4. RESULTS AND DISCUSSION

4.1. *Total Suspended Particle Concentration*

After 14 months sampling period from December 2005 to February 2007 at THU site, the observed TSP concentration shows within the range between 46.5 and 226.3 $\mu g/m^3$, while the first and last 7 month averaged TSP are 126.7 and 105.3 $\mu g/m^3$ respectively. Figure 4-1 compares the official annual TSP report from Taichung city between 2000 and 2004 and this study (Air and Noise Pollution Control Section website, Environmental Protection Bureau, Taichung City, 2007). In the same time, this study conducted a weekly sampling program collecting TSP in local area. Figure 4-1 shows TSP before 2004 are between 94.4 and 102.2 $\mu g/m^3$, which are much lower than the data obtained by Tsai's (2006) study (130.7 $\mu g/m^3$) and the first 7 months of this study (126.7 $\mu g/m^3$). Tsai's study collected THU site sample during Sep. 2004 to Aug. 2005, when CTSP was under mass construction. Thus, it indicates that a significantly growth trend of TSP value was found based on the investigation. The result possibly correlated to the influence of suspension dust during the construction of CTSP. According to the ambient environment quality in construction period from the official report, it indicates the average TSP is about 122.5 $\mu g/m^3$ between October and December 2004 (Central Taiwan Science Park official website, 2004). This finding also supports that the increment of TSP is positively correlated to the emission from CTSP constructing. The high ambient TSP is possibly raised by high frequency working of truck and large machinery on transportation and building plants around CTSP. In addition, prevailing northern bound wind is occurred during the winter sampling period, while the THU sampling sites are located downstream of CTSP. Therefore, comparing this study with Tsai's report, it shows the TSP concentration decreased thereafter since 2004, and the concentration of the recent 7 months (Aug. 2006 to Feb. 2007) study (105.3 $\mu g/m^3$) is

almost be the same as the previous official data (2000~2004). It also indicates that the mass construction was almost finished after June 2006, and the frequency of truck and large machinery on transportation and building plants reduced to the previous level. This study provides the high correlation between the ambient TSP and the emission from the construction of CTSP.

By reviewing the overall annual tendency (Figure 4-2), the similar variations were found between the period 2000 and 2007. This study displays a similar tendency to the official data (2000~2003) and a different tendency with Tsai's (2006) report. The official data and this study both have found high level TSP emission in winter (Nov. to Mar. next year) and low level TSP concentration in summer (Apr. to Aug.). However, the Tsai's report has much higher TSP level in the summer period between April and August 2005. The huge different tendency may due to some mass construction events, which influence to the downward TSP concentration during the study between Sep. 2004 to Aug. 2005, especially in summer season (Tsai, 2006). The precipitation and different monsoon also may affect the TSP measurement. In Taiwan, in summer season (between April and August), it always has heavy summer storm (or typhoon) invasion otherwise it has weak south western (SW) series wind. The abrupt rainfall precipitation or low wind speed will reduce the TSP in air and cause the much low measured TSP level than other seasons. But in winter seasons, because there is strong north eastern (NE) series wind in Taiwan, the higher wind speed and the well fit wind direction which may carry the high capacity of TSP to the downwind site. Therefore, the TSP value obtained in winter is much higher than other seasons.

Figure 4-3 shows all sampling TSP data during the investigation period of this study (Dec. 2005 to Feb. 2007) at the Taya, THU and LTGA sampling sites. From the bar chart of TSP plot, it reveals that the TSP has an unstable distribution during

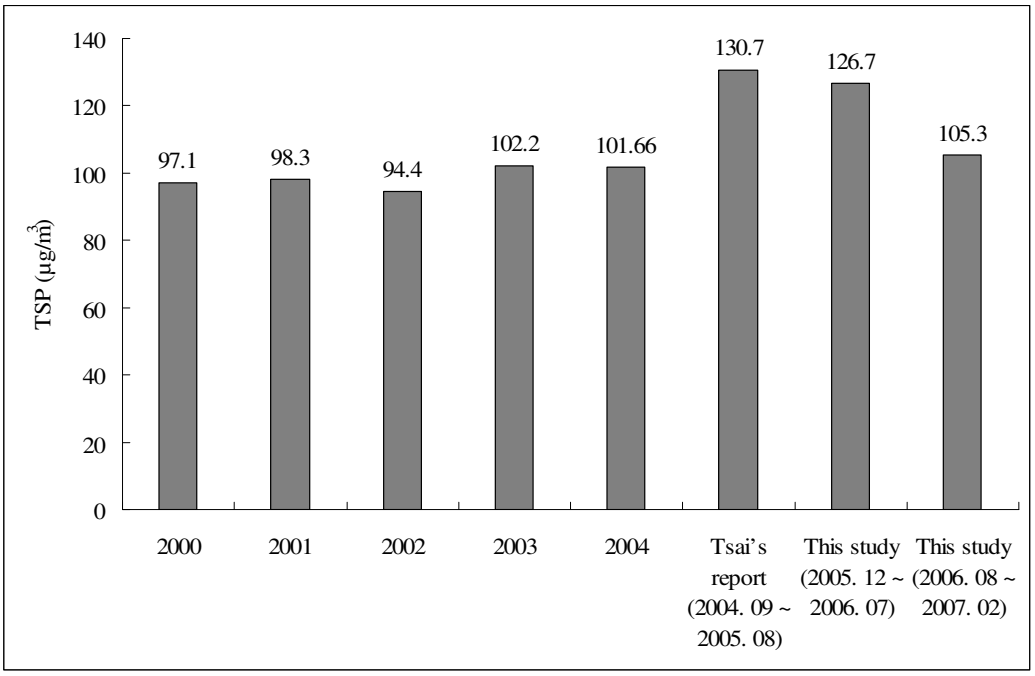

Figure 4-1. The average annual TSP ($\mu g/m^3$) of Taichung City between 2000 and 2004 compared to this study and Tsai's report. This study collected TSP at the Tunghai University site between Dec. 2005 and Feb. 2007. The data of TSP between 2000 and 2004 was collected from the Wen-Shan monitoring station in Taichung area, which was obtained from the website of Air and Noise Pollution Control Section website, Environmental Protection Bureau, Taichung City (2006).

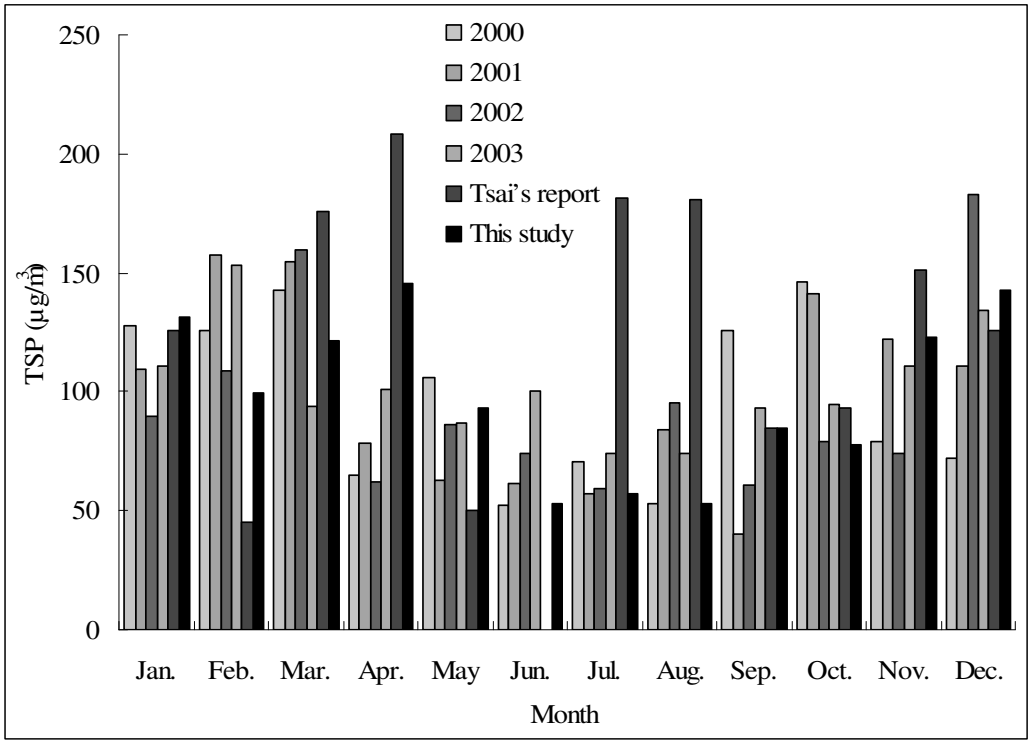

Figure 4-2. The comparison of the average monthly TSP (μg/m^3) between this study and the previous data (2000 to 2006) (Tsai's report, 2006). The data was obtained from Air Quality Monitoring website, ROC EPA, Taiwan.

