CHAPTER 3

RESULTS AND DISCUSSION

Nitrogen dioxide passive sampler test kit has been applied to monitor nitrogen dioxide levels in ambient air of Chiang Mai Province.

3.1 Analytical Characteristics of Spectrophotometer

3.1.1 Linear range

One ml of nitrite standard was mixed with 2 ml of Saltzmann reagent and standed for 10 minutes. Absorbance of nitrite standard solutions (0.01-10 mg/l) was measured at 540 nm. Concentrations were plotted against their absorbance as shown in Table 3.1 and Figure 3.1. The linear dynamic range was obtained in the range 0.01-6.0 mg/L.

3.1.2 Calibration curve of nitrogen dioxide

Nitrogen dioxide trapped in diffusion tube was presented in form of nitrite (NO_2^-). The NO_2^- concentration was determined using the linear regression equation of the calibration curve prepared from different concentrations of nitrite standard solutions in the range of 0.01-1.00 mg/L as shown in Table 3.2 and Figure 3.2. Linear regression analysis of the nitrogen dioxide as absorbance unit (Y) versus nitrite concentrations in mg/L (X) yielded an equation: $Y = 0.3803X + 0.0026$ ($r^2 = 0.9999$).

Table 3.1 Linear dynamic ranges of nitrite standard

Concentrations of NO_2^- standard solution (mg/L)	**Mean**	**SD (n = 3)**
0.01	0.0054	0.0005
0.02	0.0063	0.0001
0.04	0.0102	0.0006
0.10	0.0385	0.0004
0.20	0.0694	0.0014
0.40	0.1449	0.0011
0.60	0.2250	0.0021
0.80	0.2954	0.0033
1.00	0.3702	0.0033
2.00	0.7005	0.0076
4.00	1.4298	0.0362
6.00	2.1155	0.0886
8.00	2.6198	0.0231
10.00	2.8296	0.0358

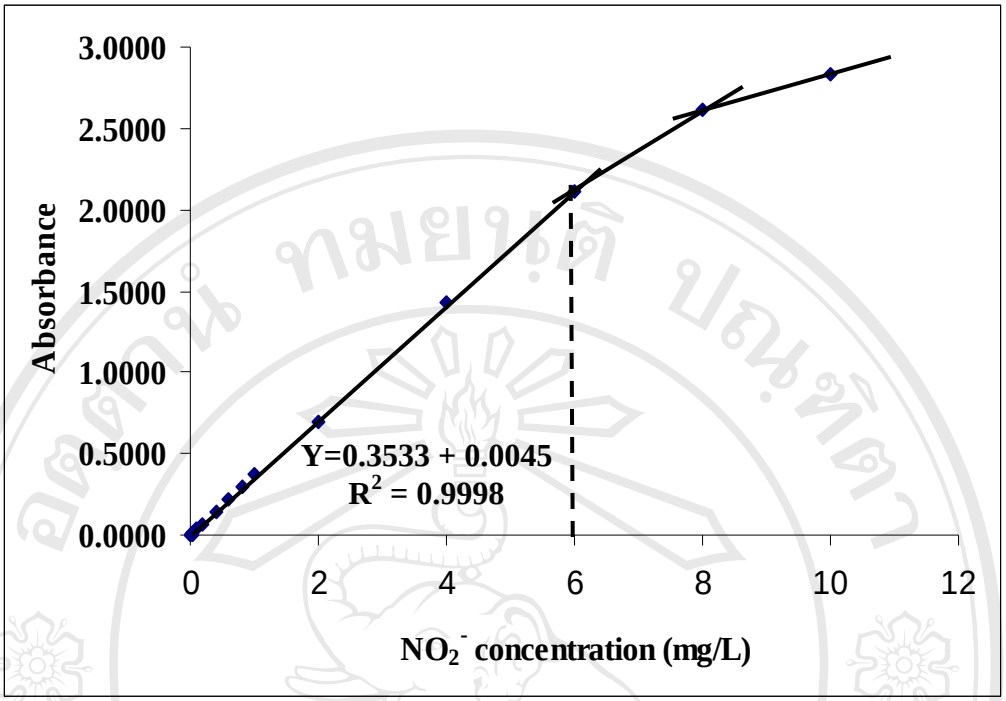


Figure 3.1 Linear dynamic range of nitrite standard

Table 3.2 Absorbance of nitrite standard solution

Nitrite (mg/L)	Absorbance
0.01	0.0056
0.02	0.0102
0.04	0.0167
0.1	0.0400
0.2	0.0802
0.4	0.1569
0.6	0.2317
0.8	0.3057
1.0	0.3824

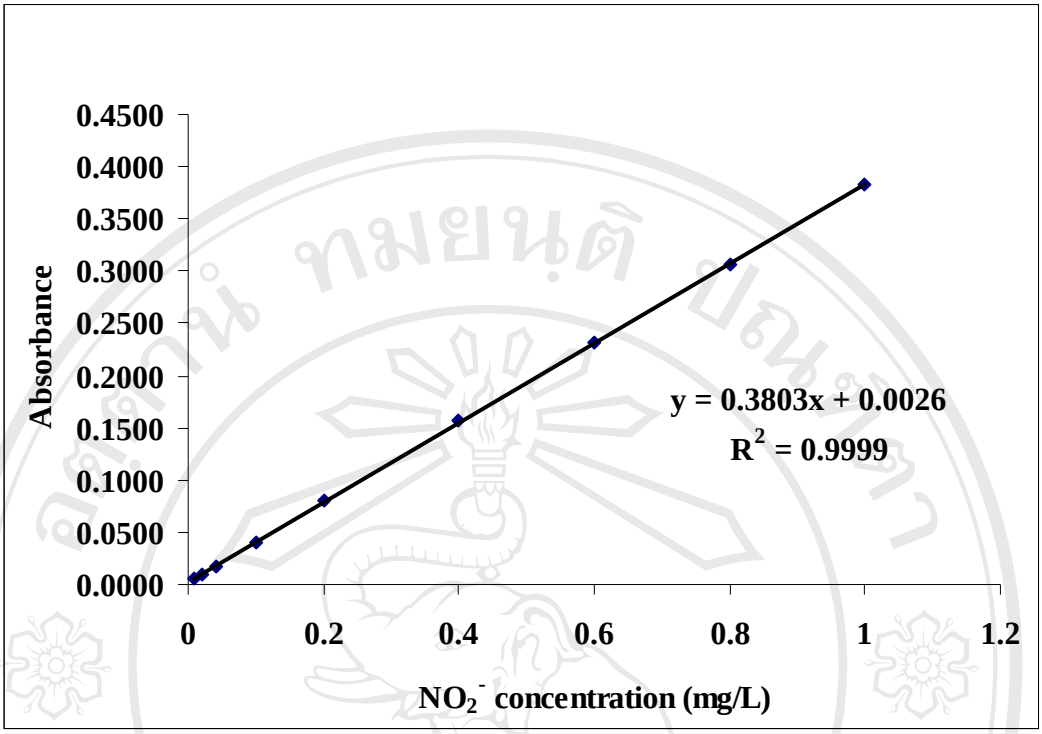


Figure 3.2 Calibration cure of nitrite standard solution

3.1.3 Limit of detection and limit of quantification

The limit of detection (LOD) was obtained by using of linearity curve of nitrite standard concentration with high correlation (r^2 >0.99). LOD was calculated using the equation 2.1 and 2.2 (topic 2.5.3) and the result is shown in Table 3.3. Ten measurements of 0.02 mg/L; the second lowest concentration standard solution were done and absorbances obtained were calculated back into concentrations. LOD and limit of quantification (LOQ) were calculated by 3 times and 10 times of standard deviation (SD) obtained from those ten measured concentrations. LOD and LOQ of spectrophotometry for nitrite measurement were 0.005 and 0.017 mg/L, respectively.

Table 3.3 Limit of detection and limit of quantification of spectrophotometry for nitrite

Number of measurement	Absorbance	Nitrite (mg/L)
1	0.0077	0.0134
2	0.0064	0.0100
3	0.0068	0.0110
4	0.0064	0.0100
5	0.0070	0.0116
6	0.0057	0.0082
7	0.0056	0.0079
8	0.0061	0.0092
9	0.0065	0.0103
10	0.0058	0.0084
Average		**0.0100**
Standard Deviation (SD)		**0.0017**
LOD (3×SD)		**0.005**
LOQ (10×SD)		**0.017**

3.1.4 Repeatability and reproducibility

The repeatability of the system was determined by repeating measurements of 0.2 mg/L nitrite solution for 10 times. The reproducibility of the system was pursued by preparing 10 solutions of 0.2 mg/l nitrite solution followed by analysis in the same manner. The results obtained are summarized in the Table 3.4. The repeatability and reproducibility of the method were reported in term of % relative standard deviation (RSD), which were 2.1 and 4.0 %, respectively.

Table 3.4 Repeatability and reproducibility of spectrophotometry

No. of measurement	Repeatability (mg/L)	Reproducibility (mg/L)
1	0.205	0.195
2	0.210	0.194
3	0.212	0.189
4	0.201	0.204
5	0.215	0.198
6	0.209	0.210
7	0.207	0.198
8	0.202	0.195
9	0.208	0.187
10	0.209	0.183
Average	**0.208**	**0.195**
Standard Deviation (SD)	**0.004**	**0.008**
% RSD	**2.1**	**4.0**

3.2 Application of NO_2 test kit in field study

3.2.1 Correlation of NO_2 concentrations determination by the test kit and spectrophotometry

To prove the efficiency of passive sampling device, comparison between nitrogen dioxide concentrations obtained from 3 days exposure of passive samplers by NO_2 test kit and those from spectrophotometry has been conducted at Chiang Mai Province from November 2007 to April 2008 by Pearson's correlation.

However, there is some limitation of using the NO_2 standard color chart (Figure 2.1). A value obtained from the color chart can be either single or range, which

depends on matching between sample and standard colors. If they are matched with each other, single value e.g. 10.6 ppbv will be reported. If they are not exactly matched, a range value i.e. 10.6 – 42.5 ppbv will be given. NO_2 concentrations measured by the test kit during November 2007- April 2008 ranged from 3.2 – 42.5 ppbv, which were 4 single values (3.2, 6.4, 10.6 and 42.5 ppbv) and 3 range values (3.2-6.4, 6.4 - 10.6, and 10.6 – 42.5 ppbv). In correlation graph, mean values of the ranges (4.8, 8.5 and 26.5 ppbv) were plotted. The NO_2 concentrations in ambient air determined by the NO_2 test kit and spectrophotometry were strongly correlated with each other ($r = 0.899$, $p \leq 0.01$) as shown in Figure 3.3 and Table E1 (Appendix E).

