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Apply appropriate statistic methods in analyzing ambient air particulate and metallic elements concentrations at a traffic sampling site

Guor-Cheng Fang [a,*], Chih-Chung Wen [a], Wen-Jhy Lee [b,c]

[a] Department of Environmental Engineering, HungKung University, Sha-Lu, Taichung 433, Taiwan
[b] Department of Environmental Engineering, National Cheng Kung University, Tainan 70101, Taiwan ROC
[c] Sustainable Environment Research Center, National Cheng Kung University, Tainan 70101, Taiwan ROC

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Abstract

A study of the characteristics of the metallic elements concentrations in fine and coarse particulates at traffic sampling site in central Taiwan by using appropriate statistical analysis methods was described in this paper. The Spearman correlation analysis and non-linear regression analysis were used to analyze the collected data during sampling period from August 2003 to March 2004. During a half-month analysis periods, the average metallic elements concentrations, the major meteorological effects and temporal variation were discussed in this study. The major meteorological parameters during daytime and nighttime sampling periods are temperature, average wind velocity and prevailing wind degree. The relationships between the metallic elements concentrations and meteorological parameters in fine and coarse particulates during daytime and nighttime are also established in this paper. According to the proposed equations, the variation of the particle concentrations can be predicted with known meteorological parameters during daytime and nighttime at traffic sampling site in central Taiwan.

Keywords: Spearman correlation analysis; Non-linear regression equation; Metallic; Elements concentrations

1. Introduction

According to a previous report by Lee et al. [1], the emission of anthropogenic air pollutants in north-eastern Asia was increasing rapidly in the past decade. Meteorological conditions and pollutant emission level were the major factors of concentrations of air pollutant [2]. In addition, ambient weather conditions can also influence chemical reactions leading to secondary aerosol formation, such as temperature, relative humidity and short wave radiation. Large particles were affected by gravity obviously, and fine particulates were affected by diffusion obviously.

Fine particles ($PM_{2.5}$) were from secondary sulfate, wood combustion, diesel exhaust, secondary nitrate, meat cooking gasoline-powered motor vehicle exhaust and road dust. The fine particles ($PM_{2.5}$) sources involved economic and social consequences widely [3–5]. In recent decades, vehicles have grown rapidly in traffic source. Motor vehicle exhaust is one of the most important sources of fine airborne particulates [6]. These fine particulates are often transported for long distances, and have damage to our health. Airborne particulates are important carriers of metals, which contain toxic properties and commonly excess the natural levels [7,8]. With a higher density of vehicles at traffic junction and different vehicle behaviors, such as idling, stopping, accelerating and decelerating, aggravated the pollution source problem at traffic junctions. Whereas the traffic exhaust is the main contributor to fine particulates near the traffic areas, the particulates concentration variations of the daytime and nighttime are concerned in our life. In order to understand the concentration characteristics of fine ($PM_{2.5}$) and coarse ($PM_{2.5–10}$) particulates during daytime and nighttime at the traffic junction in front of HungKung University in Taichung, Fang et al. [9] used a versatile air pollutant system (VAPS) to collect samples for the analyses of the above pollutants. According to Fang et al.'s [9] study, there was no obvious correlation coefficients among atmospheric temperature, wind speed, prevailing wind degree and relatively humidity in either daytime or nighttime periods for fine particulates and coarse

* Corresponding author. Tel.: +886 4 2631 8652x1111; fax: +886 4 2350 2102.
E-mail address: gcfang@sunrise.hk.edu.tw (G.-C. Fang).

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particulates at the traffic junction in front of HungKung University in Taichung. However, the meteorological parameters are one of the most important factors influencing the particulates concentration problem. In this study, we tried to find out the characteristics of the particulates concentration and the meteorological parameters by using statistical analysis method. The best regression equations are also established in this paper.

2. Meteorological parameters and sampling data

2.1. Sampling data

The sampling site is located at Chung-Chi Road in front of the HungKung University (CCRU) in central Taiwan (Fig. 1). Chung-Chi Road is a main traffic road leading to Taichung City. The sampling period was divided into daytime (09:00–21:00 h) and nighttime (21:00–09:00 h) periods. The traffic flow in Chung-Chi Road is about 3000 vehicles h^{-1} during daytime (09:00–21:00 h) and 800 vehicles h^{-1} during nighttime (21:00–09:00 h) periods. The CCRU sampling site is about 30 km from the Taichung Thermal Power Plant and Taiwan 2nd Highway. Diesel trucks and cars constructed the main vehicle flow in this traffic lane.

Fang et al. [9] used the versatile air pollutant sampler (VAPS, URG-3000K, URG Corp., Chapel Hill, NC) to collect $PM_{2.5–10}$ (coarse) and $PM_{2.5}$ (fine) particulates simultaneously at the CCRU sampling site, which was located on the safety island on Chung-Chi Road. A 12 h consecutive sampling process for fine and coarse particles was performed three to six times per month during August 2003 and March 2004 at the CCRU sampling site. CCRU samples were divided into 37 groups in daytime and 36 groups in nighttime.

2.2. Meteorological analysis

Meteorological analysis was done by WatchDog weather station Model 525 (Spectrum Technologies, Inc., USA). The weather station provided information of wind speed, wind direction and temperature during sampling period of August 2003 to March 2004. Table 1 shows the average of a half-month sampling information at the CCRU sampling site from August 2003 to March 2004. During the sampling period at both daytime and nighttime, the average temperatures were 22.7 and 22.48 °C, respectively, and the average wind velocities were 5.2 and 3.7 km/h, respectively. If the definition of the direction of north is equal to 0°, then the prevailing wind direction at daytime and nighttime were 150.2° and 202.4° at the sampling site. The dominant wind directions were SW and SE in this study.

2.3. Sampling analysis

In their previous study, Fang et al. [9] indicated that the correlation coefficients between the atmosphere temperature and wind speed in daytime or nighttime periods had lower

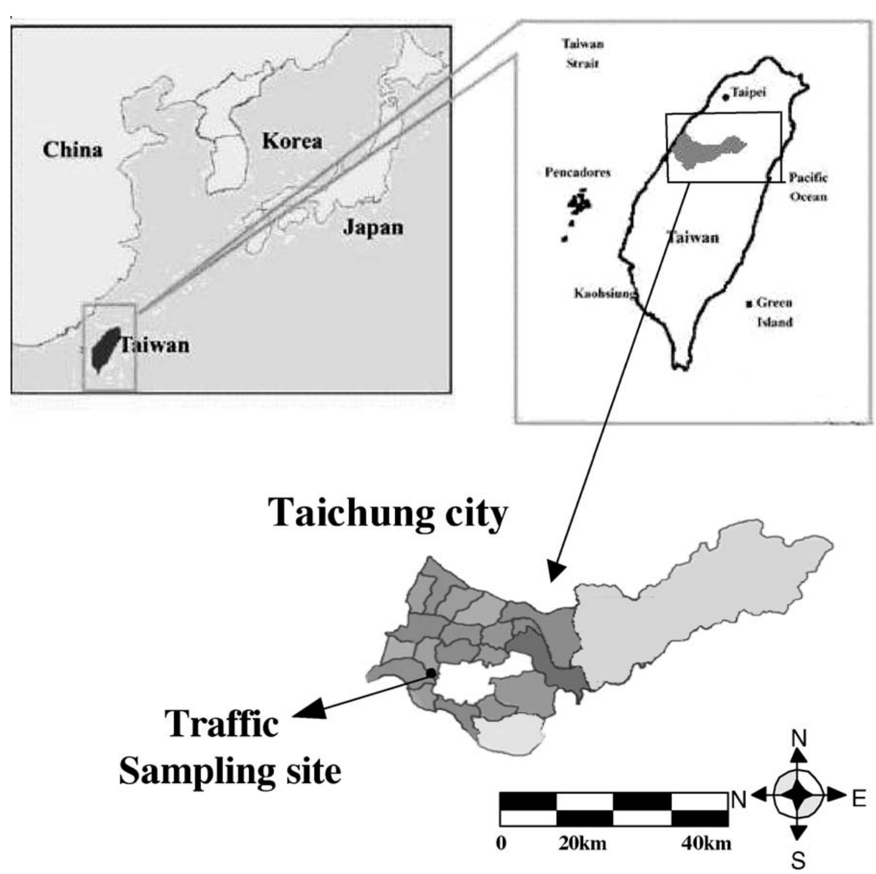

Fig. 1. The location of sampling site at Chung-Chi Road in front of the HungKung University (CCRU) in central Taiwan.

