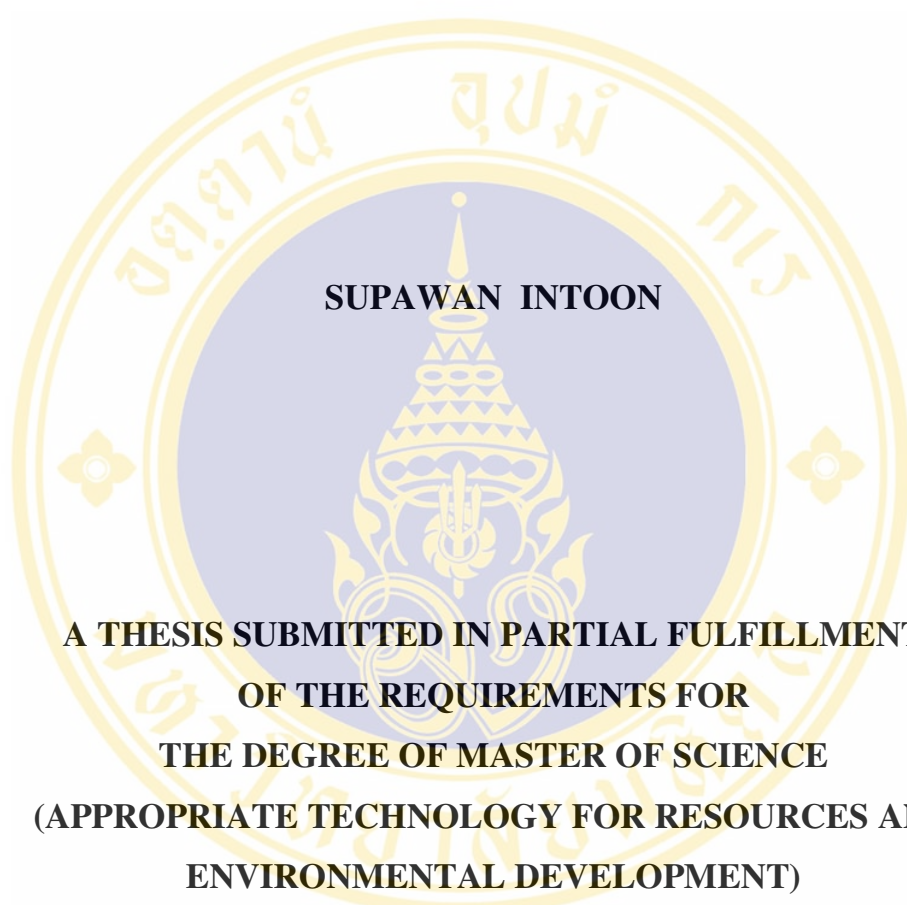


**ASSESSMENT OF NON – EXHAUST PM₁₀ LEVEL AND ITS
COMPOSITION AT THE ROADSIDE LOCATIONS IN BANGKOK**



SUPAWAN INTOON

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE
(APPROPRIATE TECHNOLOGY FOR RESOURCES AND
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ABSTRACT

The objectives of this research were to study the relationships of PM₁₀, PM_{coarse} and PM_{2.5} and to study the relationships of PM₁₀ and CO and NO_x. The data were collected during January 2001 – October 2004 from three roadside stations and two urban background stations operated by the Pollution Control Department, Ministry of Natural Resources and Environment. The study of mass concentrations of PM₁₀, PM_{coarse} and PM_{2.5} was based on the gravimetric method and were observed at Dindang roadside station. The data were pooled as pairs of PM₁₀ - PM_{2.5}, PM₁₀ - PM_{coarse} and PM_{2.5} - PM_{coarse}. The ratios of the interest pairs of size range were calculated. That ratio was used to estimate PM concentrations of interest. The values of intercept from relationships of roadside enhancement PM₁₀, CO and NO_x were used to determine the fraction of non – exhaust PM₁₀. Linear regression was applied as a statistical tool.