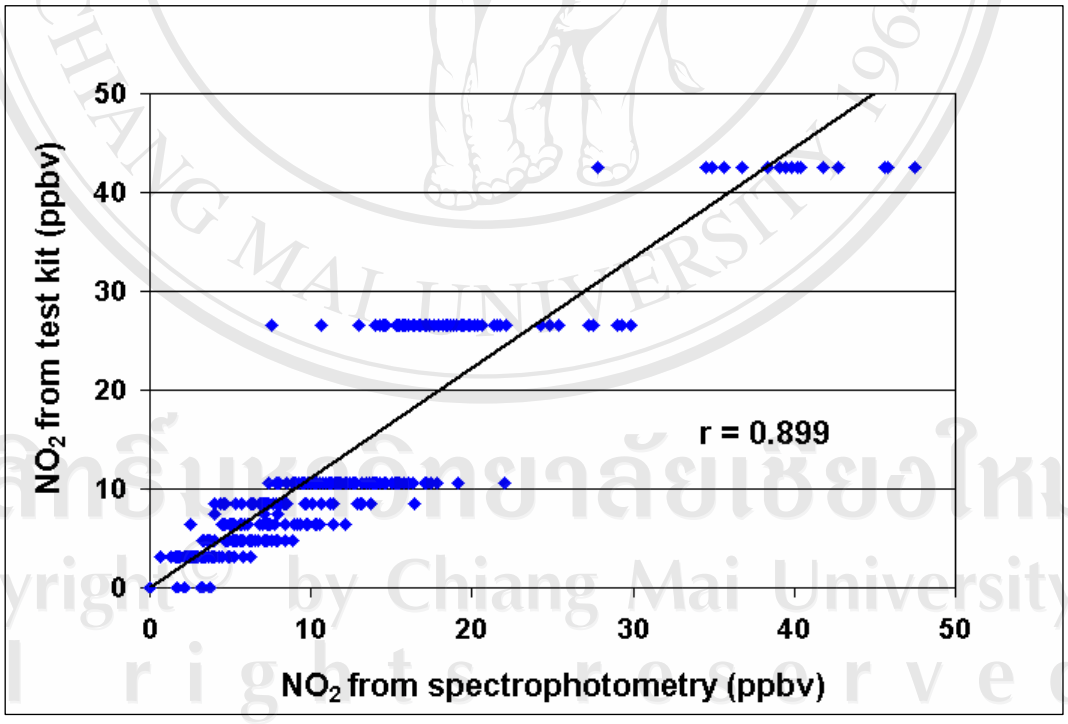


Figure 3.3 Correlation of NO_2 concentrations determined by NO_2 test kit and spectrophotometry

3.3 Comparison of urban NO_2 concentrations from spectrophotometry and chemiluminescence

The NO_2 concentrations in ambient air of urban areas of Chiang Mai Province (8 sampling sites) obtained from self measurement by passive sampling and spectrophotometry were compared with values from chemiluminescence automatic active air quality monitoring station (reference values) of Pollution Control Department (PCD) at Yupparaj Wittayalai School. The measurements have been done once a month during November 2007 to April 2008 and the results are shown in Table 3.5. In this work, the NO_2 values obtained from chemiluminescence measurement at U2 station are used as reference urban background values due to its location, which represents urban air quality of Muang Chiang Mai according to PCD. Therefore, the reference values were used to compared with the measured values to obtain the information of percent difference. In conclusion, the average percent difference of NO_2 concentrations obtained from there two techniques (32.7%) as shown in Table 3.5, was used for adjustment of NO_2 concentrations of all sampling sites. Heal and Cape (1997) measured NO_2 concentrations in urban and rural ambient air in England by using passive diffusion samplers. They found overestimation of ambient NO_2 in urban sites (13.6-27.6 %) higher than rural sites (7.5-8.6 %). The combined error due to the effect of wind on path length (30-40 %) and chemical effect (30 %) with cities caused up to 70% overestimation of NO_2. While in this work, underestimation of NO_2 (32.7%) was found, which represents the same trend (26.0 % underestimation) reported by Chalermrom (2008). Long sampling time affected to mass diffusion limit depends on the dimension of the sampler such as size of cross section (capacity of sorbent) which affect to rate of diffusion in the long time exposure. The rate of collection will

continuously decrease after 1 day. In case of application for diffusion length of the sampler, capacity of sorbent must be increased (Kotchabhakdi, 2007).

Table 3.6 illustrates NO_2 concentrations of all sampling sites in urban area (U1-U8) in comparison with those of chemiluminescence (PCD) at the same station (U2). According to One-Way ANOVA test, it was found that NO_2 concentrations of the chemiluminescence were significantly different ($\alpha<0.05$) from those of the passive sampler at site U2 (Yupparaj Witayalai School). Monthly NO_2 concentrations of the U3 (Waroros market) were significantly higher than those of the rest. Level of NO_2 detected in each area seem to be influenced by local activities more than main meteorological factors i.e. wind direction. Varshney and Singh (2003) reported that the influence of turbulence on passive sampler efficiency is likely to be site dependent. In some studies where sampling sites were chosen with care such as at the building the effect of wind was found to be small and not much consequence (Atkins *et al.,* 1986; Hargreaves, 1989). Effect of wind on passive samplers can be minimised by using a protective screen at the open end of the sampler (Ferm and Svanberg, 1998) or by mounting tubes at sheltered location (Gair and Penkett, 1995; Glasius *et al.*, 1999; Bush *et al*., 2001)

Table 3.5 Nitrogen dioxide concentrations from passive samplers in comparison with reference values

Sampling date	NO.	NO_2 concentrations			% Difference★
		Passive sampler (P)		Reference value (A)	
		(ppbv)	Mean ± SD (ppbv)	Mean ± SD (ppbv)	
11-13 Nov 07	1	11.3			
	2	11.1	11.1 ± 0.2	16.1 ± 0.8	- 31.0
	3	11.0			
16-18 Dec 07	1	20.3			
	2	27.2	22.0 ± 4.6	21.3 ± 1.3	+ 3.2
	3	18.5			
13-15 Jan 08	1	15.5			
	2	24.3	21.5 ± 5.2	29.5 ± 2.0	- 26.9
	3	24.8			
10-12 Feb 08	1	15.3			
	2	17.6	16.3 ± 1.2	29.0 ± 3.8	- 43.8
	3	15.8			
9-11 Mar 08	1	17.2			
	2	11.2	13.8 ± 3.1	30.4 ± 3.5	- 54.7
	3	12.9			
7-9 Apr 08	1	11.0			
	2	12.7	13.1 ± 2.4	20.8 ± 2.9	- 36.8
	3	15.7			
Mean ± SD		**16.3 ± 4.9**	**16.3 ± 4.5**	**24.5 ± 5.9**	**32.7 ± 17.5**

★Calculated by: (A-P/A)×100

Where A is reference value obtained from active sampling equipped with chemiluminescence (PCD)

P is monitored value obtained from passive sampling followed by spectrophotometry

Note: +: overestimate in comparison to reference value

-: underestimate in comparison to reference value

Table 3.6 Comparison of NO_2 concentrations in ambient air of urban areas of Chiang Mai Province obtained from spectrophotometry and chemiluminescence

Sampling date	Concentrations of NO_2 (ppbv)								
	Chemiluminescence (U2)	Sampling sites							
		U1	U2*	U3	U4	U5	U6	U7	U8
11-13 Nov. 07	16.1±0.8	FS	11.0±0.2	28.1± 0.8	FS	11.7±0.5	9.0±1.3	12.7±2.2	8.4±0.5
16-18 Dec. 07	21.3±1.3	22.5±2.1	22.0±4.6	42.5±3.3	18.8±3.1	16.9±1.9	6.4±2.1	15.6±1.6	10.1±1.4
13-15 Jan. 08	29.5±1.8	28.2±2.4	21.5±5.2	45.1±2.9	17.2±1.4	11.3±5.5	11.6±4.9	11.6±4.9	13.8±0.8
10-12 Feb. 08	29.0±3.8	20.2±1.2	16.3±1.2	36.5±3.2	17.6±3.1	11.1±1.4	11.9±2.3	13.1±0.9	9.4±1.2
9-11 Mar. 08	30.4±3.5	17.6±1.9	13.8±3.1	39.4±1.1	10.5±3.5	11.7±1.5	10.5±3.2	16.4±1.6	6.3±3.3
7-9 Apr. 08	20.8±2.9	16.3±0.6	13.1±2.4	37.4±2.2	15.0±1.0	10.1±0.7	12.4±4.3	12.7±1.7	12.6±4.0

Note; FS – failed sampling (e.g., broken or lost diffusion tube)

* Data from the same sampling site of chemiluminescence technique

3.4 NO_2 concentrations from passive sampling

3.4.1 NO_2 concentrations in urban, sub-urban and rural areas

The polypropylene passive samplers were used to measure ambient air concentrations of NO_2 in urban, sub-urban and rural of Chiang Mai Province. Sampling has been done once a month from November 2007 to April 2008 by 3 days exposure and the result is illustrated in Table 3.7 and Figure 3.4. One-Way ANOVA (One-way analysis of variance) with least significant difference (LSD) was used to determine the difference of mean NO_2 concentration between each area. The results showed that NO_2 concentrations during the sampling period of the rural area were significantly less than those of urban area and sub-urban area ($\alpha<0.05$). In urban and sub-urban areas, the highest NO_2 concentrations was found in January 2008, while in rural area the highest value was found in December 2007. This is probably due to open burning of agricultural waste, which takes place in the rural area in December (harvesting period). Many previous works (Sahai *et al.*, 2007, Ortiz de Zarate *et al*., 2005 and Ezcurra *et al.*, 2001) reported that nitrogen oxides (NO_X), nitric oxides (NO) and nitrogen dioxides (NO_2) and nitrous oxide (N_2O) were found in ambient air of burned cereal waste.

Ranges of NO_2 concentrations during those 6 months were 6.3-45.1, 5.1-19.1 and 1.6-8.7 ppbv in urban, sub-urban and rural areas, respectively. The highest NO_2 concentration in each month was found at site U3 (Waroros market), which is located in the urban area of Chiang Mai with high traffic density. Apart from mobile source, NO_2 is portably produced from incense burning in a shrine behind the sampling site. Lee and Wang (2004) characterized the emissions of air pollutants from incense burning and found concentrations of NO_X, NO and NO_2 in a large environmental test

chamber. Wang *et al.* (2007) used chemiluminescence to detect NO_X at two of the most famous temples in Hong Kong. They found that the NO_X levels of temples during peak period (the first or fifteenth day of each month on the Chinese lunar calendar) were significantly higher than those of non-peak period (more pilgrims appeared at temple for blessing).

High NO_2 concentrations in ambient air of sub-urban area were found at SU1 (San Sai market, which is situated near Chiang Mai – Chiang Rai road, outer ring road) and SU2 (near Ruamchok market, middle ring road and Chiang Mai – Phrao road with high traffic density). Twenty-four hours concentrations of NO_2 from roadside of Chiang Mai City in 1996 ranged from 170 ppbv to 300 ppbv in winter season (Panyaping, 2003). From the study of Gilbert *et al.* (2003), concentrations of NO_2 decreased as distance from road increased and were systematically higher downwind than upwind. In this work, the highest NO_2 concentrations at SU 4 were found in December 2007 (Ban Tam Nak), which is located in sub-urban area with opposite of a new Big C super center. During December to January is a harvesting period, and massive agricultural waste is burnt. At SU5 (Ban Ton Pin), the high NO_2 concentrations (10.3-12.0 ppbv) were found during November 2007 to January 2008. It is situated near paddy fields. It can be assumed that such high values could be from biomass burning too. At SU6 (Ban Muang Kung), the highest NO_2 concentrations was found in January and March 2008. Apart from open burning of agricultural waste, there were also exhaust pollutants from burning of pottery kilns. Ban Muang Kung is handicraft village and the main products are pottery, which are produced in small factories located in the village.

Most of NO_2 in rural area was released from open burning of agricultural waste. The NO_2 concentrations detected were in a range from 2 – 9 ppbv in rural area of Chiang Mai. When compare those values with some other places, it was found that NO_2 concentrations of Chiang Mai rural area were lower than those found in India (0.9-20.3 ppbv) during agricultural burning season (Sahai *et al.*, 2007), but higher than the value found in Spain (2 ppbv) during cereal burning season (Ezcurra *et al.*,2001).