Table 1
Summary statistics for meteorological parameters during daytime and nighttime sampling period

Month/day	Mean (Min, Max)					
	Temperature (°C)		Average wind speed (km/h)		Prevailing wind degree	
	Daytime	Nighttime	Daytime	Nighttime	Daytime	Nighttime
August 16–31	23.53 (30.4, 31.5)	27.5 (26.9, 27.23)	3.67 (3.4, 4.1)	5.7 (0.3, 0.7)	203.13 (174.1, 225)	170.23 (158.4, 190.5)
September 1–15	30.1 (29.9, 30.3)	27.1 (27.0, 27.2)	6.3 (3.5, 9.1)	3.3 (0.8, 5.8)	97.8 (57.5, 138.1)	127.75 (68.3, 187.2)
September 16–30	28.75 (29.9, 30.1)	26.0 (25.0, 27.0)	4.25 (3.6, 4.9)	0.2 (0.1, 0.3)	97.95 (97.1, 98.8)	141.2 (120.0, 162.4)
October 16–31	25.03 (23.7, 26.0)	25.53 (19.8, 21.2)	9.6 (5.6, 13.6)	3.38 (0.3, 7.8)	82.25 (59.2, 142.0)	115.28 (60.8, 132.4)
November 1–15	25.13 (23.4, 26.9)	21.95 (20.0, 23.2)	7.48 (5.8, 11.0)	1.9 (0.1, 4.7)	122.58 (94.7, 158.8)	144.13 (75.4, 203.2)
November 16–30	23.0 (21.5, 24.5)	20.6 (19.1, 22.1)	6.6 (6.4, 6.8)	1.05 (0.7, 1.4)	31.25 (89.4, 333.1)	349.5 (25.0, 332.9)
December 1–15	24.25 (20.9, 26.0)	21.55 (19.8, 22.9)	8.13 (5.9, 10.4)	1.53 (0.1, 3.1)	77.35 (82.0, 333.2)	144.68 (96.5, 223.0)
December 16–31	21.28 (14.4, 30.3)	21.8 (18.7, 26.7)	3.6 (1.7, 7.3)	5.62 (4.3, 6.8)	205.16 (86.7, 282.1)	226.92 (67.0, 287.2)
January 1–15	13.03 (8.9, 15.5)	15.5 (11.0, 19.5)	3.68 (0.6, 8.2)	8.33 (4.5, 11.4)	270.15 (221.3, 298.0)	279.05 (221.3, 298.0)
February 1–15	15.78 (13.4, 18.6)	19.48 (16.9, 22.4)	1.3 (0.1, 4.4)	5.03 (3.1, 7.9)	232.10 (200.6, 299.2)	276.33 (200.6, 299.2)
March 16–31	17.40 (15.9, 18.3)	20.33 (19.6, 21.1)	2.3 (1.7, 2.7)	4.67 (2.9, 7.4)	231.93 (242.0, 306.8)	251.37 (242.0, 306.8)
Average	22.7	22.5	5.2	3.7	150.2	202.4

correlation values with daily fine and coarse particulate concentrations. The daily vehicle flux in this traffic lane may vary, and this maybe the reason why the particle concentrations had lower correlation coefficients with the meteorological parameters. In order to find out the relationships between the meteorological parameters and suspended particles at the traffic site, we try to reanalyze the sampling data by extending each analysis process a half-month period.

The fine, coarse and PM_{10} concentrations during daytime and nighttime sampling periods at traffic sampling site were shown in Table 2. During daytime sampling period from August 2003 to March 2004, the average concentration values of fine, coarse and PM_{10} were 39.17, 34.35 and 73.52 μg/m^3 and the nighttime concentration values were 37.15, 33.72 and 70.87 μg/m^3. In addition, the average concentration range of fine particulates at daytime and nighttime were 23.53–61.03 and 24.18–63.7 μg/m^3, respectively. The average concentrations ranges of coarse particulate were 14.97–50.40 and 14.3–46.95 μg/m^3, respectively. The average concentrations of PM_{10} particulate during daytime and nighttime periods were ranged from 38.47 to 100.2 and 43.53 to 109.2 μg/m^3, respectively.

Moreover, the average particulate concentrations distribution order was coarse > fine from November 2003 to February 2004 for daytime and nighttime periods. The average concentrations of fine particulate were higher than the coarse particulate during the periods from August 2003 to October 2003 and March 2004. The average concentrations at daytime are higher than the nighttime periods for fine, coarse and PM_{10}. The particulates are more easily suspended to the atmosphere during the daytime than the nighttime period. The proposed reason is that the anthropogenic activities and natural living animals were prevailing around this region at daytime.

In order to investigate the relationship between the meteorological and the ambient particulate mass concentrations, each half a month of statistical sampling data was establish to obtain related regression equations.

Figs. 2 and 3 show a half-month variation for fine, coarse and PM_{10} particulate concentrations measured at CCRU sam-

Table 2
Summary statistics for fine, coarse and PM_{10} concentration during daytime and nighttime sampling period

Month/day	Mean (Min, Max)					
	Fine concentration (μg/m^3)		Coarse concentration (μg/m^3)		PM_{10} concentration (μg/m^3)	
	Daytime	Nighttime	Daytime	Nighttime	Daytime	Nighttime
August 16–31	23.53 (11.3, 32.4)	29.23 (25.9, 31.9)	14.97 (5.3, 22.2)	14.3 (7.8, 18.5)	38.47 (16.6, 54.6)	43.53 (37.6, 50.5)
September 1–15	36.70 (25.9, 47.5)	63.7 (63.7, 63.7)	20.7 (18.1, 23.3)	45.5 (45.5, 45.5)	57.35 (44.0, 70.7)	109.2 (109.2, 109.2)
September 16–30	34.15 (25.5, 42.8)	34.25 (19.0, 49.5)	21.9 (16.2, 27.6)	32.35 (15.0, 49.7)	56.1 (53.1, 59.1)	66.6 (34.0, 99.2)
October 16–31	49.0 (26.4, 75.5)	47.4 (37.7, 65.3)	23.7 (10.9, 34.1)	34.3 (15.3, 52.8)	72.73 (37.3, 109.6)	81.65 (53.0, 109.0)
November 1–15	41.95 (40.0, 43.8)	29.28 (19.7, 40.5)	45.83 (35.7, 52.8)	36.93 (22.9, 52.8)	87.75 (75.7, 93.3)	66.18 (42.5, 93.3)
November 16–30	40.30 (38.9, 41.7)	29.55 (28.5, 30.6)	50.40 (47.5, 53.3)	46.95 (41.9, 52.0)	90.70 (89.2, 92.2)	76.50 (72.5, 80.5)
December 1–15	36.33 (27.5, 47.7)	31.53 (22.9, 37.7)	37.88 (30.4, 43.2)	33.58 (27.9, 37.6)	74.20 (57.9, 90.9)	65.13 (50.8, 73.6)
December 16–31	36.06 (28.2, 41.0)	26.98 (22.2, 33.6)	39.74 (33.4, 43.4)	35.18 (30.9, 38.0)	75.80 (61.6, 84.2)	62.20 (53.2, 71.6)
Jan 1-15	28.55 (25.0, 34.7)	24.18 (22.7, 27.5)	35.48 (30.1, 38.6)	30.38 (26.3, 32.6)	64.05 (55.1, 73.4)	54.60 (49.9, 59.5)
February 1–15	43.28 (22.2, 61.5)	42.05 (20.4, 63.1)	48.10 (24.9, 72.2)	43.78 (21.5, 63.2)	91.38 (47.1, 133.7)	85.83 (41.9, 123.7)
March 16–31	61.03 (52.1, 72.7)	50.47 (44.2, 56.7)	39.17 (18.9, 65.8)	17.8 (12.3, 24.4)	100.2 (84.9, 124.1)	68.23 (62.7, 73.4)
Average	39.17	37.15	34.35	33.72	73.52	70.87

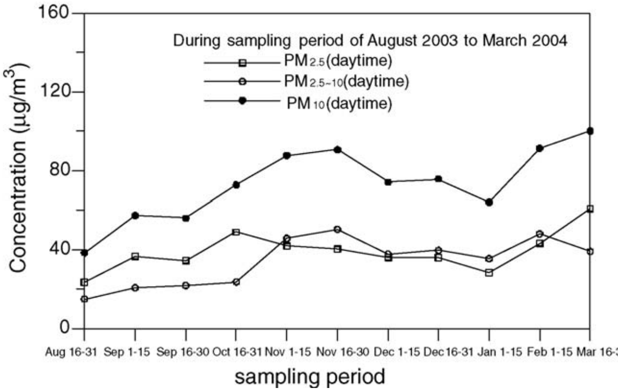

Fig. 2. Average daytime variations for fine, coarse and PM_{10} particulate concentrations measured during sampling period of August 2003–March 2004 at the CCRU sampling site.

