



The Size Distributions of Ambient Air Metallic Pollutants by Using a Multi-Stage MOUDI Sampler

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ABSTRACT

Particle concentrations of metallic elements in ambient air were determined using a micro-orifice uniform deposition impactor (MOUDI). Comparisons were also made of particle concentrations of various sizes (PM_{18}^+ , PM_{18-10} , $PM_{10-2.5}$, and $PM_{2.5-1}$) sampled at Westin Park and at Gung-Ming Junior High School (Taichung airport). Comparing the particle sizes of PM_{18}^+ , PM_{18-10} , and $PM_{10-2.5}$ revealed higher concentrations in Westin Park than those in Gung-Ming Junior High School (Taichung airport). The only exception was $PM_{2.5-1}$, indicating higher concentrations at the Gung-Ming site. The average particle concentrations order was Gung-Ming Junior High School (Taichung airport) > Westin Park for the particle size of $PM_{2.5-1}$. According to analysis results of various particle sizes of metallic elements Zn, Ni, Cu, Cd and Pb in the ambient air, the relative concentrations were $PM_{18}^+ > PM_{18-10} > PM_{2.5-1} > PM_{10-2.5}$ for all sampling sites. The only exception was particle-bound mercury Hg(p), likely owing to the proximity of the Taichung airport to the Taiwan Strait (approximately 11.6 km). Moreover, Dragon Steel Plant, Han-Shian Aerospace Industrial Development Corporation and Quan-Lien Industrial Park were located nearby.

Keywords: MOUDI; Dry deposition; Particulate-bound mercury Hg(p); Metal.

INTRODUCTION

Atmospheric particulate pollution is a major public concern in urban areas because particulate matter has a considerable effect on human health (Cheng and Li, 2010). The particulate matter in PM_{10} fractions, and especially, in $PM_{2.5}$ fractions, can reach conductive airways and detrimentally affect the respiratory system (Duhme *et al.*, 1998; Pope *et al.*, 2002), which demonstrates the associations between fine particles and various numerous health problems.

Moreover, metal in the atmosphere poses a serious risk to human health (Okuda *et al.*, 2008) generally; trace metals in the particulate phase are present in the air. In several of the mega-cities, large amounts of aerosols are emitted by anthropogenic sources and natural sources (Gutierrez-Castillo *et al.*, 2005; Manalis *et al.*, 2005; Valavanidis *et al.*, 2006; Silva *et al.*, 2008).

Multivariate statistical analysis revealed that in urban suburban street deposited sediments (SDSs), Zn, Ni, Cd, Pb, Cu and Cr were related to traffic and industry; coal

combustion led to elevated levels of Hg; and soil parent materials controlled As contents. In suburban SDSs, Pb, Cu, As and Cd tend be emitted as traffic pollution; Zn, Ni and Cr were associated with industrial contaminants; Hg primarily comes from domestic solid waste (Shi *et al.*, 2010).

In Taiwan, the concentration, composition, and size of suspended particulate matter at any given site are determined by such factors as the meteorological characteristics of the atmosphere, influences, emission sources, and particle characteristics such as density, shape, and hygroscopicity (Koliadima *et al.*, 1998). Nano/ultrafine particles from vehicle emissions may adversely affect health because of both their size and chemical properties (Lin *et al.*, 2005; Lin *et al.*, 2008). Numerous researchers are investigating the distributions of particle matter and its chemical properties in urban, suburban, rural and industrial regions. Large particles are greatly affected by gravity while fine particles are strongly most by diffusion (Chan and Kwok, 2000). Urban air pollution is rapidly becoming an environmental problem of public concern worldwide. It can affect public health and local and regional weather and climate (Bhaskar and Mehta, 2010). In urban and industrial environments, however, particles not only contain metals, but also include toxic organic compounds, such as PAHs, whose concentrations are greater in fine and ultrafine particles. This fact has caused concern about various pollution

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sources close residential habitations (Wang *et al.*, 2010). And $PM_{2.5}$ mass are vehicle exhaust (49.3–62.4%) and secondary aerosols (SO_4^{2-} , NO_3^- and NH_4^+) (31.2–37.8%), while those at Chao-Chou are the outdoor burning (25.3–50.4%) of agricultural waste, secondary aerosols (27.2–34.3%) and vehicle exhaust (12.0–26.9%), depending on the seasons (Wang *et al.*, 2008).

In addition, mercury (Hg) is a well-known persistent, toxic, bioaccumulative pollutant because it is emitted into the atmosphere from a variety of natural and anthropogenic sources and, persists there for a long time (Schroeder and Munthe, 1998). Atmospheric mercury is frequently treated as three different fractions: gaseous elemental mercury (GEM- Hg^0), gaseous oxidized mercury (GOM, a.k.a. RGM- Hg^{2+}), and particulate-bound mercury (PBM- $Hg(p)$) (Lyman and Gustin, 2009). Elemental mercury (Hg^0) is known to have an atmospheric residence time of 0.5–2 years, divalent gaseous mercury (Hg^{2+}) remains in the atmosphere for a few hours or days, and residence time for particulate mercury $Hg(p)$ is a few weeks (Lindqvist and Rodhe, 1985; Schroeder and Munthe, 1998). As further illustration, when air travels from Shanxi, which is home to several coal-fired power plants, Beijing tends to have poor air quality due to high PM_{10} concentrations. When air that originates over Inner Mongolia, where anthropogenic emissions are low, is predominant, Beijing tends to have good PM air quality (Xu *et al.*, 2008).

The speciation of mercury essentially determines its environmental fate (e.g., how far emitted mercury will travel). Hg^0 is generally considered to be fairly stable in the atmosphere, with an estimated troposphere residence time of one to two years (Pandey *et al.*, 2011). This investigation characterizes variations in the size of distribution of particles that contain mercury $Hg(p)$ using a four-stage MOUDI sampler (PM_{18}^+ , PM_{18-10} , $PM_{10-2.5}$ and $PM_{2.5-1}$) at two sampling sites in Central Taiwan. Additionally concentrations of other particles and metal elements were measured using a four-stage MOUDI sampler. Moreover, seasonal variations of concentrations of ambient air particles and particle-bound mercury $Hg(p)$ at these two characteristic sampling

sites are discussed.

