Distributions of Fine Particulate Matter (PM2.5) in the Ambient Air of Chiang Mai-Lamphun Basin

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ABSTRACT

Twenty-four hour measurements of PM2.5 particulate matter have been carried out during the two-year period between the 1 June 2004 and the 31 May 2006 in Chiang Mai-Lamphun Basin area. PM2.5 samples were collected on 47 mm filters, with the use of low volume gravimetric samplers while a meteorological station recorded meteorological data 6 m above the ground, nearby the sampling instrumentation. The mass concentration of PM2.5 annual average was 35.6 μg/m^3 during June 2004 to May 2005 and 35.7 g/m^3 during June 2005 to May 2006 higher than U.S. Environmental Pollution Agency daily limit. The mean of PM2.5 mass concentrations in rainy, winter and summer seasons between June 2004 and May 2005 were 17.8, 52.3, and 36.4 g/m^3, respectively. Regression analysis was used to investigate the relationship among PM2.5 concentrations, PM10 and inorganic gaseous pollutants, and meteorological parameters. Additionally, PM2.5 mass concentrations were correlated with PM10 and other inorganic gaseous pollutants (O_3, NO_2, SO_2) while weekly and seasonal PM2.5 variations were also investigated. The highest PM2.5 mass concentrations occur with moderate southerly winds, moderate temperature and low humidity during winter.

Keywords: PM2.5 particulate matter Air quality Meteorology Chiang Mai-Lamphun Basin

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การกระจายของอนุภาคฝุ่นขนาดเล็ก (พีเอ็ม2.5) ในอากาศของแอ่งเชียงใหม่-ลำพูน

ณรงค์พันธ์ ฉุนรัมย์*, อุษณีย์ วินิจเขตคำนวณ**
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บทคัดย่อ

การตรวจวัดหาระดับรายวันของอนุภาคฝุ่นขนาดเล็ก 2.5 ไมโครเมตร (พีเอ็ม2.5) โดยน้ำหนักในอากาศแอ่งเชียงใหม่-ลำพูน ได้ดำเนินการระหว่างเดือนมิถุนายน 2547 ถึง เดือนพฤษภาคม 2549 อนุภาคฝุ่นขนาดเล็กถูกเก็บด้วยกระดาษกรองที่มีเส้นผ่านศูนย์กลางขนาด 47 มิลลิเมตร โดยใช้เครื่องเก็บอากาศขนาดเล็ก ส่วนข้อมูลทางอุตุนิยมวิทยาที่ระดับความสูงจากพื้น 6 เมตร ได้ข้อมูลจากสถานีอุตุนิยมวิทยาภาคเหนือที่อยู่ใกล้กับจุดเก็บตัวอย่าง ระดับรายปีเฉลี่ยของอนุภาคฝุ่นขนาดเล็ก (พีเอ็ม2.5) โดยน้ำหนัก ระหว่างมิถุนายน 2547 ถึง พฤษภาคม 2548 มีค่าเฉลี่ยรายปีเท่ากับ 35.6 ไมโครกรัมต่อลูกบาศก์เมตร และ ระหว่างมิถุนายน 2548 ถึง พฤษภาคม 2549 มีค่าเฉลี่ยรายปีเท่ากับ 35.7 ไมโครกรัมต่อลูกบาศก์เมตร ซึ่งมากกว่าเกณฑ์มาตรฐานที่กำหนดไว้โดยองค์การพิทักษ์สิ่งแวดล้อมของสหรัฐอเมริกา และค่าเฉลี่ยที่วัดได้ ในฤดูฝน ฤดูหนาว และฤดูร้อนระหว่างมิถุนายน 2547 ถึง พฤษภาคม 2548 เท่ากับ 17.8, 52.3 และ 36.4 ไมโครกรัมต่อลูกบาศก์เมตร ตามลำดับ จากการวิเคราะห์หาความสัมพันธ์ระหว่างระดับรายวันของอนุภาคฝุ่นขนาดเล็ก (พีเอ็ม2.5) โดยน้ำหนักกับสารมลพิษในอากาศบางชนิด และตัวแปรทางอุตุนิยมวิทยา โดยการวิเคราะห์การถดถอย พบว่า ความเข้มข้นของอนุภาคฝุ่นขนาดเล็ก (พีเอ็ม2.5) โดยน้ำหนัก แปรตามความเข้มข้นของอนุภาคฝุ่นขนาดเล็ก (พีเอ็ม10) และสารมลพิษในอากาศบางชนิด (โอโซน ไนโตรเจนไดออกไซด์ ซัลเฟอร์ไดออกไซด์) นอกจากนี้ได้เปรียบเทียบระดับรายวันของอนุภาคฝุ่นขนาดเล็ก (พีเอ็ม2.5) โดยน้ำหนัก ระหว่างวันทำงานกับวันหยุดของสัปดาห์ และระหว่างฤดูกาล และยังพบว่าการเปลี่ยนแปลงของอนุภาคฝุ่นขนาดเล็ก (พีเอ็ม2.5) โดยน้ำหนัก มีค่าสูงสุดเมื่อทิศทางลมพัดมาจากทิศใต้โดยมีความเร็วลมในระดับปานกลาง อุณหภูมิปานกลาง และความชื้นสัมพัทธ์ต่ำ