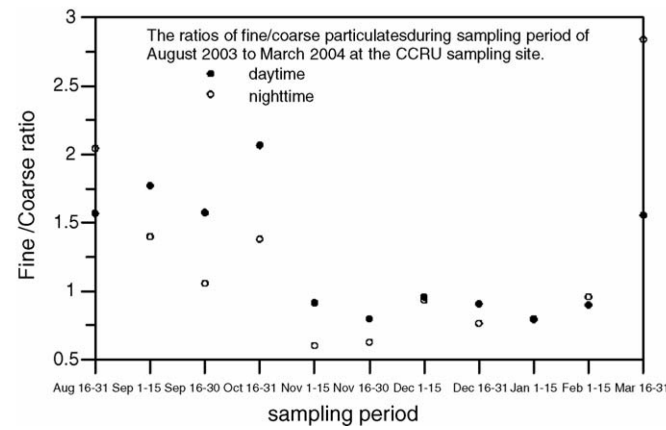

Fig. 4. The ratios of fine/coarse particulates during daytime and nighttime periods at the CCRU sampling site.

pling site during daytime and nighttime sampling period. The distribution order of the particulate concentrations was the same at daytime and nighttime from August 2003 to March 2004. During March 2004, the coarse particulate concentrations were lower than fine particulate concentrations. However, a dust storm invaded the sampling site in March 2004. Dust storms usually occur between February and April. Lee et al. [10] indicated that dust origin, transport path, duration time, inland meteorology, local source pattern might affect the results of dust storm. During the dust storm periods, coarse particulates can only be affected by local pollutant sources; fine particulates can be carried away to distant area. A comparison with the major pollutant sources of fine particulates, it can be seen that the fine particulates almost disappeared during nighttime. The reason of this phenomena was attributed to the anthropogenic activities.

Fig. 4 shows a half-month variation of fine/coarse particulates ratios during daytime and nighttime sampling periods at the CCRU sampling site. The ratios of fine/coarse particulates were higher than 1.0 from August 2003 to October 2003 and March 2004 during daytime and nighttime. In another hand, the ratios of fine/coarse particulates were less than 1.0 from November 2003 to February 2004, but the average fine/coarse particulate concentrations ratios approached to 1.0 at daytime. At nighttime, the coarse particulate concentrations were also higher than fine particulate concentrations, but the ratios of fine/coarse particulates were lower than daytime sampling period from November 2003 to February 2004. These phenomena were consisted with the contribution of resuspension of dust.

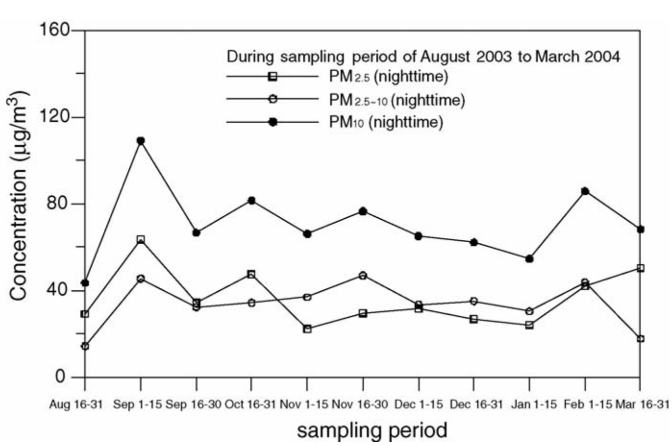

Fig. 3. Average nighttime variations for fine, coarse and PM_{10} particulate concentrations measured during sampling period of August 2003–March 2004 at the CCRU sampling site.

2.4. Metallic element concentrations

The average daytime and nighttime of half-month metallic element concentrations of fine and coarse particulates during August 2003 to March 2004 were shown in Tables 3a–3d. In general, metallic element concentrations in fine particulates were higher than coarse particulates except for the crustal elements and Mg. With regard to the variations of a half-month daytime and nighttime sampling periods, the mean metallic concentrations of fine particulates were shown in the following order: Fe (733.4 ngm^{-3}) > Zn (571.7 ngm^{-3}) > Cu (266.4 ngm^{-3}) > Cr (236.7 ngm^{-3}) > Mg (228.3 ngm^{-3}) > Pb (35.1 ngm^{-3}) > Mn (30.6 ngm^{-3}) and Fe (835.0 ngm^{-3}) > Zn (549.8 ngm^{-3}) > Mg (264.1 ngm^{-3}) > Cu (254.5 ngm^{-3}) > Cr (246.2 ngm^{-3}) > Mn (54.0 ngm^{-3}) > Pb (19.2 ngm^{-3}), respectively. In addition, the average daytime and nighttime of half-month metallic element concentrations of coarse particulates during August 2003 to March 2004 were shown in the following order: Fe (782.7 ngm^{-3}) > Mg (396.4 ngm^{-3}) > Zn (254.0 ngm^{-3}) > Cu (138.1 ngm^{-3}) > Cr (120.5 ngm^{-3}) > Mn (24.4 ngm^{-3}) > Mn (3.7 ngm^{-3}) and Fe (609.8 ngm^{-3}) > Mg (242.9 ngm^{-3}) > Zn (221.4 ngm^{-3}) > Cu (128.4 ngm^{-3}) > Cr (116.1 ngm^{-3}) > Mn (15.4 ngm^{-3}) > Pb (4.4 ngm^{-3}), respectively.

Fig. 5a–d displayed the average percentage of various kinds of metallic elements in the coarse and fine particle size modes during daytime and nighttime sampling period. The results indicated the average percentage of fine metallic elements Fe, Mg, Cr, Cu, Zn, Mn and Pb were 35.6%, 12.75%, 8.87%, 18.94%, 19.07%, 0.91% and 3.86%, respectively, during daytime sampling periods. As for nighttime sampling period, the average percentage of fine metallic elements Fe, Mg, Cr, Cu, Zn, Mn and Pb were 26.4%, 10.76%, 7.54%, 14.39%, 37.38%, 1.36% and

Table 3a
Summary statistics of the concentrations of metallic elements for $PM_{2.5}$ during daytime sampling period ($ng\,m^{-3}$)

Month/day	Mean (Min, Max)						
	Fe	Mg	Cr	Cu	Zn	Mn	Pb
August 16–31	1134.2 (579.6, 1666.7)	324.07 (208.3, 601.9)	316.37 (185.2, 509.3)	331.8 (231.5, 509.3)	744.17 (218.8, 1225.2)	30.83 (23.1, 46.3)	16.23 (0.0, 43.1)
September 1–15	1041.65 (810.2, 1273.1)	324.05 (347.2, 300.9)	254.6 (254.6, 254.6)	254.6 (254.6, 254.6)	647.75 (562.4, 733.1)	34.7 (23.1, 46.3)	49.6 (0.0, 99.2)
September 16–30	879.6 (833.3, 925.9)	208.3 (208.3, 208.3)	289.35 (254.6, 324.1)	266.2 (254.6, 277.8)	651.15 (615.6, 686.7)	11.55 (0.0, 23.1)	24.35 (5.6, 43.1)
October 16–31	465.37 (416.7, 562.7)	137.17 (92.6, 203.2)	289 (218.8, 324.1)	234.73 (231.5, 241.2)	507.93 (348.3, 592.9)	52.97 (43.2, 69.4)	1.27 (0.0, 3.8)
November 1–15	915.7 (578.3, 1158.6)	243.13 (109.4, 406.4)	170.48 (125.0, 243.8)	282.08 (210.7, 463.4)	611.85 (147.7, 914.9)	31.6 (21.1, 42.1)	50.23 (5.1, 90.3)
November 16–30	789.95 (737.3, 842.6)	231.75 (273.9, 189.6)	233.4 (171.9, 294.9)	301.8 (231.7, 371.9)	568.35 (511.8, 624.9)	20.95 (20.8, 21.1)	32.2 (5.1, 59.3)
December 1–15	692.58 (422.3, 758.4)	210.78 (184.3, 273.9)	269.93 (231.7, 294.9)	241.38 (215.7, 259.3)	498.63 (317.0, 592.9)	42.05 (17.3, 62.5)	34.58 (22.9, 47.1)
December 16–31	929.84 (770.9, 1315.0)	282.14 (163.8, 541.7)	237.6 (166.7, 358.3)	295.52 (229.2, 463.4)	686.6 (521.8, 827.3)	30.58 (20.8, 42.1)	35.32 (22.9, 48.0)
January 1–15	437.63 (281.3, 625.2)	162.23 (142.7, 178.2)	235.4 (218.8, 266.9)	236.4 (192.6, 262.0)	501.7 (313.5, 624.9)	27.5 (0.0, 43.2)	26.05 (22.8, 29.1)
February 1–15	386.63 (281.3, 562.7)	223.45 (154.3, 277.9)	193.23 (96.6, 294.8)	242.6 (225.7, 260.0)	625.85 (348.3, 833.3)	42.15 (21.9, 76.8)	67.18 (35.1, 97.2)
March 16–31	457.1 (351.2, 642.3)	163.73 (76.5, 330.5)	113.83 (96.6, 148.3)	243.13 (238.3, 252.8)	244.83 (164.8, 385.1)	11.67 (0.0, 30.5)	49.6 (25.8, 97.2)
Average	733.39	228.25	236.65	266.39	571.71	30.60	35.15

Table 3b
Summary statistics of the concentrations of metallic elements for $PM_{2.5}$ during nighttime sampling period ($ng\,m^{-3}$)

