東海大學環境科學與工程系碩士班

碩士論文

台灣中部高科技業其指標性污染物的建立

Establish indicative pollutants of high-Tech industrial park in central Taiwan

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Abstract

Particulate matters ($PM_{2.5-10}$ and $PM_{2.5}$) were measured in this research during January in 2010. The concentration of heavy metals (Al, As, Ba, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hf, Ho, K, La, Lu, Mg,Mn, Mo, Na, Nd, Ni, Pb, Pr, Rb, Sb, Se, Sm, Sn, Sr, Tb, Ti, Tm, U, V, Y, Yb, Zn, Zr) were analyzed by inductively coupled plasma mass spectrometry. There are 32 heavy metal concentrations of $PM_{2.5}$ which with the higher data than those of $PM_{10-2.5}$.

This study used T-test and Principle Component Analysis from $PM_{2.5}$ metal concentrations, it can learn from 45 kinds of elements in As, Cd, Ge, Pb, Sn, Zn and other elements, which obtained from the Central Taiwan Science Park (CTSP) indicators emissions. From the normal distribution analysis it can be worked out by the specification of these indicators substance concentration which about the following level: As 2.78 ng/m^3, Cd 1.06 ng/m^3, Ge 0.21 ng/m^3, Pb 58.48 ng/m^3, Sn 5.20 ng/m^3 and Zn 94.25 ng/m^3. In the risk assessment, the exposure of this study does calculate formula, the calculated rate of the carcinogenic hazard index and is within the limits of the standard.

Keywords: $PM_{2.5}$, T-test, principle component analysis (PCA), normal distribution, risk assessment

摘要

本研究在 2010 年 1 月期間於中部科學園區進行懸浮微粒($PM_{2.5-10}$和$PM_{2.5}$）的採樣。並且對重金屬（鋁，砷，鋇，鈣，鎘，鈰，鈷，鉻，銫，銅，鏑，鉺，銪，鐵，鎵，釔，鍺，鉿，鈥，鉀，鑭，鎦，鎂，錳，鉬，鈉，鈸，鎳，鉛，鐠，銣，銻，硒，鈐，錫，鋰，鈰，鈦，銩，鈾，釩，釓，鐿，鋅，鋯）進行了感應耦合電漿質譜儀的分析。其中有 32 個重金屬其$PM_{2.5}$濃度的較$PM_{10-2.5}$濃度來的高。

本研究利用 T 檢定以及主成分分析法從 45 種$PM_{2.5}$的金屬濃度中挑選出砷，鎘，鍺，鉛，錫，鋅等元素，以此元素來代表中部科學工業園區的指標排放金屬。從常態分佈曲線當中，可以計算出規範這些指標物質的相關濃度分別為：砷 2.78 ng/m^3，鎘 1.06 ng/m^3，鍺 0.21 ng/m^3，鉛 58.48 ng/m^3，錫 5.20 ng/m^3和鋅 94.25 ng/m^3。在風險評估中，本研究利用暴露方程式做計算，計算出的危險指數以及致癌指數皆在限制的範圍內的標準。

關鍵字: $PM_{2.5}$, T 檢定, 主成分分析法, 常態分布, 風險評估

Chapter 1 Introduction

1-1 *The environmental impact of particulate matters in high-tech industries*

The semiconductor process (Figure 1-1) and optoelectronics manufacturing processes (Figure 1-2) which involve many emissions of chemical (Chein *et al.,* 2004). Table 1-1 showed the pollutant ingredient and possible emissions of CTSP and arsenic is marked in toxic gas and conflagrant gas. Arsine (AsH_3), is widely used in many processes such as chemical vapor deposition, ion implantation and diffusion, epitaxy process, etc., which is the source of arsenic compounds in flue gas as well as surrounding ambient air contamination (Chein *et al.*, 2006).

According to the WHO, 4–8% of deaths occurring annually in the world are related to air pollution (Kathuria, 2002). The main pollution sources are associated with anthropogenic activities and it influenced the air, water and soil in environment (Pandya *et al*., 2002; Wilhelm and Ritz, 2003; Masih *et al*., 2010).

The air pollution has become a great topic of debate at all levels because of the enhanced anthropogenic activities (Sidhartha, 2002). In contrast to long-term problems, the short-term effects of air pollutant

normally can become hazardous to human health.

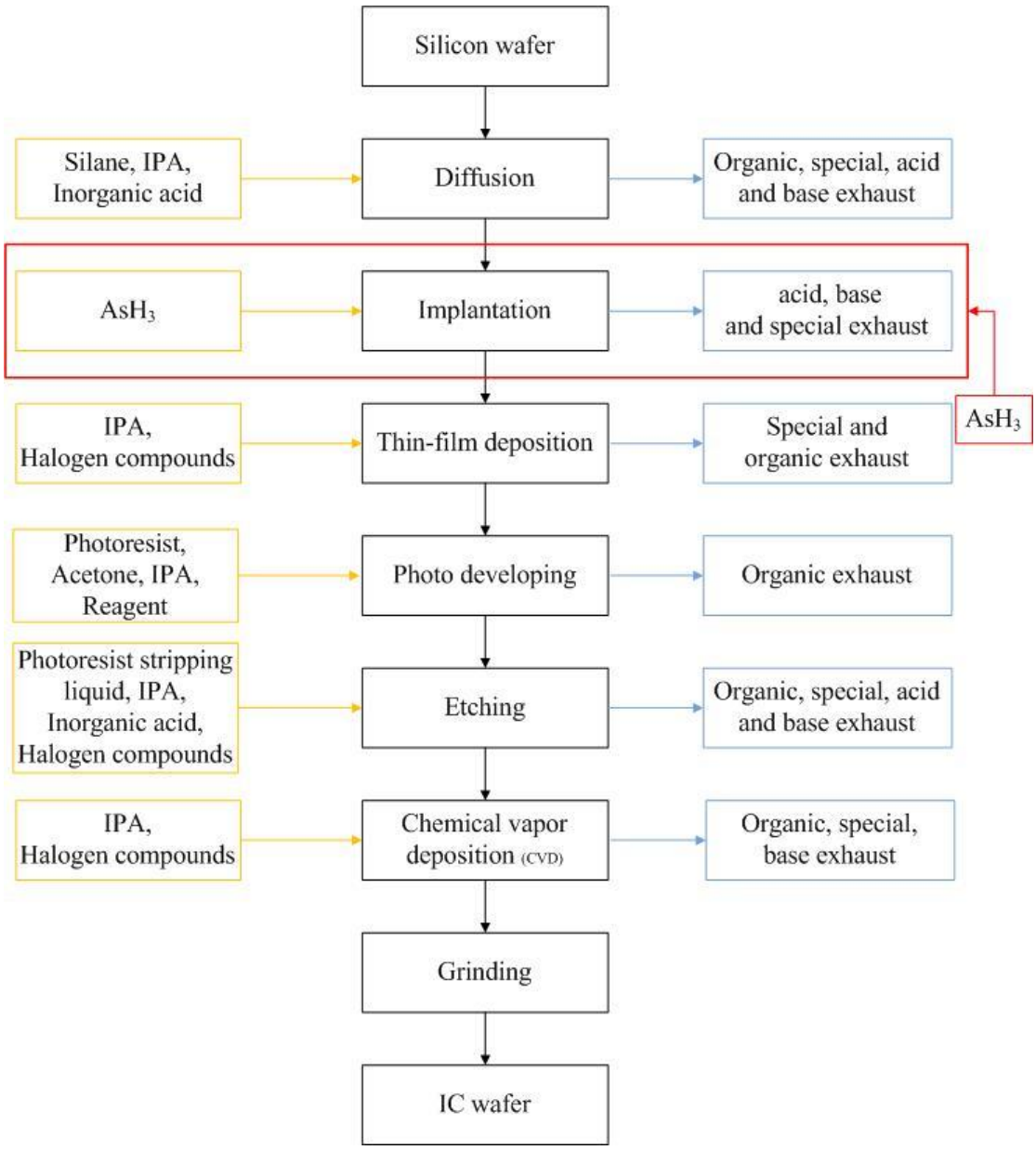

Figure 1-1. The sources of air pollution emitted from integrated circuit process.

In fact, several epidemiological studies related to the health effects of air pollution have proved the connection between high levels of particulate matters (PM) and health effects through respiratory and

cardiac diseases (Brook *et al*., 2004; Pope *et al*., 2004; Sun *et al*., 2010). In addition to negative health effects, particulate matter reduces visibility and accelerates the deterioration of buildings.

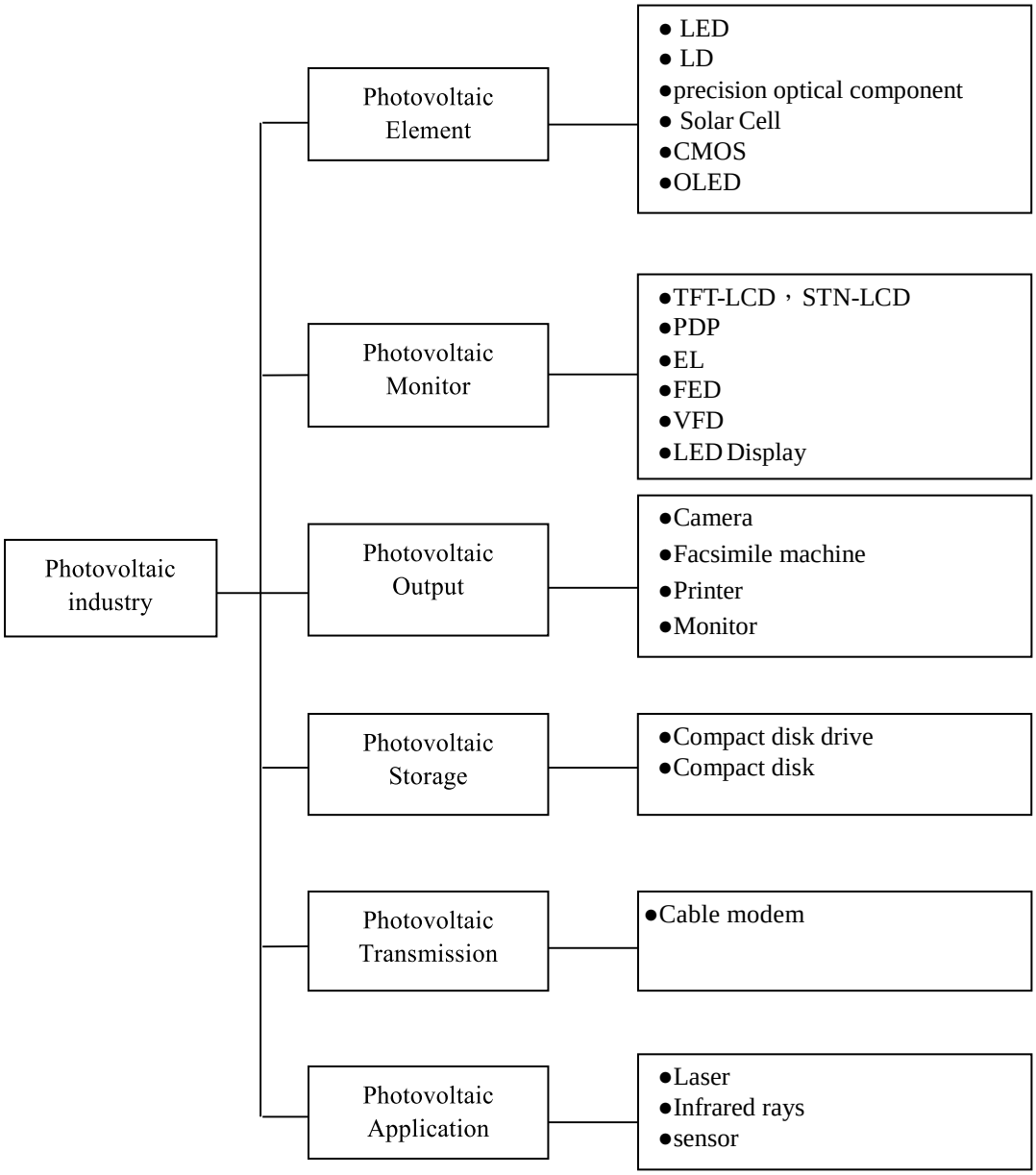

Figure 1-2. Compositions of photoelectron industry. (Information source：PIDA (Photonics Industry & Technology Development Association)

Atmospheric particulate matter in air originate from a wide variety of natural and anthropogenic processes and can vary markedly in size, chemical composition, amount distribution in space and time (Chandra *et al*., 2003). One of the many interesting aspects of the PM study is based on its composition; the airborne PM can be composed of and/or supported by organic and inorganic toxic pollutants and the organic compounds contribution between 10% and 40% of the mass of PM.