Table 3.7 The concentrations of NO_2 in ambient air samples measured by spectrophotometry

Study area	Code	Mean NO_2 concentration (ppbv, N=3)					
		Nov-07	**Dec-07**	**Jan-08**	**Feb-08**	**Mar-08**	**Apr-08**
Urban	U1	FS	22.5 ± 2.1	28.2 ± 2.4	20.2 ± 1.2	17.6 ± 1.9	16.3 ± 0.6
	U2	11.1 ± 0.2	22.0 ± 4.6	21.5 ± 5.2	16.3 ± 1.2	13.8 ± 3.1	13.1 ± 2.4
	U3	28.1 ± 0.8	42.5 ± 3.3	45.1 ± 2.9	36.5 ± 3.2	39.4 ± 1.1	37.4 ± 2.2
	U4	FS	18.8 ± 3.1	17.2 ± 1.4	17.6 ± 3.1	11.2 ± 3.5	15.0 ± 1.0
	U5	11.7 ± 0.5	16.9 ± 1.9	11.3 ± 5.5	11.1 ±1.4	11.7 ± 1.5	10.1 ± 0.7
	U6	9.0 ± 1.3	6.4 ± 2.1	11.6 ± 4.9	11.9 ± 2.3	10.5 ± 3.2	12.4 ± 4.3
	U7	12.7 ± 2.2	15.6 ± 1.6	11.6 ± 4.9	13.1 ± 0.9	16.4 ± 1.6	12.7 ± 1.7
	U8	8.4 ± 0.5	10.1 ± 1.4	13.8 ± 0.8	9.4 ± 1.2	6.3 ± 3.3	12.6 ± 4.0
Sub-urban	SU1	FS	15.4 ± 1.6	16.4 ± 4.1	18.4 ± 2.9	19.1 ± 2.8	17.1 ± 0.7
	SU2	5.4 ± 0.2	9.3 ± 0.9	13.4 ± 1.7	6.8 ± 1.9	5.1 ± 0.7	5.5 ± 1.5

Table 3.7 (continued)

Study area	Code	Mean NO_2 concentration (ppbv, N=3)					
		Nov-07	**Dec-07**	**Jan-08**	**Feb-08**	**Mar-08**	**Apr-08**
	SU3	FS	13.1 ± 1.1	16.1 ± 1.3	13.6 ± 2.7	13.3 ± 3.9	14.0 ± 1.4
	SU4	FS	14.1 ± 2.0	7.3 ± 1.3	9.1 ± 0.2	9.9 ± 1.8	10.7 ± 1.6
	SU5	10.3 ± 1.0	11.0 ± 1.6	12.0 ± 5.1	8.0 ±1.7	9.0 ± 1.0	6.3 ± 1.4
	SU6	5.4 ± 0.7	8.9 ± 1.6	17.9 ± 2.3	7.6 ± 0.6	13.6 ± 4.5	6.9 ± 1.0
Rural	R1	2.9 ± 0.5	7.9 ± 0.5	3.9 ± 0.2	6.5 ± 0.4	7.1 ± 0.9	5.7 ± 0.9
	R2	1.6 ± 0.3	5.4 ± 0.6	6.9 ± 0.1	2.9 ± 1.0	4.0 ± 1.9	4.8 ± 3.4
	R3	3.0 ± 0.9	6.1 ± 0.3	4.7 ± 1.1	5.7 ± 1.4	4.6 ± 0.6	2.9 ± 0.4
	R4	4.2 ± 0.9	8.7 ± 1.1	3.9 ± 0.0	6.9 ± 0.8	7.2 ± 0.2	5.2 ± 0.3
	R5	2.2 ± 0.5	3.4 ± 0.8	3.8 ± 1.9	4.3 ± 0.8	2.2 ± 1.5	2.7 ± 0.3
	R6	3.1 ± 0.9	4.5 ± 1.0	3.1 ± 0.5	4.2 ± 0.7	2.9 ± 1.6	3.1 ± 0.7

Note; FS – failed sampling (e.g., broken and lost diffusion tube)

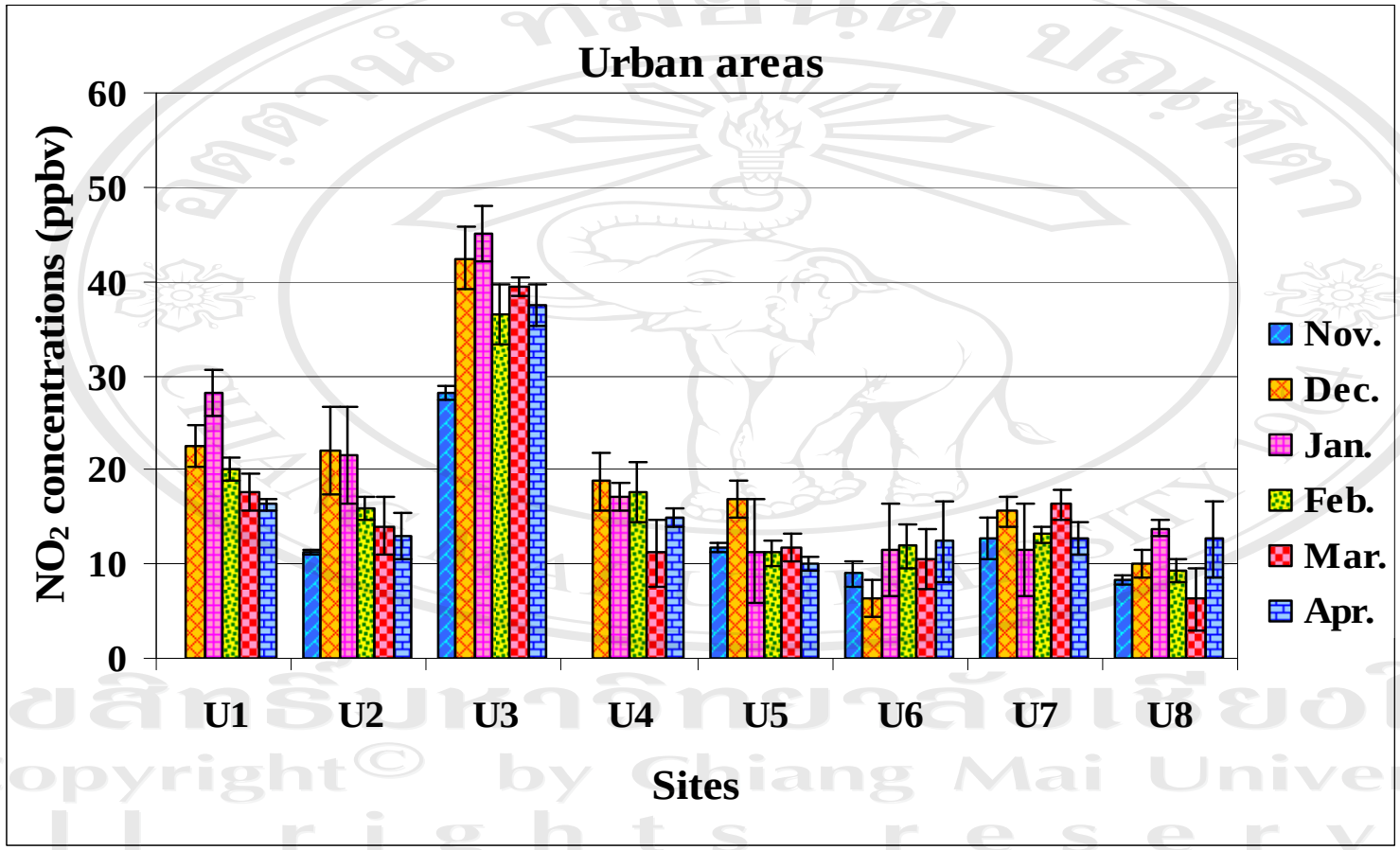


Figure 3.4 (a) Concentrations of NO_2 in ambient air of urban area November 2007 to April 2008 measured by spectrophotometry

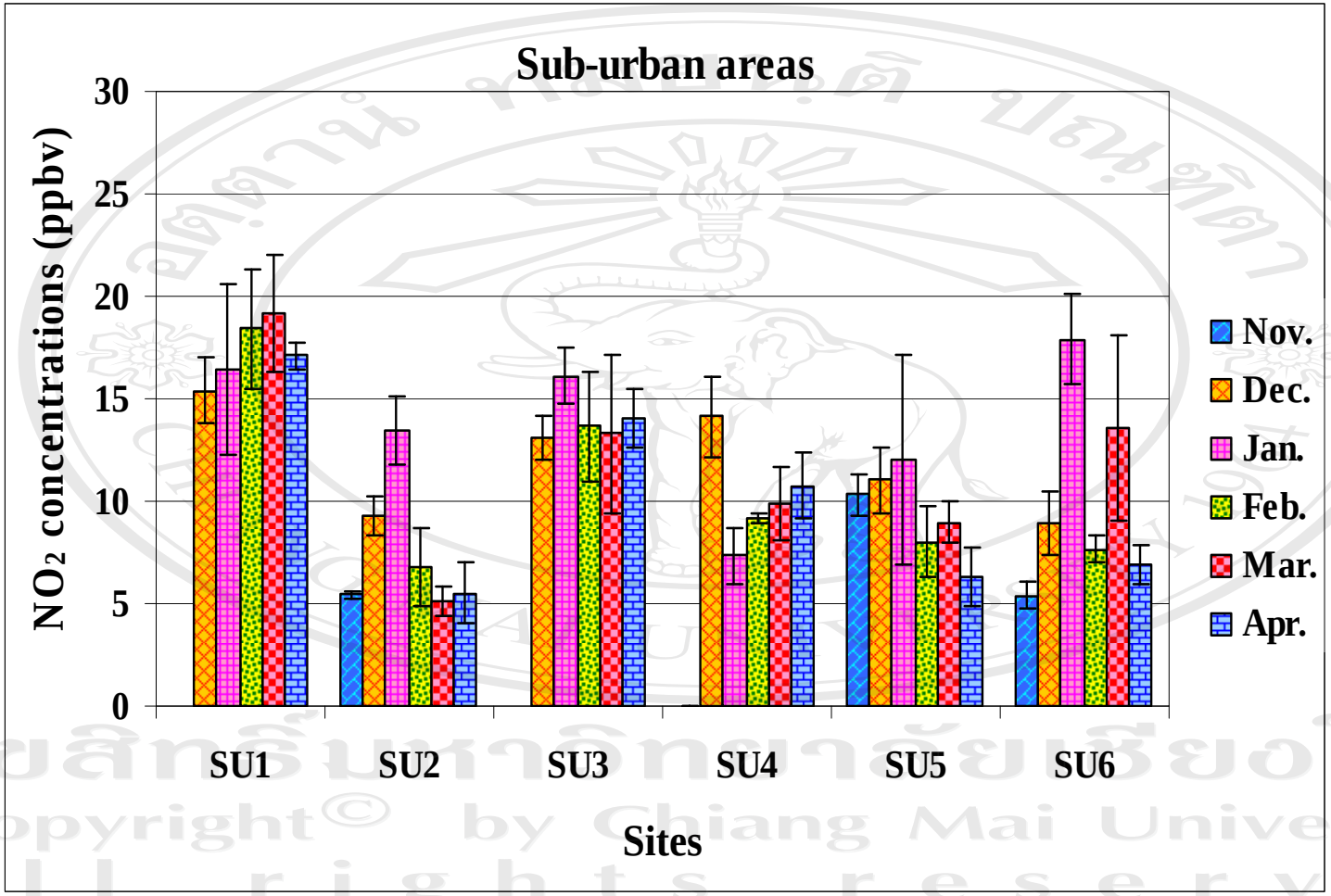


Figure 3.4 (b) Concentrations of NO_2 in ambient air of sub-urban area November 2007 to April 2008 measured by spectrophotometry

