past 10-20 years research have confirmed that ambient air pollution contributes to mobility and mortality (R. Wilson & J. Spengler, 1996).

Health effects from PM exposure have been widely discussed. Health effects can be defined into two categories – those that result from acute exposure and those that are related to chronic exposure. The health effects from acute exposure include mortality, hospitalization, increased respiratory symptoms, decreased lung function, heart rate variability, and pulmonary inflammation. Chronic PM exposure includes increased mortality rates, reduced survival times, chronic cardiopulmonary disease, and reduced lung function. Many studies had shown elderly, infants, children and persons with chronic cardiopulmonary or respiratory diseases have more risk under particulate matter exposure (Chun-Yuh Yang, Hui-Ju Hsieh, Sang-Shyue Tsai, Trong-Neng Wu, & Hui-Fen Chiu, 2006; D E Abbey, B L Hwang, R L Burchette, T Vancuren, & P K Mills, 1995; T J Woodruff, J Grillo, & K C Schoendorf, 1997).

The annual average PM_{10} level in two air monitoring stations in 2007 were 58.12$\mu g/m^3$ and 59.7$\mu g/m^3$, respectively, in Taichung City. Compared with European cities (Figure 39), residents in Taichung City might have higher risk on respiratory diseases and heart disease. Pope et al. (C. Arden Pope III, 2007) reviewed selected studies of short-time exposure and reported estimation of percent increase in mortality risk (Table 11). Approximate 0.4% ~1.3% mortality risk increases per 20 µg/m3 PM_{10} exposure increment. Schwartz et al. (1997) presented that the health effects from PM_{10} depends on the amount of fine particles. Kuo et al. (Hsien W. Kuo, Jim S. Lai, Mon C. Lee, Ru C. Tai, & Ming C. Lee, 2002) reported the prevalence rates of asthma were correlated significantly with NO_2 (r=0.63) and O_3 (r=0.51) concentrations. He also reported the levels of NO_2 and PM_{10} were correlated significantly with monthly hospital admissions.

Table 11 - Estimates of percent increase (95% confidence intervals) in mortality risk across selected studies of short-term exposure (Pope III, 2007) (partial)

Short-time exposure			Percent increases in mortality risk (95%)
Study area and type	Primary sources	Exposure increment	All causes
Meta-estimate from Single-city studies	Anderson et al. (2005)	20μg/m3 PM10	1.2 (1.0, 1.4)
U.S. 10-cities	Schwartz (2000c,2003b)	20μg/m3 PM10	1.3 (1.0, 1.6)
U.S. 14-cities case-crossover	Schwartz (2004)	20μg/m3 PM10	0.7 (0.4, 1.0)
NMMAPS 20-100 U.S. cities	Dominici et al. (2003a)	20μg/m3 PM10	0.4 (0.2, 0.8)
APHEA-2 15-29 European cities	Katsouyanni et al. (2003) Analisis et al. (2006)	20μg/m3 PM10	1.2 (0.8, 1.4)

Guo et al (1999) and Hwang et al. (B-F Hwang, et al., 2005) both found an association between traffic related air pollution concentrations and the risk of asthma in school children. The long term exposure to traffic-related out door air pollutants, such as NOx, CO and O_3, increases the risk of asthma in children were confirmed (Hwang et al., 2005). Bates et al. (DV Bates, M. Baker-Anderson, & R Sizto, 1990) also found the correlation between emergency visits caused by asthmatic symptoms and PM_{10} concentrations. The hours between 6:30am-8:30am and 5:00pm-7:00pm are traffic peak periods in Taichung City. Many people travel to work or school with motor scooters during traffic peak periods. The scenario of long time exposure should be of high concern.

Brunekreef and Forsberg reviewed published time series studies about the association between fine and coarse particles and hospital admissions for respiratory problems and indicated many studies had found hospital admissions increase when particulate matter level increases (Figure 33). The average of respiratory admissions is approximate 5.1% increase per 10μg/m^3. He also indicated chronic obstructive pulmonary disease (COPD) admissions (Figure 34) and cardiovascular admissions (Figure 35) increase when particulate matter is increasing. The average of CODP admissions and cardiovascular admissions are approximate 7.1% and 2.5% increase per 10μg/m^3, respectively.