*Tsai's report: 2004.09 ~ 2005.08

This study: 2005.12 ~ 2007.02

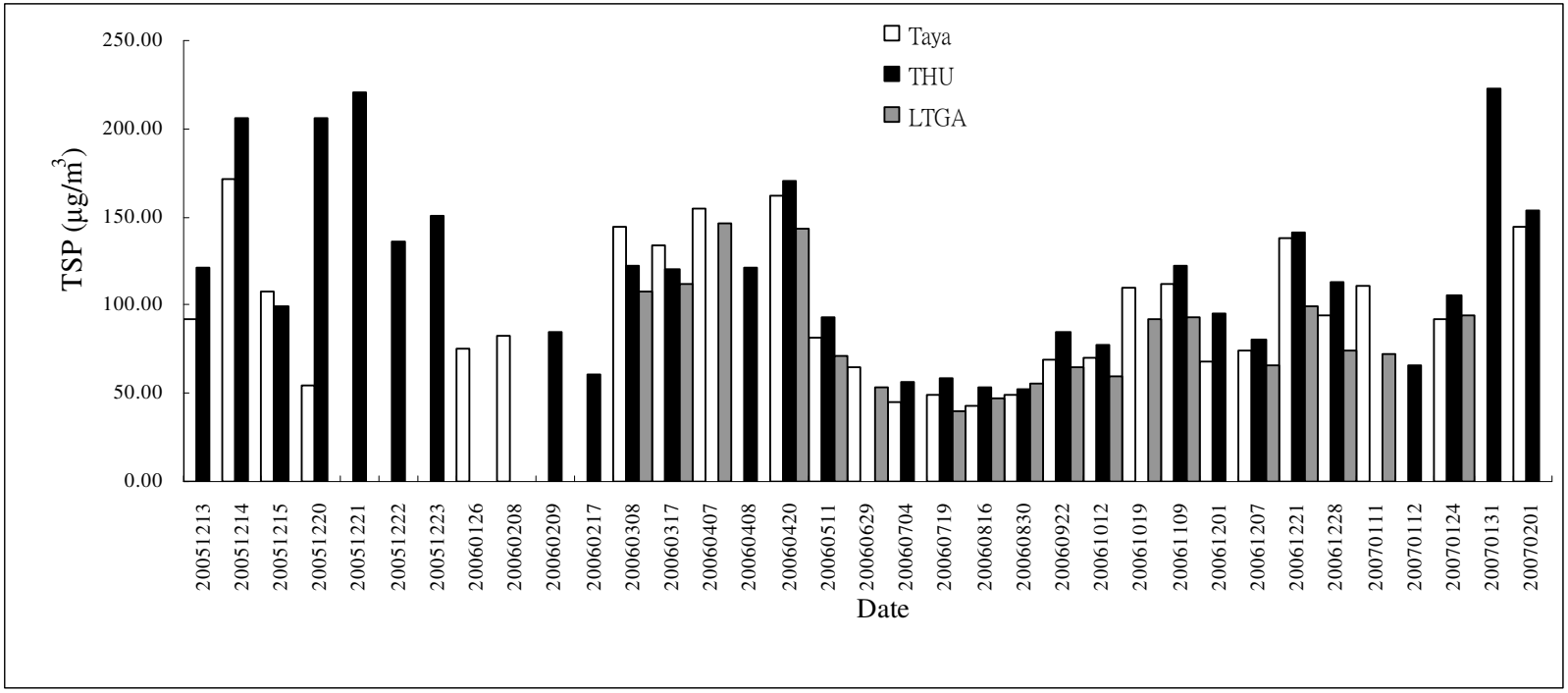

Figure 4-3. The TSP profiles during the sampling period from December 2005 to February 2007 at Taya, THU and LTGA sites.

*TSP: Total Suspended Particulate (μg/m^3).

Taya: Taya Senior Citizen Recreation Center.

THU: Tunghai University.

LTGA: Ling Tung Golf Association.

the whole sampling period. The fluctuation result maybe caused by many factors, i.e., atmospheric conditions, particle size and emitted property of contribution sources, etc. But the tendencies of all sites are similar to each other i.e., the TSP concentrations are all much higher in winter (Nov. to Feb.) than in summer (Apr. to Aug.). It indicates the monsoon with the different meteorological parameters (i.e., wind speed and direction) still has strong influence on the TSP value. However, comparing the three sampling sites with each other, the TSP value of Taya and THU sites are higher than that of LTGA site. The result indicates the traffic emission is an important factor in TSP value, because the Taya and THU sites have the broad main road used by vehicular traffic (Zhong-Qing road and Zhong-Gang road). The traffic works caused the large capacity of re-suspended particle resulted in high value of TSP at Taya and THU sites. In addition, two peaks of TSP were occurred on 2005/12/21 and 2007/01/31, with the TSP value of 220.8 and 223.3 $\mu g/m^3$, respectively. Both of the highest TSP concentrations almost reach to the upper limitation of Taiwan Air Quality Standard of short-term exposure of 250 $\mu g/m^3$ (EPA Environmental Laws and Regulations, Taiwan, ROC, 2006) and the EU limitation of short-term exposure of 300 $\mu g/m^3$ (European Community, 1992).

This study compares the sampling data with meteorological factors including wind speed and direction. Figure 4-4 shows the correlation between TSP ($\mu g/m^3$) and wind speed (m/s) and indicates the different TSP distribution influenced by the level of wind speed. The wind speed will influence the particulate transport and diffusion capability. The tendency of Taya and THU indicates the TSP value proportion to the wind speed, maybe both sites are near the broad main road used by vehicular traffic, and the road dust re-suspended by the strong wind. And the slope of the tendency in THU (slope=8.99) is much higher than that of Taya (slope=1.03), this may be caused by the distance effect, the distance from THU and Taya sites to

CTSP are 1.65 km and 4.75 km, respectively. But the tendency of LTGA site is contrary to the other two sites, the slope of tendency is minus (slope=-1.00), because LTGA is a far remote district from CTSP and there is no excess emission source at all. The result indicates the nearby environment influences the TSP value significantly.

Figure 4-5 shows that the average value of TSP separated at sixteen wind directions. The result displays the TSP value based on north series wind direction is much higher than that of south series, this is because the wind speed based on north series wind direction usually is much stronger than that of south series wind. The strong north series wind can carry more re-suspended surface particle than that of the south wind series. Comparing the three sampling sites with each other, the TSP value of THU sampling site has the maximum value in all wind directions, maybe it caused by the vehicular traffic from nearby Zong-Gang road and CTSP in the NE direction and the Taichung industrial park (TIP) in the SW direction; while the Taya site which is close to the Zong-Qing road in the NE direction and CTSP in the SW direction, the vehicular traffic from Zong-Qing road and CTSP also raised the TSP value in Taya site. While the LTGA site is far away from CTSP and has no nearby particle emission sources, therefore, the TSP value is much lower than other sites based on all wind directions. However, the TSP value based on south wind series is much lower than north wind series, except the SEE wind direction. Based on the SEE wind direction, the TSP value of Taya site has the maximum value while the THU site has the minimum value. Maybe the Zung-Shan freeway is close to the Taya site in the east direction (showed in Fig. 3-2), and the SEE wind direction can carry the most road re-suspended particle to Taya site; and the LTGA site is much closer to Zung-Shan freeway than THU site, so the TSP value is much higher than that of THU site during the SEE wind direction case. While the east portion of THU site is a large-scale pasture, therefore theoretically, the TSP value of THU site is much

lower than other two sites. The result indicates when the wind blowing from NE direction, the high speed wind carries the large capacity particle pollutant to both Taya and THU sites. While the wind blowing from SW direction, because of the low wind speed, the TSP value is low at all sampling sites. Following this case, the pollutant came from NE direction may contributed by the CTSP and Zung-Gang road to THU site.