METHOD

Sampling Sites

Fig. 1 displays the sampling region for this study. All samples were obtained by sampling for 1350–1400 min. Two characteristic sampling sites are located in Taichung City County, Taiwan. They are designated as follows:

Westin Park (24°23'77.94"N, 120°58'54.67"E) is located on the west side of Taichung city. The whole area is about 3.4 square kilometers. The total residential household is 1,463. The main occupation for these households is agriculture. In addition, Hungkuang University and Bei-shi elementary School are nearby. The total human population in the area is 82,108 people.

The Taichung Airport (TA) is located in the Shalu district in Taichung City in central Taiwan. The parking area for air planes occupies 36,280 square meters. The Gung-Ming Junior High School (24°14'59.82"N, 120°35'56.45"E) sampling site is located to the south (approximately 1 km) of TA. Approximately 50 airplanes take off and land at TA every day. The TA sampling site is approximately 10 km from the Taiwan Strait, and the Taiwan Number 2 Highway is just nearby. The TA sampling site is approximately 10–15 m above the earth's surface. The sampling site was at approximately 12 m in the highest building, in this open area.

Sampling Methods

MOUDI Sampler

The Micro-Orifice Uniform Deposit Impactor (MOUDI) (Model 100-S4; MSP Corporation, by U.S.) sampler is a cascade impactor for general-purpose aerosol sampling. This four-stage cascade impactor comprises five basic components - a rotator impactor, Magnehelic gauge, rotator unit, shelter and blower motor. Each sampler stage comprised an impaction plate for the nozzle plate above it. The use of micro-orifice nozzles can extend cut sizes of the lower stage to PM_{18}^+ , PM_{18-10} , $PM_{10-2.5}$ and $PM_{2.5-1}$ without creating an



Fig. 1. Geographical location at Westin Park (A) and Gung-Ming Junior High School (Taichung airport) (B) sampling sites in central Taiwan during the period September, 2011 to February, 2012.

excessive pressure drop across the impactor stages. Accordingly rotating the alternate stages of the sampler causes deposits to be distributed uniformly on the circular impaction areas, which have a diameter of around 1 inch (25 mm). The flow rate was 30 L/min and the diameter of the cuts ranged from 18 μm on the first stage to 1.0 μm at the last stage (Model 100-S4 Instruction Manual, MSP 2010).

Available cut diameters were 18, 10, 2.5, and 1.0 μm . A mixed cellulose ester filter was coated with absorbent silicone grease (ITW Fluid Products Group, U.S. country) as the surrogate surface. Sample substrates were attached to the impaction plate using removable clamping rings, and the entire impaction plate was held in place using magnets for easy removal. The base of the MOUDI sampler had an after-filter in a removable filter holder, which is similar to the impaction plates. Interchangeable impaction plates and filter holders were utilized to enable the impaction plate substrates and the filter to be loaded and unloaded in the laboratory, decreasing the probability of damaging particulate deposits during in-the-field substrate removal. Sealed transport covers for impaction plates and filter holders were utilized to enable the impaction plates and the used filter to be transported to and from the test site without contamination. These sealed covers also minimized sample loss by evaporation during storage or chemical reaction with ambient gases (MOUDI 100-S4 Instruction Manual, MSP 2010).

Dry Deposition Plate

In this investigation, a dry deposition plate (DDP), which has a smooth, horizontal, surrogate surface was utilized to provide a lower-bound estimate on dry deposition flux. The DDP was a smooth polyvinyl chloride (PVC) surface plate that measured 21.5 cm long by 8.0 cm wide by 0.8 cm thick. The DDP also had a sharp leading edge that was pointed into the wind. All filters were maintained at 50% relative humidity at 25°C for over 48 hours. Before sampling and all filters were weighed to an accuracy of 0.0001 g (Fang *et al.*, 2011).

CHEMICAL ANALYSIS

Hg Analysis

The samples were placed in an oven one night before they were weighed. A quarter of the filter was then cut out before the digestion process. That piece of the filter was then cut into thin pieces and placed in a Teflon cup. A 3 mL volume of hydrochloric acid (HCl) and 9 mL of nitrate (HNO_3) were mixed with each other and then added to this cup. Thereafter, the samples were heated at 500°C on a hot plate for two hours. Following digestion on the hot plate, samples were filtered and then 0.2% HNO_3 was added to a total solution volume of 100 mL. Before CVAFS (cold vapor atomic fluorescence spectrometry (Brooks Rand Inc., USA) analysis, the samples were maintained at 4°C in the refrigerator. 0.5 mL of BrCl was added to each sample and the samples were then left to stand for one hour. The soda lime trap was conditioned by purging 20 mL of a 5% HCl solution (0.3 M) for 30 minutes. The purging solution was

formed by adding 1 mL of SnCl_2 to 20 mL of 5% HCl solution (0.3 M). Purging continued to be carried out for 15 minutes. A 5 mL aliquot of the oxidized filter extract was pipetted from the Teflon vessel into 20 mL of the bubbling solution, which was prepared as described above. To reduce the halogens in the extract, 0.1 mL of $\text{NH}_2\text{OH}\cdot\text{HCl}$ was pipetted into the bubbler. The bubbler was swirled briefly to mix the solution, which was left to react for 5 minutes. A blanked gold trap was attached to the end of the soda lime trap, to collect mercury from the bubbled solution. To reduce the oxidized mercury in the solution to volatile Hg, 0.5 mL of SnCl_2 was pipetted into the bubbler, which was immediately attached to the impinge, allowing the contents to be purged onto the gold trap for seven minutes. The calibration curve for the CVAFS was obtained using standard addition and filter extraction processes. Hg(p) was extracted from each sample filter, volatilized and recaptured using the procedure described above. The gold traps were analyzed by dual amalgamation CVAFS, as described above, to quantify the Hg in the sample filter extract. Control standards were analyzed at regular intervals throughout the analysis of the samples to detect any drift in the response or change in sensitivity of the CVAFS instrument. Control standards were produced in the same manner as the calibration standards described above. The standard addition filter that was used as a control standard had to be representative of the Hg concentration of the samples to be analyzed. The CVAFS operating conditions were a gas flow rate of 55 mm cylinder at a pressure of 17 PSI, PMT of approximately 550 v, and an offset value of 10000–15000.