Month/day	Mean (Min, Max)						
	Fe	Mg	Cr	Cu	Zn	Mn	Pb
August 16–31	625.03 (463.0, 902.8)	239.2 (185.2, 324.1)	231.47 (185.2, 254.6)	239.2 (231.5, 254.6)	375.5 (60.1, 600.6)	54.0 (23.1, 92.6)	14.37 (0.0, 43.1)
September 1–15	1527.8 (1527.8, 1527.8)	231.5 (231.5, 231.5)	254.6 (254.6, 254.6)	254.6 (254.6, 254.6)	821.5 (821.5, 821.5)	46.3 (46.3, 46.3)	5.6 (5.6, 5.6)
September 16–30	925.95 (763.9, 1088.0)	219.9 (138.9, 300.9)	324.1 (324.1, 324.1)	266.2 (254.6, 277.8)	539.6 (500.3, 578.9)	69.45 (92.6, 46.3)	2.8 (0.0, 5.6)
October 16–31	1122.68 (648.1, 2245.4)	462.95 (208.3, 856.5)	324.08 (254.6, 393.5)	266.2 (254.6, 277.8)	574.38 (271.9, 823.7)	75.23 (46.3, 92.6)	1.4 (0.0, 5.6)
November 1–15	798.25 (652.8, 1164.2)	207.98 (158.8, 246.9)	164.65 (130.5, 254.7)	246.45 (194.0, 276.4)	630.85 (413.7, 840.3)	46.3 (17.6, 72.8)	24.53 (15.6, 32.5)
November 16–30	805.25 (781.5, 829.0)	224.95 (142.1, 307.8)	324.1 (324.1, 324.1)	236.45 (230.5, 242.4)	476.55 (456.4, 496.7)	66.9 (47.4, 86.4)	20.4 (15.2, 25.6)
December 1–15	1074 (663.1, 1999.0)	372.03 (130.5, 876.2)	294.43 (254.6, 324.1)	220.15 (194.0, 260.5)	443.18 (315.9, 539.4)	60.63 (35.3, 88.7)	19.43 (15.6, 24.6)
December 16–31	588.58 (237.3, 857.7)	247.06 (166.1, 301.0)	189.44 (141.1, 224.1)	261.4 (236.8, 330.5)	489.94 (441.1, 625.9)	37.58 (25.3, 47.5)	21.64 (17.2, 25.6)
January 1–15	783.83 (651.3, 1022.0)	281.13 (142.1, 439.0)	304.4 (260.5, 331.5)	272.85 (226.5, 342.4)	566.4 (471.9, 696.3)	51.95 (35.3, 89.5)	18.03 (13.4, 23.6)
February 1–15	474.5 (257.8, 787.2)	230.7 (154.1, 324.1)	166.05 (148.3, 201.7)	285.98 (252.8, 376.4)	480.08 (345.4, 823.9)	61.68 (24.8, 94.7)	45.45 (18.6, 97.2)
March 16-31	459.2 (27.3, 1254.5)	187.2 (61.8, 433.7)	131.07 (96.6, 148.3)	250.33 (245.5, 260.0)	650.13 (161.5, 989.7)	23.67 (0.0, 71.0)	37.67 (25.8, 43.6)
Average	835.01	264.05	246.22	254.53	549.83	53.97	19.21

Table 3c
Summary statistics of the concentrations of metallic elements for $PM_{2.5–10}$ during daytime sampling period (ng m^{-3})

Month/day	Mean (Min, Max)						
	Fe	Mg	Cr	Cu	Zn	Mn	Pb
August 16–31	905.37 (759.5, 1117.6)	965.7 (260.4, 2191.8)	159.17 (119.4, 238.7)	188.07 (130.2, 303.8)	311.63 (79.4, 567.3)	65.10 (43.4, 108.5)	7.6 (0.0, 22.8)
September 1–15	1052.55 (889.8, 1215.3)	330.95 (282.1, 379.8)	135.65 (119.4, 151.9)	130.25 (119.4, 141.1)	269.4 (245.7, 293.1)	21.7 (21.7, 21.7)	0 (0.0, 0.0)
September 16–30	1041.55 (878.9, 1204.4)	271.3 (227.9, 314.7)	135.65 (119.4, 151.9)	135.65 (130.2, 141.1)	271.55 (264.7, 278.4)	27.15 (21.7, 32.6)	0 (0.0, 0.0)
October 16–31	788.47 (282.1, 1269.5)	282.13 (162.8, 368.9)	151.9 (151.9, 151.9)	126.6 (119.4, 130.2)	299.9 (211.3, 445.8)	18.1 (21.7, 10.9)	0 (0.0, 0.0)
November 1–15	797.58 (751.3, 870.0)	592.05 (261.5, 936.1)	119.68 (116.6, 122.3)	139.1 (112.3, 173.2)	212.18 (125.2, 289.4)	36.7 (21.7, 43.4)	5.45 (0.0, 11.3)
November 16–30	883.25 (873.0, 893.5)	227.55 (203.3, 251.8)	118.6 (118.6, 118.6)	123.35 (118.6, 128.1)	281.05 (273.8, 288.3)	21.7 (21.7, 21.7)	0 (0.0, 0.0)
December 1–15	590.23 (280.2, 808.3)	367.83 (312.6, 423.6)	135.83 (112.2, 149.4)	144.43 (128.1, 181.5)	262.1 (209.9, 337.2)	21.73 (10.9, 32.6)	4.85 (0.0, 7.8)
December 16–31	771.8 (692.3, 794.0)	459.9 (258.7, 726.1)	106.84 (72.5, 122.4)	139.64 (115.3, 184.3)	207.3 (122.4, 247.2)	22.46 (20.1, 26.3)	6.08 (3.4, 12.7)
January 1–15	792.65 (775.8, 802.2)	366.6 (316.0, 433.6)	128.23 (116.8, 149.4)	137.73 (125.9, 151.2)	305.55 (243.6, 442.8)	18.63 (10.9, 21.7)	4.45 (0.0, 10.1)
February 1–15	682.73 (139.0, 885.2)	364.1 (226.3, 503.2)	72.65 (45.3, 106.5)	134.78 (116.2, 172.3)	174.84 (90.7, 279.5)	13.75 (0.0, 21.7)	3.95 (0.0, 12.1)
March 16–31	302.87 (199.7, 366.1)	132.37 (75.0, 162.2)	61.43 (45.3, 69.5)	119.63 (115.1, 128.7)	198.93 (43.7, 482.0)	1.17 (0.0, 3.5)	8.07 (0.0, 12.1)
Average	782.65	396.41	120.51	138.11	254.04	24.38	3.68

Table 3d
Summary statistics of the concentrations of metallic elements for $PM_{2.5–10}$ during nighttime sampling period (ng m^{-3})

Month/day	Mean (Min, Max)						
	Fe	Mg	Cr	Cu	Zn	Mn	Pb
August 16–31	661.9 (553.4, 835.5)	220.63 (173.6, 282.1)	97.67 (86.8, 119.4)	126.6 (119.4, 130.2)	230.17 (183.3, 265.7)	14.5 (10.9, 21.7)	0.0 (0.0, 0.0)
September 1–15	1345.5 (1345.5, 1345.5)	336.4 (336.4, 336.4)	151.9 (151.9, 151.9)	151.9 (151.9, 151.9)	228.2 (228.2, 228.2)	21.7 (21.7, 21.7)	2.6 (2.6, 2.6)
September 16–30	678.2 (553.4, 803.0)	200.75 (130.2, 271.3)	135.65 (119.4, 151.9)	130.2 (130.2, 130.2)	264.15 (246.1, 282.2)	21.7 (21.7, 21.7)	1.3 (0.0, 2.6)
October 16–31	857.2 (293.0, 1356.3)	333.65 (76.0, 651.0)	151.9 (151.9, 151.9)	127.5 (119.4, 130.2)	296.28 (259.1, 322.2)	21.73 (0.0, 32.6)	11.63 (0.0, 46.5)
November 1–15	690.83 (578.7, 867.6)	246.35 (171.4, 332.0)	106.33 (86.8, 132.3)	132.93 (119.4, 151.9)	238.5 (190.3, 275.9)	16.63 (11.3, 22.5)	6.68 (2.3, 18.2)
November 16–30	704.2 (574.6, 833.8)	199 (130.2, 267.8)	134.7 (119.4, 150.0)	117.7 (105.2, 130.2)	212.55 (182.2, 242.9)	22.5 (22.5, 22.5)	3.5 (2.6, 4.4)
December 1–15	693.48 (304.2, 912.7)	293.98 (227.1, 347.2)	112.24 (90.1, 125.3)	122.12 (114.2, 131.4)	220.48 (180.9, 285.5)	13.18 (0.0, 22.5)	4.62 (1.2, 7.2)
December 16–31	730.83 (546.2, 824.7)	248.85 (173.6, 336.4)	110.3 (85.7, 122.3)	129.18 (115.2, 151.9)	254.9 (237.0, 278.6)	12.7 (10.9, 17.2)	3.3 (1.5, 5.3)
January 1–15	610.33 (282.0, 859.8)	200 (95.2, 347.2)	112.13 (104.8, 122.0)	126.75 (119.4, 135.2)	218.1 (170.2, 265.2)	9.5 (0.0, 14.5)	6.63 (0.0, 22.2)
February 1–15	714 (561.8, 991.0)	277.88 (164.6, 404.4)	86.23 (69.5, 102.5)	131.15 (128.7, 135.5)	167.75 (123.7, 178.0)	14.8 (7.5, 22.4)	4.48 (0.0, 12.1)
March 16–31	232.77 (62.4, 336.9)	114.2 (59.6, 152.5)	77.6 (69.5, 93.8)	116.23 (115.1, 118.5)	131.23 (95.3, 334.3)	0.0 (0.0, 0.0)	3.7 (3.7, 3.7)
Average	609.84	242.88	116.06	128.39	221.39	15.36	4.40