คำสำคัญ : อนุภาคฝุ่นขนาดเล็ก คุณภาพอากาศ อุตุนิยมวิทยา แอ่งเชียงใหม่-ลำพูน

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Introduction

The Chiang Mai-Lamphun Basin which includes the cities of Chiang Mai and Lamphun in Northern Thailand (Figure1). faces significant air pollution problems, especially during the non-rainy season. Its atmospheric environment is polluted by continuing industrial development, transportation vehicles that are not subject to inspection, an increasing population and rapidly expanding urbanization and suburbanization. The situation is exacerbated by local topography, a mountain-rimmed basin with poor ventilation, and high solar irradiation levels that greatly favors the production of many photochemical pollutants. To better understand the daily and seasonal variation in PM2.5 levels it is important to conduct repeated 12-month assessments of levels of particulate matter less than 2.5 μm in diameter (PM2.5), long associated with adverse health effects, and examine correlations with meteorological conditions in the basin. Since meteorological conditions can influence the formation and transport of particles, the efficacy of regulatory actions taken to improve air quality cannot be adequately established without reference to the state of the atmosphere in particular regions. Meteorological conditions are well known to confound analysis examining the impacts of high particulate concentrations(1). During the experimental period of the present study, major construction projects (buildings, roads, highways, etc.) were in progress, so dust levels may have contributed considerably to the particulate levels. However, since continued growth and expansion is planned or anticipated in the coming years, it is important to establish the relationships between environmental measurements and meteorological conditions.

Figure 1 The Chiang Mai-Lamphun Intermountain Basin.

Studies around the world have consistently shown that high levels of atmospheric aerosol particles have significant health effects, especially respiratory problems (including allergies, painful breathing, chronic bronchitis and asthma) in children and the elderly who live in large metropolitan areas(2,3). High PM2.5 levels have been shown to absorb and scatter solar radiation the atmospheric particles effectively reduce visibility (4-6) which may affect transportation safety and aesthetics. Elevated atmospheric concentrations of fine particulates can be associated with both local sources of emission and regional transport(7). Other anthropogenic sources, like smelting, as well as natural phenomena such as wildfires also emit particulate matter in this size range(8).

Spatial and temporal variations in PM2.5 concentration can be influenced by a variety of anthropogenic and meteorological factors(1). Hien et al(9). found that the most important determinants of PM2.5 were wind speed and air temperature, while rainfall and relative humidity largely controlled the daily variations of PM2.5-10 for both the winter and summer monsoon periods. The highest concentration events were observed in conjunction with atmospheric temperature inversions. Bogo et al.(10) have shown the influence of both traffic volume and wind speed on the PM2.5 climatology of Buenos Aires. PM2.5 data for Bangkok show that 24 h PM2.5 in busy parts of the city may be as high as 100 g/m^3(11). Vinitketkumnuen et al(12). illustrated the maximum concentrations of PM2.5 (24 h average) in Chiang Mai air from December 1998 to April 1999 were higher than the US Environmental Protection Agency (USEPA), PM2.5, 24 h standard of 65 g/m^3.

In this study, we present and evaluate the results of PM2.5 particulate matter measurements in Chiang Mai City over two 12-month period. The relationships among PM2.5 and meteorological conditions, as well as PM10 and inorganic pollutant levels were also examined and correlations established. It was found that the highest PM2.5 mass concentrations occurred with moderate southerly/southwesterly winds, moderate temperatures and low humidity during winter.

Methods

The sampling sites

From June 2004 to May 2005, PM2.5 data were taken at 2 different sampling sites: a residential apartment at Chiang Mai Rajabhat University (site RB) just north of the central district and the Bioassay Research Laboratory, Faculty of Medicine, Chiang Mai University (site WB). These two sites are impacted by heavy traffic on nearby roads. From June 2005 to May 2006, PM2.5 data were taken at 5 different sampling sites: Site 1 was a rural area which is limited direct automotive traffic exposure (Mae Rim district, Chiang Mai Province); Site 2 was a typical commercial area impacted by busy streets with heavy year-round traffic (Waroros Market, Chiang Mai Province); Site 3 was located in an area known to have a high incidence of lung cancer and one which was heavily impacted by the local traffic (Sarapee district, Chiang Mai Province); Site 4 was located about 4 km east of the Lamphun industrialized area (Ban Klang, Lamphun Province); and Site 5 was in an urban area with local traffic emission (Kai Kaew community, Lamphun Province).