The results showed that there is a relationship between PM₁₀ and PM_{2.5} with 1% level of significance and the PM_{2.5}/ PM₁₀ ratio was 0.622 ($r^2 = 0.903$). PM₁₀ and PM_{coarse} with 1% level of significance and PM_{coarse}/ PM₁₀ ratio was 0.378 ($r^2 = 0.539$). The ratio of PM_{coarse} and PM_{2.5} was 0.568 ($r^2 = 0.374$). It is found that the mass concentrations of PM₁₀ and PM_{2.5} were higher in the dry season. The wet season had no effect on variation of PM concentrations.

The relationship between roadside enhancement PM₁₀ and roadside enhancement CO at Dindang station and Nonsiwitthaya school station showed that the fraction of non – exhaust PM₁₀ in daily average PM₁₀ at Dindang station was 0.40. The fraction of non – exhaust PM₁₀ in daily average PM₁₀ from the relationship between roadside enhancement PM₁₀ and roadside enhancement NO_x was 0.37. Both of the fraction values were similar. It was noticeable that the fraction of non – exhaust PM₁₀ in daily average PM₁₀ was higher during the wet season than in the dry season.

KEY WORDS: PM₁₀/PM_{2.5}/PM_{coarse}/NON – EXHAUST PARTICLE
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การประเมินระดับของอนุภาคฝุ่นขนาด 10 ไมครอน ที่ไม่ได้เกิดจากไอเสียรถยนต์และ
องค์ประกอบที่บริเวณริมถนนในเขตกรุงเทพมหานคร (ASSESSMENT OF NON-
EXHAUST PM₁₀ LEVEL AND ITS COMPOSITION AT THE ROADSIDE
LOCATIONS IN BANGKOK)

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บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาความสัมพันธ์ระหว่างปริมาณฝุ่นละอองที่มีขนาดเล็กกว่า 10 ไมครอน (PM₁₀) ฝุ่นหยาบ (PM_{coarse}) และฝุ่นละอองที่มีขนาดเล็กกว่า 2.5 ไมครอน (PM_{2.5}) รวมถึงศึกษาความสัมพันธ์ระหว่างฝุ่นละอองที่มีขนาดเล็กกว่า 10 ไมครอน (PM₁₀) กับก๊าซคาร์บอนมอนอกไซด์ (CO) และก๊าซออกไซด์ของไนโตรเจน (NO_x) โดยใช้ข้อมูลในเขตกรุงเทพมหานคร ระหว่างเดือนมกราคม 2544 – ตุลาคม 2547 จากสถานีตรวจวัดคุณภาพอากาศของกรมควบคุมมลพิษ กระทรวงทรัพยากรธรรมชาติและสิ่งแวดล้อม บริเวณพื้นที่ทั่วไป และพื้นที่ริมถนน การศึกษาความสัมพันธ์ระหว่างฝุ่นละอองทั้ง 3 ขนาด ด้วยวิธีการตรวจวัดแบบ Gravimetric Method โดยนำปริมาณฝุ่นละอองทั้ง 3 ขนาดจากสถานีดินแดงมาจับคู่ในวันที่มีการตรวจวัดพร้อมกัน แล้วนำมาหาสัดส่วนของปริมาณฝุ่นละออง ทำให้สามารถคาดการณ์ปริมาณของฝุ่นละอองได้ ค่า Interception ที่ความสัมพันธ์ระหว่างค่า Roadside enhancement ของ PM₁₀, CO และ NO_x ระหว่างบริเวณพื้นที่ริมเส้นทางจราจรและบริเวณพื้นที่ทั่วไป ใช้ในการหาสัดส่วนของ PM₁₀ ที่ไม่ได้เกิดจากไอเสียรถยนต์ ซึ่งการวิเคราะห์ข้อมูลทางสถิติใช้วิธีการวิเคราะห์หาคออยเชิงเส้นอย่างง่าย