Metallic Elements Analysis

One quarter of each filter was cut away before digestion. The filters were then cut into thin pieces and placed in a Teflon cup. Next, 3 mL of HCl and 9 mL of HNO_3 were mixed together and then poured into this cup. The samples were then heated at 50°C on a hotplate for 2 hours. Following digestion on the hotplate, the samples were filtered. Following filtration, the sample solution was added to 0.2% HNO_3 to yield a solution with a final volume of 100 mL. The samples 96 were stored in a refrigerator at 4°C before they underwent inductively coupled plasma-atomic emission spectrometer (ICP-AES) analysis. Concentrations of Zn, Ni, Cu, Cd and Pb were determined. To analyze the metallic elements, ICP-AES analysis was carried out using a PerkinElmer Optima 2100 Plasma Emission Spectrometer. A 30 s delay and an argon gas plasma flow rate of 15 L/min were used. The nebulizer flow rate was set to 0.65 L/min, and the sample flow rate was set to 1.5 mL/min (Fang *et al.*, 2012).

Quality Control

Hg Quality Control

The background contamination in the blank test was monitored using operational blanks (mixed cellulose ester filters) that were processed at the same time as the field samples. The field blanks were exposed in the field when the sampling box was opened to remove and replace the field samples. Background contamination of Hg(p) was

accounted for by subtracting field blank concentrations from the measured concentrations. Field blank values were very low-typically below or around the method detection limits. In this investigation, the background contamination was negligible and ignored. The blank test result was 0.0013 ng for Hg(p).

Metallic Elements Quality Control

Blank test background contamination was quantified using operational blanks (unexposed projection film and a quartz filter) that were processed at the same time as field samples. The field blanks were exposed in the field when the field sampling box was opened to remove and replace filters. This study accounted for background contamination by metallic elements by subtracting field blank concentrations from concentrations. Field blank values were extremely low, typically below or around the method detection limits. In this investigation, the background contamination was insignificant and can be ignored. Blank test results were 0.30, 0.28, 0.25, 0.20 and 0.22 μg for Zn, Ni, Cu, Cd and Pb, respectively.

RESULTS AND DISCUSSION

Table 1 displays the meteorological conditions and dry deposition, total suspended particulates (TSP) and dry deposition velocities obtained at a sampling site from September, 2011 to February, 2012. At the Westin Park sampling site, the mean temperature, relative humidity, and wind speed were $22.09 \pm 4.72^\circ\text{C}$, $74.55 \pm 3.51\%$ and 1.31 ± 0.16 (m/sec), respectively. At the Westin Park sampling site, the average deposition of dry particulate matter was 103.73 ± 72.02 ($\mu\text{g}/\text{m}^2/\text{min}$). Additionally, the average TSP concentrations were 57.16 ± 19.07 ($\mu\text{g}/\text{m}^3$). Finally, the average dry deposition velocity of particulate matter during the period September, 2011 to February - 2012 was 1.28 ± 0.44 (cm/sec). At the Gung-Ming Junior High School (Taichung airport) sampling site, the mean temperature, relative humidity, and wind speed were $21.48 \pm 4.77^\circ\text{C}$, $75.27 \pm 3.25\%$ and 1.30 ± 0.61 m/sec, respectively. The sampling results also revealed that the average dry deposition rate of particulate matter was 105.55 ± 47.67 ($\mu\text{g}/\text{m}^2/\text{min}$). Additionally, the average concentrations of total suspended particulates (TSP) were 92.61 ± 35.69 ($\mu\text{g}/\text{m}^3$). Finally, the dry deposition of particulate matter had an average velocity of 1.93 ± 0.70 (cm/sec) during the sampling period.

Fig. 2 compares the average concentrations of PM_{18}^+ , PM_{18-10} , $\text{PM}_{10-2.5}$ and $\text{PM}_{2.5-1}$ ($\mu\text{g}/\text{m}^3$), determined simultaneously using the MOUDI at the Westin Park (A) and Gung-Ming Junior High School (Taichung airport) (B) sampling sites. At the Westin Park sampling site, the average concentrations of PM_{18}^+ , PM_{18-10} , $\text{PM}_{10-2.5}$ and $\text{PM}_{2.5-1}$ were 19.67 ± 4.62 ($\mu\text{g}/\text{m}^3$), 16.42 ± 2.25 ($\mu\text{g}/\text{m}^3$), 16.09 ± 3.18 ($\mu\text{g}/\text{m}^3$) and 12.38 ± 2.01 ($\mu\text{g}/\text{m}^3$), respectively. At the Gung-Ming Junior High School (Taichung airport) sampling site, the mean particle concentrations of PM_{18}^+ , PM_{18-10} , $\text{PM}_{10-2.5}$ and $\text{PM}_{2.5-1}$, were 14.54 ± 2.27 ($\mu\text{g}/\text{m}^3$), 9.90 ± 3.28 ($\mu\text{g}/\text{m}^3$), 12.70 ± 2.98 ($\mu\text{g}/\text{m}^3$) and 12.63 ± 1.44 ($\mu\text{g}/\text{m}^3$), respectively. The average concentrations of PM_{18}^+ , PM_{18-10}

and $\text{PM}_{10-2.5}$, were higher at the Westin Park site compared to the Gung-Ming Junior High School (Taichung airport) site. For $\text{PM}_{2.5-1}$, the average concentrations were higher at the Gung-Ming Junior High School (Taichung airport) site than at the Westin Park site.