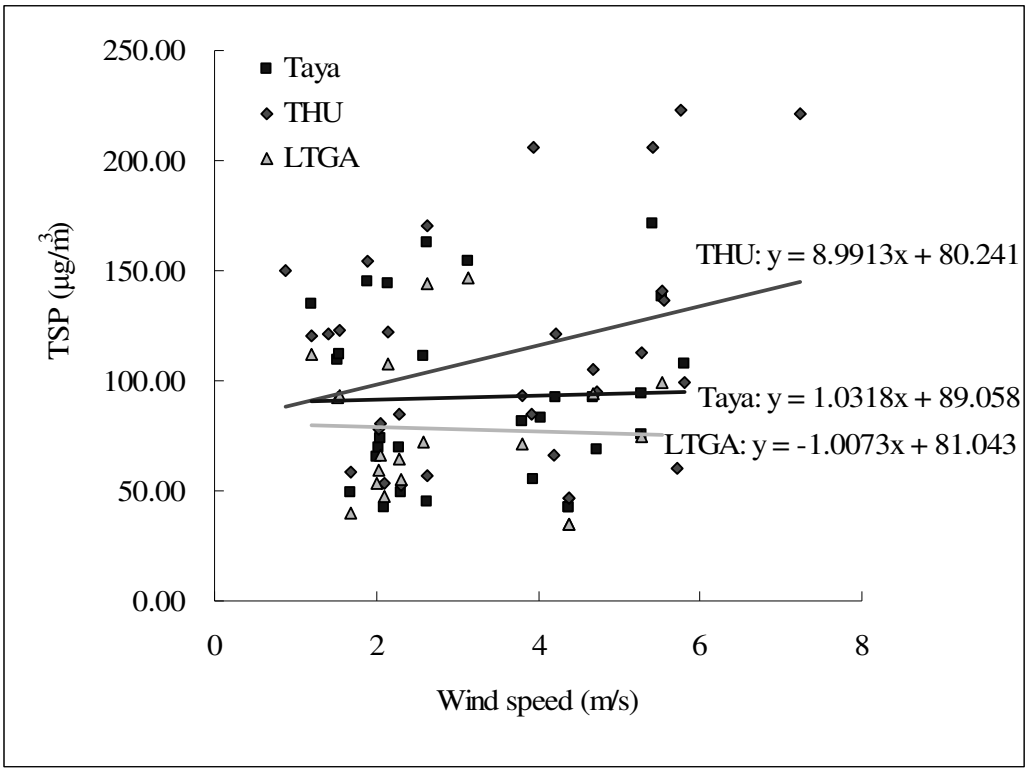

Figure 4-4. The correlation of the tendency between TSP (µg/m^3) and the wind speed (m/s) at all sampling sites (Taya, THU and LTGA).

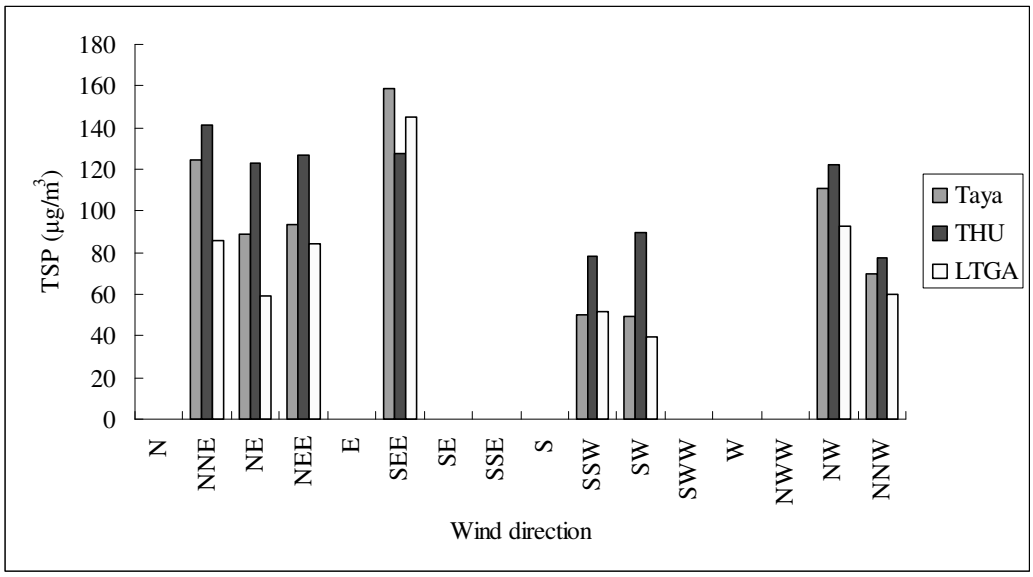

Figure 4-5. Average value of total suspended particulate (TSP: µg/m^3) separated on the sixteen wind directions at all sampling sites (Taya, THU and LTGA).

4.2. *Metal Concentration*

Table 4-2 shows the comparison of the ambient metal concentration obtained by this study and other references. In this study, the average metal concentrations are between 2.0 and 3,200 ng/m^3, and in the order of Fe > Ca > Mg > Zn > Cu > Cr > Pb > Mn > Ni > As > Cd. The result indicates Fe, Ca and Mg have higher average concentrations than other metals. According to Sofuoglu *et al*. (1998), it indicates that Fe, Ca and Mg are the common crustal metals and usually emitted from natural sources. Thus, these major metal contents in TSP are composed of crustal element emitted at Taichung area. The average concentration of Fe and Ca is obviously much higher than other metals of this study. The main possible reason of high content of Fe is coming from the red topsoil (Wang, 2002).

As, Cd and Ni are considered as the carcinogenic metals and have been proposed to control in EU with the limitations of As, Cd and Ni are 6.0, 5.0 and 20.0 ng/m^3, respectively (European Community, 2007). This study shows the concentration of As (11.1 ng/m^3) in THU site which is obviously much higher than that of the EU limitation (6.0 ng/m^3) while, Cd (2.5 ng/m^3) and Ni (14.9 ng/m^3) in THU site all approach the EU limitations. Besides, Pb (32.5 ng/m^3) is much lower than the limit value of World Health Organization Standards of 500 ng/m^3 (World Health Organization Ambient Air Quality Standards website, 2007). Comparing with Taya sampling site (background site, in winter), it is significantly displayed that the elements level of As, Ca and Fe were higher in downstream than those of upstream. Other elements tend to have the similar trend for all sampling sites. The possible reason is the downstream sampling site, THU, always affected by the red top soil emission from CTSP construction, therefore, the crust elements such as Fe and Ca tend to be high. Arsenic could be emitted from the CTSP plants and dispersed by NE bound wind to the sampling site. Comparing with LTGA site, except As

concentration (7.1 ng/m^3) which is a little lower than that of THU site, other elements tend to be similar to Taya site. This indicates that the Taichung industrial park (TIP) located NE direction that of from LTGA site also emits the arsenic pollutant while it is lower than that emitted from CTSP. Comparing with Tsai's report (2006), during the CTSP heavily developing seasons, the level of crust elements such as Cu, Fe, Mg, Pb and Zn, were found frequently high in that moment at THU site. In these sampling seasons, due to the finish of CTSP mass construction, pavement works block the emission from the topsoil surface, therefore, the crust elements were found reduced significantly. While sometimes the arsenic level is increasing after the operation of high-tech industries, however, the arsenic is low in the crust elements of the local top soil contents. The arsenic concentration of CTSP (7.26 mg/kg) is shown in Table D-5, which indicates the top soil arsenic level of this area is not higher than other areas