Instrumentation and sampling

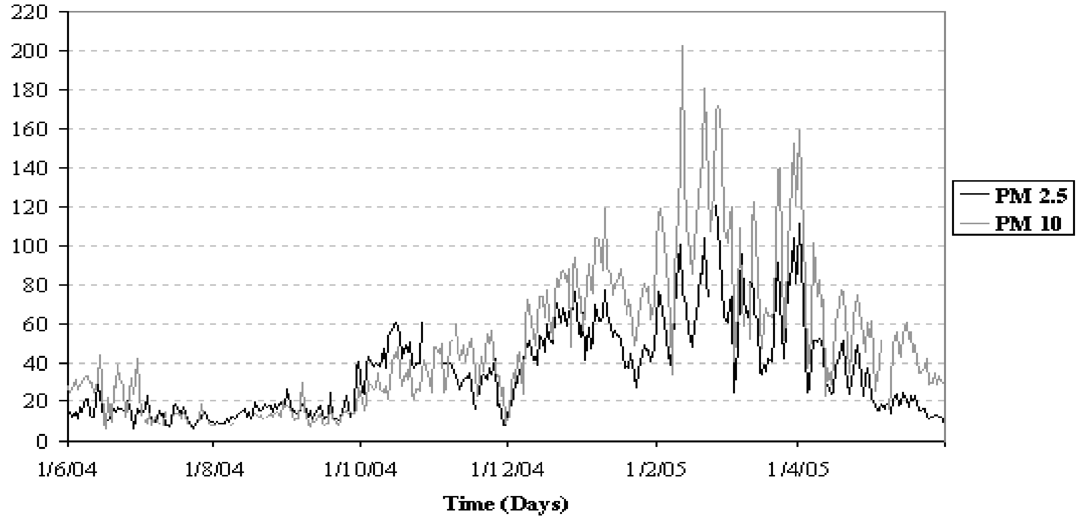
Twenty-four-hour particle samples were collected using mini-volume portable air samplers (AIRmetrics MiniVol®portable air samplers, Springfield, OR 97477, USA, www.airmetrics.com) with cut points of 2.5 m, as described in previous research(12). Samplers were operated at a flow rate of 5 liters min-1, and the flow rates were checked before and at the end of the study to ensure a constant flow rate throughout the sampling period. Samples were collected on 47 mm fiber-film filters (type T60A20, Pallflex Products Corporation, Putnam, CT, USA). A micrometric balance (Sartorius Ag, Germany), with accuracy of 0.001 mg, was used to weigh the filters. The filters were conditioned in an electronic dessicator, with a temperature of 25°C and relative humidity of 50%, before and after sample collection. The balance was placed on an anti-vibration table, on top of a concrete bench.

μ

Air quality and meteorological data were collected during June 2004 till May 2005. PM10, Ozone (O_3), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) were continuously measured by the Pollution Control Department (PCD), Ministry Resources and Environment located near Chiang Mai City Hall and Yuparaj Wittayalai School. These co-pollutant monitoring data were available for our analysis. Finally, meteorological parameters (wind speed and direction, temperature and relative humidity) were recorded by a meteorological mast 6 m above the ground, near the monitoring station.

Results

The concentrations measured by the two samplers during June 2004 till May 2005 were very well correlated (R =0.92). The daily values of PM2.5 concentrations arise from the average of the two similar samplers' values. The daily variation of PM2.5 concentrations (g/m^3) during the experimental period is shown in Figure 2a. Figure.2 shows the daily variations of PM2.5 with PM10, SO_2, NO_2 and O_3 concentrations during the sampling period. PM2.5 mass concentration ranged from 6 to 121 g/m^3 and annual averages was 35.6 g/m^3, which exceeded the annual standard of 15 g/m^3 (established in 1997). The daily levels for PM2.5 mass concentration of five sites between June 2005 and May 2006 ranged from 3 to 258 g/m^3, respectively (Table 1). The mass concentrations of PM2.5, as annual averages of five sites, was 35.7 g/m^2, which exceeded the annual standard. Figure.3 shows the daily variations of PM2.5 with temperature, relative humidity and wind speed during the sampling period. It can be seen from these figures that the highest PM2.5 mass concentrations occurred with moderate temperatures and low humidity during winter.