According to the population of Taichung City, with 10 μg/m^3 PM_{10} increase, approximately 54,409 residents will be admitted in the hospital because of respiratory problems, approximately 74,679 residents will be admitted in the hospital because of CODP problems, and approximately 26,671 residents will be admitted in the hospital because of cardiovascular problems. Schwarts et al. (1993) found the daily emergency visits for people under age 65 years were associated significantly with PM_{10} exposure on the previous day. In this study I found that PM_{10} level increased after CTSP was built ($t=-2.52$, $p=0.012$, CI=(-1.04, -8.44)). The results indicate residents in the Taichung City exposure higher PM_{10} level since the CTSP started construction.

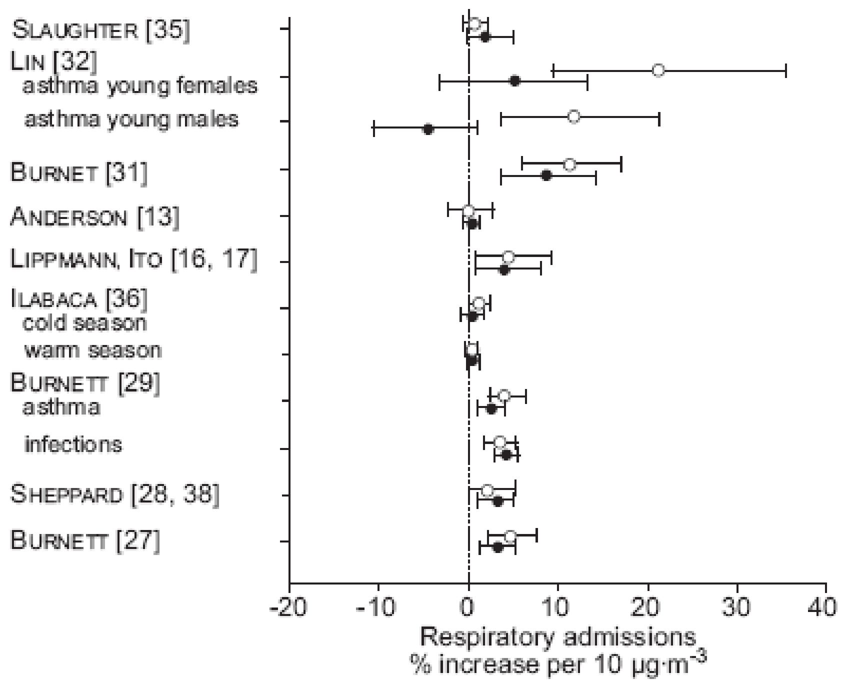

Figure 35 - Effects of fine (•) and coarse (◦) particles on respiratory admissions in published time series studies (Brunekreef and Forsberg, 2005).