The average particles sizes of PM_{18}^+ concentrations in MOUDI were 16.670 ($\mu\text{g}/\text{m}^3$) at Westin Park and 14.545 ($\mu\text{g}/\text{m}^3$) at Gung-Ming Junior High School (Taichung airport). Statistical analysis of the average particle sizes of PM_{18}^+ at the 24hour period sampling sites yielded a T statistic of 2.214, which is greater than $t_{\alpha/0.05} = 0.027$, suggesting that the sample population means are significantly different. As for the PM_{18-10} concentrations in MOUDI, they were 16.425 ($\mu\text{g}/\text{m}^3$) at Westin Park and 9.900 ($\mu\text{g}/\text{m}^3$) Gung-Ming Junior High School (Taichung airport). Statistical analysis of the average particle sizes of PM_{18-10} at the 24 hours period sampling sites yielded a T statistic of 3.492, which is greater than $t_{\alpha/0.05} = 0.002$, suggesting that the sample population means are significantly different. Moreover, the average particle sizes of $\text{PM}_{10-2.5}$ concentrations in MOUDI were 16.088 ($\mu\text{g}/\text{m}^3$) at Westin Park and 12.701 ($\mu\text{g}/\text{m}^3$) at Gung-Ming Junior High School (Taichung airport). Statistical analysis of the average particles sizes of $\text{PM}_{10-2.5}$ at the 24 hours period sampling sites yielded a T statistic of 1.895, which is greater than $t_{\alpha/0.05} = 0.043$, suggesting that the sample population means are significantly different. Finally, the average particles sizes of $\text{PM}_{2.5-1}$ concentrations in MOUDI were 16.828 ($\mu\text{g}/\text{m}^3$) at Westin Park and 14.293 ($\mu\text{g}/\text{m}^3$) at Gung-Ming Junior High School (Taichung airport). Statistical analysis of the average particle sizes of $\text{PM}_{2.5-1}$ at the 24 hours period sampling sites yielded a T statistic of 1.835, which is greater than $t_{\alpha/0.05} = 0.048$, suggesting that the sample population means are significantly different.

Fig. 3 displays the average metallic element concentrations of PM_{18}^+ , PM_{18-10} , $\text{PM}_{10-2.5}$ and $\text{PM}_{2.5-1}$ ($\mu\text{g}/\text{m}^3$), which was measured simultaneously using the MOUDI (Model 100-S4) at the Westin Park site. Sampling was performed from September to November, 2011. The sampling results are as follows:

The relative concentrations of Zn particles were $\text{PM}_{18}^+ > \text{PM}_{10-2.5} > \text{PM}_{2.5-1} > \text{PM}_{18-10}$; the relative concentrations of Ni particles were $\text{PM}_{10-2.5} > \text{PM}_{18}^+ > \text{PM}_{18-10} > \text{PM}_{2.5-1}$; the relative concentrations of Cu and Hg particles were $\text{PM}_{18}^+ > \text{PM}_{18-10} > \text{PM}_{10-2.5} > \text{PM}_{2.5-1}$ and the relative concentrations of Cd particles were $\text{PM}_{10-2.5} > \text{PM}_{18}^+ > \text{PM}_{2.5-1} > \text{PM}_{18-10}$. Fig. 3 indicates that the metallic elements Zn, Cu, and Hg tended to associated in the particle sizes of PM_{10-18} during the sampling period of September–November of 2011 at the Westin Park sampling site. However, the metallic elements Ni and Cd tended to associate in the particle sizes of $\text{PM}_{10-2.5}$ at this sampling site.

Fig. 4 displays the average metallic element concentrations of PM_{18}^+ , PM_{18-10} , $\text{PM}_{10-2.5}$ and $\text{PM}_{2.5-1}$ ($\mu\text{g}/\text{m}^3$), determined simultaneously using the MOUDI (Model 100-S4) at the Westin Park site. Sampling was performed in the winter season from December to February, 2012. The sampling results for the winter season are as follows:

The relative concentrations of Zn particles were $\text{PM}_{18}^+ > \text{PM}_{10-2.5} > \text{PM}_{2.5-1} > \text{PM}_{18-10}$; the relative concentrations of

Table 1. Displayed the relative humidity, wind speed, temperature, prevailing wind direction and particulates bound in dry deposition, total suspended particulates (TSP) and dry deposition velocities at the Westin Park and Gung-Ming Junior High School sampling sites during year September (2011)–November (2011).

Sample No	Sample date	Temp (°C)	RH (%)	WS (m/sec)	PWD	Dry deposition ($\mu\text{g}/\text{m}^3/\text{min}$)	TSP ($\mu\text{g}/\text{m}^3$)	Dry deposition Velocities, Vd (cm/sec)
Westin Park								
	2011/September	28.50	69.01	1.51	S	29.70	65.97	1.60
	2011/October	25.08	74.00	1.40	ESE	112.85	38.63	0.88
	2011/November	25.08	74.00	1.40	SSE	209.70	53.39	1.15
	2012/December	18.32	77.59	1.30	NNE	161.62	85.42	1.84
	2012/January	17.11	73.64	1.11	ESE	75.36	65.19	1.48
	2012/February	18.42	79.04	1.13	SSE	33.14	34.38	0.72
N = 24	Average	22.09	74.55	1.31	SE	103.73	57.16	1.28
	SD	4.72	3.51	0.16		72.02	19.07	0.44
Gung-Ming								
	2011/September	28.29	70.14	1.55	S	50.90	34.64	0.83
	2011/October	24.88	74.36	1.44	ESE	43.01	77.40	1.76
	2011/November	23.90	77.70	1.22	S	118.77	125.49	2.07
	2012/December	18.08	77.37	1.27	E	120.27	113.07	2.44
	2012/January	16.95	73.36	1.18	SSE	143.62	125.07	2.85
	2012/February	16.95	78.68	1.16	SE	156.76	77.60	1.65
N = 24	Average	21.48	75.27	1.30	SE	105.55	92.21	1.93
	SD	4.77	3.25	0.16		47.67	35.69	0.70