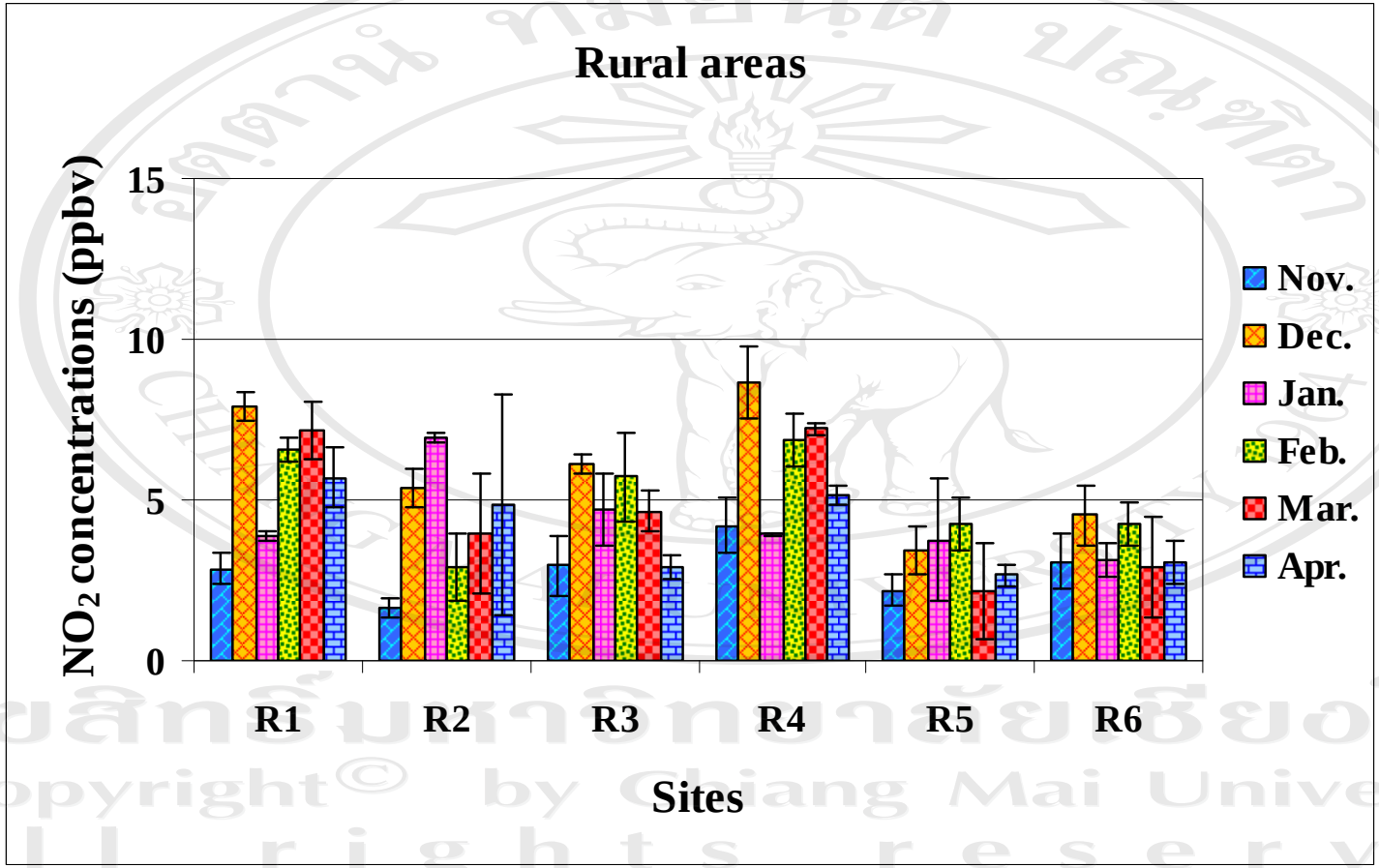


Figure 3.4 (c) Concentrations of NO_2 in ambient air of rural area November 2007 to April 2008 measured by spectrophotometry

3.4.2 Contribution of NO_2 from incense burning

Incense has been used since ancient time to produce pleasant fragrances or to mask odors and incense burning has been incorporated in many religious ceremonies and practices. Incense burning is a traditional and common practice in many families and in most temples and shrine. The burning is either for religious reasons or for providing pleasant smell with the rising environmental and health awareness, people are paying more attention to the problems caused by incenses burning in the indoor and public environments. Exposure to incense smoke may be linked to health effect including cancers, asthma, dermatitis mutagenesis and genotoxic effects (Jetter *at el.,* 2002).

A wide variety of substances are used to produce incense, which include resin (such as frankincense and myrrh), spices, aromatic wood and bark, herbs, seeds, roots, flowers, essential oils and synthetic substitute chemicals which are used in the perfume industry (Jetter *et al.,* 2002). Emissions of some specific compounds from burning incense are carbon monoxide (Lofroth *et al.,* 1991), volatile organic compounds (Lin and Tang, 1994; Lin and Wang, 1994; Madany and Crump, 1994; Lee and Lin, 1996) and carcinogenic polycylic aromatic hydrocarbons (Schoental and Gibbard, 1967; Brunnemmann and Hoffman, 1978; Sato *et al.,* 1980; Li and Ro, 2000). Emission of NO_2 from incense burning has been characterized in pervious studies such as Koo *et al.* (1990) found that levels of NO_2 exposure among mother in Hong Kong were increased by an average of 10 % when incense was burned in the home. The highest emission rate measured for NO was 4.39 mg/h for an incense cone that burned for 15 minutes (Jetter *et al.,* 2002). Lee and Wang (2004) studied incense burning in a large

environmental test chamber and found that NO, NO_2 and NO_x ranged between 0.3-2.6, 0.1-0.7 and 0.4-3.3 mg/g incense, respectively.

In this work, the highest NO_2 concentration was found at site U3 (Waroros market), which is situated in front of shine. Therefore, it has to be proved that how much NO_2 from incense burning contributes to ambient NO_2 concentrations detected at site U3?

a. NO_2 concentrations from incense burning

In order to prove that incense smoke may increase NO_2 concentrations in ambient air of the study site located nearby the shrine, an experiment was set in a laboratory. The result of NO_2 concentrations from testing of incense burning in the laboratory for 1 hour and 8 hours sampling are shown in Table 3.8. It was found that NO_2 concentrations of indoor sampling were approximately 10 times higher than those of outdoor. This means that NO_2 released from incense burning influence ambient NO_2 concentrations. In this case, NO_2 concentrations is 10 times increasing from background level (outdoor measurement). Moreover, 1 hour NO_2 concentrations sampling were higher than those of 8 hours sampling because rate of NO_2 mass is lower than collecting duration.

Table 3.8 NO_2 concentrations from testing of incense burning in laboratory

Sampling period	Location	average NO_2 (ppbv) (N = 3)
1 hour	Indoor	111 ± 29.4
	Outdoor	13 ± 2.1
8 hours	Indoor	69 ± 23.3
	Outdoor	6 ± 3.3

b. NO_2 concentrations from U3 site (shrine)

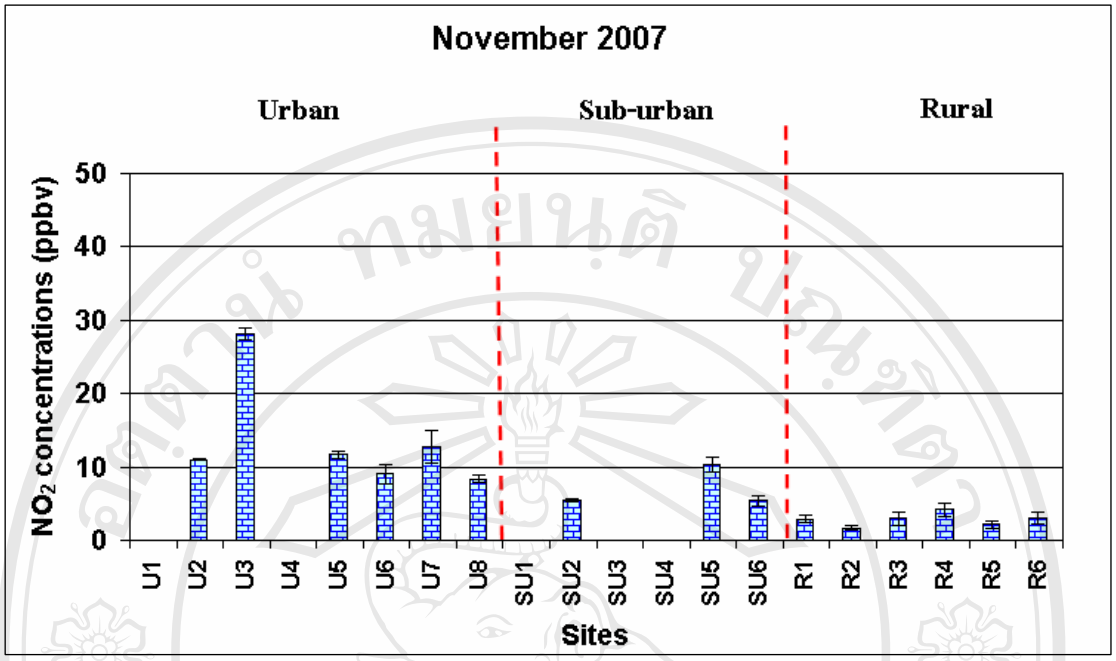
In order to prove that NO_2 produced from incense burning affect to the NO_2 concentrations detected at site U3, where the shrine is located nearby. Passive samplers were placed in and outside the shrine. Various sampling duration including 8, 24 hours and 3 days were tested at the site. It was found that the outdoor NO_2 concentrations were 1.5-2.0 times higher than those of indoor inside the shrine (Table 3.9). Unlike the test in the lab, indoor sampling provides 10 times NO_2 concentrations higher than outdoors. In the lab test, indoors was a closed system, therefore NO_2 hardly released to outside. In the real environment, indoor and outdoor was not complete separated. Therefore, air can flow in and out. It can be concluded that NO_2 produced from incense burning in the shrine could partly increase outdoor level, but higher impact must be from traffic conditions outside.