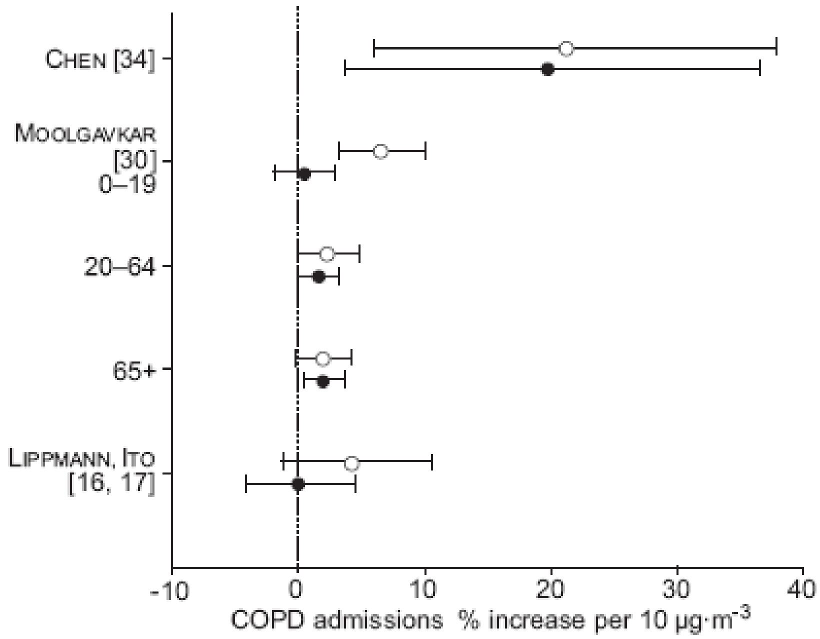

Figure 36 - Effects of fine (•) and coarse (◦) particles on chronic obstructive pulmonary disease (COPD) admissions in published time series studies (Brunekreef and Forsberg, 2005).

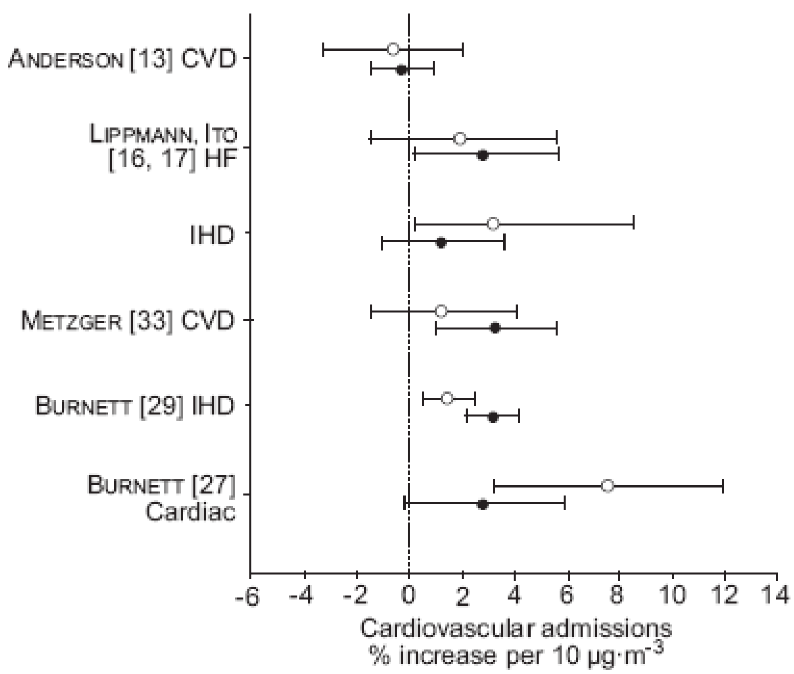

Figure 37 - Effects of fine (•) and coarse (◦) particles on cardiovascular admissions in published time series studies. CVD: cardiovascular disease; HF: heart failure; IHD: ischaemic heart disease (Brunekreef and Forsberg, 2005).

The correlation between PM_{10} exposure and increasing risk of lung cancer has been observed (Pope et al., (C.A.r. Pope & D.W. Dockery, 2006). Y. Sanchez-Perez et al. (Yesennia Sanchez-Perez, et al., 2009) also suggested that DNA damage could be the way by which particulate matter exposure increases the risk of lung cancer. Lung cancer has been the top one or two cancers in Taichung City last decade. The average death rate of lung cancer was 24.1 per 100,000 people during 2001-2007. The time trend showed the prevalence of lung cancer in Taichung has been increasing (Figure 32). The death rate of lung cancer in 2007 was 26.3 per 100,000 people. In the Washington State and US nation, the death rate of lung and bronchus cancer were 51.5 and 52.8 per 100,000 people, respectively (Figure 38). It seems like more research are needed to investigate the association between PM_{10} exposure and lung cancer risk. The scenario is still unclear, especially since smoking is a critical and significant confounding factor for lung cancer. The prevalence of smoking in Taichung that may be responsible for lung cancer has also been increasing.