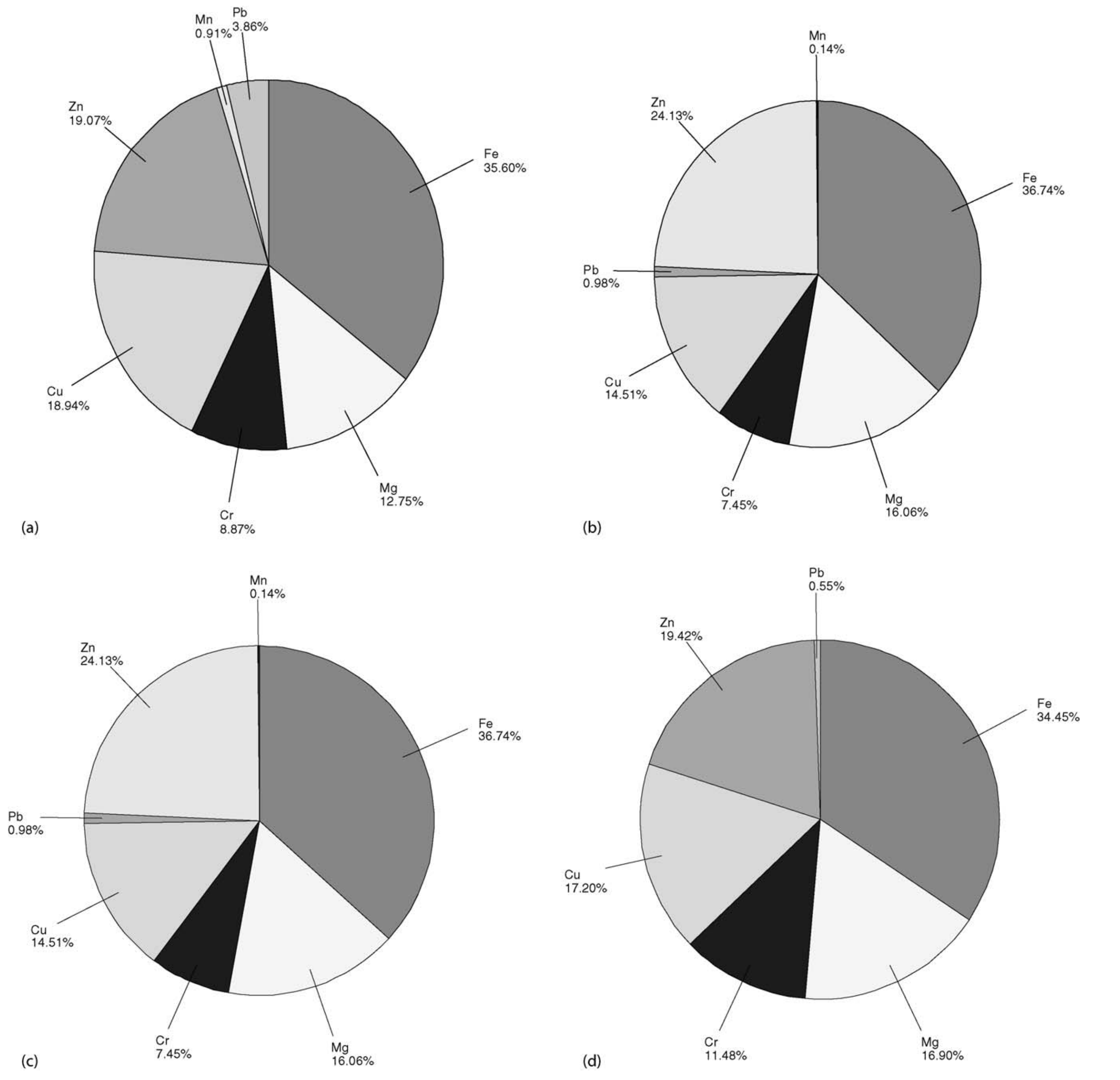

Fig. 5. (a) Average percentage of metallic elements concentrations in fine particle size during daytime sampling period. (b) Average percentage of metallic elements concentrations in fine particle size during nighttime sampling period. (c) Average percentage of metallic elements concentrations in coarse particle size during daytime sampling period. (d) Average percentage of metallic elements concentrations in coarse particle size during nighttime sampling period.

2.17%, respectively. As for coarse particle size mode, the results showed the average percentage of metallic elements Fe, Mg, Cr, Cu, Zn, Mn and Pb were 36.74%, 16.06%, 7.45%, 14.51%, 24.13%, 0.14% and 0.98%, respectively, during daytime sampling period. As for coarse particle size during nighttime sampling period, the results also displayed the average percentage of metallic elements Fe, Mg, Cr, Cu, Zn, Mn and Pb were 34.45%, 16.9%, 11.48%, 17.2%, 19.42%, 0% and 0.55%, respectively, during nighttime sampling period.

Metallic element Fe and Zn were the main components on the fine particulates, and the Fe and Mg were the main components on the coarse particulates during sampling period. According to previous studies [11,12], Fe is one of the indicatory metallic elements of crustal, re-suspended dust and metal industry. In this paper, the major source of Fe might come from the soil and re-suspended. In previous studies [12,13], Pb was an important index in traffic pollutant. However, Zheng et al. [5] indicated that Pb can not consider a traffic emission index after the phase-out of leaded gasoline by comparing with lead isotope ratios. Though, Zn has been suggested as a good maker for unleaded isotope fuel vehicular emissions [14]. Hence, gasoline engine vehicles were responsible for these results in fine particulates.

Funasaka et al. [15] indicated coarse particulates were the major local contaminants. Hence, the concentrations distribution tendency of the metallic elements for coarse particulates at this traffic sampling site was similar as the previous study. In general, the metallic elements concentrations were higher in daytime than nighttime sampling periods. Magnesium is the pollutants index of marine salt, construction materials and resuspended dust.

3. Statistical analysis

3.1. Spearman correlation analysis method

In this paper, Spearman correlation analysis is used to analyze the correlation between the concentrations and meteorological parameters. Suppose that data (X_1Y_1), (X_2Y_2), ..., (X_nY_n) are available. We can obtain Spearman correlation to replace the sample correlation coefficient $r_{x,y}$ and examine the independence of data X and Y. The observed data of $(X_1, X_2, \ldots, X_n)$, $(Y_1, Y_2, \ldots, Y_n)$ are arranged from large to small, then we can get the arranged values R_i and S_i, where $i = 1, 2, 3, \ldots, n$. We can define the Spearman correlation analysis is

$$r_{\text{sp}} \frac{12}{n(n^2-1)} \sum_{i=1}^{n} \left(R_i - \frac{n+1}{2}\right)\left(S_i - \frac{n+1}{2}\right) \quad (1)$$

the value of r_{sp} is $-1 \le r_{\text{sp}} \le 1$.

3.2. Non-linear regression analysis method

In this paper, the statistical analysis methods are used to find the relationship between the particulate concentrations ($PM_{2.5}$–PM_{10}) and the meteorology conditions (temperature, average wind speed and prevailing wind angles), which collected during the study period. The non-linear model analysis procedure is used to summarize data and the relationship between the variables can be studied in this paper. A general non-linear regression equation, which has three independent variables, expressed as

$$Y_i = \alpha + \beta_1 \cos(\beta_2 X_{1,i} + \beta_3) + \gamma_1 X_{2,i}^{\gamma_2} \cos(\gamma_3 X_{3,i} + \gamma_4) + E_i \quad (i = 1, \ldots, n) \quad (2)$$

where α, β, β_1, β_2, β_3, γ_1, γ_2, γ_3, γ_4 are the coefficients of regression. The error E_1, E_2, ..., E_n are taken independently normally distributed with mean value of zero and the variance σ. The parameters α, β_1, β_2, β_3, γ_1, γ_2, γ_3, are determined by using the least squares method, which minimizes the errors sum of squares (SSE).

$$\text{SSE} = \sum_{i=1}^{n} E_i^2 = \sum_{i=1}^{n} [Y_i - \alpha - \beta_1 \cos(\beta_2 X_{1,i} + \beta_3) - \gamma_1 X_{2,i}^{\gamma_2} \cos(\gamma_3 X_{3,i} + \gamma_4)]^2 \quad (3)$$

The meteorological factors are considered as independent variables, and particulate matters ($PM_{2.5}$–PM_{10}) are considered as dependent variables.