Table 3.9 NO_2 concentrations from U3 site (shrine)

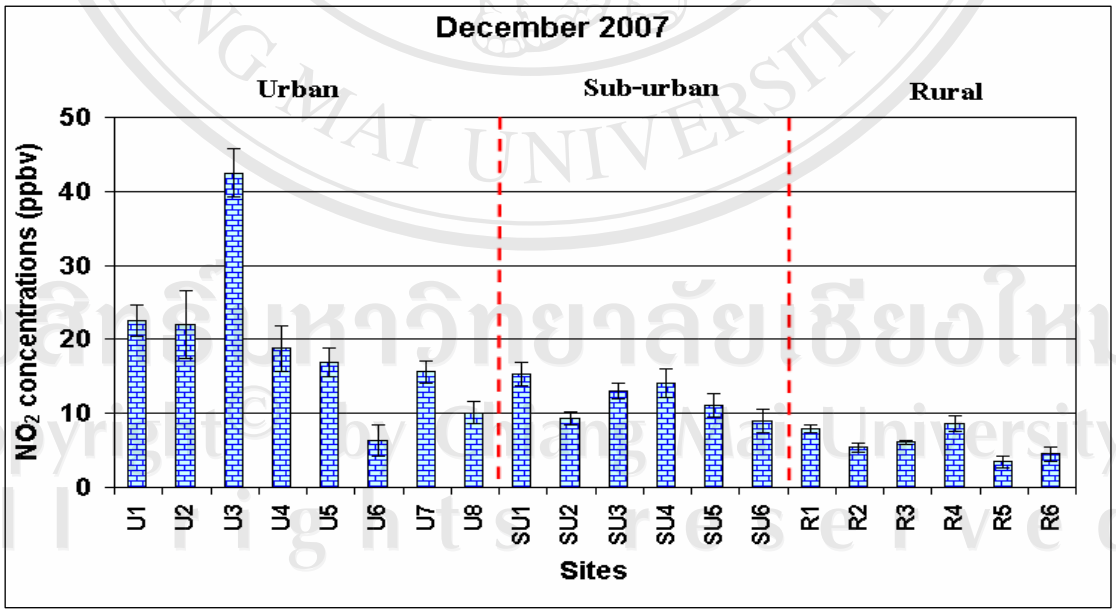
Site	NO_2 (ppbv)				
	8 hours (8.00 a.m.-16.00 p.m.)		24 hours		3 days
	1st (15 Dec. 08)	2rd (18 Dec. 08)	1st (25 Nov.08)	2rd (27 Nov. 08)	(21-23 June 08)
Indoor	8.3 ± 3.6	21.3 ± 3.4	14.7 ± 2.9	10.8 ± 3.0	21.7 ± 1.5
Outdoor	16.1 ± 4.2	29.1 ± 9.1	27.6 ± 3.1	19.7 ± 4.5	28.3 ± 1.9

3.4.3 Temporal variation of NO_2 concentrations

The One-Way ANOVA (One-way analysis of variance) with least significant difference (LSD) was used to determine the difference of mean NO_2 concentration in each month. Figure 3.5 shows that the mean NO_2 concentrations of all sites in December 2007 to March 2008 were not significantly different (α>0.05). Concentrations of NO_2 from December 2007 to March 2008 were significantly higher than those in November 2007 and April 2008. The total precipitation of Chiang Mai area in November 2007 and April 2008 were 73.5 and 57.2 mm, respectively (Norththern Meteorological Center, 2008), which were higher than that of other months during the sampling period. Therefore, least NO_2 concentrations were found in November 2007 and April 2008. Monthly precipitation in January to March 2008 were 16.6, 13.8 and 9.4 mm, respectively, whereas there was no precipitation in December 2007. Total precipitation and NO_2 concentrations in Chiang Mai Province from November 2007 to April 2008 is shown in Appendix B and D. From these information, we could divided the sampling into 2 periods; dry period (December 2007 to March 2008) and transition period (November 2007 and April 2008). It can be concluded that there is more pollutant concentration (NO_2) in dry season. It is significantly higher than those of transition period. It can be assumed that rainy season has lower pollutants concentrations than those of two periods. The result are agreed with many previous studies (Ashenden and Edge, 1995; Madsen *et al.,* 2007; Verma *et al.,* 2008)



a



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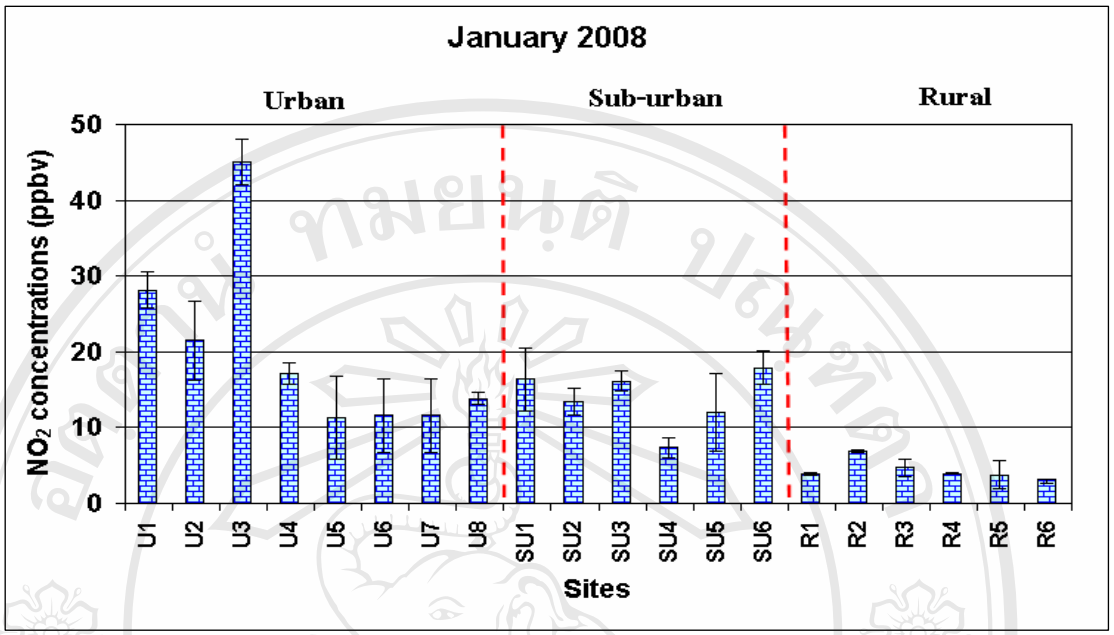

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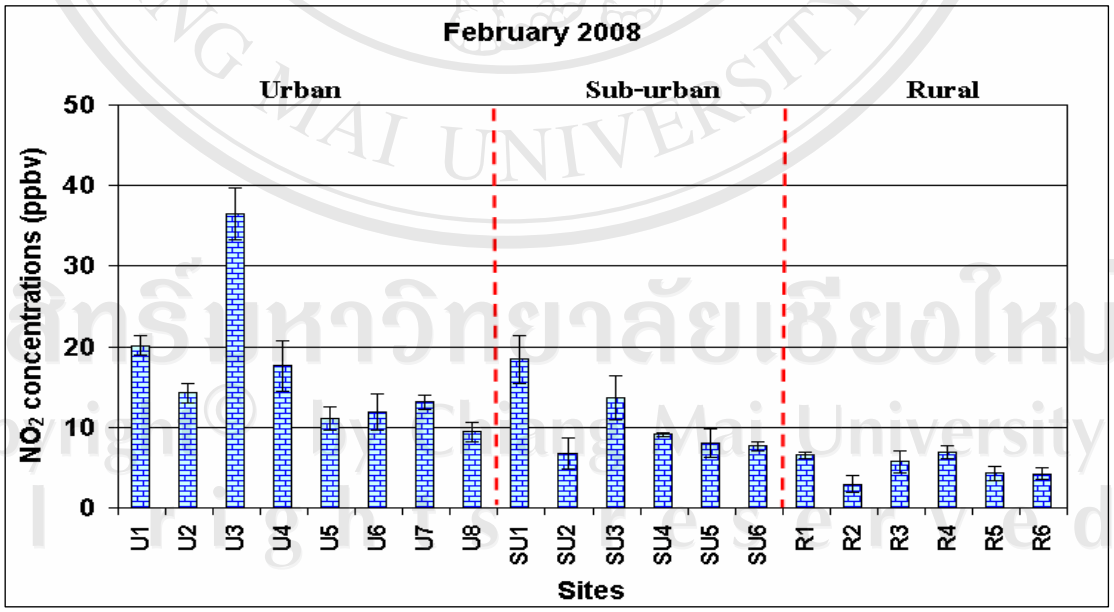

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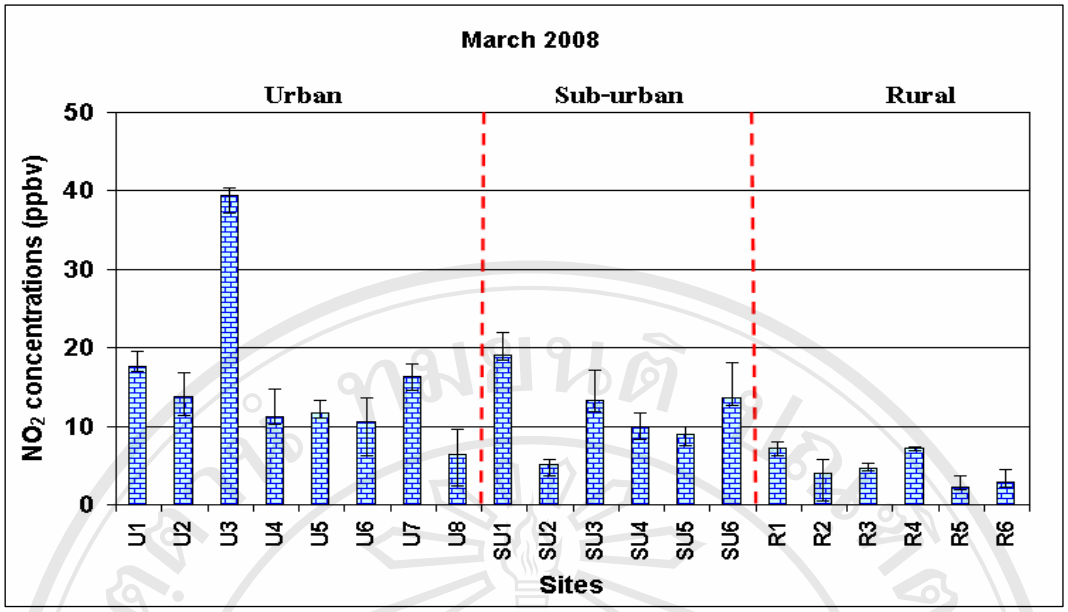

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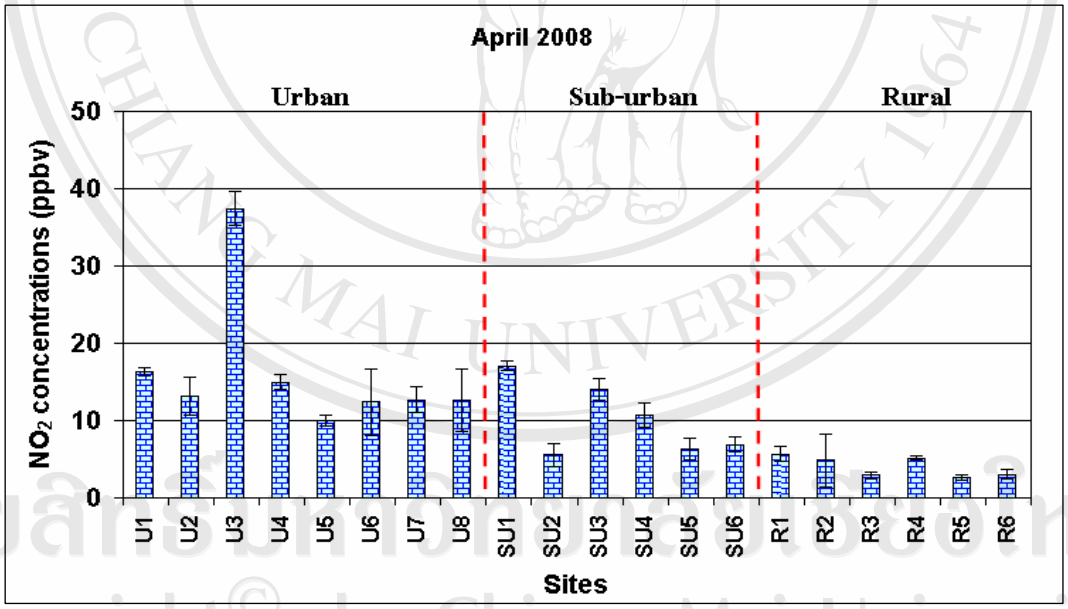

f

Figure 3.5 Concentrations of NO_2 in November 2007 to April 2008 measured by spectrophotometry: a. November 2007, b. December 2007, c. January 2008, d. February 2008, e. March 2008 and f. April 2008

3.4.4 Geographic distribution of NO_2 in Chiang Mai

Classification of NO_2 concentrations have been done based on measurement data of Chiang Mai Province during the study period. Six colors including blue, light blue, green, yellow, orange and red were used to classify concentrations from <10 to >30 ppbv (Table 3.10).