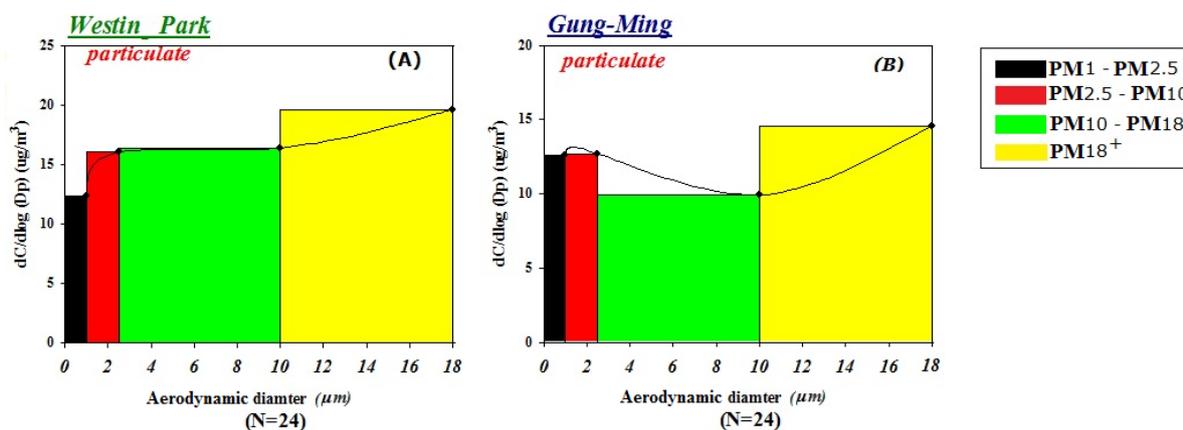


Fig. 2. Variations of particulate in size distributions ($\mu\text{g}/\text{m}^3$) at the two sampling sites.

Ni and Cu particles were $\text{PM}_{18^+} > \text{PM}_{18-10} > \text{PM}_{10-2.5} > \text{PM}_{2.5-1}$; the relative concentrations Cd particles were $\text{PM}_{10-2.5} > \text{PM}_{18^+} > \text{PM}_{2.5-1} > \text{PM}_{18-10}$; the relative concentrations of metallic elements Pb and Hg were $\text{PM}_{18-10} > \text{PM}_{18^+} > \text{PM}_{2.5-1} > \text{PM}_{10-2.5}$. Fig. 4 indicates that the metallic elements Zn, Ni, and Cu tended to associate in the particle sizes of PM_{18^+} during the sampling period of December, 2011 to February, 2012 at the Westin Park sampling site.

Fig. 5 displays the average metallic element concentrations of PM_{18^+} , PM_{18-10} , $\text{PM}_{10-2.5}$ and $\text{PM}_{2.5-1}$ ($\mu\text{g}/\text{m}^3$), determined simultaneously using the MOUDI (Model 100-S4) at the Gung-Ming Junior High School (Taichung airport) site. The sampling results for the fall season September to November of 2011 are as follows:

In the fall season, the relative concentrations of Zn, Ni, Cu, Cd and Pb were $\text{PM}_{18^+} > \text{PM}_{18-10} > \text{PM}_{2.5-1} > \text{PM}_{10-2.5}$; the relative concentrations of Hg, were $\text{PM}_{2.5-1} > \text{PM}_{18-10} > \text{PM}_{10-2.5} > \text{PM}_{18^+}$. Fig. 5 indicated that all the metallic elements tended to associate in the particle sizes of PM_{18^+} during the sampling period of September to November of 2011 at the Gung-Ming Junior High School (Taichung airport) except for the metallic element of mercury.

Fig. 6 displays the average metallic element concentrations of PM_{18^+} , PM_{18-10} , $\text{PM}_{10-2.5}$ and $\text{PM}_{2.5-1}$ ($\mu\text{g}/\text{m}^3$), determined simultaneously using the MOUDI (Model 100-S4) at the Gung-Ming Junior High School (Taichung airport) site. The sampling results for the period December to February, 2012 are as follows:

In the winter the relative concentrations of metallic elements Zn, Ni, Cu, Cd and Pb were $\text{PM}_{18^+} > \text{PM}_{18-10} > \text{PM}_{2.5-1} > \text{PM}_{10-2.5}$, respectively. The relative concentrations of metallic element Hg were $\text{PM}_{2.5-1} > \text{PM}_{10-2.5} > \text{PM}_{18^+} > \text{PM}_{18-10}$. Fig. 6 indicates that all the metallic elements tended to associate in the particle sizes of PM_{18^+} during the sampling period of December, 2011 to February, 2012 at the Gung-Ming Junior High School (Taichung airport) except for the metallic element of mercury.

Trace metal concentrations measured at two different sites in central Taiwan show distinctive size distributions (ng/m^3) for all pollutants with concentrations during the Fall and Winter. Mercury (Hg) was also a pollutant of concern mainly due to the toxicity and bioaccumulation of

methyl mercury in aquatic environments, where atmospheric deposition is the major input route (Mason *et al.*, 1994; Mason *et al.*, 1997; Landis *et al.*, 2002; Lai *et al.*, 2007). Moreover, in urban SDSs, Zn, Ni, Cd, Pb, Cu and Cr were related to traffic and industry; coal combustion increases Hg levels. Therefore, this study focused on measuring dry deposition of particulate-bound mercury Hg(p) and metal elements concentrations in the ambient air. Notably, Dragon Steel Plant, Taichung thermal power plant (TTPP), Han-Shian Aerospace Industrial Development Corporation and Quan-Lien Industrial Park were located near the two characteristic sampling sites in this study.