Table 4-2 lists the comparison of TSP levels between this study and other literature, Cong *et al.* (2007) shows all kinds of metal concentrations at Tibetan Plateau. Which indicates every metal concentration is much lower than that of this study and other references. The Tibetan Plateau site is very nature, and far away from pollution, therefore, it is much more suitable to be a background site than else where. In addition, the result also indicates the anthropogenic pollutant sources in the site of this study or other literature sites are more than that in the Tibetan Plateau. Gidhagan *et al.* (2002) displayed metal values in central Chile, where is a copper and gold smelters region and contributes to approximately 40% of Chilean exports and the possible necessity to close down some of the smelters due to environmental concerns would have had severe economical impacts (O'Ryan and Díaz, 2000). Most metal values in Chile are similar to this study, and Ca (860.0 ng/m^3), Cr (6.7 ng/m^3), Zn (54.4 ng/m^3) are lower than this study obviously, it indicates the different surface of

earth coverage caused the different crustal element level. However, the air As value (30.7 ng/m^3) is much higher than this study, it indicates the smelter industry emits more arsenic pollutant than that of high-tech industry in Taiwan, and has serious arsenic pollutant problem.

At Hsinchu, Taiwan, it has large industrial parks including conventional and science-based industries. The Hsinchu Science-Based Industrial Park (HSBIP) is operated since 1980, and its highlight industry is semiconductor and mixed a number of traditional and high-tech industries. Su (2000) indicated that the metal concentration at 1999 of Hsinchu area is significant higher than its rural area. The result indicates anthropogenic pollution has been generated at the HSBIP. The HSBIP plays an important role on the affect of metal quantity for ambient atmosphere. Table 4-2 shows that Cd (12.8 ng/m^3), and Pb (135.0 ng/m^3) in Hsinchu area are higher than those data observed from this study, while Ni (13.9 ng/m^3) almost identical to that of this study. But the As (6.3 ng/m^3) is lower than THU (11.1 ng/m^3) and LTGA (7.1 ng/m^3). According to Chein *et al*. (2006), it indicated the arsenic level in the 4~5 km downstream of Hsinchu science-based industrial park at 2002 was found as high as N.D. to 120 ng/m^3, the highest value is much higher than that of Su (2000) and this study. The result indicates the emitted arsenic pollutants in Hsinchu have much variation with each other, maybe it caused by the wind field and the overall industrial growth between 1999 (Su, 2000) and 2002 (Chein *et al.*, 2006). While the arsenic pollutant emitted from CTSP might approach to that level of HSBIP step by step following its expansion program. It also revealed that both the sampling site and the change of wind field will strongly affect the measurement of arsenic in ambient environment. Both Taichung and Hsinchu areas have large industrial parks, which covering conventional and science-based industries, their anthropogenic metal also shown high levels around sampling sites. Table 4-2 also shows the proposed

national standard for some metals, comparing with this study, only As value (THU: 11.1 ng/m^3; LTGA: 7.1 ng/m^3) exceed the EU recommend standard (6.0 ng/m^3). It indicates the arsenic emission in Taiwan from science based park is significant and need be controlled in all.

Table 4-2. The metal concentration (ng/m^3) comparison of total suspended particulate (TSP) obtained by this study and other researches.

Sites	Taya [a]	THU [a]	Tsai's report [a]	LTGA [a]	Tibetan China [b]	Quillota Chile [c]	Hsinchu Taiwan [d]	Hsinchu Taiwan [e]	Proposed Standard
Source type	Science-based industrial park (This study)				Background	Smelter	Science-based industrial park		
As	5.9±3.9	11.1±9.2	1.4	7.1±4.9	0.04±0.13	30.7	6.3	N.D. ~ 120.0	6.0 (EU)
Ca	1,500±800	3,200±2,300	2,138.6	1,200±1,000	251±261	860.0	2,300.0	-	-
Cd	2.7±1.7	2.5±1.5	4.0	2.0±1.4	-	-	12.8	-	5.0 (EU)
Cu	86.9±47.3	87.6±47.4	401.1	87.0±50.2	0.56±0.43	73.9	58.7	-	-
Cr	32.5±16.6	35.6±18.6	51.5	31.9±18.5	1.0±0.7	6.7	12.9	-	-
Fe	1,600±1,000	2,300±1,400	6,790.7	1,400±800	94±81	1,089.0	1,460.0	-	-
Mg	610±340	710±360	1,715.0	540±320	12±10	410.0	742.0	-	-
Mn	26.1±13.4	26.7±13.1	219.9	26.8±14.6	3.7±3.9	43.4	37.0	-	-
Ni	11.4±6.0	14.9±8.4	5.1	14.8±8.0	0.95±1.4	2.5	13.9	-	20 (EU)
Pb	30.7±20.7	32.5±20.6	471.4	29.2±18.3	-	58.5	135.0	-	500 (WHO)
Zn	400±200	500±200	1,552.5	400±200	1.8±1.1	54.4	191.0	-	-

a: THU (Sep. 2004 to Aug. 2005), n=39; THU (Dec. 2005 to Feb. 2007), n=85

b: Cong *et al.*, 2007, n=13

c: Gidhagen *et al.*, 2002, n=39

d: Su, 2000, n=59

e: Chein *et al.*, 2006, n=23

*WHO: World Health Organization, 2007 n: sample number

EU: European Union, 2007 N.D.: not detected

Figure 4-5 shows the monthly arsenic (As) concentration at all sampling sites of this study. It displays the As concentrations in winter (Nov. to Feb.) at all sampling sites are much higher than that of summer season (Jun. to Aug.), and the As value in THU site is much higher than that of Taya during winter period. It indicates the NE monsoon carry the high As level at all sampling sites caused of strong wind speed; and the NE wind direction also carry the high As pollutant from CTSP (source) and bring the much higher As value found at THU site (downstream) than Taya (upstream). In order to prove the As pollutant vary based on the meteorological parameters, this study focus the As element to compare with wind speed, wind direction, and TSP concentration. Figure 4-6 displays the tendency of arsenic concentrations based on the wind speed during the sampling period at all sites. It shows the slope of tendency line for THU site (slope=2.74) is much higher than that of Taya (slope=0.25) site. This indicates the strong wind from NE influences the As pollutant value at THU site much more than that of Taya site, maybe it caused As pollutant emitted from CTSP and carried by the strong NE monsoon. However, the slope for LTGA is minus (-0.64), it indicates the As pollutant is not significantly based on wind speed at LTGA site. The As value profile based on wind direction is displayed in Figure 4-7. It has more As value at THU and LTGA sites based on north wind series than that of south bound wind series; while at Taya site, more As value based on south wind series than north wind series was found. This implies most of the arsenic pollutant from CTSP is spreading to THU site (short range downstream, 1.65 km) and some of that is going to LTGA site (long range downstream, 5.59 km), when in NE monsoon; while in SW monsoon, most of that is brought north bound to Taya site (downstream). Figure 4-8 shows the tendency of As concentration based on the TSP concentration. The highest slope of tendency is obtained at THU site (0.09) while the lowest was found at Taya site (0.07), it indicates the slope of tendency vary slightly from site to