The coefficient of determination R^2 is commonly used to measure the goodness of fit of a regression model. The coefficient R^2 is defined as the proportion of the variation in the dependent variable. The coefficient can be expressed as

$$R^2 = 1 - \frac{\sum_{i=1}^{n} \tilde{Y}_i - \bar{Y}_i}{\sum_{i=1}^{n} Y_i - \bar{Y}_i} \quad (4)$$

where $\tilde{Y}$ is the value of Y predicted by regression line, Y_i the value of Y observed and $\bar{Y}$ is the mean value of the Y_i. If all the observation data fall on the regression data, then the value of R^2 is equal to one. Otherwise, if it has no any relationship between the dependent and independent variables, then R^2 is equal to zero.

4. Results and discussion

4.1. A non-parametric (Spearman) correlation analysis

In this section, a non-parametric (Spearman) correlation analysis is taken to investigate the traffic pollutants correlate with the meteorology data. The correlation analysis of the particulate matters (fine, coarse and PM_{10}) and the meteorological parameters (temperature, average wind velocity) are presented in the summary Table 4. According to the Spearman rank, the particulate concentrations (fine, coarse and PM_{10}) r_{sp} are inversely cor-

Table 4
Spearman rank correlation coefficients of particulate concentrations and meteorological factors

	Fine (daytime)	Coarse (daytime)	PM_{10} (daytime)	Fine (nighttime)	Coarse (nighttime)	PM_{10} (nighttime)	Temp (daytime)	Temp (nighttime)	Avwnid (daytime)	Avwind (nighttime)
Fine (daytime)	1.0									
Coarse (daytime)	0.49	1.0								
PM_{10} (daytime)	0.76[a]	0.88[a]	1.0							
Fine (nighttime)	0.51	−0.26	0.07	1.0						
Coarse (nighttime)	0.36	0.54	0.36	0.11	1.0					
PM_{10} (nighttime)	0.71[b]	0.19	0.34	0.76[a]	0.66[b]	1.0				
Temp (daytime)	−0.27	−0.63[b]	−0.66[b]	0.12	−0.03	0.01	1.0			
Temp (nighttime)	−0.44	−0.52	−0.6	−0.05	0.01	−0.16	0.92[a]	1.0		
Avwnid (daytime)	0.08	−0.13	−0.25	−0.06	0.25	0.11	0.42	0.20	1.0	
Avwind (nighttime)	0.25	0.29	0.40	−0.04	0.05	0.04	−0.76[a]	−0.68[b]	−0.40	1.0

[a] Correlation is significant at the 0.01 level (two-tailed).
[b] Correlation is significant at the 0.05 level (two-tailed).

Table 5a
Correlation coefficients of the concentrations of metallic for fine ($PM_{2.5}$) and coarse ($PM_{2.5–10}$) particulates during daytime sampling period at the CCRU sampling site

Metal	Fe	Mg	Cr	Cu	Zn	Mn	Pb
$PM_{2.5}$ (daytime)							
Fe	1.0						
Mg	0.80[a]	1.0					
Cr	0.46	0.12	1.0				
Cu	0.74[a]	0.79[a]	0.06	1.0			
Zn	0.71[b]	0.72[b]	0.47	0.66[b]	1.0		
Mn	−0.1	0.06	0.14	−0.44	−0.04	1.0	
Pb	−0.15	0.29	−0.77[a]	0.04	−0.10	0.14	1.0
$PM_{2.5–10}$ (daytime)							
Fe	1.0						
Mg	0.06	1.0					
Cr	0.46	0.34	1.0				
Cu	0.07	0.91[a]	0.44	1.0			
Zn	0.57	0.12	0.75[a]	0.18	1.0		
Mn	0.54	0.65[b]	0.47	0.75[a]	0.32	1.0	
Pb	−0.49	0.46	−0.25	0.41	−0.28	0.16	1.0

[a] Correlation is significant at the 0.01 level (two-tailed).
[b] Correlation is significant at the 0.05 level (two-tailed).

related with temperature at daytime with correlation coefficients $r_{sp} = -0.273$, -0.627 and -0.655, respectively. Moreover, the results show that PM_{10} has higher correlation coefficients with fine and coarse particulate concentrations at daytime and nighttime, respectively.

Tables 5a and 5b shows the correlation coefficients matrix of seven selected metallic elements during daytime and nighttime sampling periods at CCRU sampling site. On fine particulates, higher correlation coefficients were observed among on (Fe and Mg), (Fe and Cu), (Fe and Zn), (Mg and Cu), (Mg and Zn) and (Cr and Pb) during daytime period. On the coarse particulates, higher correlation coefficients were observed among on (Cu and Mg), (Cu and Mn) and (Cr and Zn) during nighttime period, respectively.

Table 5b
Correlation coefficients of the concentrations of metallic for fine ($PM_{2.5}$) and coarse ($PM_{2.5–10}$) particulates during nighttime sampling period at the CCRU sampling site

Metal	Fe	Mg	Cr	Cu	Zn	Mn	Pb
$PM_{2.5}$ (nighttime)							
Fe	1.0						
Mg	0.06	1.0					
Cr	0.46	0.34	1.0				
Cu	0.07	0.91[a]	0.44	1.0			
Zn	0.57	0.12	0.75	0.18	1.0		
Mn	0.54	0.65	0.47	0.75[a]	0.32	1.0	
Pb	−0.49	0.46	−0.25	0.41	−0.28	0.16	1.0
$PM_{2.5–10}$ (nighttime)							
Fe	1.0						
Mg	0.30	1.0					
Cr	0.11	0.44	1.0				
Cu	0.02	0.59	0.25	1.0			
Zn	0.40	0.46	0.45	0.44	1.0		
Mn	0.32	0.30	0.67[b]	0.32	0.32	1.0	
Pb	0.36	0.17	0.02	−0.09	0.06	−0.03	1.0

[a] Correlation is significant at the 0.01 level (two-tailed).
[b] Correlation is significant at the 0.05 level (two-tailed).

Table 6a
Multiple regression coefficients for different particulate size concentrations with temperature variations

Particulate size/regression coefficients	α	β_1	β_2	β_3	R^2
Fine (daytime)	41.67	−11.74	0.71	9.40	0.68
Coarse (daytime)	33.02	−9.21	0.63	12.68	0.34
PM_{10} (daytime)	73.60	37.89	0.16	34.56	0.78
Fine (nighttime)	35.85	11.77	1.88	31.45	0.51
Coarse (nighttime)	34.25	2.9	2.05	−21.03	0.03
PM_{10} (nighttime)	72.26	4.86	3.55	−63.31	0.03

4.2. Regression analysis

Regression analysis is also performed to further discuss the quantitative relationship between the particulate concentrations and the meteorological parameters. The period of a half-month variations for fine, coarse and PM_{10} particulate concentrations data measured at the CCRU sampling site during daytime and nighttime sampling periods are shown in Table 2. According to the above meteorological parameters, the characteristic function F of the particulate concentration could be expressed as

$$F = f(\text{temp, avewind, angwind}). \quad (5)$$

The correlation study of the average of a half-month of the particulate concentrations of all the periods with meteorological factors have been conducted to establish in this paper by using multiple regression method. The multiple regression equations obtain for the particulate concentrations (fine, coarse and PM_{10}) are expressed as

$$F = \alpha_1 + \beta_1 \cos[\beta_2(\text{temp}) + \beta_3] + \gamma_1(\text{avwind})^{\gamma_2} \cos\left[\frac{\gamma_3(\text{angwind})}{57.7} + \gamma_4\right] \quad (6)$$

where F is the particulate concentrations, temp the temperature in °C, avwind the average wind speed in (km/h) and angwind is the prevailing wind degree (°).