CONCLUSIONS

The Main Conclusions for this Study are Listed as Follows:

This study found that, for particle sizes of PM_{18^+} , PM_{18-10} , and $\text{PM}_{10-2.5}$ the average particle concentrations were higher at the Westin Park site than at the Gung-Ming Junior High School (Taichung airport) site. The only exception is $\text{PM}_{2.5-1}$. The average concentrations of particle size $\text{PM}_{2.5-1}$ was higher at the Gung-Ming Junior High School (Taichung airport) than at the Westin Park site. At all sampling sites, analysis of average metallic element (Zn, Ni, Cu, Cd and Pb) concentrations in the ambient air showed that the relative concentrations of particle sizes were $\text{PM}_{18^+} > \text{PM}_{18-10} > \text{PM}_{2.5-1} > \text{PM}_{10-2.5}$. The only exception was particle-bound mercury Hg(p). The proposed reason for this exception is the proximity of the Taichung airport to the Taiwan Straits (approximately 11.6 km). Dragon Steel Plant, Han-Shian Aerospace Industrial Development Corporation and Quan-Lien Industrial Park are also located nearby. Therefore, particle-bound mercury Hg(p) had higher concentrations and finer particles at the Taichung airport site than at the Westin Park site.

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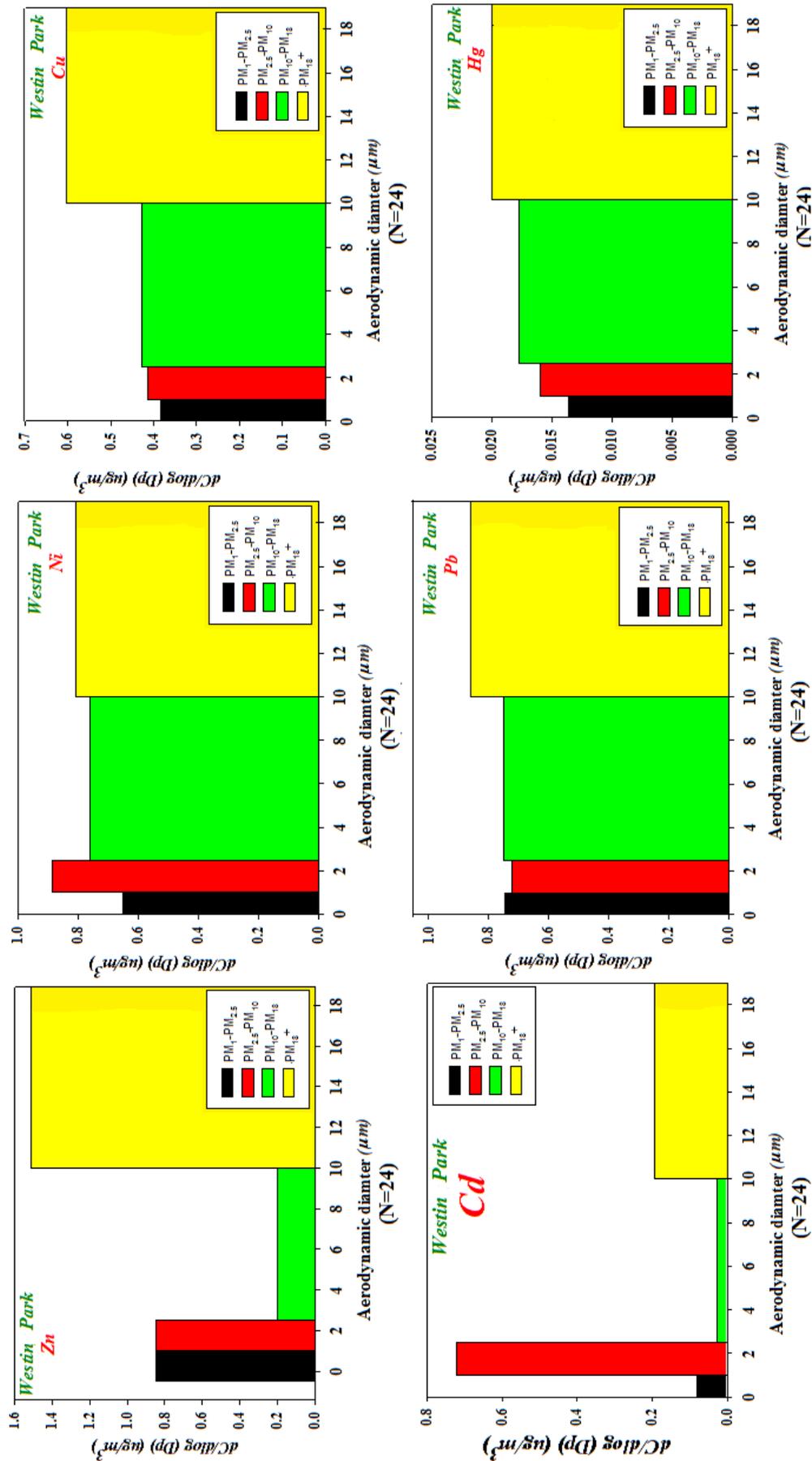


Fig. 3. Seasonal (Fall) variations of average metallic element concentrations (ng/m^3) at the Westin Park during year September to November 2011.