ผลการศึกษาพบว่า ปริมาณ PM₁₀ และ ฝุ่น PM_{2.5} มีความสัมพันธ์ที่ระดับนัยสำคัญทางสถิติ 0.01 โดยค่าสัดส่วนของ PM_{2.5} ต่อ PM₁₀ ตลอดระยะเวลาศึกษาเท่ากับ 0.622 ($r^2 = 0.903$) ปริมาณ PM₁₀ กับ PM_{coarse} มีความสัมพันธ์ที่ระดับนัยสำคัญทางสถิติ 0.01 โดยค่าสัดส่วนของ PM_{coarse} กับ PM₁₀ เท่ากับ 0.378 ($r^2 = 0.539$) ส่วนฝุ่น PM_{coarse} กับ PM_{2.5} มีค่าสัดส่วนเท่ากับ 0.568 ($r^2 = 0.374$) เมื่อพิจารณาค่าสัดส่วนของปริมาณฝุ่นขนาดต่าง ๆ ในแต่ละฤดูกาล พบว่า ปริมาณ PM_{2.5} และ PM₁₀ มีค่าสูงในช่วงฤดูแล้ง ส่วนฤดูฝนไม่มีอิทธิพลต่อการผันแปรสัดส่วนของ PM₁₀ กับ PM_{coarse} และ PM_{coarse} กับ PM_{2.5}

จากความสัมพันธ์ระหว่างปริมาณ Roadside enhancement ของ PM₁₀ กับ CO ระหว่างสถานีดินแดงและสถานีโรงเรียนนทรวิวิทยา พบว่า ค่าสัดส่วนระหว่าง PM₁₀ ที่ไม่ได้มาจากไอเสียของยานยนต์กับปริมาณ PM₁₀ เฉลี่ยของสถานีดินแดง เท่ากับ 0.40 ค่าสัดส่วนของ PM₁₀ ที่ไม่ได้มาจากไอเสียของยานยนต์กับปริมาณ PM₁₀ เฉลี่ยของสถานีดินแดงที่ได้จากความสัมพันธ์ระหว่าง ปริมาณ Roadside enhancement PM₁₀ กับก๊าซ NO_x มีค่าเท่ากับ 0.37 และเมื่อเปรียบเทียบค่าสัดส่วนดังกล่าวที่ได้จากความสัมพันธ์ทั้ง 2 ความสัมพันธ์ พบว่ามีค่าใกล้เคียงกัน ซึ่งค่าสัดส่วนของฤดูกาลต่าง ๆ พบว่า ในฤดูฝนมีค่าสัดส่วนสูงกว่าฤดูกาลอื่น ๆ

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CONTENTS

	Page
ACKNOWLEDGMENT	iii
ABSTRACT (ENGLISH)	iv
ABSTRACT (THAI)	v
LIST OF TABLES	viii
LIST OF FIGURES	x
CHAPTER	
I INTRODUCTION	
1.1 State of the Problem	1
1.2 Objectives	6
1.3 Scope of Study	6
1.4 Expected Results	6
1.5 Conceptual framework of the study	7
1.6 Definition	7
II LITERATURE REVIEW	
2.1 Air pollution	8
2.2 Particulate matter	9
2.3 The major source of the fine particulate matter in Bangkok	14
2.4 Effect of particulate matter	18
2.5 Particulate matter measurement	25
2.6 Carbon monoxide	31
2.7 Nitrogen oxide	35
2.8 Air pollution situation in Bangkok	37
2.9 Relevant researches	40

CONTENTS (CONTINUED)

	Page
III RESEARCH METHODOLOGY	
3.1 Study site	44
3.2 Data collection	44
3.3 Data processing	45
3.4 Data analysis	46
IV RESULTS AND DISCUSSIONS	
4.1 Relationship of PM ₁₀ , PM _{2.5} and PM _{coarse}	48
4.2 Relationship between Roadside enhancement PM ₁₀ and Roadside enhancement CO	55
4.3 Relationship between Roadside enhancement PM ₁₀ and Roadside enhancement NO _x	65
V CONCLUSIONS AND RECOMMENDATIONS	
5.1 Conclusions	78
5.2 Recommendations for Further Study	79
REFERENCES	80
APPENDIX	85
BIOGRAPHY	118