Table 1-1.
The components of air pollution during producing process

Pernicious gas item	Pollutant ingredient	Process
Acid and Base gas	Acid gas: HF, HNO_3, H_2SO_4,CH_3COOH, H_3PO_4, $H_2Cr_2O_7$ Base gas: NaOH	Oxidation, Reticle, Glass etching, Reactor of the cleaning, CVD
Organic gas	CH_2Cl_2,$CHCl_3$, $[(CH_3)_2CHCH_2COCH_3]$ Trans-1,2-Dichloroethene	Photoresist cleaning fluid, Imaging of clear fluid, Etched clear liquid, Wafer cleaning fluid
Toxic gas	AsH_3, PH_3, SiH_4, B_2H_6, B_4H_{10}, P_2O_5, SiF_4, CCl_4, HBr, BF_3, $AlCl_3$, B_2O_5, As_2O_3, BCl_3, $POCl_3$, Cl_2, HCN, SiH_2Cl_2	Oxidation, Reticle, Glass etching, diffusion, CVD, Ion implantation
Conflagrant gas	SiH_4, AsH_3,PH_3, BF_3, H_2, SiH_2Cl_2	Ion implantation, CVD, diffusion

Among the inorganic elements constituting the PM, heavy metals and other toxic elements are an important group to be considered, which arise from different environmental sources. Natural sources of particulate matter are usually emitted from volcanism, wind erosion, the earth's crust activity, as well as from forests fires, and evaporated the oceans sea spray. While the anthropogenic sources of particulate are generated by combustion and various industrial processes, which include the fossil fuel burning, heating and household cooking, agricultural burning, diesel-fuel engine combustion, cement manufacturing, mining, stone crushing and metal milling. Many other sources of PM are come from dusts re-suspension by vehicles and large conveyances (Nelin *et al*., 2012; Allen *et al*., 2001).

There have many air pollutants in the industrial area, especially for the PM are the important pollutants. Fang *et al*., (2003) investigated that in central Taiwan, the average concentrations of $PM_{2.5}$ and PM_{10} were recorded as 42.8 and 62.2 $\mu g/m^3$, respectively in the period of 2002 (January–April). Moreover, the monthly average $PM_{2.5}/PM_{10}$ ratio was between 0.63 and 0.73. There are many $PM_{2.5}$ emissions from the advanced industrial processes (Backes *et al*., 2013).

1-2 *Heavy metal for human health*

Suzuki *et al.*, (2007) had analyzed 17 kinds of trace metals in the body of a squirrel in Taiwan and Japan, found that squirrel contain high

Table 1-2.
Trace element concentration in the kidney, liver, lung and muscle of Formosan squirrels captured in Miaoli, Taiwan. (unit: μg/m^3)

Organ	Kidney	Liver	Lung	Muscle
As	0.04	0.04	0.03	0.04
Cd	11.7	2.94	0.74	0.20
Co	0.28	0.21	0.24	0.04
Cs	0.10	0.08	0.11	0.14
Cu	28.9	808	34.5	11.7
Ga	0.02	0.03	0.05	0.01
Mn	11.2	8.41	3.10	1.91
Ni	0.17	0.08	0.12	0.07
Pb	0.54	0.40	0.15	0.04
Se	5.28	2.87	1.07	1.01
Sr	0.43	0.35	0.53	0.28
V	0.03	0.06	0.04	0.02
Zn	143	117	64.0	71.1

levels of heavy metals concentration in Miaoli County (Table 1-2) and most importantly, the study shown the source of these high concentrations of heavy metals maybe come from high-tech industrial area nearby Hsinchu.

1-2-1 *Heavy metal source*

Different sources of air pollution emissions of suspended particles, their chemical composition is also different, and different pollution emission source has its specific emissions species, as metal components can track the specific suspended particulate emission sources tracer, can be used to determination of the receptor suspended particles of pollution sources (Hu *et al*, 2003; Querol *et al*, 2007; Tsai *et al*, 2007)

Atmospheric aerosol elements which will be affected by the impact of the different sources, leaving the composition and characteristics are different; their main source of pollution can be divided into natural sources and anthropogenic pollution emissions (Rahn, 1999). Natural sources of dust and sea salt aerosols. Si, Al, Fe, Ca, Sr, Ti, Mg index element of the index element of the dust source (Rahn, 1999; Hsu *et al*., 2004; Wang *et al*., 2005), the sea salt aerosol of Na and Mg (Rahn, 1999; Hsu *et al*., 2004). The man-made pollution emission sources, in

accordance with specific indicators elements of different types of pollution emissions.

Table 1-3 shows the elements of different indicators of pollution sources.

1-2-2 *The effects of heavy metals on human body*

Many results of epidemiological studies show that the human cardiovascular diseases and respiratory diseases attendance rate, death rate and the concentration of suspended particles in the atmosphere were closely related (Wilson *et al.*, 2005), but recently study, more than to explore the components of the particulate elements (Harrison *et al.*, 2004; Schaumann *et al.*, 2004; Lippmann *et al.*, 2006; Falta *et al.*, 2008; Jayasekher, 2009; Chen, and Lippmann, 2009; Bell *et al*., 2009).

Many elements of the particles (as of As, Cd, Pb, Se) generated by the combustion process, mainly in less than 2.5μm particle size or base gathered at 0.1μm, the combustion process has the impact on human health hazards far serious than the coarser particles (Schaumann *et al.*, 2004; Falta *et al.*, 2008).

According to the International Classification of Cancer Research Department, currently classified in 1A Group (the elements of the human

Table 1-3.
Emission sources of pollution indicators

Pollution sources	Particle size	Indicator elements	Literature
Crustal and dust	$PM_{2.5-10}$	Si、Al、Fe、Ca、Mg、Ti、Sr、Ba、K、Mn、Co	Rahn (1999); Hsu *et al*. (2004); Wang *et al*. (2005); Wang *et al*. (2006)
Sea salt aerosols	$PM_{2.5-10}$	Na、Mg	Rahn (1999); Hsu *et al*. (2004)
Traffic Source	PM_1 $PM_{2.5}$ $PM_{2.5-10}$	Sb、Cu、Zn、Pb、Cr、Co、Mn、Ba、Mo、Cd、As	Wang *et al*. (2003); Wang *et al*. (2005); Gómez *et al*. (2005); Lin *et al*. (2005); Dongarrà *et al*. (2007); Thorpe and Harrison (2008); Iijima *et al*. (2008); Smichowski *et al*. (2008); Dongarrà *et al*. (2009); Kuo *et al*. (2009); Cheng *et al*. (2009)
Construction	$PM_{2.5-10}$	Ca、Fe、Al、K、Mn、Ti	Chio *et al*. (2004)
Smelter	PM_1 $PM_{2.5}$	Cr、Cd、Cu、As、Pb、Se、Zn	Kuo *et al*. (2007); Querol *et al*. (2007)
coal combustion	PM_1	As、Se、Cr、Cd、Pb、Sb	Xie *et al*. (2006); Moreno *et al*. (2007); Okuda *et al*. (2008);
fuel-oil combustion	PM_1 $PM_{2.5}$	Ni、V	Querol *et al*. (2007); Cheng *et al*.(2008b)
Steel production	PM_1 $PM_{2.5}$	Fe、Zn、Pb、Mn、Ca、K、Cr	Tsai *et al*. (2007); Querol *et al*. (2007)
Waste incineration	$PM_{2.5}$	Cd、Pb、Zn、As、Sb	Hu *et al*. (2003); Chang *et al*. (2009); Christian *et al*. (2009)

body to determine carcinogenic substances) are, Arsenic and its compounds, Be and its compounds, Cd and its compounds, Cr (VI) and Ni and its compounds, which the elements of 2A Group (most likely people carcinogen) are Pb (inorganic) and their compounds, and the other 2B Group (be probable carcinogen) Sb oxides containing Co (II) compounds.

Therefore human long-term exposure to the rich in particles of 1A, 1B and 2B groups toxic elements in the atmospheric environment, and are dangerous to the health.

In addition, other elements such as Cu, Zn, Mn and Fe also human impact, according to Falta *et al.*, (2008), results show that Zn, Mn and Cu by adhering to the suspended particles by inhaled its dissolution in body fluids and bioavailability. Bioaccessibility, resulting affect the activities of cells in the body. Jayasekher (2009) has also assessment of the comet assay (Comet Assay) wind at atmospheric particulate elements in the coal power plant; the results show the impact of atmospheric particulate samples by coal-fired power plants cells, the cells will rupture causes DNA (Deoxyribonucleic Acid) mutation.

Suspension as the particles are attached to the element, such as As,

Co, Cr, V, Fe, Mn, and Ni are with the ability of the electronic exchange, and easy to make the cells to produce free radicals or the formation of reactive oxygen species (Reactive Oxygen Species, ROS) by respiratory receive damage (Schaumann *et al.*, 2004; Chen and Lippmann, 2009).

According to Lippmann *et al.*, (2006), through the results of the animal experiments also showed that short-term exposure to the atmosphere rich in Ni particles will affect the effort function of the human body, and the death rate rose Bell *et al.*, (2009) also confirmed different seasons in the United States, the rate of treatment of cardiovascular diseases and respiratory diseases and $PM_{2.5}$ concentrations of Ni and V, the relationship than the quality of suspended particles at high concentrations.

From above study results, and show great harm to toxic elements in the atmospheric aerosol, many studies or government units are recommended to set the value of element concentrations in atmospheric particles specifications, and regulate the value with suspended particles mass concentration, as view the merits and evaluation of air quality on the basis of the degree of harm human health (Harrison *et al*, 2004; Cozzi *et al*., 2008; Moreno, *et al*, 2008; Hopke *et al*, 2008).

1-3 *Objectives*

The objectives of this study are to analyze the air emissions from Central Taiwan Science Park's (CTSP) fine particles concentrations of heavy metals (Al, As, Ba, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hf, Ho, K, La, Lu, Mg, Mn, Mo, Na, Nd, Ni, Pb, Pr, Rb, Sb, Se, Sm, Sn, Sr, Tb, Ti, Tm, U, V, Y, Yb, Zn, and Zr) by inductively coupled plasma mass spectrometry (ICP-MS). It also using statistical methods to find metal indicators which are represents an important indicator of substance emission from CTSP. Finally using risk assessment to determine whether the concentration which the indicator of harmful.

Chapter 2 Materials and Method

Figure 2-1 shows the flow chart in this study. First, the definition of areas for the study, then the selected sampling points is collected. There is the data after analysis which is selected by T-test and PCA to choose indicators element. Finally, it used the normal distribution to set the concentration of confident level.