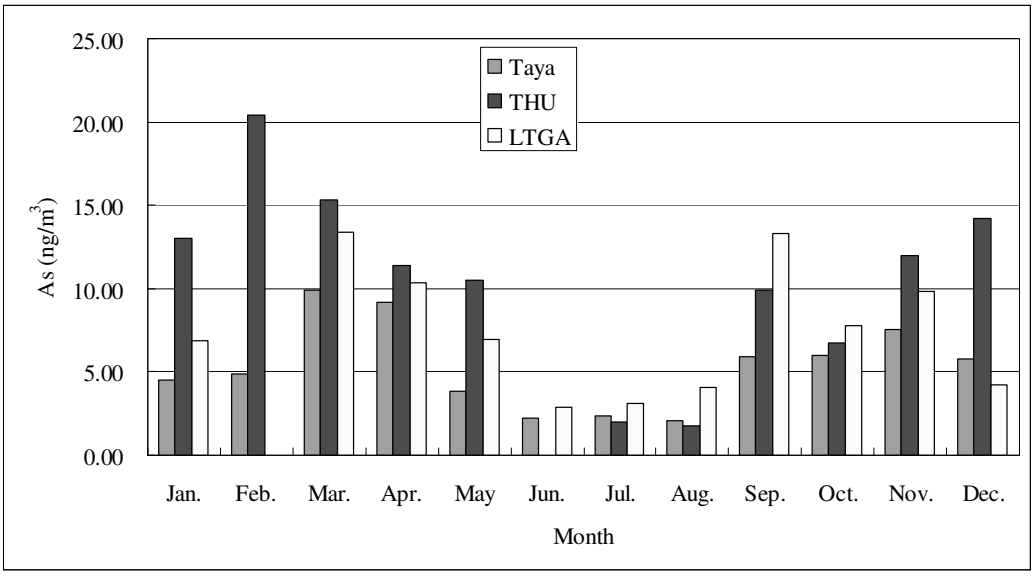

Fig 4-5. The correlation of sampling site for the monthly (Dec. 2005 to Feb. 2007) arsenic concentration (ng/m^3) obtained from the total suspended particulate (TSP).

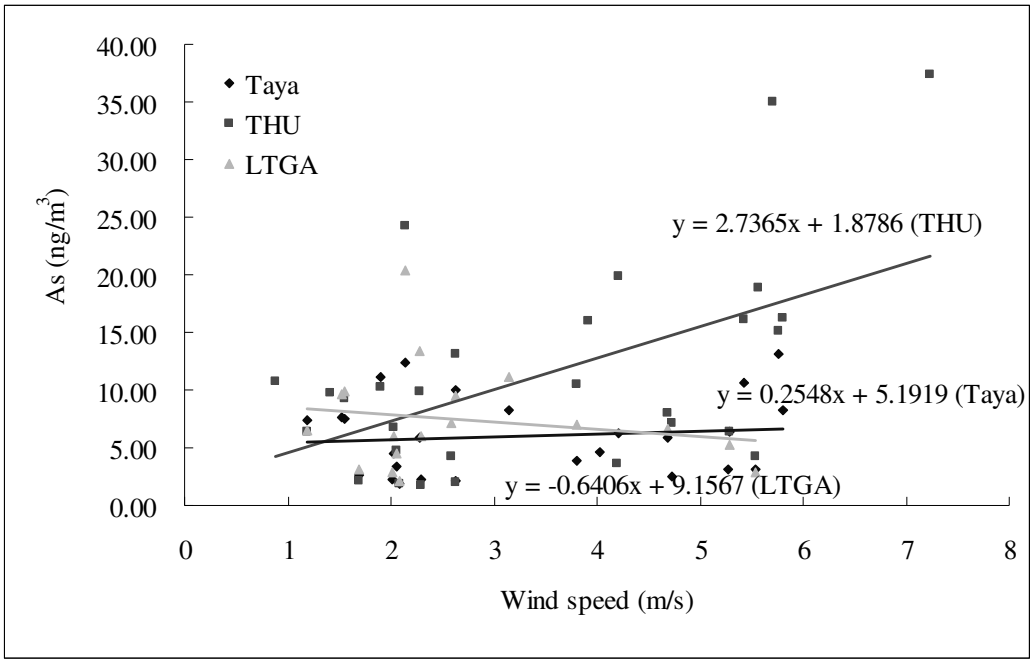

Fig 4-6. The tendency of arsenic concentrations (ng/m^3) based on the wind speed (m/s) during sampling period (Dec. 2005 to Feb. 2007) at all sampling sites.

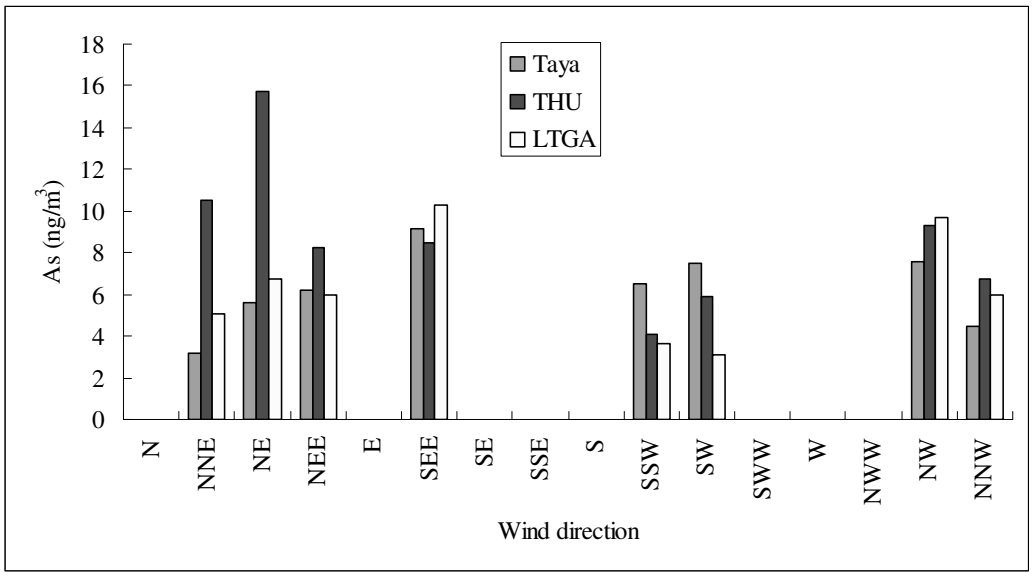

Fig 4-7. The As concentrations (ng/m^3) based on the 16 wind directions at all sampling sites.

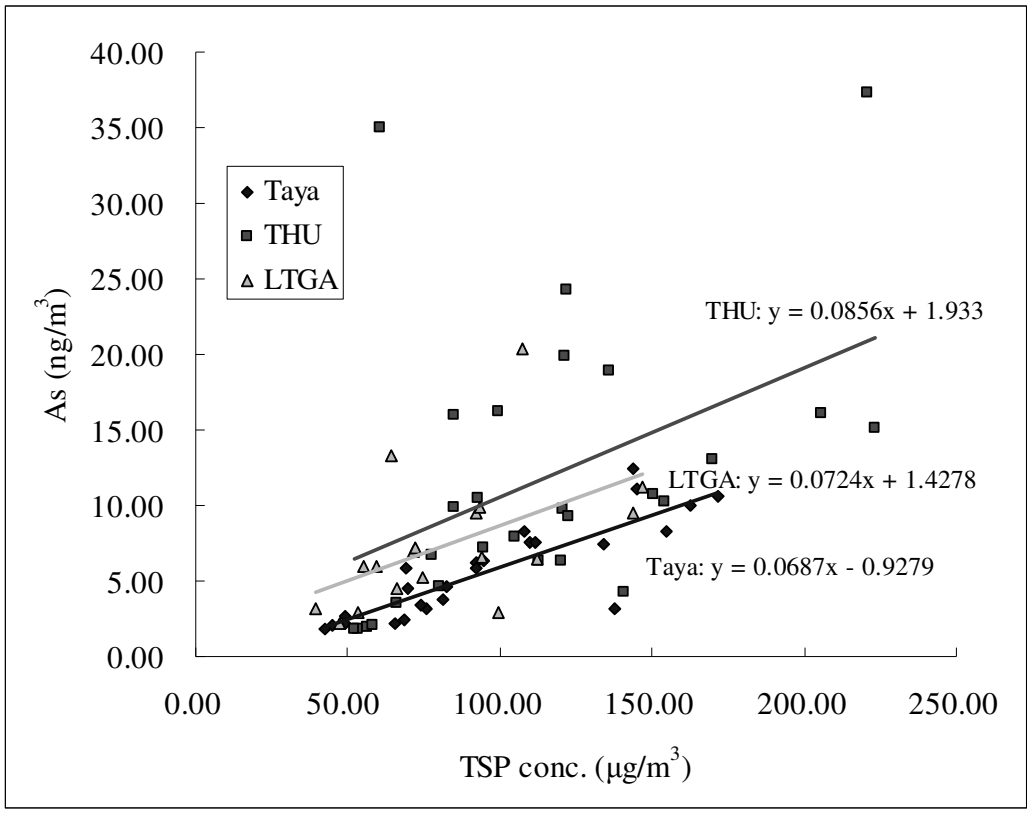

Fig 4-8. The correlation of As concentration (ng/m^3) VS. the TSP (µg/m^3) concentration at all sampling sites.