The regression parameters between the fine, coarse and PM_{10} particulates concentrations and meteorological parameters during a period of a half-month in the daytime and nighttime are shown in Tables 6a–6c. In Table 6a, meteorological parameter

Table 6b
Multiple regression coefficients for different particulate size concentrations with wind speed and prevailing wind degree variations

Particulate size/regression coefficients	α	γ_1	γ_2	γ_3	γ_4	R^2
Fine (daytime)	40.85	1219.95	−3.48	10.42	−2.66	0.76
Coarse (daytime)	31.81	29.81	−1.08	1.42	−0.33	0.24
PM_{10} (daytime)	73.48	−40.32	−17.05	−44.58	81.50	0.01
Fine (nighttime)	37.06	−19.50	−0.06	5.21	−14.04	0.72
Coarse (nighttime)	30.06	−11.75	−0.04	5.02	−14.79	0.61
PM_{10} (nighttime)	74.09	−13.99	−0.10	9.81	−29.97	0.22

Table 6c
Multiple regression coefficients for different particulate size concentrations with temperature, wind speed and prevailing wind degree variations

Particulate size/regression coefficients	α	β_1	β_2	β_3	γ_1	γ_2	γ_3	γ_4	R^2
Fine (daytime)	40.24	7.48	1.71	6.45	257.2	−2.44	9.97	5.40	0.93
Coarse (daytime)	32.67	50.59	0.49	20.60	61.51	−0.79	2.92	−6.22	0.95
PM_{10} (daytime)	79.82	17.09	−1.40	47.92	−6.46	1.00	−3.64	6.25	0.75
Fine (nighttime)	25.05	−10.91	0.75	−10.67	−6.48	1.00	2.94	−3.37	0.88
Coarse (nighttime)	40.18	14.10	1.31	0.87	−17.81	−1.16	3.32	−0.972	0.81
PM_{10} (nighttime)	75.28	18.62	0.75	−1.40	39.00	−1.22	1.29	−1.53	0.85

temperature was considered as the predominant constituent on the particulates concentration. The results showed that the values of the correlation coefficients (R^2) between the fine, coarse and PM_{10} particulates concentrations and temperature were ranged from 0.03 to 0.78. The higher correlation coefficients (R^2) only occurred in fine and PM_{10} particulates during daytime sampling periods. From Table 6c, the parameter of α was closed to the average particulates concentrations during sampling periods but the regression equation were not agree to describe the variances in particulate concentrations. In Table 6b, the meteorological parameters wind speed and prevailing wind degrees were considered in the regression equation. The results also showed that the values of the correlation coefficients (R^2) between the fine, coarse and PM_{10} particulates concentrations and wind speed and prevailing wind degree were ranged from 0.01 to 0.76. By using the type of Eq. (6) to predict the different particulates size concentration, the regression equation in fine particulate has better results than those of coarse and PM_{10} particulates to describe the particulate concentrations during the sampling periods. Comparison of Tables 6a and 6b, we can find that the average concentration value in different particulate size were close.

From Table 6c, we can see that the values of the correlation coefficients (R^2) between the fine, coarse and PM_{10} particulates concentrations and meteorological parameters are 0.75–0.95. Eq. (6) presents the prediction equation of the fine, coarse and PM_{10} particulates concentrations. The regression coefficient α_1 means the mean value of the particulates concentrations. The coefficients β_1 and $\gamma_1(\text{avwind})^{\gamma_2}$ mean the secondary variation amplitude with the triangle function of cosine in Eq. (6). By taking out the mean values, the above equation reveals that the fine, coarse and PM_{10} concentrations vary with different temperature, average wind velocity and prevailing wind angle. During daytime, the mean values of the particulate concentrations are PM_{10} > fine > coarse, and the mean values of the particulate concentrations are PM_{10} > coarse > fine during nighttime. At nighttime, the mean values of the fine and coarse particulate concentrations are 25.05 and 40.18 μg/m³, respectively. The results indicate that the values have some different with the daily average values, and the particulate concentrations are effected by meteorological parameters obviously.

According to above analytic results, the characteristics of the particulate concentrations, including meteorological factors, are governed by the temperature, average wind velocity and prevailing wind angle. The results of the sampling data and the regression equation are shown in Figs. 6–11. Figs. 6–8 are shown

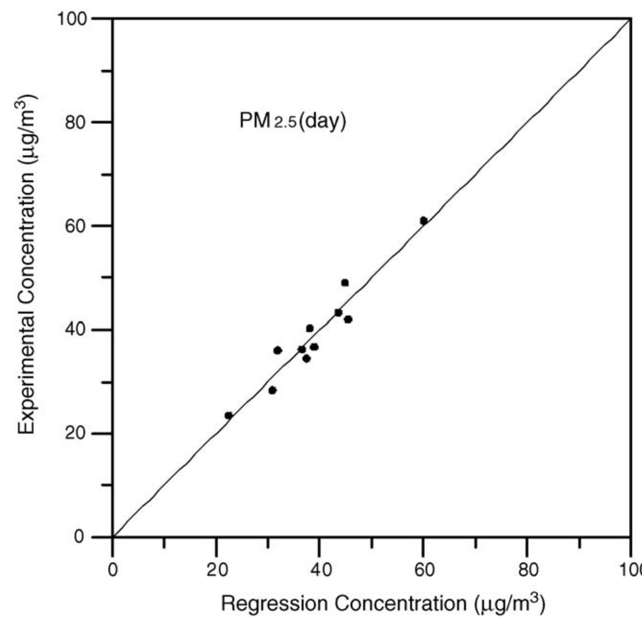

Fig. 6. Comparison of the $PM_{2.5}$ particulate concentrations predicted by the regression equation with that observed during daytime periods at the CCRU sampling site.

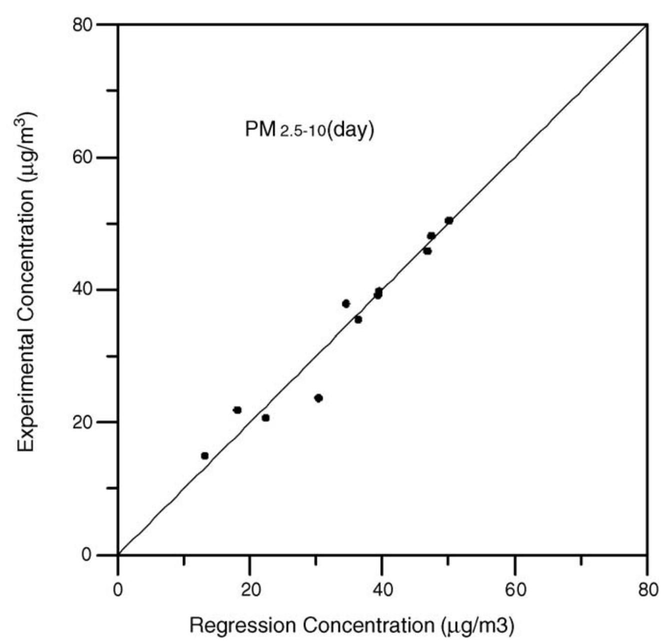

Fig. 7. Comparison of the $PM_{2.5-10}$ particulate concentrations predicted by the regression equation with that observed during daytime periods at the CCRU sampling site.

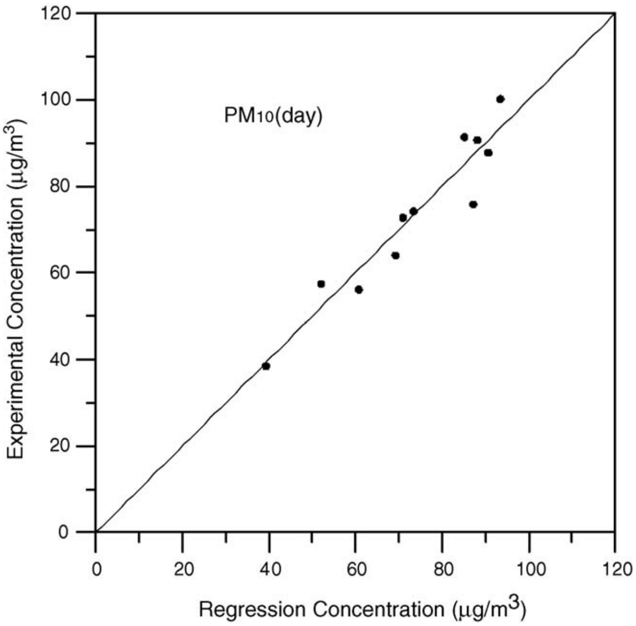

Fig. 8. Comparison of the PM_{10} particulate concentrations predicted by the regression equation with that observed during daytime periods at the CCRU sampling site.

the relationships between the regression data and sampling data at daytime. From the figures, we can see that the fitting curves are closed to the sampling data, and the coefficients of determination are $r^2 = 0.75–0.95$.

Figs. 9–11 are shown the relationships between the regression data and sampling data at nighttime period. From the figures, the equation accounts for 81–88% of the sampling data ($r^2 = 0.81–0.88$). The regression equation for PM_{10}, coarse and fine particulate expressed well results in describing the particulate concentrations during sampling periods.

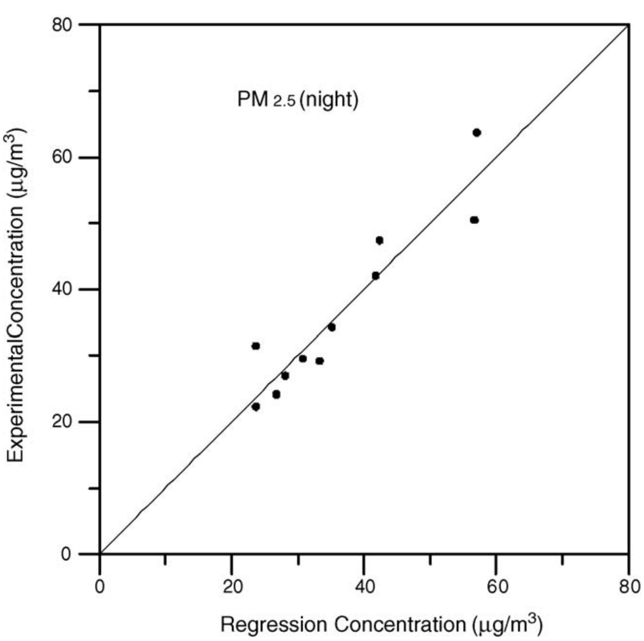

Fig. 9. Comparison of the $PM_{2.5}$ particulate concentrations predicted by the regression equation with that observed during nighttime periods at the CCRU sampling site.