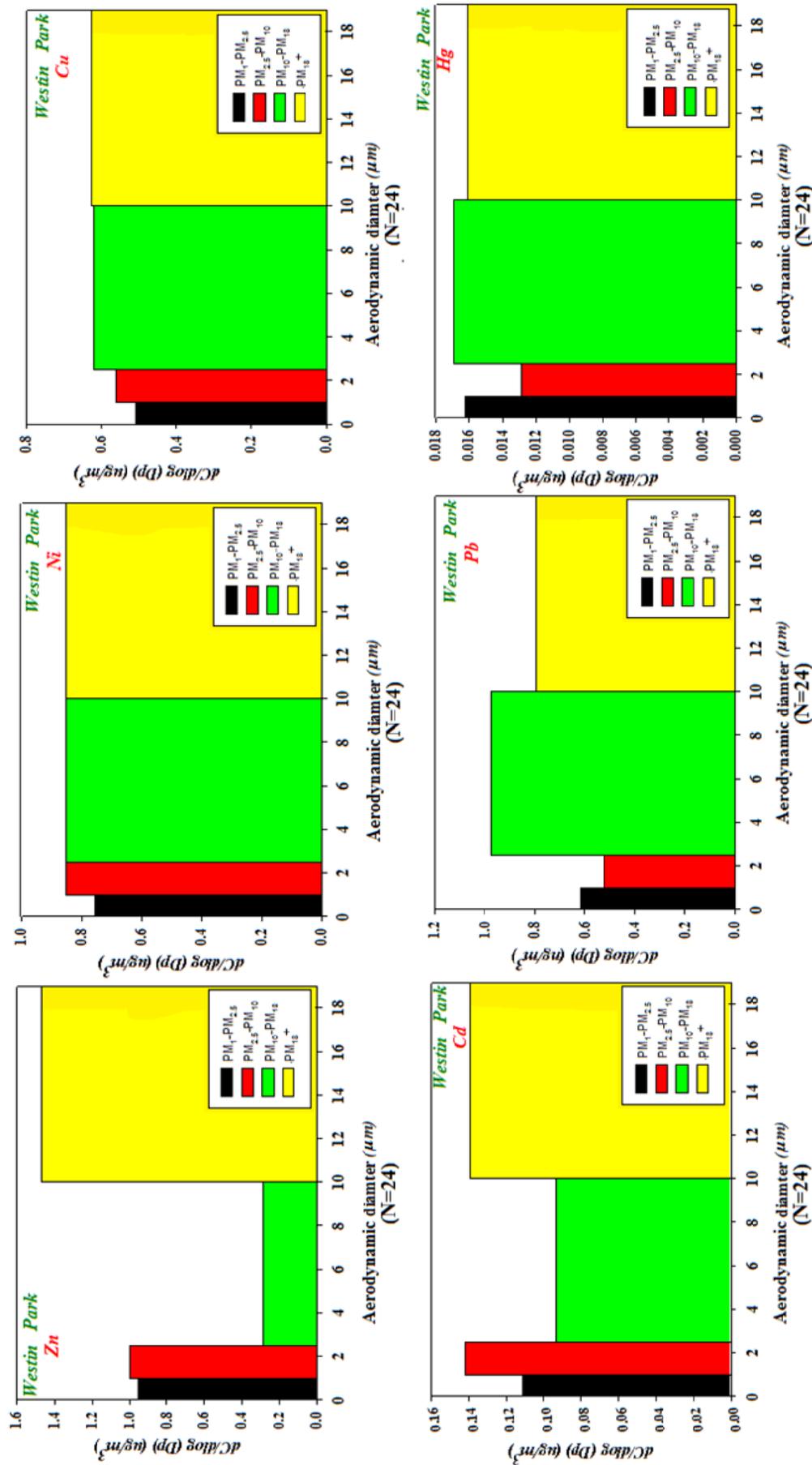


Fig. 4. Seasonal (winter) variations of average metallic element concentrations in size distributions (ng/m^3) at the Westin Park during the period December, 2011 to February, 2012.