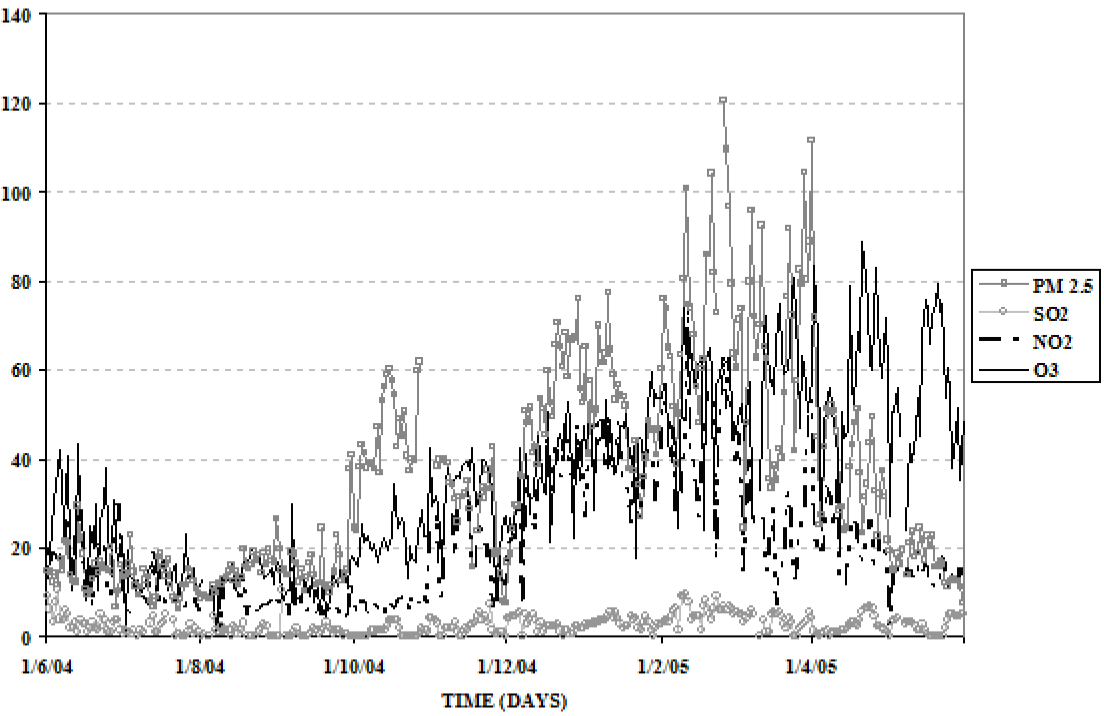


Figure 2 (a) Daily variation of PM2.5 and PM10 concentrations during the sampling period,

(b) Daily variation of PM 2.5, SO_2, NO_2 and O_3 concentrations during the sampling period.