LIST OF TABLES

TABLE	Page
2 – 1 Uncontrolled Reentrainment Emission (Tons per year PM ₁₀)	14
2 – 2 PM ₁₀ split between coarse and fine fraction and estimated contributions by source type at four Bangkok monitoring sites	14
2 – 3 Uncontrolled Mobile Source PM ₁₀ Inventory (Ton per year)	15
2 – 4 Uncontrolled Construction Source PM ₁₀ Emission (Ton per year)	15
2 – 5 Uncontrolled Industrial Boiler PM ₁₀ Emission (Ton per year)	16
2 – 6 Uncontrolled Power Plant PM ₁₀ Emissions (Ton per year)	16
2 – 7 PM ₁₀ Emission in Bangkok in 1996 (Ton per year)	17
2 – 8 Particle Effect to Human Health	23
2 – 9 International Air Quality Standards on CO in comparison to Thai standard	25
2 – 10 International Air Quality Standards on PM ₁₀ and PM _{2.5} in comparison to Thai standard	25
2 – 11 International Air Quality Standards on NO ₂ in comparison to Thai standard	26
2 – 12 Estimated global man – made emissions of carbon monoxide	32
2 – 13 Concentration of PM ₁₀ at urban background area in Bangkok during 1996 – 2002	38
2 – 14 Concentration of PM ₁₀ at roadside area in Bangkok during 1996 – 2002	38
2 – 15 Concentration of CO at urban background area in Bangkok during 1998 – 2002	39
2 – 16 Concentration of CO at roadside area in Bangkok during 1998 – 2002	39
2 – 17 Concentration of NO ₂ at urban background area in Bangkok during 1996 – 2002	39

LIST OF TABLES (CONTINUED)

TABLE	Page
2 – 18 Concentration of NO ₂ at roadside area in Bangkok during 1996 – 2002	40
3 – 1 Pattern of data analysis	45
4 – 1 The best – fit equation of relationship between PM ₁₀ and PM _{2.5} for prediction PM _{2.5} concentration of Dindang station	50
4 – 2 The best – fit equation of relationship between PM ₁₀ and PM _{coarse} for prediction PM _{coarse} concentration of Dindang station	53
4 – 3 The best – fit equation of relationship between PM _{2.5} and PM _{coarse} for prediction PM _{coarse} concentration of Dindang station	54
4 – 4 Result of regression analyses of PM ₁₀ and CO of Dindang station and Nonsiwitthaya school station, 2001 – 2003	58
4 – 5 Result of regression analyses of PM ₁₀ and CO of Intrapitak station and Nonsiwitthaya school station , 2001 – 2004	61
4 – 6 Result of regression analyses of PM ₁₀ and CO of Chokchai 4 station and Klongjan station, 2002 – 2004	64
4 – 7 The fraction of non - exhaust particle to average PM ₁₀ concentrations of PM ₁₀ and CO at Dindang station, 2001 – 2004	65
4 – 8 Result of regression analyses of PM ₁₀ and NO _x of Dindang station and Nonsiwitthaya school station, 2001 – 2004	68
4 – 9 Result of regression analyses of PM ₁₀ and NO _x of Intrapitak station and Nonsiwitthaya school station, 2001 – 2003	71
4 – 10 Result of regression analyses of PM ₁₀ and NO _x of Chokchai 4 station and Klongjan station, 2001 – 2004	74
4 – 11 The fraction of non - exhaust particle to PM ₁₀ from concentrations of PM ₁₀ and NO _x at Dindang station, 2001 – 2004	75
4 – 12 Comparison of the fraction of non - exhaust particle to average PM ₁₀ at Dindang station, 2001 – 2004	75

LIST OF FIGURES

FIGURE	Page
1 – 1 Conceptual Framework of the study	7
3 – 1 Methodology of Non – exhaust particle	47
4 – 1 Average annual concentration of PM ₁₀ at Dindang station during 2002 – 2004	49
4 – 2 Range and Average concentration of PM _{2.5} at Dindang station during 2002 – 2004	50
4 – 3 Range and Average concentration of PM _{coarse} at Dindang station during 2002 – 2004	52
4 – 4 Roadside enhancements PM ₁₀ of Dindang station and Nonsiwitthaya school station during 2001 – 2003	56
4 – 5 Roadside enhancements CO of Dindang station and Nonsiwitthaya school station during 2001 – 2003	57
4 – 6 Roadside enhancements PM ₁₀ of Intrapitak station and Nonsiwitthaya school station during 2001 – 2004	59
4 – 7 Roadside enhancements CO of Intrapitak station and Nonsiwitthaya school station during 2001 – 2004	60
4 – 8 Roadside enhancements PM ₁₀ of Chokchai 4 station and Klongjan station during 2002 – 2004	62
4 – 9 Roadside enhancements CO of Chokchai 4 station and Klongjan station during 2002 – 2004	63
4 – 10 Roadside enhancements PM ₁₀ of Dindang station and Nonsiwitthaya school station during 2001 – 2004	66
4 – 11 Roadside enhancements NO _x of Dindang station and Nonsiwitthaya school station during 2001 – 2004	67
4 – 12 Roadside enhancements PM ₁₀ of Intrapitak station and Nonsiwitthaya school station during 2001 – 2003	69