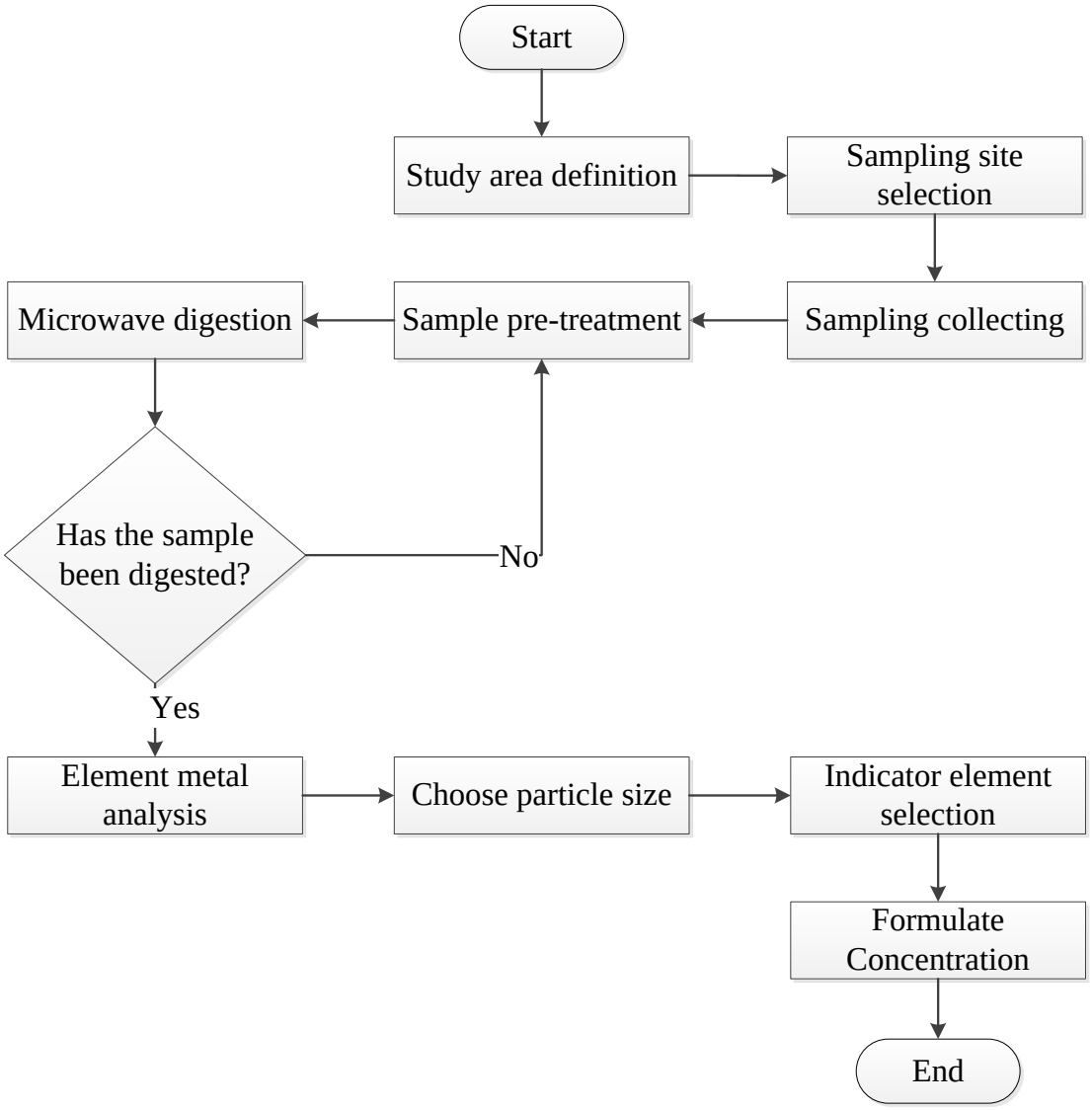

Figure 2-1. The investigation of the indicator pollutant from CTSP

2-1 *Study area definition and Sampling sites selection*

There are six major industries including Integrated Circuits (IC), Computer, Telecommunications, Optoelectronics, Precision Machinery, Biotechnology industries in CTSP and running for many years. The pollutants generated from these manufactures have been indicated as well. Although EPA has set the effluent standards of wastewater except for atmosphere. Nowadays the standards are still not set the standards for Science Park. It was hoped the indicated elements and level standards would be intended by this study.

This research selected (1) Tunghai University (THU), a campus with 150 hectares land space, located at the southern borderline of Taichung City as the sampling point. (2) Taya Indigenous People Service Center located at the sampling point, north of Central Taiwan Science Park (CTSP).

The sampling points of this research tended to be located at the prevailing wind direction for summer and winter which was northeast and southwest bound. In Figure 2-2, it depicts the major emissions and neighboring related sampling points. For cases like northeast bound wind in the winter, site 1 THU is the same and located about 2~3 km

(downwind location) away from the CTSP southwest direction. Site 2 Taya is located about 2~3 km (windward location) away from the CTSP northeast direction. Within the Central region science-based park, the bulk of the industrial varieties included optoelectronics, semi-conductors, and biotechnology and precision machinery factories.

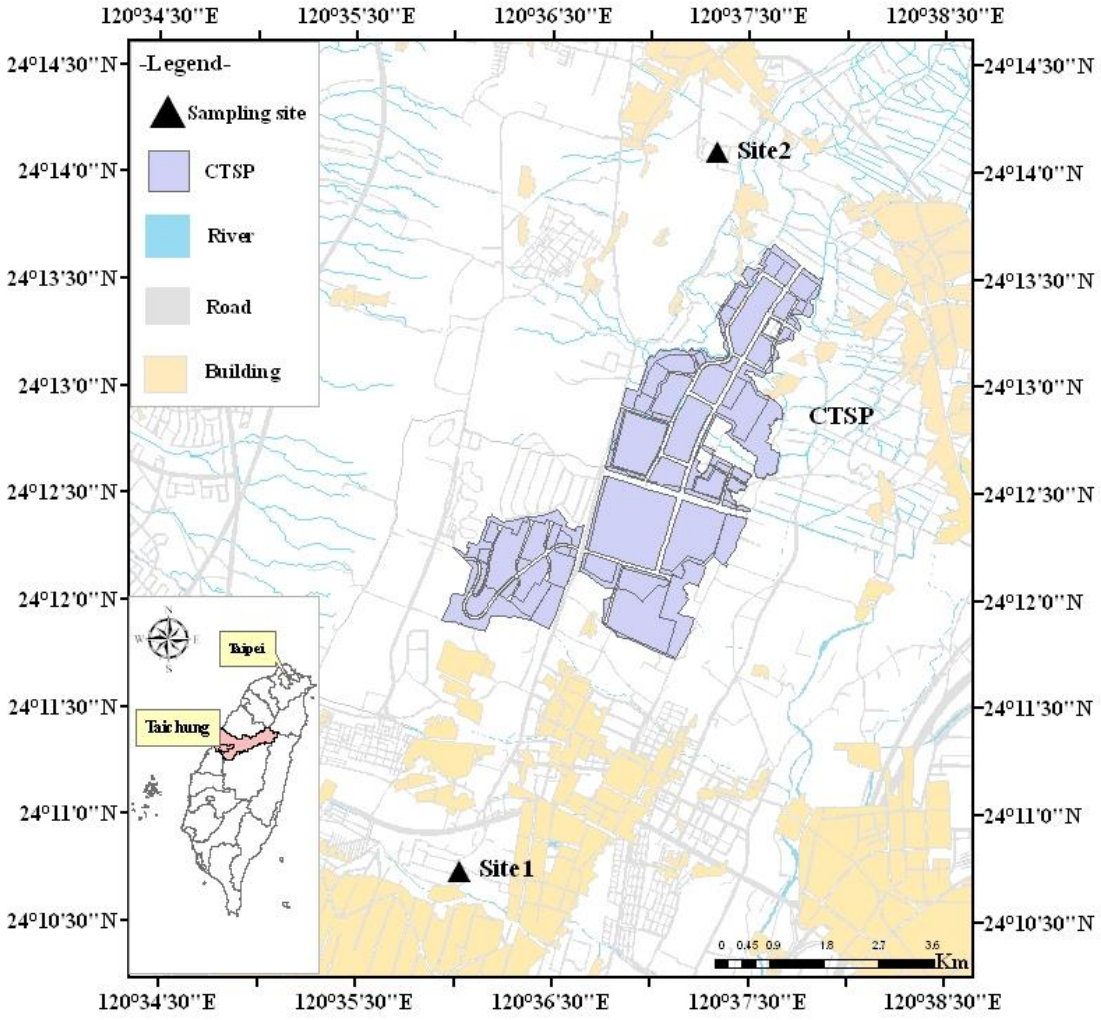

Figure 2-2. The sampling sites nearby CTSP, site 1: THU and site 2: Taya

2-2 *Sampling method*

All atmospheric particulate sampling are based on the NIEA A102. 12A and it was followed during all sampling periods by PM_{10} high volume air sampler. All samples were acquired during the 24 hour time span with a total of 96 samplings.

Figure 2-3 depicted the PM_{10} high volume air sampler (Particulate matter 10 microns and less High volume air sampler, Tisch Environmental, Inc., TE-6070 High Volume MFC) for this research, which was used to collect the surrounding PM_{10}, $PM_{2.5}$. The cellulose filter paper (Whatman 47mm diameter, 20μm pore) was used to collect the atmospheric particulate. And its initial input rate was approximately 1.7 m^3/min.

2-3 *Sample pre-treatment and microwave digestion*

Before sampling, put the filter (Whatman 41mm diameter) in the incubator to condition at least 24 hours, keep the temperature at 25 ± 5℃, the relative humidity at 50 ± 5%. After weigh, condition again. This study used the electronic weighing machine (TB 215D, Denver, Germany) to weigh (Fig 3-4 . The filter can be used for sampling under constant weigh (up to 5 digit decimal).

Figure 2-3. PM_{10} high volume air sampler, Tisch Environmental, Inc., TE-6070 High Volume MFC.

2-4 *Heavy Metal analysis*

Elements of atmospheric aerosol component analysis, is cut one-eighth after conditioning and weighing finished acetate fiber filter analysis. In each prior to the digestion process, to ensure that digestion bottle from pollution, the need for the pickling step to digest bottles sequentially added 2.0ml nitrate (Merck, 65% GR for Analysis) and 1.7ml of deionized water, for 28 minutes of microwave heating, and then rinsed two times with deionized water and dried, before they can be the actual particulate samples digestion.

Suspended particles in the sample digestion process in the present study is by Hsu *et al*., (2008) and Hsu *et al*., (2009) created by the filter paper samples into the Teflon digestion flask. Adding 4 ml of nitric acid (Merck, 60% Ultrapur) with the the 2.0ml of hydrofluoric acid (Merck, 48% Ultrapur), add locks bottle machine (CEM) will then be to digest bottle locking.

Subsequently, the high output microwave digestion system (CEM, MARS Xpress) digestion, microwave digestion set of power with warming conditions, and is divided into two stages of heating, the first stage of the power set 1440W, heated to 170 degrees to 7 minutes, and power to hold on10 minutes after connecting the second phase of warming, its power is increased to 1600W and eight minutes to heat up to 200 degrees for 16 minutes, until the completion of a two-stage heating, Cool down 30 minutes to 80 degrees. And subsequently then digested bottles sequentially loaded the enrichment device subsidiary kit (CEM Xpress Vap TM), and placed in an available temperature sensing fiber (CEM, No. 431-6494) monitoring bottle to catch the acid step time acid in microwave digestive setting power of 800W, the temperature set at 80 degrees, with by boric acid (Merck, GR for Analysis) and sodium

hydroxide (Merck, GR for Analysis) aeration hurry acid and digestive juices concentrated The approach to evaporated to dryness so far to remove the hydrogen the Buddha acid, completed catch the acid process, power and warming conditions of the digestive beginning.

Be digested procedures have been completed, start the quantitative step of this study was to digestive transferred to a polypropylene centrifuge tube, while adding 15ppb (In) as the internal standard, and finally diluted with deionized water volume to 15ml and refrigerated at 4 degrees up to analysis.