Table 3.10 Classification of NO_2 concentrations based on measurement data

NO_2 (ppbv)	**Color**
< 10	Blue
10 – 15	Light blue
15 – 20	Green
20 – 25	Yellow
25 – 30	Orange
> 30	Red

NO_2 concentrations in ambient air of Chiang Mai have been monitored using passive sampling following with spectrophotometry (Appendix D). As mentioned in topic 3.3, percent difference of NO_2 concentrations obtained from two techniques (32.7 %) was used to adjust concentrations of NO_2 in all sites. The result is shown in table 3.11. It was found that NO_2 concentrations of almost every site were changing. In November and December 2007 and April 2008, the values are one step up for most of sampling sites. While most of the values in January to March 2008 are two steps up. All adjusted values were then plotted to see ambient NO_2 geographic distribution (Figure 3.5)

Figure 3.6 (a-f) presents plots of NO_2 concentrations in all monitoring locations in Chiang Mai Province during November 2007 to April 2008. Levels of NO_2 concentrations were found to correspond with land use type, the population density and human activities in the sampling areas. In November 2007, most of NO_2 concentrations were lower than 10 ppbv in rural area, therefore most of spots plotted was blue. Only at U3 site (Waroros market) was red (> 30 ppbv, Figure 3.6 (a)). In this month, the major wind was from Northeast direction. However, it was not affected to NO_2 concentration in downwind sampling sites. In December 2007, more color appeared especially in urban area. Most of classification of NO_2 concentrations were increased one step in every sampling site in comparison with the levels in previous month. U2 and R4 sites were two steps exceptionally increased. In this month, the major wind direction was blown from Northwest to Southeast and Southwest to Northeast, which might be affected to sampling site in Northeast related to the data that NO_2 concentrations were increased in urban sites (Figure 3.6 (b)). In January 2008, the red color (>30 ppbv) appeared in two sampling sites (U1 and U2). Most of sub-urban sites was increased one step. Extra for, U6 and SU6 in which two steps were increased. In this month, the major wind direction was blown in the direction of South to North. The sites in urban area presented one step increasing of NO_2 concentrations (Figure 3.6 (c)). In February 2008, NO_2 concentrations of SU2, SU5, R1, R3 and R4 were increased one step (Figure 3.6 (d)). In March 2008, it was almost no change of classification of NO_2 concentrations except at sites U7 and SU6, which were increased one step. On the other hand sites U2, U4 and R3 were decreased one step (Figure 3.6 (e)). In April 2008, NO_2 concentrations in almost every site were decreased one step, which was similar to the trend found in November 2007 (Figure 3.6 (f)). It was found

that NO_2 concentrations in ambient air of Chiang Mai Province were not depended on wind direction, but pollutions from local activities such as traffic density and biomass burning. However, the influence of turbulence on passive sampler efficiency is likely to be site dependent (Varshney and Singh, 2003).

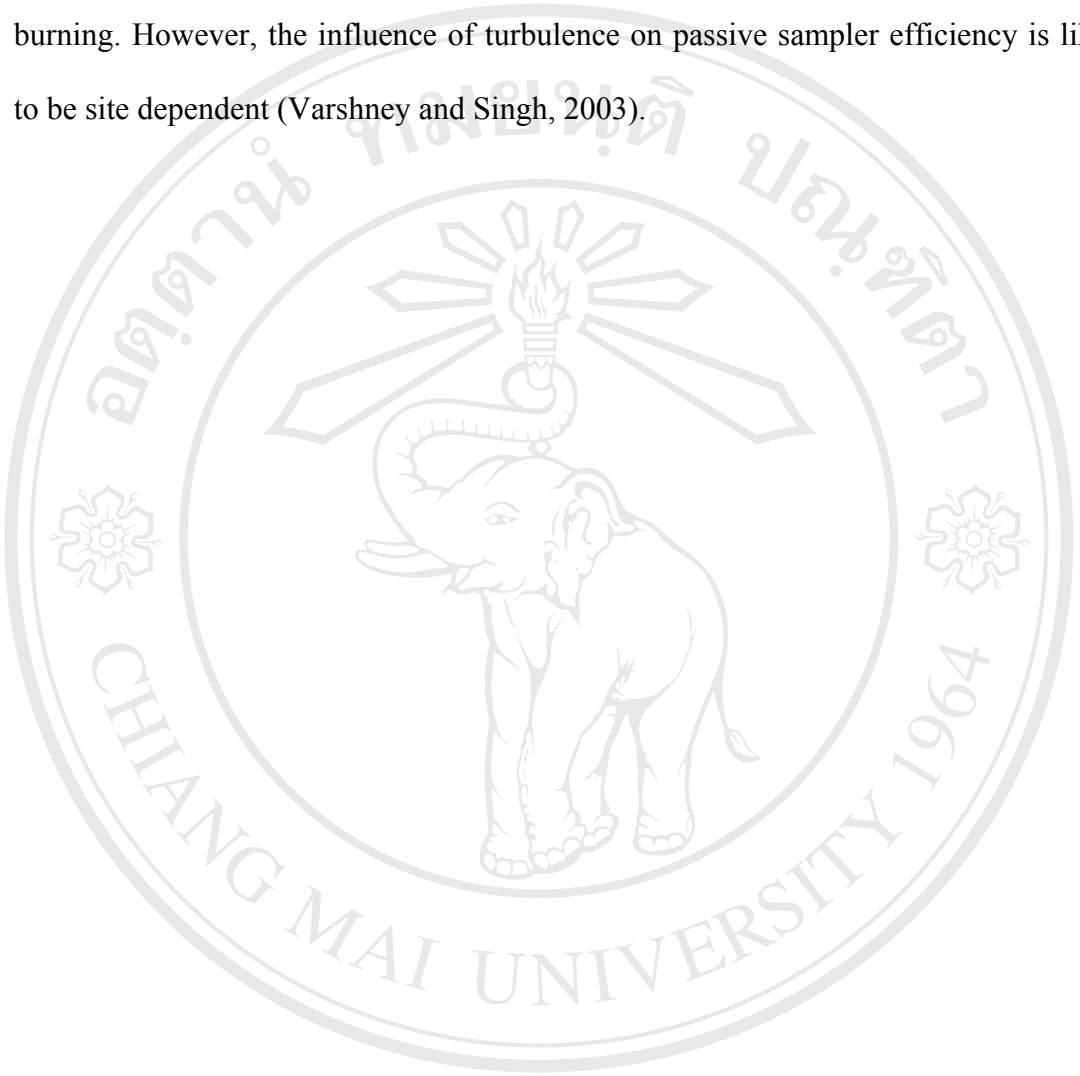

Table 3.11 Adjustment of NO_2 concentrations from passive sampling

Code	Mean NO_2 concentration (ppbv, N=3)																	
	November 2007			December 2007			January 2008			Febuary 2008			March 2008			April 2008		
	Before	After adjust	Level	Before	After adjust	Level	Before	After adjust	Level	Before	After adjust	Level	Before	After adjust	Level	Before	After adjust	Level
U1	FS	FS		22.5	29.5	+	28.2	37.8	+	20.2	29.7	+	17.6	27.6	++	16.3	23.1	+
U2	11.0	16.3	+	22.0	29.0	+	21.5	31.2	++	16.0	25.5	++	13.8	23.7	++	13.1	20.0	++
U3	28.1	33.4	+	42.5	49.4		45.1	54.7		36.5	46.0		39.4	49.3		37.4	44.2	
U4	FS	FS		18.8	25.7	++	17.2	26.9	++	17.6	27.1	++	11.2	21.2	++	15.0	21.8	++
U5	11.7	17.0	+	16.9	23.9	+	11.3	21.0	++	11.1	20.6	++	11.7	21.7	++	10.1	16.9	+
U6	9.0	14.3	+	6.4	13.3	+	11.6	21.2	++	11.9	21.4	++	10.5	20.5	++	12.4	19.2	+
U7	12.7	18.0	+	15.6	22.6	+	11.6	21.2	++	13.1	22.6	++	16.4	26.3	++	12.7	19.5	+
U8	8.4	13.7	+	10.1	17.1	+	13.8	23.5	++	9.4	18.9	++	6.3	16.3	++	12.6	19.5	+
SU1	FS	FS		15.4	22.3	+	16.4	26.1	++	18.4	27.9	++	19.1	29.1	++	17.1	23.9	+
SU2	5.4	10.7	+	9.3	16.3	++	13.4	23.1	++	6.8	16.2	++	5.1	15.1	++	5.5	12.3	+
SU3	FS	FS		13.1	20.0	+	16.1	25.8	++	13.6	23.1	++	13.3	23.2	++	14.0	20.8	+
SU4	FS	FS		14.1	21.1	+	7.3	17.0	++	9.1	18.6	++	9.9	19.8	++	10.7	17.5	+
SU5	10.3	15.6	+	11.0	18.0	+	12.0	21.7	++	8.0	17.5	++	9.0	18.9	++	6.3	13.1	+
SU6	5.0	10.3	+	8.9	15.9	++	17.9	27.6	++	7.6	17.1	++	13.6	23.5	++	6.9	13.7	+
R1	2.9	8.1		7.9	14.9	+	3.9	13.5	+	6.5	16.0	++	7.1	17.1	++	5.7	12.5	+
R2	1.6	6.9		5.4	12.4	+	6.9	16.6	++	2.9	12.4	+	4.0	13.9	+	4.8	11.6	+
R3	3.0	8.2		6.1	13.1	+	4.7	14.3	+	5.7	15.2	++	4.6	14.6	+	2.9	9.7	
R4	4.2	9.5		8.7	15.6	++	3.9	13.6	+	6.9	16.4	++	7.2	17.2	++	5.2	12.0	+
R5	2.2	7.5		3.4	10.4	+	3.8	13.4	+	4.3	13.8	+	2.2	12.1	+	2.7	9.5	
R6	3.1	8.4		4.5	11.5	+	3.1	12.8	+	4.2	13.7	+	2.9	12.9	+	3.1	9.9	

Note; FS – failed sampling (e.g., broken and lost diffusion tube)