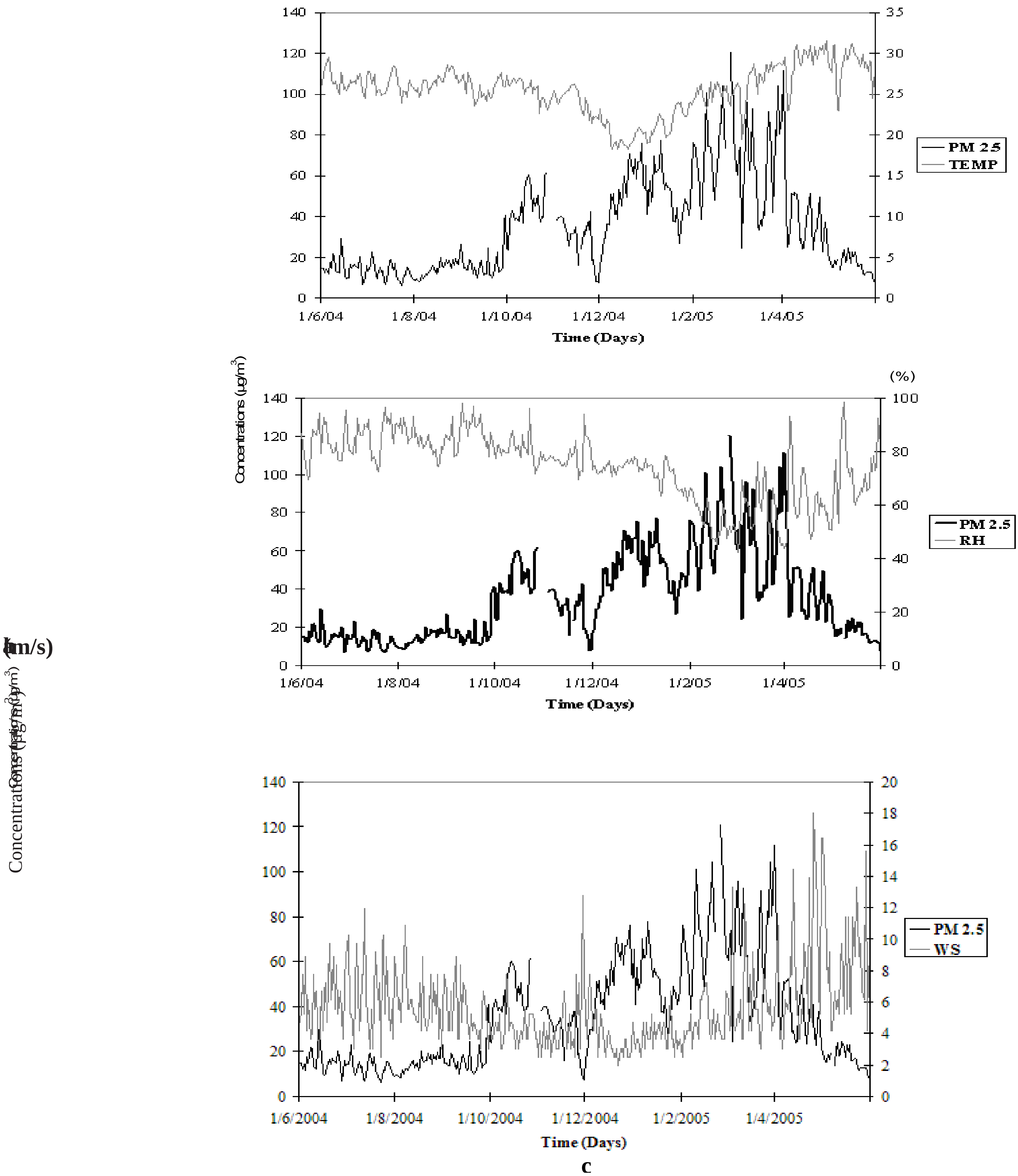


Figure 3 (a) Daily variation of PM2.5 and temperature during the sampling period.
(b) Daily variation of PM2.5 and relative humidity during the sampling period.
(c) Daily variation of PM2.5 and wind speed during the sampling period.

Table 1 Annual average of PM2.5 mass concentrations in Chiang Mai-Lamphun Basin from June 2004 to May 2006

	PM2.5 mass concentration (μg/m^3)						
	Site RB*	Site WB*	Site1**	Site 2**	Site 3**	Site 4**	Site 5**
N	349	258	287	350	336	327	346
Average	35.3	40.6	29.9	44.5	41.5	28.1	34.6
Max	127.2	115.1	211.2	230.6	257.5	134.6	173.7
Min	6.4	5.8	4.5	2.6	6.0	2.9	4.4
S.D.	23.7	23.7	30.3	27.3	30.5	21.4	24.9

* Sampling period; June 2004 – May 2005
** Sampling period; June 2005 – May 2006

Disscussion

PM2.5 concentration trends

The 1997 annual standard of USEPA was established as a level of 15 micrograms per cubic meter, based on the 3-year average of annual mean PM2.5 concentrations(13). The 1997 24-hour standard was established as a level of 65 micrograms per cubic meter, determined by the 3-year average of the annual 98th percentile concentrations. The PM2.5 USEPA level of 65 g/m^3 for the two sites was exceeded on 10(2.9%) and 14(4.1%) days during June 2004 to May 2005. Also, PM2.5 mass concentrations of five sites exceed 65 g/m^3 on 31(11%), 52(15%), 50(15%), 24(7%), and 40(12%) of the days during June 2005 to May 2006. Recently, the USEPA Office of Air Quality Planning and Standards (OAQPS) has set new National Ambient Air Quality Standards which states that the annual mean PM2.5 concentrations must not exceed 15.0 g/m^3 and average of 24-hour concentrations must not exceed 35 g/m^3 (effective December 17, 2006). The PM2.5 USEPA level of 35 g/m^3 was exceeded at the two sites on 113(32.8%) and 99(29.2%) days. Also, PM2.5 mass concentrations of the five sites exceeded 35 g/m^3 on 74(26%), 174(50%), 156(46%), 101(31%) and 137(40%) of the days during June 2005 to May 2006. The lowest monthly averaged concentrations were recorded in July-September, during which prolonged rains occurred. PM2.5 may have health implications associated with these high concentrations. It has been demonstrated that for each 10 g/m^3 increment in PM2.5 was associated with increased mortality of 4%, 3% and 2% from pneumonia, chronic obstructive pulmonary disease and ischemic heart disease respectively(14).