Atmospheric aerosol elements of quantitative analysis, this study is the Elan 6100 inductively coupled plasma mass spectrometry (ICP-MS) analysis, which has a multi-element concentration can be analyzed simultaneously and the high sensitivity of the advantages. Thus, analysis of Al, As, Ba, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hf, Ho, K, La, Lu, Mg,Mn, Mo, Na, Nd, Ni, Pb, Pr, Rb, Sb, Se, Sm, Sn, Sr, Tb, Ti, Tm, U, V, Y, Yb, Zn, Zr, a total of 45 kinds of elements

2-5 *Statistical hypothesis tests*

A statistical hypothesis test is a method of making decisions using data from a scientific study. In statistics, a result is called statistically

significant if it has been predicted as unlikely to have occurred by chance alone, according to a pre-determined threshold probability, the significance level Interpretation of statistical information can often involve the development of a null hypothesis in that the assumption is that whatever is proposed as a cause has no effect on the variable being measured.

The best illustration for a novice is the predicament encountered by a jury trial. The null hypothesis, H_0, asserts that the defendant is innocent, whereas the alternative hypothesis, H_1, asserts that the defendant is guilty. The indictment comes because of suspicion of the guilt. The H_0 (status quo) stands in opposition to H_1 and is maintained unless H_1 is supported by evidence"beyond a reasonable doubt". However,"failure to reject H_0" in this case does not imply innocence, but merely that the evidence was insufficient to convict. So the jury does not necessarily accept H_0 but fails to reject H_0. While one cannot "prove" a null hypothesis one can test how close it is to being true with a power test, which tests for type II errors. Workings from a null hypothesis two basic forms of error are recognized:

Type I errors where the null hypothesis is falsely rejected giving a "false positive".

Type II errors where the null hypothesis fails to be rejected and an actual difference between populations is missed giving a false negative.

Statistics rarely give a simple Yes/No type answer to the question asked of them. Interpretation often comes down to the level of statistical significance applied to the numbers and often refers to the probability of a value accurately rejecting the null hypothesis.

2-6 *Principle component analysis (PCA)*

Generally, the identification of pollution source can be conducted either by statistical analysis or simulation model. The major statistical function is to identify the emission source from available data. While dispersion model is to simulate the receptor by pollutant diffusion and the accumulating, with the major computer arguments input of meteorological and emission data. Some researchers also suggest applied the simple statistical method to identify the pollutant source. The statistical method is calculated much faster and simple than the simulation method. This study adapts common statistical method, Principal Component Analysis (PCA) to identify the possible pollutant emission sources surrounding THU campus.

The PCA method reduces variables and categorizing

variability-related groups, then it extracts factors corresponding to identify possible emission sources. According to previous literatures of Espinosa *et al*. (2002), Manalis *et al*. (2005), Quiterio *et al*. (2005) and Salvador *et al*. (2004) illustrated that the PCA method can successfully identify the pollutant sources for various local deposition cases. In this study, the PCA method is conducted by SPSS 19.0.

Chapter 3 Results and Discussion

3-1 *Particulate matters basic analysis*

Suspended particles in the atmosphere, on its formation in terms of status and sources could be roughly divided into two categories: native pollutants and secondary pollutants. Native sources of pollution from major pollution sources directly produce, such as stirring up dust, sea spray, volcanic eruptions, volcanic ash released from the burning of agricultural waste and via direct emissions of industrial processes and transport emissions of such pollutants tablets wider diameter distribution, of which a large part of the combustion process produces particles less than 2.5μm, secondary pollutants formed by chemical reaction of gaseous pollutants from the atmosphere, and its particle size is mostly concentrated in the fine particles of less than 2.5μm.

Many studies have shown that when the particle size in the range of 2-5μm absorbed by the human respiratory tract, about 10% is deposited in the bronchial, about 20-30% deposition in the alveolar; suspended particles of size less than 2μm, mostly deposited in alveolar tissue, absorbed by the lungs through the blood and lymphatic spread to the whole body and cause harm to humans.

This study in January 2010 during the intensive sampling atmospheric aerosol samples were collected from 48 groups in the Central Taiwan Science Park perimeter of the sampling period, wind speed, wind direction, relative humidity and atmospheric temperature listed in Table 3-1.

The main prevailing wind direction is north-easterly, followed by northwest winds are northerly wind, the TAYA located upwind, while THU located downwind. Wind speed ranged between 1.28 ~ 5.98 m/s, the average temperature range between 11.49 to 21.51℃, relative humidity range between 56 to 83%, in addition to the 1/13 and 1/14 the past two days was relatively dry.

In Table 3-2, the particle concentration of the sample, the point downwind position almost higher than upwind point. The ratio of $PM_{2.5}$ with PM_{10} is almost higher than 0.5 and some reach as high as 0.8. The $PM_{2.5}$ concentrations higher than 65 ($\mu g/m^3$) dates regarded as pollution episodes. This section will discuss some of the concentrations of heavy metals.

In Table 3-3 which $PM_{2.5}$ and PM_{10} ratio compared with past literature and the apparent trend of fine-grained particles. The object

Table 3-1.
The meteorological information of sampling date

Date	Wind direction	Temp.[1] (℃)	Wind speed (m/s)	RH[2] (%)
2010/01/05	NE	16.60	3.08	73.17
2010/01/06	NE	15.13	3.59	82.08
2010/01/07	NE	15.33	3.17	80.00
2010/01/08	NE	14.13	3.32	83.54
2010/01/09	NW	16.00	1.95	79.08
2010/01/10	NE	17.65	2.77	73.13
2010/01/12	NE	11.49	5.98	72.41
2010/01/13	NE	13.42	5.02	20.85
2010/01/14	NE	14.03	1.85	45.97
2010/01/15	NW	14.58	1.28	65.00
2010/01/16	NW	16.00	1.92	67.04
2010/01/17	NE	17.29	1.63	69.03
2010/01/19	NE	20.11	2.20	60.22
2010/01/20	NE	21.20	1.54	56.45
2010/01/21	NW	21.15	2.68	64.33
2010/01/22	NW	16.33	4.61	76.39
2010/01/23	NW	15.84	3.82	75.83
2010/01/24	NE	18.26	2.65	78.14
2010/01/26	NE	16.60	2.95	68.74
2010/01/27	NW	19.42	1.30	71.53
2010/01/28	NW	21.25	2.34	78.02
2010/01/29	NW	20.47	3.16	76.11
2010/01/30	NE	19.64	1.45	76.86
2010/01/31	N	21.51	1.36	72.37

Temp.[1]: Temperature; RH[2]: Relative Humidity;

pollution sources, the same as the Hi-Tech Park, and the chemical industry. The ratio of $PM_{2.5}$ with PM_{10} in this study came out the highest value all literature.

Therefore it focused on the portion of the fine particles of discussion.

Table 3-2.

Sampling data and information for this research and the ratios for $PM_{2.5}/PM_{10}$

Date	$PM_{2.5}(\mu g/m^3)$		$PM_{2.5-10}(\mu g/m^3)$			$PM_{2.5}/PM_{10}$	
	TAYA	THU	TAYA	THU	trend	TAYA	THU
2010/1/5	52.97	67.91	14.82	26.41	+	0.78	0.72
2010/1/6	53.84	56.56	12.55	15.03	+	0.81	0.79
2010/1/7	59.24	50.38	13.65	13.19	-	0.81	0.79
2010/1/8	60.58	68.11	15.49	19.76	+	0.80	0.78
2010/1/9	67.35	57.77	9.79	9.59	-	0.87	0.86
2010/1/10	58.03	72.64	16.91	16.83	+	0.77	0.81
2010/1/12	68.03	88.49	16.77	13.94	+	0.80	0.86
2010/1/13	49.35	78.05	12.12	20.98	+	0.80	0.79
2010/1/14	89.14	119.52	22.97	44.61	+	0.80	0.73
2010/1/15	96.07	83.38	22.45	31.04	-	0.81	0.73
2010/1/16	63.46	101.34	21.14	19.45	+	0.75	0.84
2010/1/17	107.42	67.01	27.21	43.02	-	0.80	0.61
2010/1/19	120.33	147.97	24.45	24.17	+	0.83	0.86
2010/1/20	93.65	37.10	12.51	35.82	-	0.88	0.51
2010/1/21	73.92	91.39	34.51	45.89	+	0.68	0.67
2010/1/22	62.63	97.97	26.21	21.07	+	0.71	0.82
2010/1/23	78.02	111.04	15.52	26.42	+	0.83	0.81
2010/1/24	88.40	91.53	21.72	29.75	+	0.80	0.75
2010/1/26	29.08	41.87	31.87	45.18	+	0.48	0.48
2010/1/27	74.14	92.40	24.87	49.69	+	0.75	0.65
2010/1/28	96.77	110.74	26.24	20.03	+	0.79	0.85
2010/1/29	112.30	126.16	35.88	36.5	+	0.76	0.78
2010/1/30	120.33	135.21	42.64	63.03	+	0.74	0.68
2010/1/31	112.07	141.17	27.42	40.99	+	0.80	0.77

Table 3-3.
Compare the $PM_{2.5}/PM_{10}$ with other countries.

Country	Site	$PM_{2.5}/PM_{10}$	Type of pollutant source	Reference
Taiwan	Taichung TAYA	0.77	High-tech science park	This study
	Taichung THU	0.74		
	Taichung	0.66	High-tech science park	Lu (2009)
	Taichung	0.62	Traffic	Fang *et al.*, (2008)
Hong Kong	Hok Tusi	0.50	-	Lai *et al.*, (2007)
	Hung Hom	0.68	Traffic	Cheng *et al.*, (2006)
China	Shenzhen	0.73	High-tech science park	Lai *et al.*, (2007)
	Zhuhai	0.71	High-tech science park	
Korea	Ulsan	0.55	Petrochemical industry	Hieu and Lee, (2010)
	Busan	0.56	Developing city	Kim *et al.*, (2006)
	Seoul	0.73	Developing city	
UK	Birmingham	0.66	Urban	Yin and Harrison, (2008)
Spain	Barcelona	0.64	Chemical industry	Pérez *et al.*, (2008)

3-2 *Heavy metal analysis*

Table 3-4 shows that 45 kinds of elements concentrations in $PM_{2.5}$ with THU and Taya in this study. The concentration of following: (1) the highest mean level of elements Na, Fe, K, Al, Ca, Mg, Zn; (2) the secondly level elements Pb, Mn, Cu, Ti, Sb, Ba, V, Sn, Ni; (3) the trace elements include Cr, Sr, As, Se, Rb, Mo, Zr, Cd, Ga, Ce, La, Co, Nd, Ge, Cs; (4) the sub-trace elements include Y, Hf, Gd, Pr, Sm, U, Dy, Er, Eu, Ho, Tb, Tm, Yb, Lu. The $PM_{2.5}$ concentration of above analytical elements summary is 2.7% in THU and 1.7% in Taya.

Table 3-4.