site. This is due to the arsenic pollutant adheres to the coarse particle, and therefore it shows a proportional relationship between As and TSP at different sites. However, the intercept for y axis at THU site is much higher than that of Taya site. The result proves there is a large upstream anthropogenic pollutant discharge impacting the ambient environment around THU site.

In order to prove the emission of arsenic pollutant from CTSP is depending on NE monsoon, this study also conducted a comprehensive sampling program from Jan. 12, 2007 to Feb. 01, 2007. Figure 4-9 shows the sampling sites (Taya, Tung-An building (TA), Xin-Hang building (XH) and Telecom) of this full scale sampling program, the sites are arranged in the order based on the NE wind direction to catch the arsenic pollutant. Table 4-3 lists the As concentration obtained at the sampling sites for this case. The arsenic value at TA (13F, 52 m), XH (14F, 56 m) and telecom (6F, 24 m) sites (downstream) are much higher than that of Taya site (upstream, 12 m), while the highest arsenic value was found to 51.8 ng/m^3 at TA site. It indicates due to the NE wind direction, the TA (38.7 ng/m^3), XH (47.7 ng/m^3) and telecom (47.4 ng/m^3) sites (downstream) could catch much more arsenic pollutant than Taya site (7.2 ng/m^3) (upstream) on Jan. 31, 2007. The result also indicates that there is a significant arsenic pollutant source between upstream and downstream sampling sites.

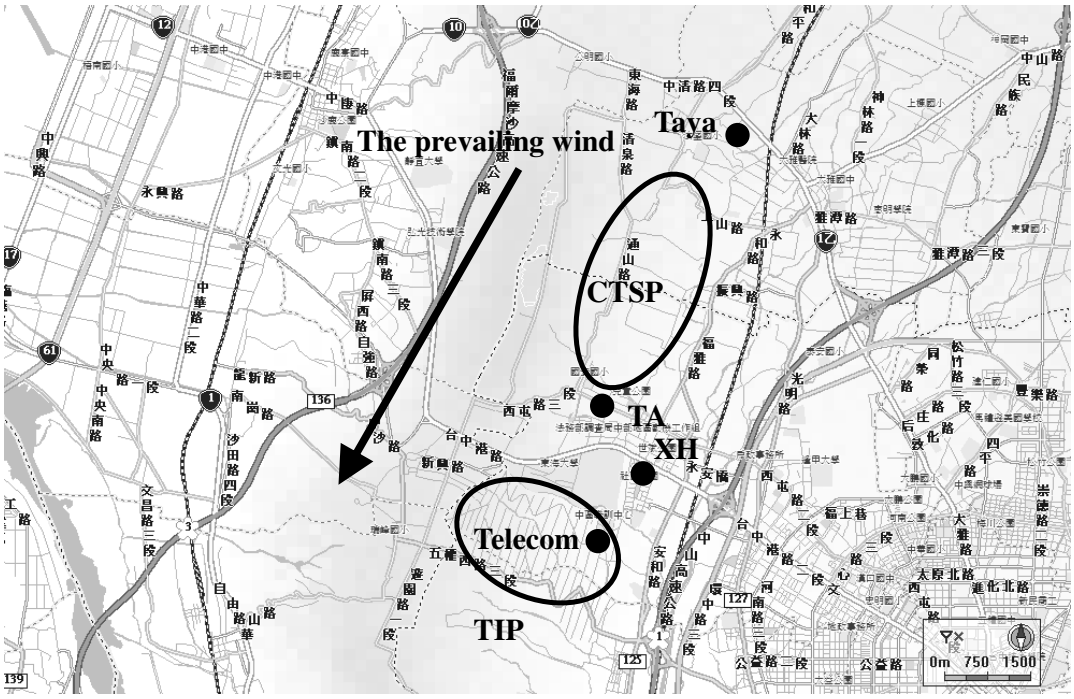

Fig 4-9. The sampling sites for the comprehensive sampling program from Jan. 12 to Feb. 01, 2007. (Papago, R12)

*Sampling sites: Taya (3F, 12 m), distance to CTSP 4.75 km

TA: Tang-An building (13F, 52 m), distance to CTSP 0.75 km

XH: Xin Hang building (14F, 56 m), distance to CTSP 1.85 km

Telecom (6F, 24 m), distance to CTSP 3.15 km

Table 4-3. As concentrations (ng/m^3) at all sites for the comprehensive sampling programs from Jan. 12, 2007 to Feb. 01, 2007

Date	Relative Humidity (%)	Wind speed (m/s)	Prevailing wind direction	Taya	TA	XH	Telecom
				As (ng/m^3)			
20070112	80	4.19	NEE	-	-	7.3	-
20070113	76	1.90	NEE	-	14.3	8.1	-
20070131	67	4.68	NE	7.2	38.7	47.7	47.4
20070201	61	4.37	NE	8.3	51.8	-	30.1

*Taya: 120° 37′ 46.2″ , 24° 14′ 08.7″ (3F, 12 m), distance to CTSP 4.75 km

TA: 120° 36′ 46.3″ , 24° 11′ 30.0″ (13F, 52 m), distance to CTSP 0.75 km

XH: 120° 36′ 48.4″ , 24° 10′ 55.6″ (14F, 56 m), distance to CTSP 1.85 km

Telecom: 120° 36′ 26.2″ , 24° 09′ 57.3″ (6F, 24 m), distance to CTSP 3.15 km

4.3. *Statistic analysis*

Table 4-4 shows the correlation coefficients of TSP, arsenic concentrations and meteorological parameters at all sampling sites based on spearman coefficient. The coefficient 1.0 implies the two parameters have close relationship, while vise versa. The coefficients between wind speed and wind direction are all have very high value at all sites, i.e., Taya, THU and LTGA have the value 0.78, 0.84 and 0.90, respectively. Maybe the significant coefficients between wind speed and wind direction are caused by the very high wind speed during the NE monsoon. While the coefficient between particle and arsenic concentration at Taya site is 0.94, which is much higher than the other sites with 0.49 and 0.63 for THU and LTGA sites. The correlation between wind speed, wind direction and As value at THU site has two identical value of 0.72 and 0.72, which are much higher than the other sites (0.22, 0.34 of Taya and 0.16, 0.45 of LTGA). The Taya site is theoretical a background site, it causes the rising of As value only from natural TSP emission (with correlation coefficient of 0.94) and low meteorological effects (with wind speed and direction coefficients of 0.2 and 0.33, respectively). While, the As value is highly depend on the meteorological parameters at THU site (with coefficient of 0.72). It indicates the THU site is the exact downstream site of the potential pollution sources during the NE monsoon season.