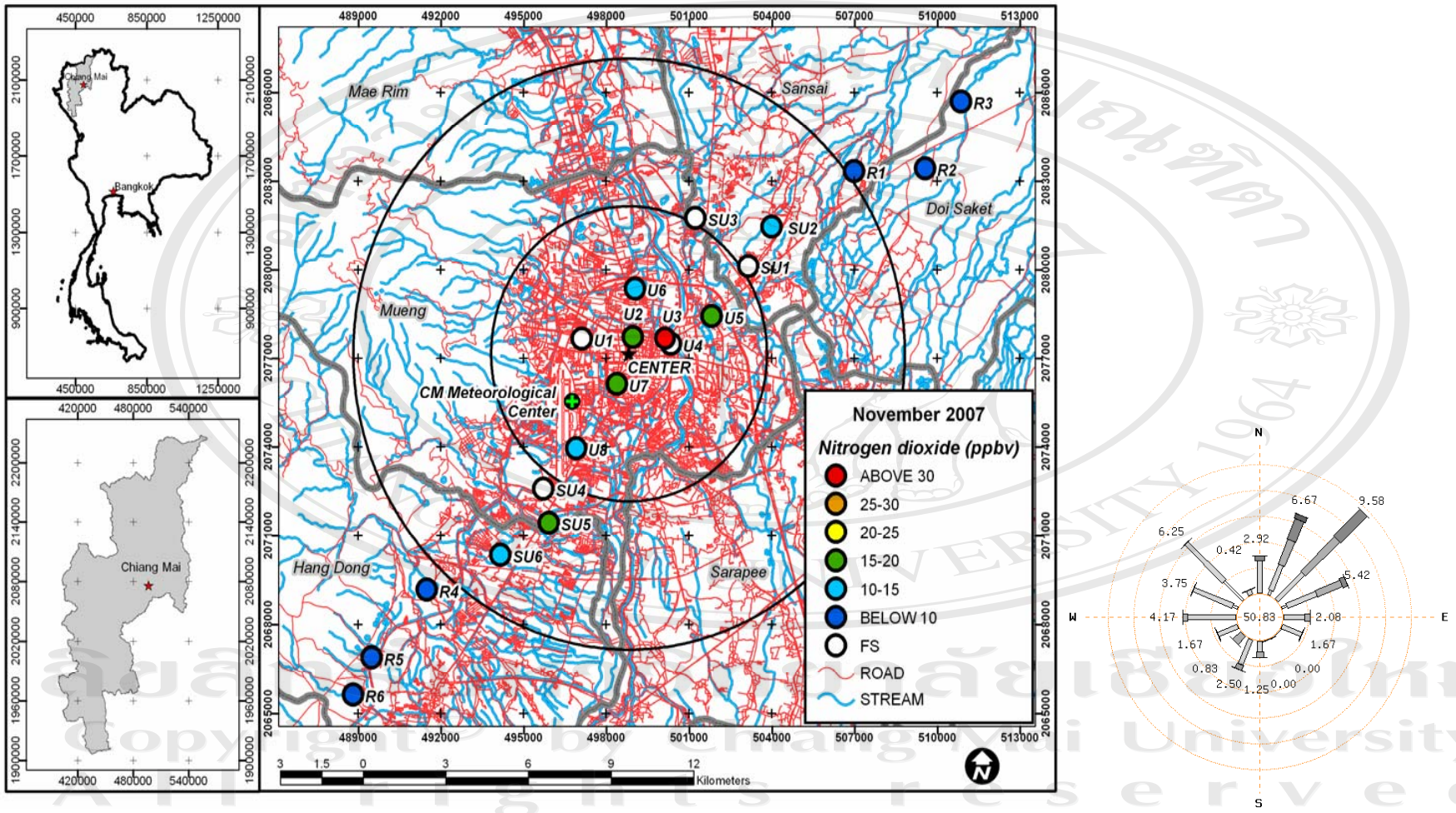

Figure 3.6 (a) Ambient NO_2 concentrations and wind rose of Chiang Mai Province in November 2007

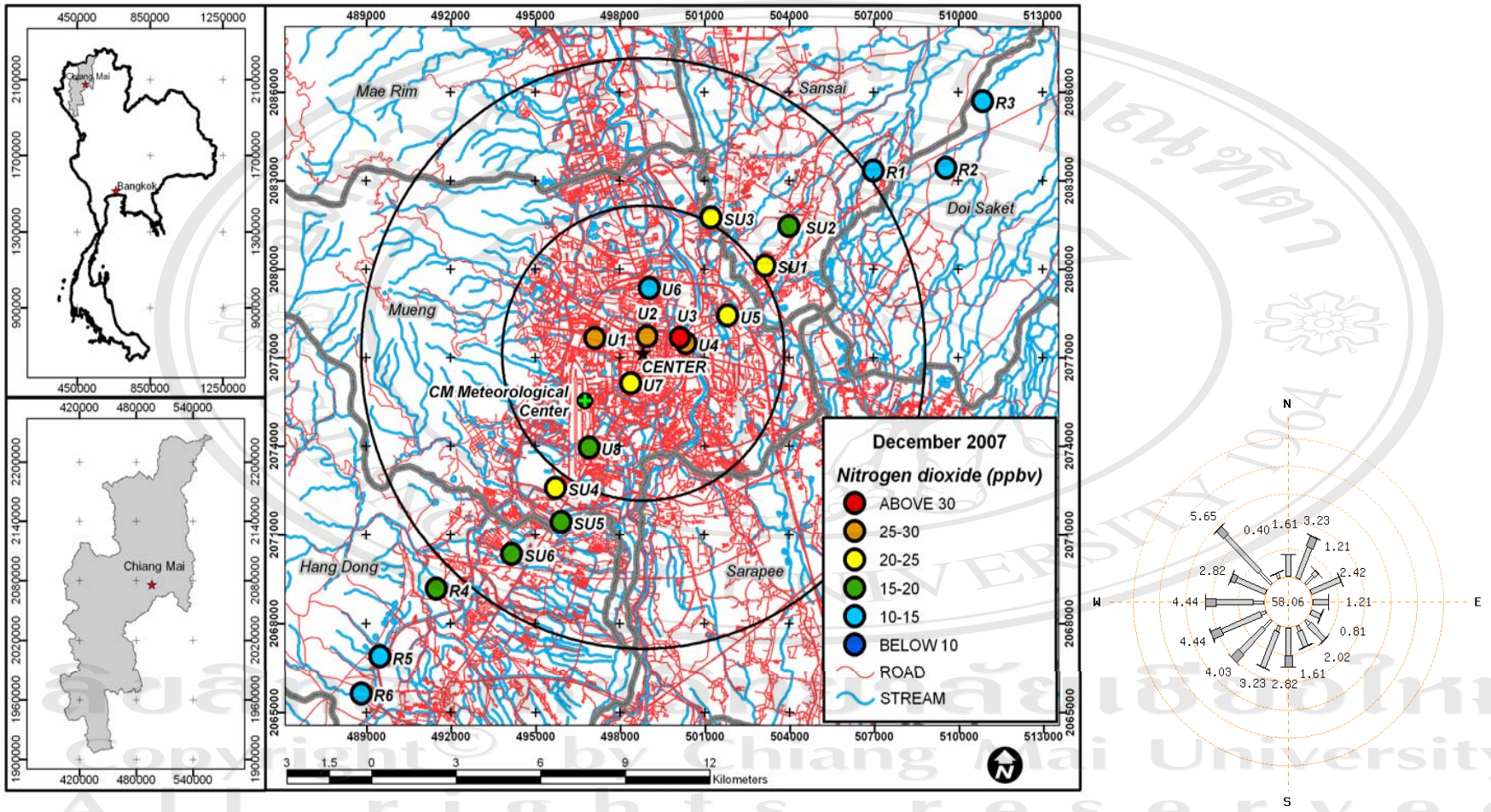

Figure 3.6 (b) Ambient NO_2 concentrations and wind rose of Chiang Mai Province in December 2007

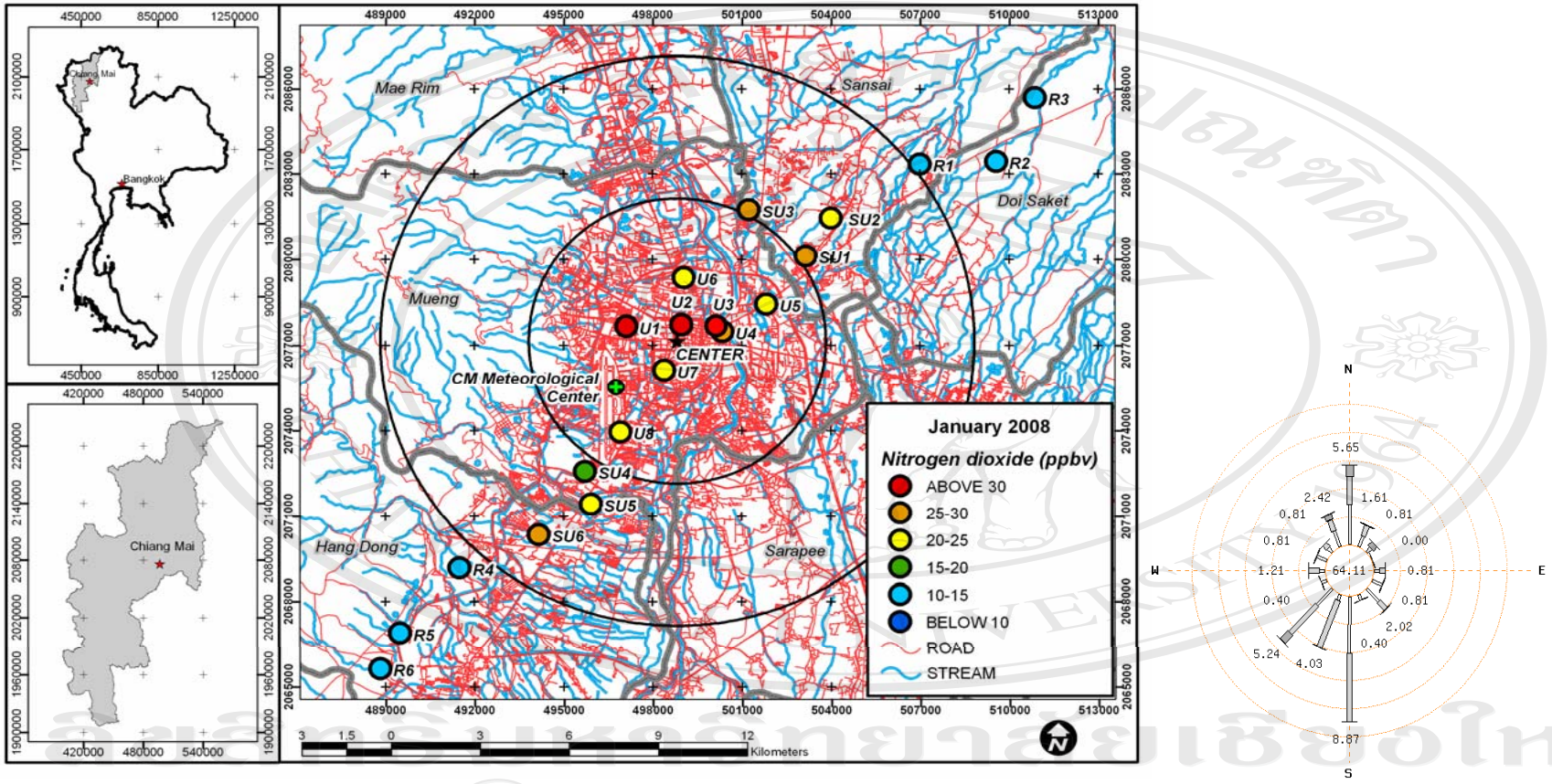

Figure 3.6 (c) Ambient NO_2 concentrations and wind rose of Chiang Mai Province in January 2008