The concentrations of heavy metals in particulars with $PM_{2.5}$ (unit: ng/m^3)

Metal	Tung Hai University			Taya Indigenous People Service Center		
	Max	Min	Mean±std	Max	Min	Mean±std
Al	572.06	90.31	247.93±137.78	639.06	51.19	187.63±140.89
As	5.72	0.41	2.02±1.37	3.70	0.39	1.34±0.81
Ba	22.41	2.53	9.70±5.09	20.90	1.77	6.97±4.26
Ca	700.08	56.20	211.25±136.44	644.17	43.45	169.31±159.88
Cd	1.98	0.24	0.86±0.53	1.18	0.14	0.60±0.31
Ce	1.60	0.13	0.62±0.36	1.48	0.10	0.46±0.32
Co	0.55	0.11	0.28±0.14	0.43	0.07	0.17±0.08
Cr	8.58	1.47	3.82±1.75	11.23	0.00	2.84±2.20
Cs	0.34	0.04	0.14±0.09	0.21	0.03	0.10±0.05
Cu	63.10	8.05	33.37±18.83	133.75	11.16	34.89±27.77
Dy	0.06	0.01	0.02±0.01	0.06	0.01	0.02±0.01
Er	0.04	0.01	0.02±0.01	0.04	0.00	0.01±0.01
Eu	0.02	0.00	0.01±0.01	0.02	0.00	0.01±0.00
Fe	976.24	106.52	385.78±233.79	737.85	76.78	275.94±171.03
Ga	2.03	0.20	0.75±0.44	1.13	0.18	0.52±0.28

Table 3-4.
The concentrations of heavy metals in particulars with $PM_{2.5}$ (unit: ng/m^3) (continued)

	Tung Hai University			Taya Indigenous People Service Center		
Metal	Max	Min	Mean±std	Max	Min	Mean±std
Gd	0.09	0.01	0.04±0.02	0.10	0.01	0.03±0.02
Ge	0.46	0.04	0.17±0.11	0.22	0.03	0.11±0.06
Hf	0.16	0.00	0.06±0.05	0.14	0.00	0.04±0.04
Ho	0.01	0.00	0.01±0.00	0.01	0.00	0.00±0.00
K	694.15	123.71	327.64±167.71	442.97	49.62	223.10±109.78
La	1.09	0.09	0.47±0.29	1.03	0.06	0.32±0.22
Lu	0.00	0.00	0.00±0.00	0.00	0.00	0.00±0.00
Mg	368.39	18.60	100.82±71.30	354.09	8.92	84.18±87.25
Mn	112.30	7.06	34.71±26.01	89.89	4.26	23.83±18.94
Mo	8.45	0.32	1.31±1.67	6.12	0.26	0.85±1.18
Na	2523.93	234.16	565.29±470.81	1998.32	0.00	378.99±405.35
Nd	0.63	0.05	0.25±0.14	0.65	0.04	0.19±0.14
Ni	12.16	1.59	4.05±2.45	4.81	0.82	2.32±1.09
Pb	108.71	5.63	44.30±28.74	61.47	3.83	28.49±16.06
Pr	0.10	0.01	0.04±0.02	0.12	0.01	0.03±0.03
Rb	3.63	0.55	1.56±0.85	1.99	0.31	1.07±0.5
Sb	151.04	0.78	10.72±31.67	129.79	0.54	7.77±26.69
Se	4.97	0.45	1.61±1.21	3.10	0.27	0.91±0.62
Sm	0.09	0.01	0.04±0.02	0.10	0.01	0.03±0.02
Sn	10.26	0.92	5.02±2.60	5.29	0.95	3.03±1.34
Sr	8.34	0.51	2.34±1.61	6.41	0.40	1.91±1.60
Tb	0.01	0.00	0.01±0.00	0.01	0.00	0.00±0.00
Ti	110.35	8.17	31.03±22.27	70.04	5.99	21.05±14.43
Tm	0.12	0.00	0.01±0.03	0.08	0.00	0.01±0.02
U	0.11	0.01	0.04±0.03	0.07	0.01	0.03±0.02
V	26.82	1.12	6.04±5.74	13.56	0.99	3.63±2.91
Y	0.26	0.03	0.11±0.06	0.27	0.02	0.08±0.06
Yb	0.03	0.00	0.01±0.01	0.04	0.00	0.01±0.01
Zn	186.08	30.19	85.26±47.39	125.60	12.88	53.29±26.98
Zr	2.50	0.34	1.16±0.59	2.84	0.20	0.76±0.54

Table 3-5 shows that 45 kinds of elements concentrations in $PM_{2.5-10}$ with THU and Taya in this study. The concentration of following: (1) the highest mean level of the elements Na, Al, Fe, Ca, Mg, K, (2) the secondly level the elements Ti, Zn, Cu, Ba, Mn, Pb, (3)the trace elements Sr, Cr, Ni, V, Zr, Sb, Rb, Ce, Sn, La, Mo, Ga, Nd, As, Co, Cd, (4)the sub-trace elements Y, Se, Pr, Cs, Gd, Hf, Sm, U, Dy, Er, Yb, Eu, Ge, Ho, Tb, Lu, Tm. The concentration $PM_{2.5-10}$ of above analytical elements summery is 12.0% in THU and 5.1% in Taya.

Table 3-5.
The concentrations of heavy metals in particulars with $PM_{2.5-10}$ (unit: ng/m^3)

	Tung Hai University			Taya Indigenous People Service Center		
Metal	Max	Min	Mean±std.	Max	Min	Mean±std
Al	755.37	95.62	305.84±169.02	465.67	45.04	190.28±105.84
As	0.66	0.05	0.21±0.15	0.39	0.02	0.12±0.08
Ba	22.20	1.91	9.40±6.06	12.74	1.24	5.60±3.12
Ca	722.62	55.77	273.41±184.22	399.64	23.86	160.91±106.58
Cd	0.35	0.03	0.12±0.09	0.14	0.01	0.06±0.04
Ce	1.54	0.09	0.59±0.37	0.89	0.05	0.36±0.21
Co	0.40	0.08	0.18±0.10	0.24	0.04	0.11±0.06
Cr	4.55	0.48	1.70±1.15	2.01	0.22	0.91±0.49
Cs	0.12	0.00	0.05±0.03	0.07	0.00	0.03±0.02
Cu	31.30	1.50	10.07±7.73	13.20	1.39	6.04±3.56
Dy	0.07	0.00	0.02±0.02	0.04	0.00	0.02±0.01
Er	0.05	0.00	0.02±0.01	0.03	0.00	0.01±0.01
Eu	0.02	0.00	0.01±0.01	0.01	0.00	0.01±0.00
Fe	751.76	44.90	291.67±191.07	433.49	28.07	176.03±110.18
Ga	0.80	0.09	0.36±0.21	0.47	0.05	0.21±0.11
Gd	0.11	0.01	0.04±0.03	0.06	0.00	0.02±0.02

Table 3-5.

The concentrations of heavy metals in particulars with $PM_{2.5-10}$ (unit: ng/m^3) (continued)

	Tung Hai University			Taya Indigenous People Service Center		
Metal	Max	Min	Mean±std	Max	Min	Mean±std
Ge	0.05	0.00	0.01±0.01	0.02	0.00	0.01±0.01
Hf	0.09	0.01	0.04±0.02	0.06	0.01	0.02±0.01
Ho	0.02	0.00	0.01±0.00	0.01	0.00	0.00±0.00
K	308.32	41.18	126.71±62.16	177.12	15.78	74.89±39.31
La	1.61	0.06	0.48±0.37	0.64	0.03	0.26±0.16
Lu	0.01	0.00	0.00±0.00	0.00	0.00	0.00±0.00
Mg	533.57	49.78	199.80±110.75	300.87	15.57	113.17±73.57
Mn	22.07	2.08	8.66±4.72	12.14	1.09	5.11±3.08
Mo	1.74	0.15	0.42±0.35	1.07	0.09	0.25±0.21
Na	4008.03	345.04	1368.29±871.97	1901.85	108.04	754.46±544.23
Nd	0.67	0.04	0.25±0.16	0.40	0.02	0.16±0.10
Ni	3.54	0.42	1.25±0.84	1.76	0.21	0.68±0.41
Pb	17.09	1.18	5.74±3.91	6.84	0.30	3.06±1.77
Pr	0.12	0.01	0.05±0.03	0.08	0.00	0.03±0.02
Rb	1.53	0.18	0.63±0.35	0.88	0.06	0.40±0.22
Sb	6.04	0.21	0.88±1.29	3.31	0.06	0.44±0.72
Se	0.33	0.02	0.08±0.07	0.11	0.00	0.05±0.03
Sm	0.10	0.01	0.04±0.02	0.06	0.00	0.02±0.01
Sn	1.14	0.13	0.52±0.25	0.62	0.07	0.30±0.14
Sr	7.81	0.60	2.69±1.77	4.34	0.22	1.57±1.09
Tb	0.02	0.00	0.01±0.00	0.01	0.00	0.00±0.00
Ti	65.14	4.32	26.06±16.77	41.39	3.17	16.32±9.93
Tm	0.01	0.00	0.00±0.00	0.00	0.00	0.00±0.00
U	0.07	0.00	0.03±0.02	0.05	0.00	0.02±0.01
V	3.35	0.25	1.05±0.78	1.39	0.13	0.56±0.34
Y	0.26	0.02	0.10±0.06	0.16	0.01	0.06±0.04
Yb	0.04	0.00	0.02±0.01	0.02	0.00	0.01±0.01
Zn	58.23	6.00	21.17±14.13	21.26	2.33	10.37±5.19
Zr	2.02	0.34	0.94±0.53	1.42	0.18	0.56±0.30

The heavy metal concentrations of PM_{10} is the summation total of the $PM_{2.5}$ and $PM_{2.5-10}$ concentrations. The profiles of metals are list as following: (1) the highest mean level of the elements: Na, Fe, Al, Ca, K, Mg, Zn (2) the secondly level the elements: Ti, Pb, Cu, Mn, Ba, Sb, V (3) the trace elements: Cr, Sn, Ni, Sr, Rb, Zr, As, Mo, Se, Ce, Ga, La, Cd, Nd, Co (4) and the sub-trace elements: Y, Ge, Cs, Hf, Pr, Gd, Sm, U, Dy, Er, Yb, Eu, Tm, Tb, Ho, Lu. The $PM_{2.5}$ concentration of above analytical elements is with the summery ratio of 4.7% in THU and 2.5% in Taya.

This study analyzed the ratio of the concentration of 45 elements in $PM_{2.5}$ accounted for PM_{10}. In Figure 3-1, which the elements of Na, Mg and the percentage is less than 40%, while Al, Lu, Ca, Tb, Ho, Hf, Eu, Sr, Yb, Tm, Pr, are with the percentage of between 40-50%. The Dy, Gd, Sm, Er, Nd, Y, La, Ba, Ce, Ti, Zr, Fe, U, Co, are with the percentage between 50-60%. Ga, Rb, Cr, K, Mo, Cs, Ni, Mn, Cu, Zn, V, are with the percentage between 65-85%. The Sb, Cd, Pb, Ge, Sn, As, Se, are with the the percentage of elements more than 85%. Among all, the most potential impact metals to human beings are Sb, Cd, Pb, Ge and Se.

With respect to the ratio of particle size, the metal levels in $PM_{2.5}$ are higher than levels in PM_{10}. Metal concentration in $PM_{2.5}$ above in PM_{10}

(Figure 3-1) was selected as indicated pollutants.

Because there are many types of metal included therefore it used T-test to select the metal which has significant differences in the concentration profile.