Seasonal variations

The mean concentrations of PM2.5 were lower in the rainy season compared to the summer period (Table 2). Additionally, the winter average concentration was slightly increased compared to the summer level. This could be attributed to high biogenic emissions observed during this season of the year.(12) Winter traditionally has the worst air pollution in the Chiang Mai-Lamphun Basin. The season is characterized by cold weather and thermal inversion conditions which frequently form in the valley. These inversions are characterized by cold weather, fog, and a lack of wind and dispersion, which allows pollutant concentrations to build up(9). A slight increase during the winter and summer period could be attributed to high biogenic emissions observed during this time of year. Rainy period presented the lowest PM2.5 average concentration.

Table 2 Statistical parameters of various air pollutants concentration and meteorological data during the sampling period

μ

	PM2.5	PM10	SO_2	NO_2	O_3	T *	RH **	WS ***
	(g/m^3)	(g/m^3)	(g/m^3)	(g/m^3)	(g/m^3)	(°C)	(%)	(m/s^1)
Rainy season (1/06/04 - 15/10/04)								
N	137	117	127	128	133	137	137	137
Average	17.8	18.2	1.9	10.7	16.7	26.3	84.8	5.8
Max	60.2	43.9	10.5	30.1	43.4	35.4	99.0	11.9
Min	6.4	5.5	0.0	1.7	4.9	21.2	48.0	2.5
S.D.	10.6	9.7	2.0	6.2	7.4	1.1	5.9	1.9
Winter season (16/10/04 - 15/03/05)								
N	142	149	148	147	149	151	151	151
Average	52.3	72.3	3.3	31.2	40.4	23.2	69.6	4.3
Max	120.5	202.9	9.8	74.0	74.1	37.7	99.0	13.3
Min	7.5	8.5	0.0	5.6	8.5	11.3	18.0	1.9
S.D.	20.6	37.4	2.2	14.2	13.7	2.5	10.7	1.7
Summer season (16/03/05 - 31/05/05)								
N	76	75	75	76	76	77	77	77
Average	36.4	60.9	2.8	19.7	57.6	28.7	64.6	7.6
Max	111.6	158.7	6.9	53.4	88.9	42.4	99.0	18.1
Min	7.7	16.2	0.0	2.4	18.7	19.3	17.0	3.1
S.D.	23.6	31.5	1.9	8.9	15.1	1.9	12.4	3.5

* Temperature ** Relative humidity *** Wind speed

Weekly variations

Regardless of time or season, PM2.5 concentrations are expected to be lower on Saturdays and Sundays and uniformly high during the other days of the week as shown in Table 3. A slight decrease of 1% in PM 2.5 levels was observed during weekends compared to the ones detected during weekdays. Continuing road construction work during the weekends on the local superhighway which wraps around the city probably contributed to the maintenance of relatively similar PM2.5 concentrations compared to the weekdays. The blend of anthropogentic and meteorological influences result in some peaking of values so more rigorous chemical analysis is required to ascribe sources to these concentration peaks.

Table 3 Statistical analysis of PM2.5 concentrations during working days and weekends.

PM2.5	**All the days** (g/m^{-3})	**Working days** (g/m^{-3})	**Weekend** (g/m^{-3})	**Working days/** Weekend ratio
N	355	254	101	2.51
Average	35.58	35.61	35.49	1.0
Max	120.54	120.54	109.64	1.1
Mn	6.39	6.39	8.50	0.75
S.D.	23.8	24.0	23.2	

Meteorological parameters

The variations of PM2.5 mass concentrations in combination with temperature, relative humidity and wind speed variations are shown in Figure 3a, b and c. Temperature (T), relative humidity (RH) and wind speed (WS) were negatively correlated with PM2.5 mass concentrations in all wind sectors (Table 4). Wind direction in combination with wind speed is an important factor for pollutants' transportation, dispersion and accumulation. Prevailing winds from the SW were present most often (Figure 4) and high PM2.5 values (>100 g/m^3) were recorded during days with southwestern and southern prevailing winds. This could be attributed to the primary emissions from the southern industrial sites southern industrial sites and airport where hecommercial air flights coming into and leaving Chiang Mai during the winter and summer seasons. There is direct visual evidence of large smoke plumes and a persistent haze that hangs over the fields and forests in the winter. Finally, elevated PM2.5 values were recorded during days with northern and northeastern prevailing winds, blowing from the construction sites for the new highway tunnel constructions and associated intersections. Negative correlations between PM2.5 concentrations and temperature or relative humidity were observed, as expected. A negative correlation with wind speed suggests the importance of mass transport in bringing pollutants to the monitoring sites.