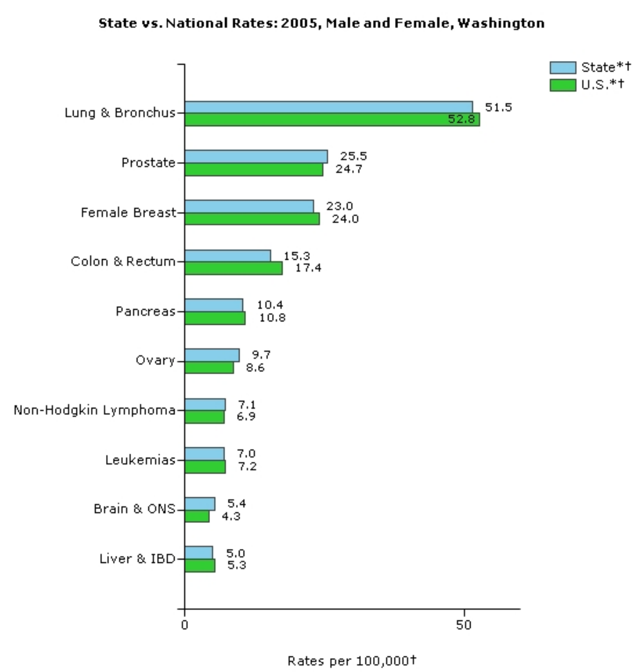

Figure 38 - Age-Adjusted Cancer Death Rates for the 10 Primary Sites with the Highest Rates within State- and Sex-Specific Categories (United States Cancer Statistics, CDC)

Daniels et al. (Michael J. Daniels, Francesca Dominici, Jonathan M. Samet, & Scott L. Zeger, 2000) reported PM_{10} and cardiorespiratory deaths numbers in 20 largest cities in the US (Figure 39). It showed the PM_{10} concentrations in most of cities were between 20μg/m^3 and 40μg/m^3. The PM_{10} concentrations in big cities range from 3.6 μg/m^3 to 46 μg/m^3, in San Diego and Los Angeles respectively. Compared to the PM_{10} concentration in Taichung was 66.3μg/m^3, there is reason for concern for higher cardiorespiratory disease risk in Taiwan. However, from the figure it seems that there is no good relationship between deaths and PM_{10} levels. Specifically, with the exception of NYC, LA and Chicago all other cities seem to have low death rates despite differences in PM_{10} levels, so it is clear that other factors contribute too.

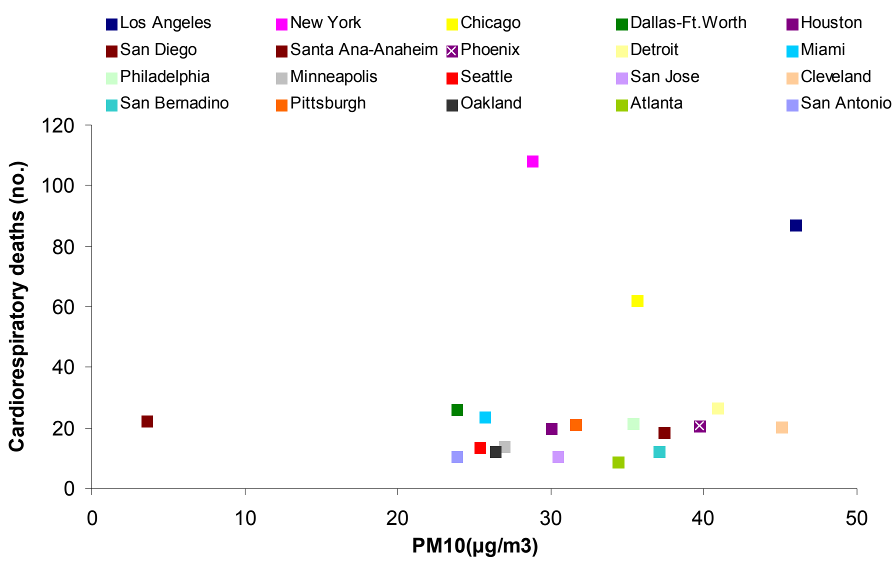

Figure 39 - PM_{10} and Cardiorespiratory deaths no. in 20 largest US cities, 1987–1994 (Daniels et al., 2000)