The heavy metal levels obtained between Dec. 2005 and Feb. 2007 were analyzed by PCA method. Figure 4-10 indicates the metal element correlation obtained by PCA analysis for both sites of Taya, THU and LTGA. This study conduct the analysis by adapted the high correlation coefficient case when loading value above 0.7, which was proposed by many references. The identified major pollutant sources: anthropogenic sources (Wang *et al*., 2003), natural geological materials (Gao *et al*., 2002), industrial process (Chao and Wong, 2002) and traffic

emission (Marcazzan *et al*., 2001) were taken into consideration at Taya and LTGA sites. The metal emission (Holsen *et al*., 1993), iron-steel factories and pyrometallurgical industry (Kumar *et al*., 2001 and Funasaka *et al*., 2003) and incinerator factors (Voutsa and Samara, 2002) were included in THU site. Both pollutants found in THU site were belonging to the industrial process emission. While the Taya and LTGA sites may be affected by the mass vehicle transportation pollution, which can not be identified the emission information from either crust elements or artificial sources based upon the existing literature.

Table 4-4. The correlation coefficients of TSP and arsenic concentrations and meteorological parameters (wind speed and direction) at all sampling sites

Site	Taya			
	TSP conc.	As conc.	Wind speed	Wind direction
TSP conc.	1			
As conc.	0.94	1		
Wind speed	0.20	0.22	1	
Wind direction	0.33	0.34	0.78	1
Site	THU			
	TSP conc.	As conc.	Wind speed	Wind direction
TSP conc.	1			
As conc.	0.49	1		
Wind speed	0.30	0.72	1	
Wind direction	0.38	0.72	0.84	1
Site	LTGA			
	TSP conc.	As conc.	Wind speed	Wind direction
TSP conc.	1			
As conc.	0.63	1		
Wind speed	0.30	0.16	1	
Wind direction	0.38	0.45	0.90	1

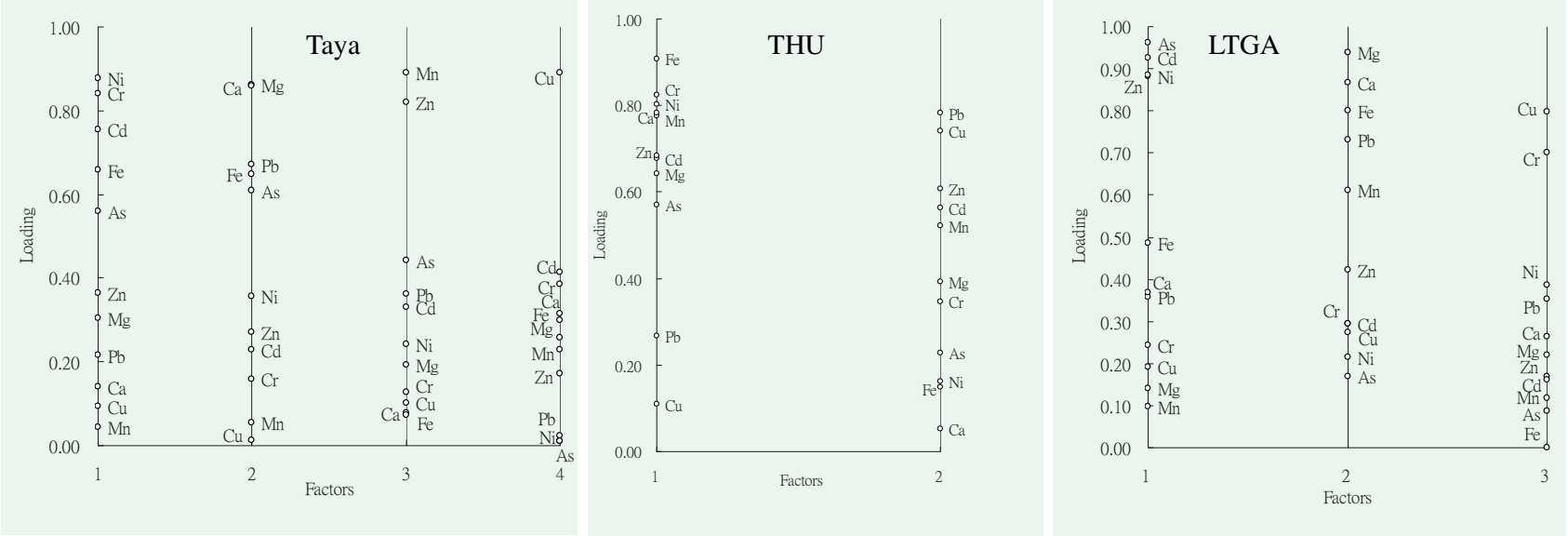

Fig. 4-10. The factor analysis of the potential pollution source of metallic elements in total suspended particles at Taya, THU and LTGA sites. Taya: 1 (Anthropogenic sources), 2 (Natural geological materials), 3 (Industrial process) and 4 (Traffic emission); THU: 1 (Metal emission, Iron-steel factories) and 2 (Pyrometallurgical industry, Incinerators); LTGA: 1 (Anthropogenic sources), 2 (Natural geological materials) and 3 (Traffic emission).

4.4. *Model analysis*

In order to catch the detailed emission characteristics, this study conducted a comprehensive investigation during high NE wind season. This study adapted the downstream sampling data at (1) THU (during the NE wind direction season) (2) Tang-An building sites (Feb. 01, 2007) and traced back by one-dimensional Gaussian dispersion model to obtain the amount of emission. The mathematical approach and parameters of the Gaussian dispersion model were listed in the Appendix C. Because the USEPA listed As, Cd, Pb, and Ni as the four major air toxic substances, therefore, in Table 4-5 displays those emission amount with the level of 6.4, 0.9, 10.2, and 3.8 kg day^{-1}, respectively, based on Gaussian dispersion model. According to the USEPA ambient air level goal (AALG) for arsenic (Chein *et al*., 2006), it was set to the emission level of 2.4×10^{-4} kg day^{-1}, which is significantly much lower than the data obtained in this study.

In order to verify the model, this study adapted different sampling date's data to compare with the calculated results and shown in Table 4-6. Three data sets used to compare were collected at Dec. 21, 2005 (THU), Feb. 17, 2006 (THU) and Jan. 31, 2007 (5 sites: TA, THU, XH, Telecom and LTGA). The distance between the possible emission source and the sampling sites are: TA-0.75 km, THU-1.65 km, XH-1.85 km, Telcom-3.15 km and LTGA-5.59 km. All data sets were under the same (NE) prevailing wind direction and with the daily average velocity between 4.37 and 5.71 m/s. Those observed high As data cases were compared with the emission source calculated based upon the Feb. 01, 2007 case and has the discharge amount of 6.4 kg day^{-1}. The variations of model prediction are at the range between 19.4% to -44.1%. The possible factors affecting the results of model prediction are:

1. The attitude of emission sources and the sampling sites. The sampling heights are between 12 m to 56 m, which will have the significantly level

affect on observed data.

2. The variation of emission units, which may affected by the change of production or process.
3. The wind direction, which may vary from hour to hour. Therefore, it may dilute the sample level in many cases.
4. The sampling sites, some are not identically located down stream from the emission source, therefore it may not well predicted based upon the longitude dispersion model.

The data collected at THU site, due to 4 new tall buildings accomplished just in front of the emission pathway may interference the pollution dispersion. Therefore, the observed As level since Jan. 2007 of THU site tends to be low (15.2 ng/m^3) and have high (67.2%) variation from the model prediction value (46.4 ng/m^3). The THU site has the height of 16 m (4F), which is much lower than the four new tall buildings of 60 m (15F) and just 100 m ahead across Zhong-Gang road, will definitely block the pollution dispersion from CTSP. Therefore, it is recommended that the data of THU since 2007 can not properly represent the ambient air quality any more.

The Air Pollution Model (TAPM) was adapted to simulate the same local atmospheric profile at the typical sampling date of Feb. 01, 2006. The related factors of TAPM were listed in the Appendix C, which including meteorological, location and sampling date parameters. Figure 4-11 shows the main wind direction of 200 m high above ground was NE bound, therefore, the downwind (SW) sampling sites may obtain with high As level. The different heights (200, 400, 1,000, 3,000 and 10,000 m) of TAPM modeling results were listed in Appendix-C, which showed under high wind speed case all winds blow in the same NE bound direction without any difference of the height attitude. Figure 4-12 also shows the contour map (obtained from Surfer, version of 6.02) of the arsenic pollutant level and has high

plume at downstream sites from CTSP. It indicates the CTSP emits some arsenic pollutant to the downstream area during the NE monsoon season. This basic assumption was also confirmed by the model and closely meets the monitoring results.