Table 4 Correlation co-efficient of PM2.5 mass concentrations with various air pollutants concentrations and meteorological parameters.

R	PM10	SO_2	NO_2	O_3	T *	RH **	WS ***
PM2.5 N sector (337.5°- 22.5°)	+0.93	+0.32	+0.62	+0.62	-0.13	-0.76	-0.48
PM2.5 NE sector (22.5°- 67.5°)	+0.85	+0.35	+0.69	+0.41	-0.31	-0.56	-0.29
PM2.5 E sector (67.5°- 112.5°)	+0.92	+0.09	+0.83	+0.68	-0.44	-0.57	-0.57
PM2.5 SE sector (112.5°- 157.5°)	+0.87	-0.58	+0.54	+0.36	-0.37	-0.60	-0.67
PM2.5 S sector (157.5°- 202.5°)	+0.93	+0.54	+0.80	+0.66	-0.15	-0.75	-0.33
PM2.5 SW sector (202.5°- 247.5°)	+0.89	+0.37	+0.76	+0.59	-0.17	-0.72	-0.26
PM2.5 W sector (247.5°- 292.5°)	+0.88	+0.35	+0.79	+0.49	-0.38	-0.63	-0.32
PM2.5 NW sector (292.5°- 337.5°)	+0.76	+0.30	+0.63	+0.19	-0.45	-0.59	-0.42

* Temperature ** Relative humidity *** Wind speed

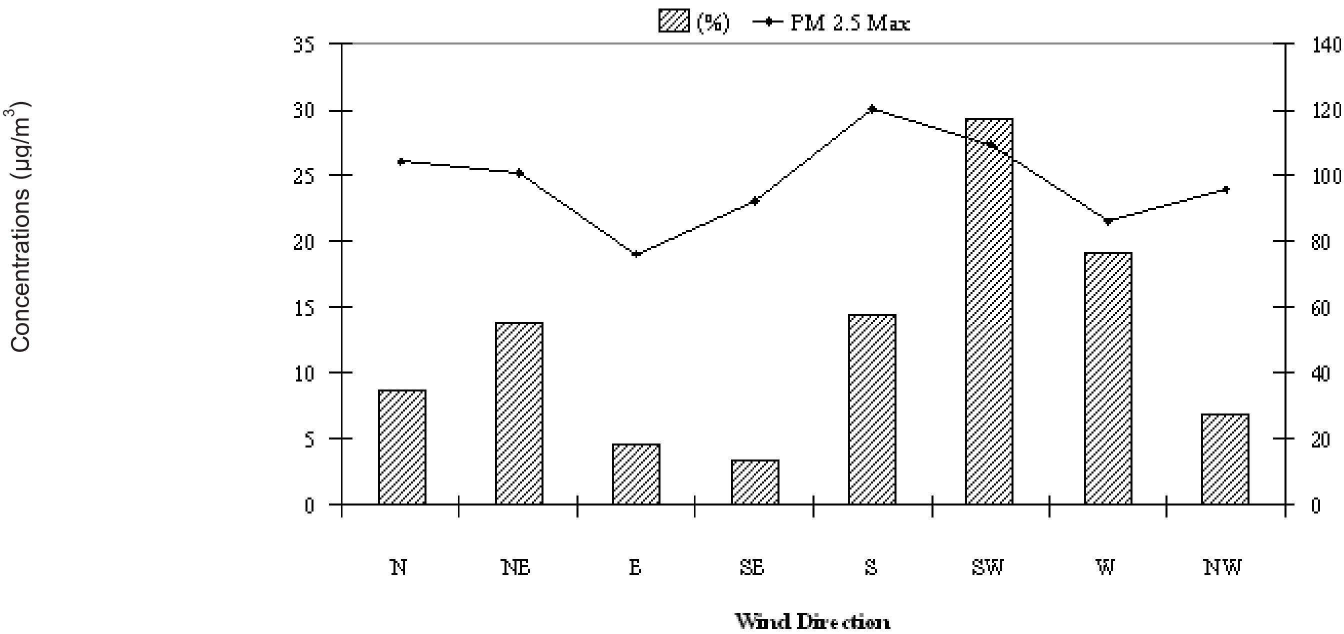


Figure 4 Frequency of wind direction and PM2.5 maximum during the sampling period.