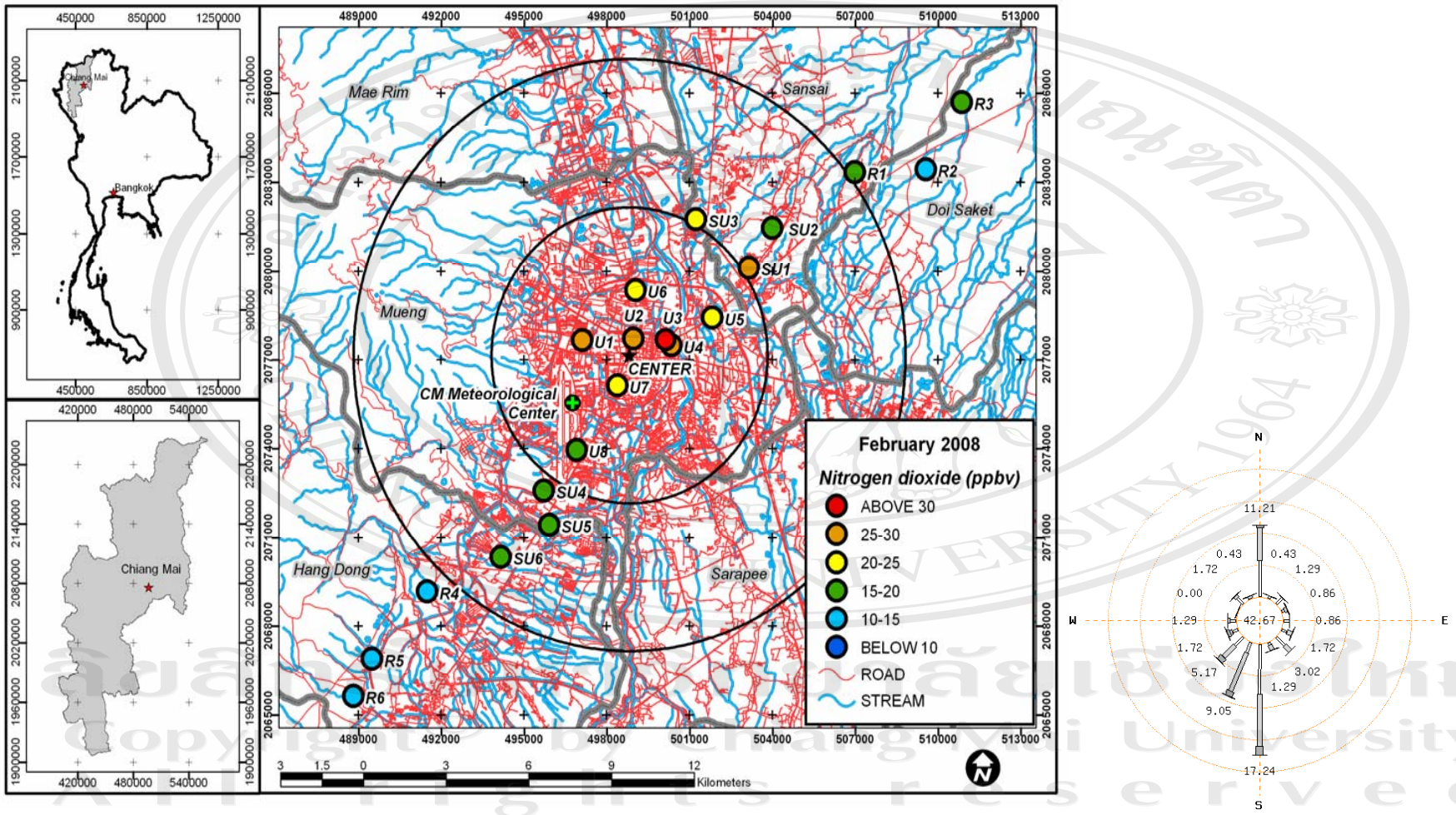

Figure 3.6 (d) Ambient NO_2 concentrations and wind rose of Chiang Mai Province in February 2008

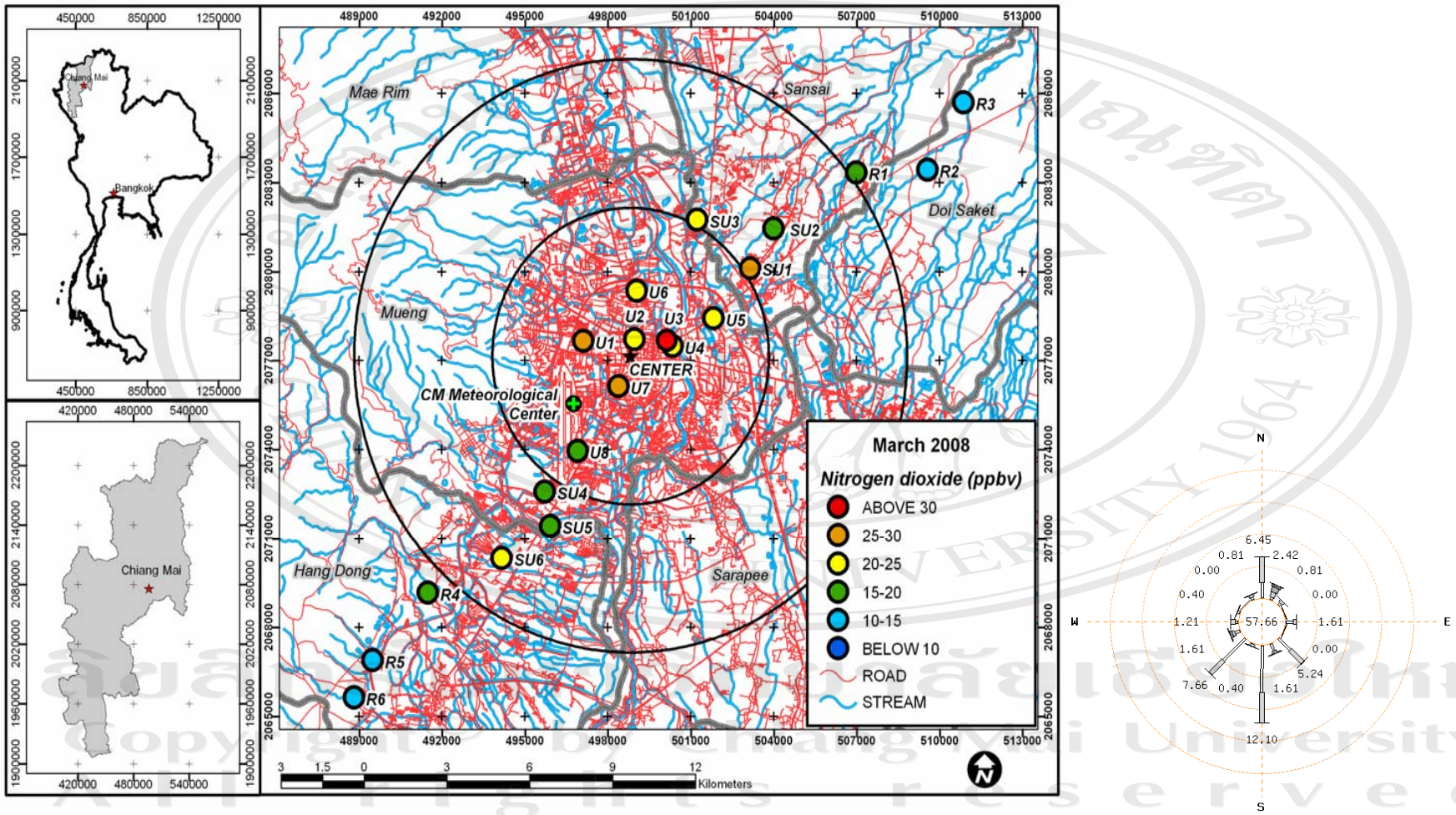

Figure 3.6 (e) Ambient NO_2 concentrations and wind rose of Chiang Mai Province in March 2008

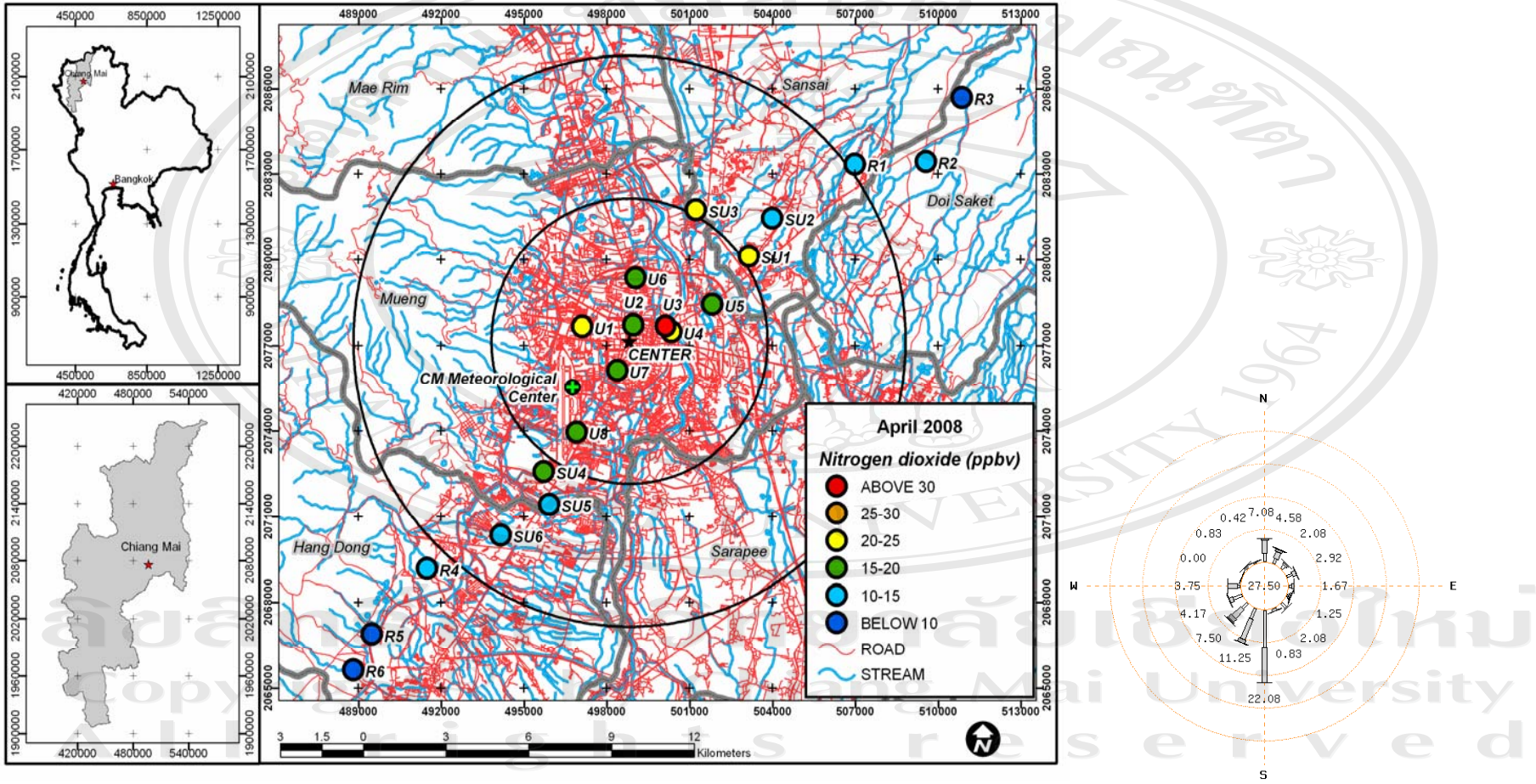

Figure 3.6 (f) Ambient NO_2 concentrations and wind rose of Chiang Mai Province in April 2008