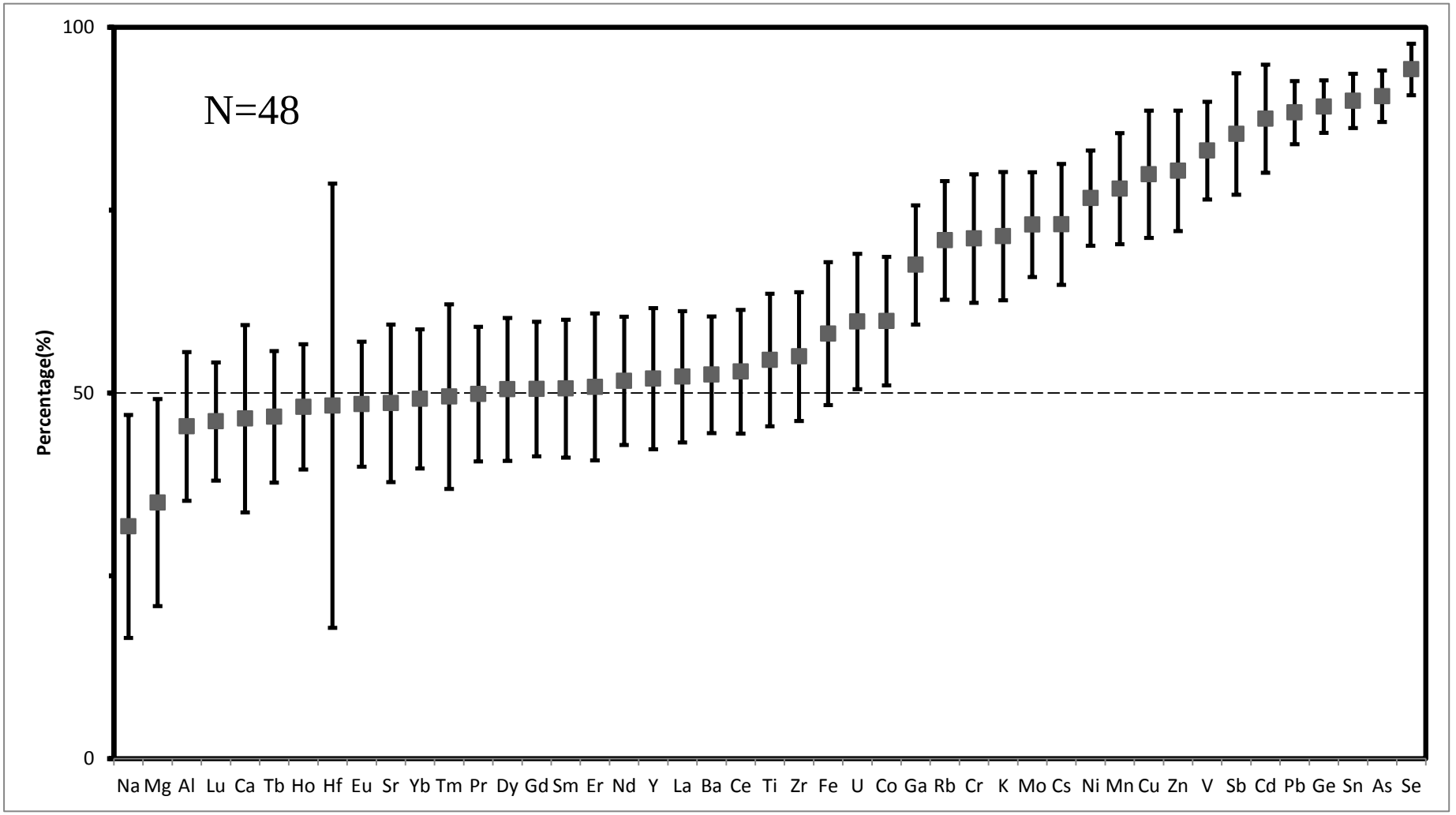

Figure 3-1. The ratio is $PM_{2.5}$ concentration per PM_{10} concentration in elements.

3-3 *The selection of indicator element*

3-3-1 *T-test*

Table 3-6 shows the $PM_{2.5}$ concentration T test values of THU and Taya sites.

Null hypothesis H_0 is located at THU concentrations equals to the concentration of Taya, alternatively hypothesis H_1 is not equals to the THU concentration and the concentration of Taya. When the value of T exceeds a certain standardized value, it means that H_0 is not accepted, that is, the alternative hypothesis accepted.

There is an asterisk followed by the value means that the T statistic falls outside the 95% confidence interval, and such elements have a significant difference concentration in THU and Taya. Those elements are selected from Table 3-6 are As, Ba, Cd, Co, Cs, Fe, Ga, Ge, K, La, Ni, Pb, Rb, Se, Sn, Zn and Zr. Because of the number of elements selected by T-test are excessive, therefore the elements have significant difference use PCA to find the index element.

Table 3-6.
There is the T value of $PM_{2.5}$ analysis elements between THU and Taya.

Metal	T-value	Metal	T-value
Al	1.78	Mn	1.63
As	2.09*	Mo	1.04
Ba	2.12*	Na	1.28
Ca	1.45	Nd	1.63
Cd	2.28*	Ni	3.13**
Ce	1.79	Pb	2.43*
Co	3.31**	Pr	1.49
Cr	1.76	Rb	2.51*
Cs	2.13*	Sb	0.30
Cu	0.54	Se	2.47*
Dy	1.49	Sm	1.49
Er	1.52	Sn	3.26**
Eu	1.58	Sr	1.35
Fe	2.03*	Tb	1.55
Ga	2.31*	Ti	1.95
Gd	1.60	Tm	0.26
Ge	2.51*	U	1.74
Hf	1.95	V	1.88
Ho	1.53	Y	1.61
K	2.74**	Yb	1.73
La	2.15*	Zn	3.15**
Lu	0.49	Zr	2.41*
Mg	1.40		

3-3-2 *Indicative of the heavy metal screening*

The PCA of $PM_{2.5}$ showed that the variables can be divided into two groups with the percentage of variation 81.01% and 7.19% (Table 3-7), with a cumulative sum of 88.20%. On the other hand, it represents that this study can satisfactorily use these two factors to explain all data of

$PM_{2.5}$. As stated earlier, the data are separated into two groups obtained by PCA; As, Pb, Cd, Ge, Sn and Zn are differentiated to Factor 1, while Zr, La, Fe, Ba and Co are differentiated to Factor 2 in $PM_{2.5}$ (Table 3-7).

Factor 1 among Pb, Zn explain the contribution of emissions from the transport (Wang *et al*., 2003; Lin *et al*., 2005; Kulshrestha *et al*., 2009; Tecer *et al*., 2012); while As, Cd, Sn, explain the contribution of anthropogenic emissions (Vincent and Passant, 2006; Shaofei Kong *et al.*, 2011; Pant and Harrison 2012). As, Cd, the EU regulatory standards, namely 6 ng/m^3, 5 ng/m^3, Ge is set by the manufacturing process in the semiconductor industry, the metal compound is used.

Factor 2 among Zr, La, Fe, Ba, Co elements interpreted by the crustal elements (natural factors) contributed (Hsu *et al*., 2004; Wang *et al*., 2005; Wang *et al*., 2006).

Because these elements are significant differences with CTSP, so Factor 1 is called anthropogenic emissions associated with CTSP; Factor 2 is called natural factors associated with CTSP.

The results from Factor 1 can realize it belongs to the anthropogenic emissions, as well as the control elements of As, Cd, Sn, Ge, Pb, and Zn these six metals. Those elements will result in this study as an indicator of

pollution material, while the concentration of the standard set.

Table 3-7.
The PCA result after T-test.

Metals	Factor 1	Factor 2
As	**0.91**	0.28
Pb	**0.90**	0.39
Cd	**0.89**	0.39
Ge	**0.82**	0.50
Sn	**0.81**	0.42
Zn	**0.80**	0.51
Cs	0.78	0.53
K	0.73	0.62
Rb	0.69	0.67
Se	0.64	0.34
Ni	0.63	0.54
Zr	0.33	**0.90**
La	0.40	**0.89**
Fe	0.42	**0.88**
Ba	0.44	**0.88**
Co	0.48	**0.81**
Ga	0.67	0.68
% of Variance	81.01	7.19
Cumulative (%)	81.01	88.20

3-3-3 *The normal distribution of indicator element*

Figure 3-2 is the normal distribution plots of As in $PM_{2.5}$, THU and Taya. It can be seen that the concentration of THU is higher than that of Taya. Because Taya located upwind to the CTSP while THU is located in downwind, therefore THU concentration may higher than those of Taya.

It is confirmed that As was generated by CTSP, and not came from the ambient. It can see from the Taya normal distribution concentration curve, while the null hypothesis (H_0) is the Taya average concentration that means alternative hypothesis (H_1) is not the Taya average concentration range.

Table 3-6 shows that the As T statistic is greater than its critical value T, so the alternative hypothesis (H_1) is accepted. This means a 95% confidence interval exceeds this value represents the concentration of this value is too high in Taya, not belongs to the general average concentration values.

In Figure 3-2, it can thus determine when the As concentration exceeds 95% confidence interval of the concentration values, it may prove to be CTSP emissions, and with a value of 2.78 ng/m^3.

It can also set more than 99% confidence interval concentration values as a standard, with this more relaxed standard value and obtain its value of 3.419 ng/m^3.

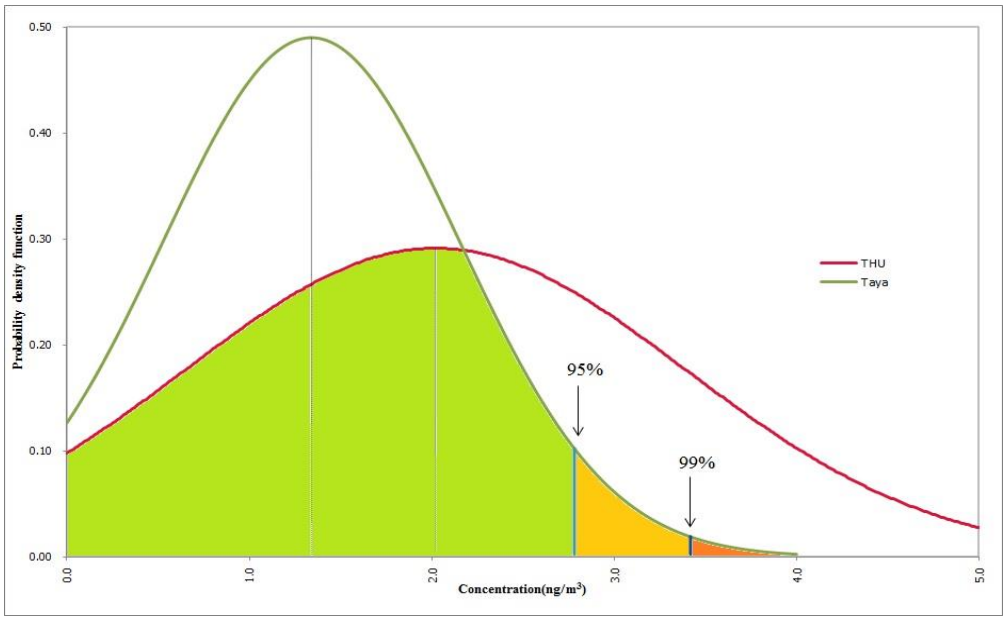

Figure 3-2. The normal distribution curve on $PM_{2.5}$ concentration of As in THU and Taya.

Figure 3-3 shows the normal distribution curve on $PM_{2.5}$ concentration of Cd in THU and Taya. It can see this figure trends and have a similar curve distribution of Figure 3-2. Over 95% confidence interval Cd concentration is 1.06 ng/m^3. Over 99% confidence interval Cd concentration is 1.33 ng/m^3.