Table 4-5. The concentrations and the simulated results of the metal elements at THU site during the NE wind direction and the Tang-An building site at Feb. 01, 2007

Elements	Measured Concentration (ng/m^3)	Simulated Emission Rate (kg/day)
As	37.4±2.8	6.4
As*	51.8	7.2
Cd	5.3±0.8	0.9
Pb	58.3±10.2	10.2
Ni	21.6±2.3	3.8
AALG**	4.7×10^{-2}	2.4×10^{-4}

As*: At Tang-An building site (Feb. 01, 2007).

AALG**: The ambient air level goal for arsenic (Chein *et al.*, 2006).

Table 4-6. The verification of Gaussian dispersion model in the NE direction wind seasons (2005 to 2007)

Site	Height (m)	Distance from CTSP (km)	Observed	Model prediction	Variation
			As (ng/m^3)		(%)
TA(3)	52	0.75	38.7	52.4	26.1 %
THU(3)	16	1.65	15.2	46.4	67.2 %
THU(1)	16	1.65	37.4	46.4	19.4 %
THU(2)	16	1.65	34.9	46.4	24.6 %
XH(3)	56	1.85	47.7	42.5	-12.2 %
Telecom(3)	24	3.15	47.4	32.9	-44.1 %
LTGA(4)	16	5.59	2.9	2.2	-31.8 %

(1): sampling at Dec. 21, 2005, with wind speed=7.23 m/s

(2): sampling at Feb. 17, 2006, with wind speed=5.71 m/s

(3): sampling at Jan. 31, 2007, with wind speed=4.68 m/s

(4): sampling at Dec. 21, 2006, with wind speed=5.54 m/s

Note: The Gaussian model simulation cases of (1), (2) and (4): belong to the atmospheric stability C; the case (3) belongs to the atmospheric stability B.

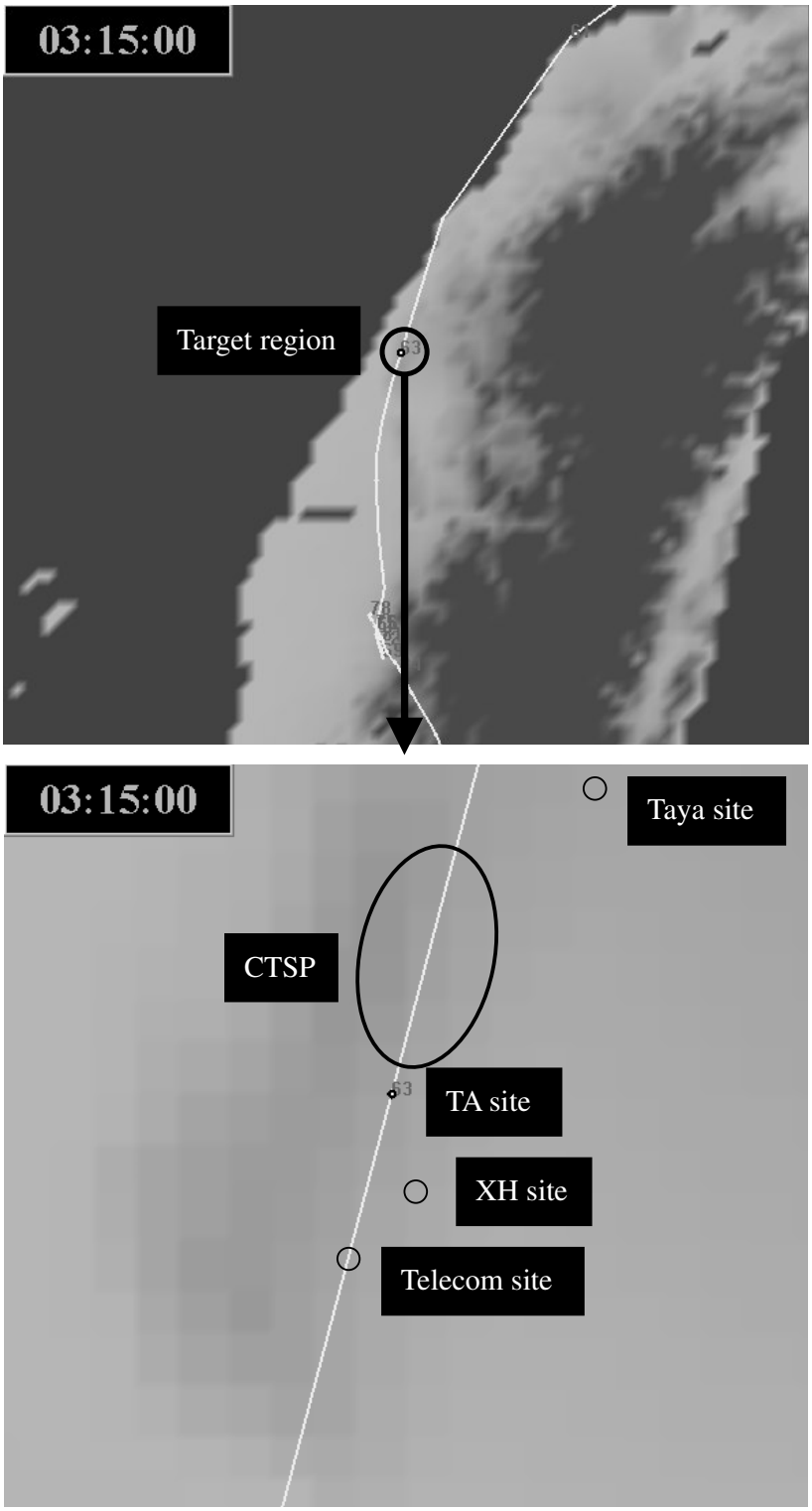

Fig. 4-11. The simulation air parcel trajectory by TAPM at CTSP site (Feb. 01, 2006) of 200 m height. The main wind direction was NE bound, therefore, the downwind (SW) sampling sites (TA, THU, XH and Telecom site) may found with high As level. (The figure is obtained from TAPM model.)

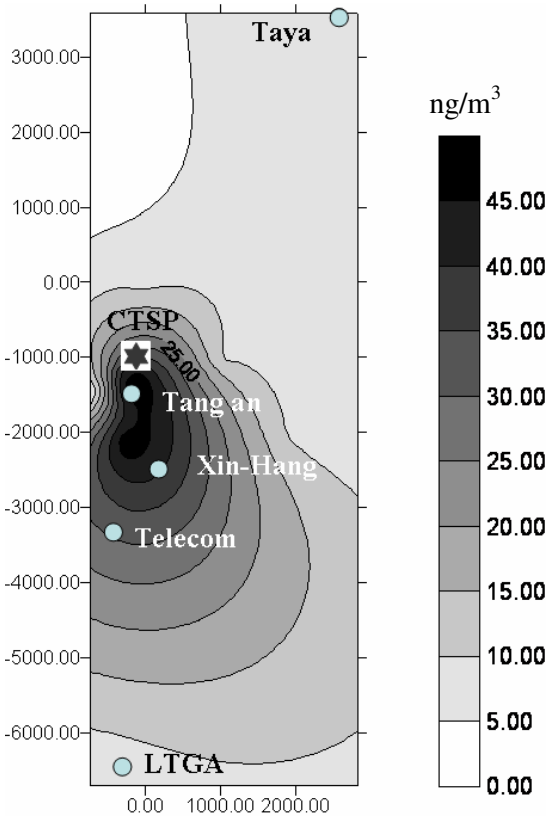

Fig. 4-12. The contour map for arsenic pollutant plume at the sampling area (Feb. 01, 2007 with wind speed=4.37 m/s). (obtained from Surfer, version of 6.02)