6.2 Limitations of the Study

The first limitation concerns health effects associated with air pollution in this study. Due to lack of accurate health data for Taichung city specifically, I cannot illustrate the relationship between PM_{10} and its associated diseases directly for Taichung City. The second limitation is that there is no access to the data of daily temperature, precipitation and humidity to properly conduct multiple linear regression method. Using average values increased uncertainty because the daily levels cannot be parsed out. The third limitation is that I did not have well-designed cohort study. I used existing air monitoring data from Taiwan EPA and the mortality rates of air pollution associated diseases to estimate the health outcome. I also extrapolated the health effects based on previous epidemiological research results conducted in western countries, which may involve other confounding factors such as climate differences. Thus, it is important to emphasize that methodological problems in the research design limit its interpretations.

Although the present study cannot show a strong association between air pollution and health effects, it does seem to demonstrate that high air pollution level in Taichung city is very likely to cause respiratory and cardiovascular health effects, based on the overall weight of evidence from published studies.

6.3 Recommendations for the Future Research

Park et al. (Eun-Jung Park, Dae-Seon Kim, & Kwangsik Park, 2008) found heavy metals detected in $PM_{2.5}$ as well as in PM_{10} in Seoul, Korea. With high PM_{10} values, the concentration of heavy metals in PM_{10} should be also addressed in Taichung City. Future work will hopefully clarify the concern of PM_{10} with heavy metals in Taichung City.

For the purpose of economic growth, the Taiwan government has opened many opportunities to import goods via ships and airplanes. This may in turn increase the heavy load of truck traffic in Taichung City. Many products come from other countries could arrive in Taichung Port and transport to other locations by trucks. Increased truck traffic might become a driver for future increase in PM_{10} levels. Many Cities, such as Los Angeles and Seattle have studies on the relationship on port and air pollution. Air monitoring stations in Los Angeles port detected annual average PM_{10} levels in 2005, 2006 and 2007 were 27.1 $\mu g/m^3$, 27.8$\mu g/m^3$ and 29.3$\mu g/m^3$, respectively (http://www.portoflosangeles.org/environment/air_quality.asp). The annual average PM_{10} levels in Si-Tun station in 2005, 2006 and 2007 were 71.70μg/m3, 60.44$\mu g/m^3$ and 59.7$\mu g/m^3$, respectively. It appears that the annual average PM_{10} level in Taichung City is more than twice of annual average PM_{10} levels in Los Angeles. Therefore health effects related to air pollution may be expected to be double than those in LA. More research should be conduct to address the issue of Taichung Port and air quality and its health effect as well.

Recent years, many researches have raised the attention on the toxicity of O_3. The longer time or the higher O_3 concentration that people are exposed to, the more impact on human health it has. This study found O_3 is the only pollutant which is increasing over time in Taichung city. It is important to study what the driver is for increasing O_3 levels and find a way to reduce its levels. O_3 is a photochemical pollutant driven by automobile exhaust hydrocarbons and NO_2 in the presence of sunlight. Therefore increased traffic can be reasonably expected to lead to increased O_3 levels. Asthma prevalence rates are increasing in Taiwan because there is increased exposure to ambient air pollution, harmful indoor sources of allergens and exposure to passive smoking. A positive association between the risk of childhood asthma and exposure to O_3 has been identified (David B Peden, 2002). The prevalence of childhood asthma has been associated with O_3 (Hwang et al., 2009). Since O_3 levels have been increasing over time in Taichung City, more studies are needed to address this public health concern.

6.4 Conclusions

This study was designed to investigate the status of air pollution in Taichung City. The results showed air pollutants (PM_{10}, NO, NO_2 and SO_2) were decreasing over years except O_3. Two air monitoring stations in Taichung City showed similar pollution levels, which indicated air pollutants levels in Taichung City were consistent. Although PM_{10} is decreasing, its concentration is still much higher than western countries. The overall pollution in Taichung City is higher than in other cities and should be improved to protect public. healthSchindler et al. (Christian Schindler, et al., 2009) had found that reductions in particle levels in Switzerland over the 11-year follow-up period had a beneficial effect on respiratory symptoms among adults. The results imply that it is important to control and reduce the emission of particles in Taichung City, Taiwan.

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