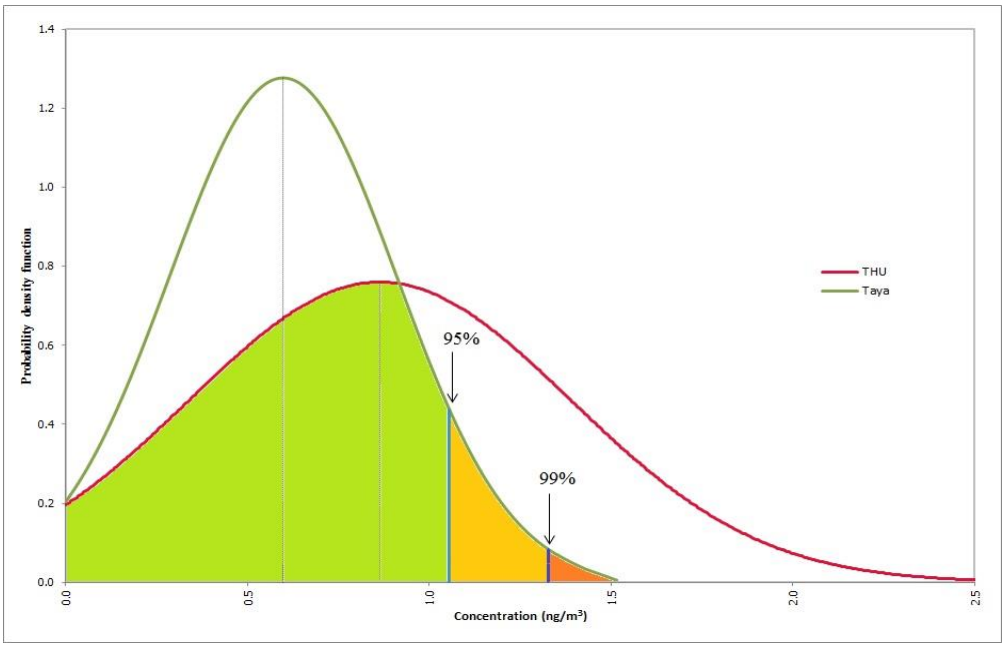

Figure 3-3. The normal distribution curve on $PM_{2.5}$ concentration of Cd in THU and Taya.

Figure 3-4 shows the normal distribution curve on $PM_{2.5}$ concentration of Ge in THU and Taya. It can see this figure trends and have a similar curve distribution of Figure 3-2. Over 95% confidence interval Ge concentration is 0.21 ng/m^3. Over 99% confidence interval Ge concentration is 0.25 ng/m^3.

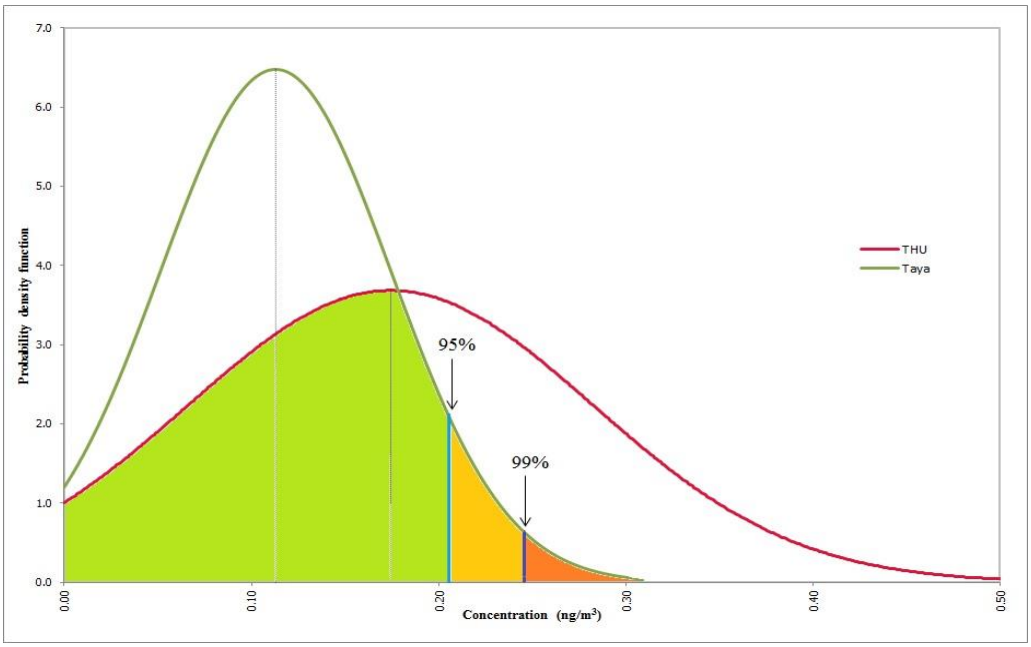

Figure 3-4. The normal distribution curve on $PM_{2.5}$ concentration of Ge in THU and Taya.

Figure 3-5 shows the normal distribution curve on $PM_{2.5}$ concentration of Pb in THU and Taya. It can see this figure trends and have a similar curve distribution to Figure 3-2. Over 95% confidence interval Pb concentration is 58.48 ng/m^3. Over 99% confidence interval Pb concentration is 69.91 ng/m^3.

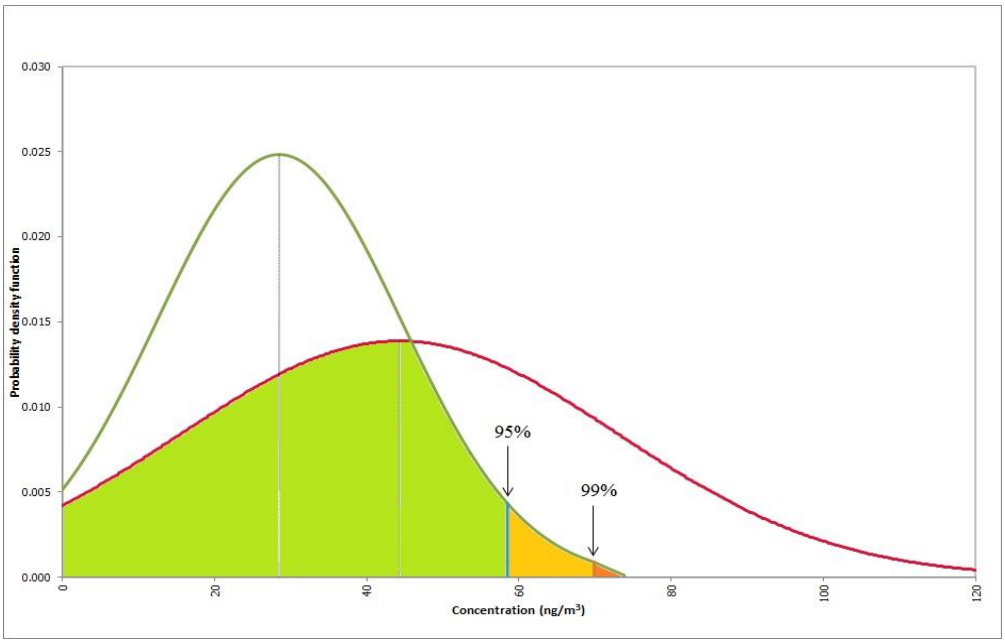

Figure 3-5. The normal distribution curve on $PM_{2.5}$ concentration of Pb in THU and Taya.

Figure 3-6 shows the normal distribution curve on $PM_{2.5}$ concentration of Sn in THU and Taya. It can see this figure trends and have a similar curve distribution to Figure 3-2. Over 95% confidence interval Sn concentration is 5.20 ng/m^3. Over 99% confidence interval Sn concentration is 6.46 ng/m^3.

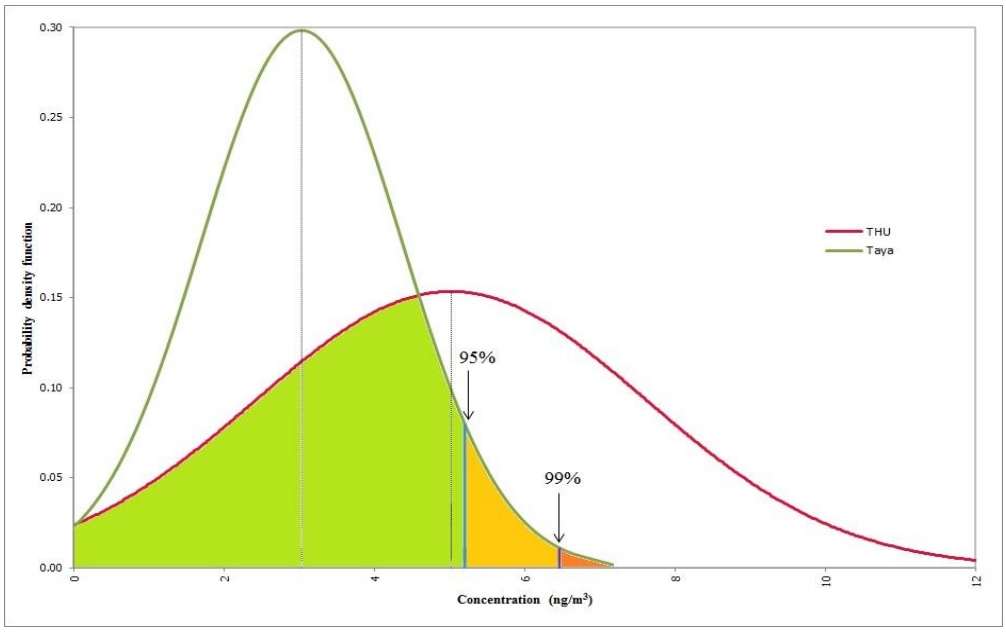

Figure 3-6. There is normal distribution curve on $PM_{2.5}$ concentration of Sn in THU and Taya

Figure 3-7 shows the normal distribution curve on $PM_{2.5}$ concentration of Zn in THU and Taya. It can see this figure trends and have a similar curve distribution to Figure 3-2. Over 95% confidence interval Zn concentration is 94.25 ng/m^3. Over 99% confidence interval Zn concentration is 122.82 ng/m^3.

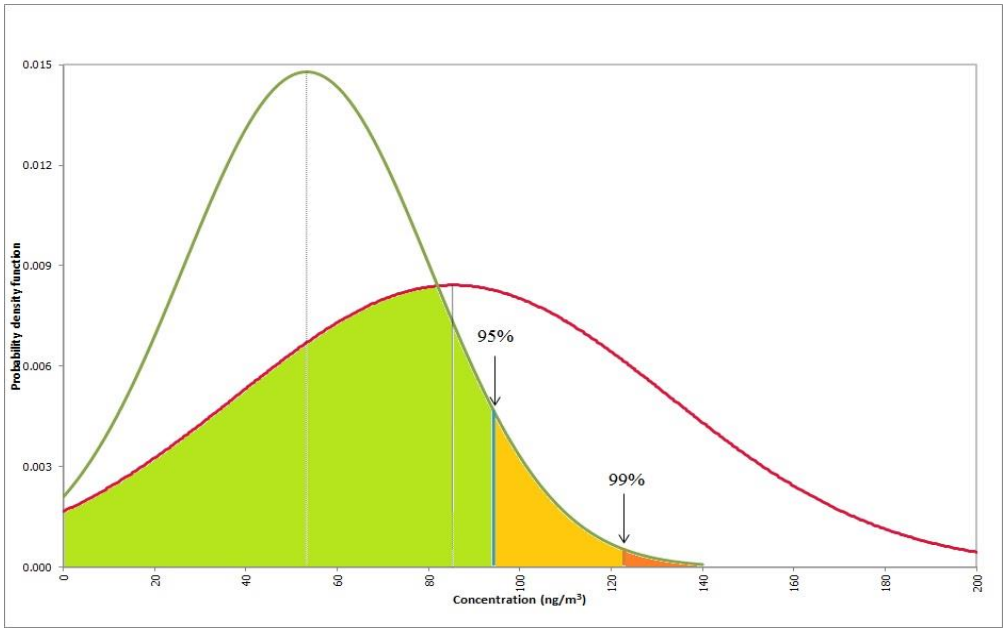

Figure 3-7. The normal distribution curve on $PM_{2.5}$ concentration of Zn in THU and Taya.

Where the two curves overlap, the possible errors is more than the standard value of the original value (H_1) puts it to find no case exceed, this situation is called Type II error.

Another error does not exceed the standard value is a value (H_0) to be recognized as a value exceeding, this situation is called the Type I Error.