Correlations with PM10 and gaseous pollutants

In order to examine PM2.5 correlation with gaseous pollutants the experimental days were divided into eight categories according to the prevailing wind direction as shown in Table 4. It presents the correlation co-efficient among PM2.5 and PM10, O_3, NO_2, SO_2 which are clearly positive correlated in all sectors.The predominance of local sources such as vehicular traffic, central heating and industrial facilities is indicated. PM2.5 and SO_2 were positively correlated on southern ern sector. SO_2 can react with NH_3 and some organic compounds producing secondary particulate matter(15). The correlation is stronger during days with prevailing south winds that blow from the industrial activities and airport, leading to primary and secondary pollutant accumulation in the Chiang Mai-Lamphun Basin. PM2.5 maximum values were recorded during days with northern and northeastern prevailing winds, probably due to the peripheral highway existence and the construction of highway. The concentrations of NO_2 and SO_2 are very low in the sampling sites during those conditions and the levels depended on the metrological parameters. Positive correlation among PM 2.5 concentrations and the above mentioned air pollutants is observed when the winds are blowing from the city center or other pollution sources. As expected, O_3 concentrations are quite high in the area and significantly correlated with PM2.5 in all sec tors. Cox and Chu(16) have suggested that atmospheric chemistry, rather than transport, may be responsible for these high summer concentrations.

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References

1. DeGaetano, A. and Doherty, O.: Temporal, spatial and meteorological variations in hourly PM2.5 concentration extremes in New York city. Atmos. Environ. 38: 1547-1558, 2004.
2. Pope, C.A., Burnett, R., Thun, M. J., Calle, E.E., Krewskik, D., Ito, K. and Thurston, G.D.: Lung cancer, cardiopulmonary mortality and long term exposure to fine particulate air pollution. J. Am. Med. Assoc. 287:1132-1141, 2002.
3. Samet, J.M., Dominici, F., Curriero, F.C., Coursac, I. and Zeger, S.L.: Fine particulate air pollution and mortality in 20 US cities, 1987-1994. N. Engl. J.Med 343:1742-1749, 2000.
4. Shendriker, A.D. and Steinmetz, W.K.: Integrating nepholometer measurements for air-borne fine particulate matter (PM2.5) mass concentration.Atmos. Environ.37:1383-1392, 2003.

5. Watson, J.G.: Visibility: science and regulation. J. Air Waste Manag. Assoc.52: 628-713, 2002.
6. Kim, Y.J., Kim, K.W. and Oh, S.J.: Seasonal characteristics of haze observed by con tinuous visibility monitoring in the urban atmosphere of Kwangju, Korea. Environ. Monit. Assess. 70:35-46, 2001.
7. Bari, A., Ferraro, V., Wilson, L.R., Luttinger, D. and Husain, L.: Measurements of gas eous HONO, HNO_3, SO_2, HCL, NH_3, particulate sulfate and PM2.5 in New York,NY. Atmos. Environ. 37:2825-2835, 2003.
8. Ward, T.J., Hamilton Jr, R.F., Dixon, R.W., Paulsen,M.,Simpson,C.D.: Characterization and evaluation of smoke tracers in PM: Results from the 2003 Montana wildfire season. Atmos. Environ. 40:7005-7017, 2006.
9. Hien, P.D., Bac, V.T., Tham, H.C., Nhan, D.D. and Vinh, L.D.: Influence of meteorological conditions on PM2.5 and PM2.5-10 concentrations during the monsoon season in Hanoi,Vietnam. Atmos. Environ.36:3473-3484, 2002.
10. Bogo, H., Otero, M., Castro, P., Ozafran, M.J., Kreiner, A., Calvo, E.J. and Negri, R.M. : Study of atmospheric particulate matter in Buenos Ares city.+6+6Atmos. Environ. 37:1135-1147, 2003.
11. Ostro, B., Chestnut, L.,Vichit-vadakan, N. and Laixthai, A.: The impact of par ticulate matters on daily mortality in Bangkok, Thailand. J. Air Waste Manag. Assoc. 49:100-107, 1999.
12. Vinitketkumnuen, U., Kalayanamitra, K., Chewonarin ,T.and Kamens, R.M.: Particulate matter, PM10 & PM2.5 levels and airborne mutagenicity in Chiang Mai, Thailand. Mutat. Res. 519:121-31, 2002.
13. USEPA.: PM2.5 general information. Office of Air Quality Planning and Standards, USEPA 1998.
14. Neas, L.M.: Fine particulate matter and cardiovascular disease. Fuel Process. Tech. 65-66:55-67, 2000.
15. Vassilakos ,Ch., Saraga, D., Maggos, Th., Michopoulos, J., Pateraki, S. and Helmis, C.G.: Temporal variations of PM2.5 in the ambient air of a suburban site in Athens, Greece. Sci. Total Environ. 349:223-231, 2005.
16. Cox, W.M. and Chu, S-H.: Assessment of interannual ozone variation in urban areas from a climatological perspective. Atmos. Environ. 30:2615-2625, 1996.