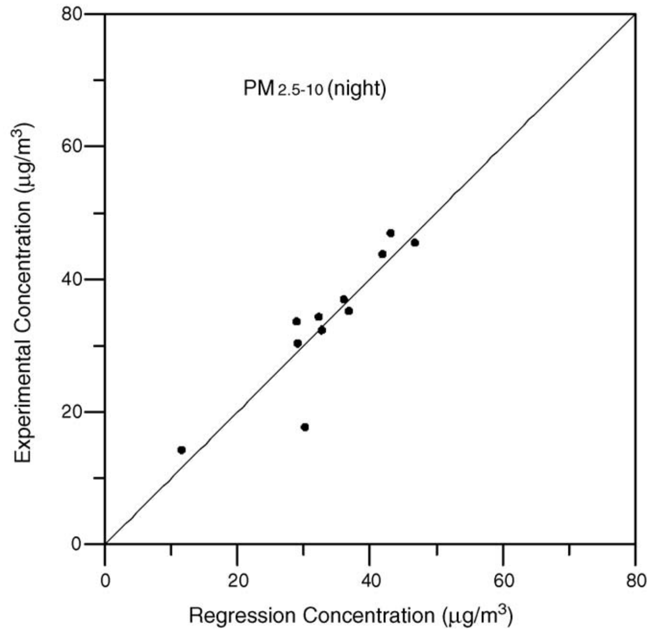

Fig. 10. Comparison of the $PM_{2.5–10}$ particulate concentrations predicted by the regression equation with that observed during nighttime periods at the CCRU sampling site.

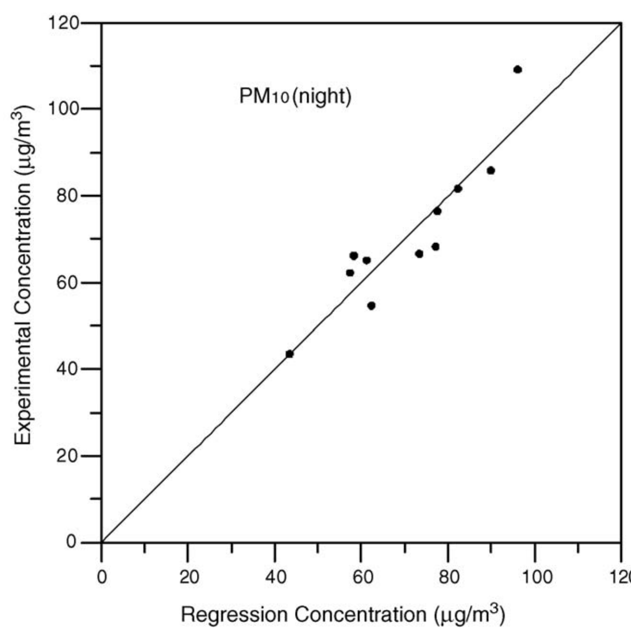

Fig. 11. Comparison of the PM_{10} particulate concentrations predicted by the regression equation with that observed during nighttime periods at the CCRU sampling site.

5. Conclusion

The major conclusions for this research are as followings:

(1) During a half-month analysis periods, the average source terms can be obtained in this paper. By using the statistics

analysis method, the suspended particles tendency by the meteorological parameters can also be described.

(2) The major meteorological parameters during daytime and nighttime sampling periods are temperature, average wind velocity and prevailing wind degree. These parameters are used to establish the regression equations for metallic elements concentrations in fine and coarse particulates at a traffic sampling site in central Taiwan. Temperature was found to have significant relative coefficients to predict the metallic elements concentrations in fine and PM_{10} particulates at daytime, and the average wind velocity and prevailing wind degree were found to have significant relative coefficients to predict the metallic elements concentrations in fine particulate at nighttime.

(3) The proposed model indicated that the average concentrations of fine particulates during daytime and nighttime sampling periods at traffic sampling site were 39.17 and 37.15 $\mu g/m^3$, respectively. By the same token, the average concentrations of coarse particles during daytime and nighttime sampling periods at traffic sampling site were 34.35 and 33.72 $\mu g/m^3$, respectively. The average concentrations of PM_{10} particles during daytime and nighttime sampling periods at traffic sampling site were 73.52 and 70.87 $\mu g/m^3$, respectively. In general, the concentrations of the proposed model are closed to the collected concentrations during daytime and nighttime and the tendency of the suspended particle concentrations presents the variation of the triangle function of cosine during daytime and nighttime.

(4) In this study, the metallic element Fe and Zn were the main components on the fine and the coarse particulates during daytime and nighttime sampling period. In general, the metallic elements concentrations were higher in daytime than nighttime sampling periods.

(5) According to the proposed method, the particle concentrations can be predicted with known meteorological parameters during daytime and nighttime at the CCRU sampling site of central Taiwan.

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References

[1] J.H. Lee, Y.P. Kim, K.C. Moon, H.K. Kim, C.B. Lee, Fine particle measurements at two background sites in Korea between 1996 and 1997, Atmos. Environ. 35 (4) (2001) 635–643.
[2] H.C. Lu, The statistical characters of PM_{10} concentration in Taiwan area, Atmos. Environ. 36 (3) (2002) 491–502.
[3] M.J. Kleeman, G.R. Gass, A 3D Eulerian source-oriented model for an externally mixed aerosol, Environ. Sci. Technol. 35 (2001) 4834–4848.
[4] J.J. Schauer, M.P. Fraser, G.R. Gass, B.R.T. Simoneit, Source reconciliation of atmospheric gas-phase and particle-phase pollutant during a severe photochemical smog episode, Environ. Sci. Technol. 36 (2002) 3806–3814.
[5] M. Zheng, R.G. Gass, J.J. Schauer, E.S. Edgerton, Source apportionment of $PM_{2.5}$ in the southeastern United States using solvent-extractable organic compounds as tracers, Environ. Sci. Technol. 36 (2002) 2361–2371.
[6] C.G. Nolte, J.J. Schauer, G.R. Gass, B.R.T. Simoneit, Trimethysilyl derivatives of organic compounds in source samples and in atmospheric fine particulate matter, Environ. Sci. Technol. 36 (2002) 4273–4281.
[7] J. Sternbeck, Sjödin, K. Andréasson, Metal emissions from road traffic and the influence of resuspension-results from two tunnel studies, Atmos. Environ. 36 (2002) 4735–4744.
[8] A. Cincinelli, D. Mandorol, R.M. Dickhut, L. Lepri, Particulate organic compounds in the atmosphere surrounding an industrialised area of Prato (Italy), Atmos. Environ. 37 (2003) 3125–3133.
[9] G.G. Fang, Y.S. Wu, J.C. Chen, P.C. Fu, Metallic elements study on fine and coarse particulates during daytime and nighttime sampling periods at a traffic sampling site, Sci. Total Environ. (2004).
[10] B.K. Lee, N.Y. Jun, H.K. Lee, Comparison of particulate matter characteristics before, during, and after Asian dust events in Incheon and Ulsan, Korea, Atmos. Environ. 38 (2004) 1535–1545.
[11] A.G. Allen, E. Nemitz, J.P. Shi, R.M. Harrison, J.C. Greenwood, Size distributions of trace metals in atmospheric aerosols in the United Kingdom, Atmos. Environ. 35 (2001) 4581–4591.
[12] A.V. Kumar, R.S. Patil, K.S.V. Nambi, Source apportionment of suspended particulate matter at two traffic junctions in Mumbai, India, Atmos. Environ. 35 (25) (2001) 4245–4251.
[13] J. Shu, J.A. Dearing, A.P. Morse, L. Yu, N. Yuan, Determining the sources of atmospheric particles in Shanghai, China, from magnetic and geochemical properties, Atmos. Environ. 35 (2001) 2615–2625.
[14] P. Salvador, B. Artíñano, D.G. Alonso, X. Querol, A. Alastuey, Identification and characterisation of sources of PM10 in Madrid (Spain) by statistical methods, Atmos. Environ. 38 (2004) 435–447.
[15] K. Funasaka, M. Sakai, M. Shinya, T. miyazaki, T. Kamiura, S. Kaneco, K. Ohta, T. Fujita, Size distribution and characteristics of atmospheric inorganic particles by regional comparative study in Urban Osaka, Japan, Atmos. Environ. 37 (2003) 4597–4605.