3-4 *Risk Characterization*

3-4-1 *Risk Characterization steps*

The risk characterization include four steps: (a) Hazard Identification (b) Dose-Response Assessment (c) Exposure Assessment and (d) Risk Characterization (Environmental Protection administration Executive Yuan, R.O.C., 2011)

3-4-2 *The selection of Indicator Chemicals*

Patricia *et al*., (1992) pointed out that many kind of chemicals will possible found in a pollutant site, put all of the chemical concentrations into the risk characterization to calculate will be huge but no necessary work. Because not every chemical are harmful to human health, some of them are damage slightly. Possibly includes some that are not easy to calculate and easy to misinterpret the results. Before calculating the risk characterization, it should decide which chemicals are necessary that also called indicator chemicals.

The indicator chemicals may harmful to human body seriously which, have greater mobility, not easy to degrade in nature and, have toxicity, carcinogenicity or east to accumulation creatures. All the factors have greater risk potentially and generalize some principles in choosing

indicator chemicals. The indicator chemicals have to include: (a) any carcinogens (benzene, arsenic, chloroethene). (b) Have exceeded in maximum health standard concentration. (c) Will spread the pollutants to outer area. (d) Will accumulation in human bodies. The indicator chemicals exclude: (a) Chemicals that not often to measure (b) Only measured in medium, but will not harmful to human body and (c) Have slightly exceeded the background concentration.

3-4-3 *Calculation method*

The major purpose in risk characterization of this study is to calculate the Hazard Index (HI) for confirming the risk to damage human being. To calculate the HI, it needs to get EXP (amount of hazard matte in contact surface) first. It can divide Reference Dose (RfDs) to get the HQ (Hazard Quotient) if pollutants are non- carcinogenicity matters. Add all kinds of HQ will be HI. When the HI is bigger than 1.0, it will unhealthy to human health. It also can get carcinogenic ratio from RfDs multiply slope factor if the pollutants are carcinogenicity matters. The standard in American environment is 10^{-6}.

3-4-4 *Exposure equation*

Absorption gateway：

$$EXP = \frac{C_{metal} \times CR \times FI \times ABS_f \times EF \times ED}{BW \times AT}$$ **Equation 3-1.**

EXP =amount of hazard matte in contact surface (mg/kg-day)

C_{Metal} =concentration of hazard matte in transmission medium (ng/m^3)

CR =contact velocity (m^3/day)

FI = absorption amount from pollutant source (dimensionless)

ABS_f = absorption factor (%)

EF = exposure frequency (day/yr)

ED = exposure period (yr)

BW =the average weight during exposure period (kg)

AT = average time

= ED ×365 days/yr (non- carcinogenicity matter)

= 70 ×365 days/yr (carcinogenicity matter)

Doses were derived from inhalation reference concentrations (mg/m^3) from IRIS and HEAST by multiplying a conversion factor of 20 m^3/day per 70 kg by the reference concentrations (U.S. E.P.A Risk Assessment).

3-4-5 *Calculation*

$$EXP_{As} = \frac{\left(2.78\frac{ng}{m^3}\right)\left(20\frac{m^3}{day}\right)\left(8\frac{hr}{day}\right)\left(5\frac{day}{wk}\right)\left(52\frac{wk}{yr}\right)}{(70kg)\left(365\frac{day}{yr}\right)\left(24\frac{hr}{day}\right)} = 0.189\frac{ng}{kg-day}$$

$$= 1.9 \times 10^{-7}\frac{mg}{kg-day}$$

$$EXP_{Cd} = \frac{\left(1.06\frac{ng}{m^3}\right)\left(20\frac{m^3}{day}\right)\left(8\frac{hr}{day}\right)\left(5\frac{day}{wk}\right)\left(52\frac{wk}{yr}\right)}{(70kg)\left(365\frac{day}{yr}\right)\left(24\frac{hr}{day}\right)} = 0.072\frac{ng}{kg-day}$$

$$= 7.2 \times 10^{-8}\frac{mg}{kg-day}$$

$$EXP_{Sn} = \frac{\left(5.20\frac{ng}{m^3}\right)\left(20\frac{m^3}{day}\right)\left(8\frac{hr}{day}\right)\left(5\frac{day}{wk}\right)\left(52\frac{wk}{yr}\right)}{(70kg)\left(365\frac{day}{yr}\right)\left(24\frac{hr}{day}\right)} = 0.353\frac{ng}{kg-day}$$

$$= 3.5 \times 10^{-7}\frac{mg}{kg-day}$$

$$EXP_{Zn} = \frac{\left(94.25\frac{ng}{m^3}\right)\left(20\frac{m^3}{day}\right)\left(8\frac{hr}{day}\right)\left(5\frac{day}{wk}\right)\left(52\frac{wk}{yr}\right)}{(70kg)\left(365\frac{day}{yr}\right)\left(24\frac{hr}{day}\right)} = 6.394\frac{ng}{kg-day}$$

$$= 6.4 \times 10^{-6}\frac{mg}{kg-day}$$

$$HQ_{As} = \frac{EXP_{As}}{RfD_{As}} = \frac{1.9 \times 10^{-7}}{0.0003} = 6.3 \times 10^{-4}$$

$$HQ_{Cd} = \frac{EXP_{Cd}}{RfD_{Cd}} = \frac{7.2 \times 10^{-8}}{0.0005} = 1.4 \times 10^{-4}$$

$$HQ_{Sn} = \frac{EXP_{Sn}}{RfD_{Sn}} = \frac{3.5 \times 10^{-7}}{0.0003} = 1.2 \times 10^{-3}$$

$$HQ_{Zn} = \frac{EXP_{Zn}}{RfD_{Zn}} = \frac{6.4 \times 10^{-6}}{0.3} = 2.1 \times 10^{-5}$$

Table 3-8.
WOE definition carcinogenic category

IARC	IRIS	Classification	Identification
1	A	human carcinogen	Evidence is sufficient for epidemiology.
2A	B1	probable human carcinogen	Evidence is suggestive but not sufficient for epidemiology, but animal experiment is sufficient.
2B	B2	little or no human evidence + strong animal evidence	Evidence is suggestive but not sufficient for epidemiology and animal experiment is not sufficient.
-	C	weak evidence from human and animal data	-
3	D	little evidence for or against carcingenicity	Evidence is inadequate for epidemiology, and animal experiment is not sufficient or can't classify.
4	E	good evidence for absence of carcingenicity	It's lack of carcinogenicity in human beings and animals. Evidence is inadequate for epidemiology.

Table 3-9.
Reference Dose and Slope factor of metals: Cd, Sn, Zn, Ge, Pb and As

type		WOE (Weight-of-Evidence Characterization)		Chronic Oral Reference Dose	Oral Slope Factor
		IRIS	IARC	(mg/kg-day)	$(mg/kg\text{-}day)^{-1}$
Cd	Cadmium	B1	1	0.0005(water)	-
Sn	Tributyltin oxide	D	-	0.0003	-
Zn	Zinc and Compounds	D	-	0.3	-
Ge	Germanium	-	-	-	-
Pb	Lead and compounds (inorganic)	B2	2B	-	-
As	Arsenic, Inorganic	A	1	0.0003	1.50

Information source：(Risk Assessment Information System (RAIS); Integrated Risk Information System (IRIS); International Agency for Research on Cancer (IARC))

$$\text{HI} = HQ_{As} + HQ_{Cd} + HQ_{Sn} + HQ_{Zn}$$
$$= 6.3 \times 10^{-4} + 1.4 \times 10^{-4} + 1.2 \times 10^{-3} + 2.1 \times 10^{-5}$$
$$= 1.991 \times 10^{-3}$$
$$\text{HI} = 1.991 \times 10^{-3} < 1$$

It shows still hazard indicators within the permissible range.

Multiplied by the total intake of cancer slope, it can get cancer rate. Environment in the United States of carcinogenic pollutants shall not exceed the rate of one of the millions prevail (10^{-6}) is currently the most widely-accepted guidelines. In Table 3-9, because the data is not enough houses, only to figure out the carcinogenic heavy metals As rates are as follows:

$$Cancer\ Risk = Intake \times Slope\ factor$$

$$R_{As} = 1.9 \times 10^{-7} \frac{mg}{kg - day} \times 1.5 \frac{kg - day}{mg} = 2.85 \times 10^{-7}$$
$$2.85 \times 10^{-7} < 1.0 \times 10^{-6}$$

The cancer rate of As metal which only 4.8×10^{-7}. It does not exceed the standard rate which the U.S. Environmental carcinogenic pollutants.

Chapter 4. Conclusions and Suggestions

4-1 *Conclusions*

1. The $PM_{2.5}$ concentrations are higher than $PM_{10-2.5}$ concentrations. In this study, the ratio of $PM_{2.5}$ /PM_{10} is 0.76.
2. There are 32 Heavy metal concentrations of $PM_{2.5}$ higher than $PM_{10-2.5}$.
3. Do T-test and PCA from $PM_{2.5}$ metal concentrations, it can learn from 45 kinds of elements in As, Cd, Ge, Pb, Sn, Zn and other elements, as the CTSP indicators emissions.
4. From the normal distribution which can be worked out by the specification of these indicators substance concentration, As was 2.78 ng/m^3, Cd 1.06 ng/m^3, Ge is 0.21 ng/m^3, Pb to 58.48 ng/m^3, Sn 5.20 ng/m^3, Zn 94.25 ng/m^3.
5. In the risk assessment, the exposure of this study does calculation formula, the calculated rate of the carcinogenic hazard index and is within the limits of the standard.

4-2 *Suggestions*

1. To be sampled according to seasonal determine whether the industry has been affected by the seasons.
2. The ratio of particles still has the tendency to fine particles; it may be for the finer particles for analysis in the future.
3. The object of this study was CTSP, so if there are other science parks sampled data, it is recommended to apply the same method to find indicators.

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Q&A

問	答
楊錫賢老師	
摘要分太多段,以及補充中文摘要	已修改
如何判斷是否完全消化?	看濾紙是否殘留
P.13 SIZE 是在此區分的嗎?	此 SIZE 選擇為細顆粒以方便做指標物的挑選
P.13 Formulate Concentration 為何意思?	利用 normal distribution curve 訂定其規範濃度,參見 P.39
T-test 做何分析?	請參見 P.35
是否同步採樣?	是
NIEA A102 非 $PM_{2.5}$ 標準方法	此樣本採樣時間為 2010 年,此方法還是標準方法, $PM_{2.5}$ 新標準方法於 2012 年公告
樣品金屬濃度在哪裡分析的?	中研院環境研究變遷中心
樣品分幾組檢量線?	1 組
P.40 訂出濃度值以後用途?	以此當作標準濃度值

問	答
P.24 為何用 65 ng/m^3 當標準?	採樣當時所規定的日平均標準值為此數值,現在則改為 35 ng/m^3

問	答
張士昱老師	
此方法僅針對中部科學工業園區的產業?	目前尚無嘗試其他區域
樣本僅為冬季,產業製程可能有季節效應,對於指標性污染物的建立,應如何規劃?	應該全季節性採樣看其指標性污染物是否相似
如何確認東海之於中部科學工業園區是下風處	利用盛行風向以及相對位置來判斷
採樣是否連續 24 小時	是
並非所有採樣期間皆為上下風,若出現海陸風對流,影響為何?	依照大肚山的地形來看,海陸風對中部科學工業園區的影響並不大
數據的有效位數的改正	已於內文全文改正
OBJECTIVE 未提及風險評估	已補上
微波消化如何判斷是否完全消化?	看濾紙是否殘留
問	答
濾紙秤重是否有做靜電去除	未來的研究會加入此項目

為何以 $PM_{2.5}$ > 65 ng/m^3 污染事件當標準?而不是以 35 ng/m^3 當作標準	採樣當時所規定的日平均標準值為此數值,現在則改為 35 ng/m^3
$PM_{2.5}$/PM_{10} 氣態污染物(干擾)的去除	採樣回來後盡速秤重,以及本研究所使用的醋酸纖維濾紙對於氣狀污染物的干擾較低
P.28 金屬分四類的依據為何?	依據濃度高低