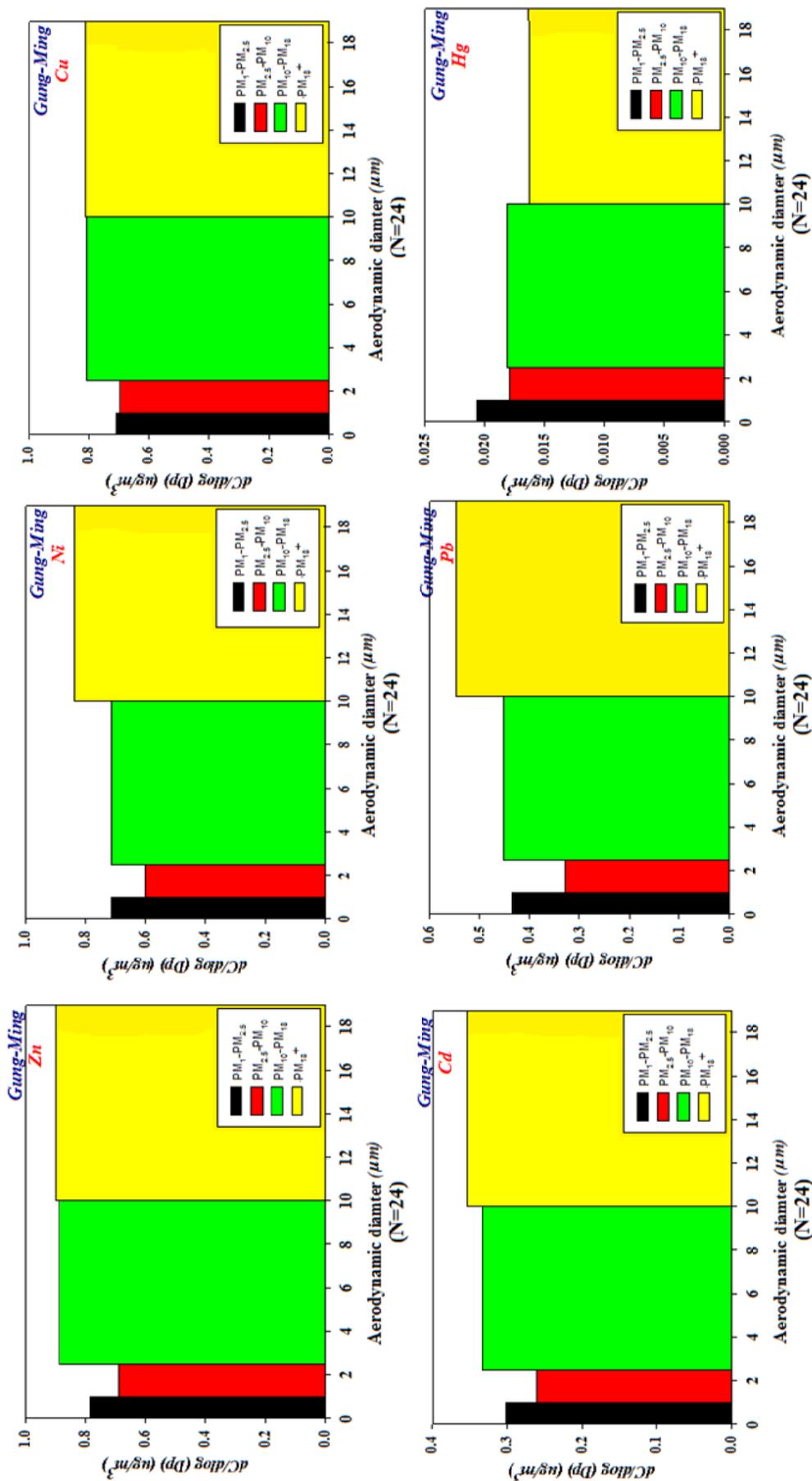


Fig. 5. Seasonal (Fall) variations of average metallic element concentrations (ng/m^3) at the Gung-Ming Junior High School (Taichung airport) during year September to November, 2011.

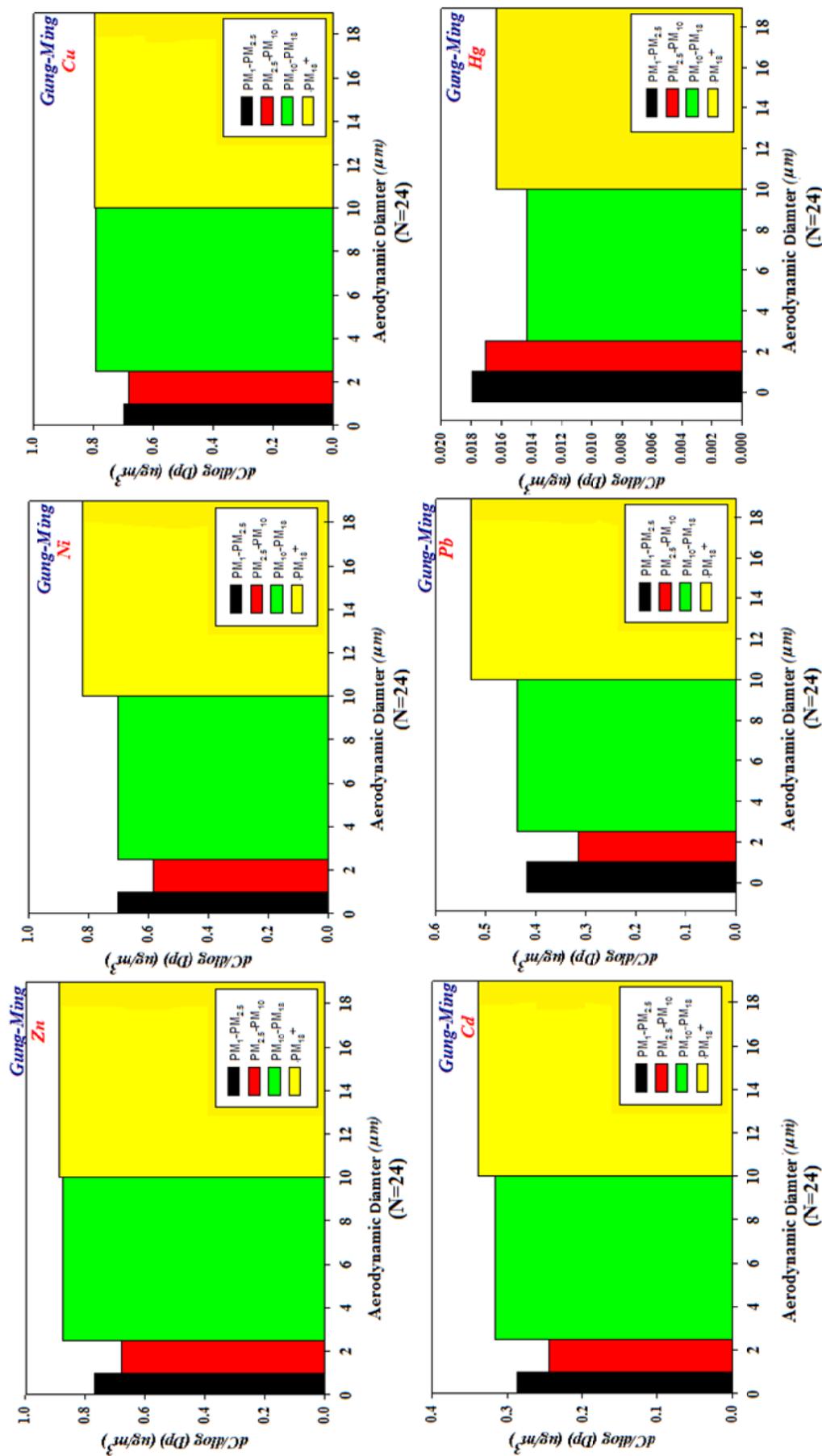


Fig. 6. Seasonal (Winter) variations of average metallic element concentrations in size distributions (ng/m^3) at the Gung-Ming Junior High School (Taichung airport) during year December (2011)–February (2012).

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