LIST OF FIGURES (CONTINUED)

FIGURE	Page
4 – 13 Roadside enhancements NO _x of Intrapitak station and Nonsiwitthaya school station during 2001 – 2003	70
4 – 14 Roadside enhancements PM ₁₀ of Chokchai 4 station and Klongjan station during 2001 – 2004	72
4 – 15 Roadside enhancements NO _x of Chokchai 4 station and Klongjan station during 2001 – 2004	73
B – 1 Dindang station	114
B – 2 High volume air sampler for PM ₁₀ measurement	114
B – 3 Partisol - Plus air sampler for PM _{2.5} measurement	115
B – 4 Intrapitak station	115
B – 5 Nonsiwitthaya school station	116
B – 6 Chokchai 4 station	116
B – 7 Klongjan station	117

CHAPTER I

INTRODUCTION

1.1 State of the Problem

Air pollution is a serious environmental problem in Thailand. The problem is worse in the urban area than the country area, especially Bangkok area, which is the center of economic and social development. The main source of air pollution problem in Bangkok is the road transport (1) due to traffic congestion, the rapid growth of vehicles which is not corresponding to the road area, and the use of impure fuel, including the deficient implementation of the environmental law. Vehicle exhaust deteriorates air quality by increasing the levels of air pollutants such as CO, SO₂, and particulate matter in the air. Currently, the level of particulate matter near to the roadside sites is the most significant problem in Bangkok due to the traffic congestion and the dense traffic.

Road traffic is one of the most important sources of particle air pollution, with the main source being the combustion process. The majority of the particles emitted to the atmosphere from vehicle exhaust, especially in urban area, are due to combustion in diesel engine. However, there are a number of the non – exhaust processes which have received relatively little attention and which may contribute significantly to atmospheric particle concentrations. Exhaust particles from diesel engines are subjects to regulatory control, whereas non – exhaust particle emissions are not regulated for any type of road vehicle. As exhaust particle emissions per vehicle decreases with time, the relative contribution from the non – exhaust sources increases. The main non – exhaust particles sources relating to road traffic are considered to be tire wear, brake wear, clutch wear, road surface wear, and corrosion of traffic related components and resuspension of road dust.

PM₁₀ and PM_{2.5} are produced by a wide range of activities including natural wind erosion of soil, combustion of fossil fuel, mining, handling of minerals and transportation. Particulate matter in ambient air causes several impacts on human and environment, for example, visibility reduction, aesthetics impairment, human health problems. The particle size is of major importance in determining the toxic significance as the inhaled particles are deposited in different regions of the respiratory system depending on their aerodynamic particle size. The larger particles (5 – 10 µm) are deposited in the nasopharyngeal and tracheobronchial regions and are generally removed after a short time by ciliary action and are subsequently swallowed. Smaller particles (0.01 – 2.5 µm) are deposited more efficiently in the pulmonary region of the lung. The efficiency of extraction of toxic species from particles deposited in the pulmonary region is high (60 – 80 %), whereas the efficiencies of extraction in the nasopharyngeal, tracheobronchial and stomach regions are low (5 – 15%). A number of observational population – based epidemiological studies have reported associations between airborne particles and a range of outcomes from decreased respiratory capacity to mortality (2). Moreover, a study in the relation between truck traffic and lung function in children living near motorways in the Netherlands found that the chronic respiratory symptoms and lung function decrements in children were associated with local truck traffic density and with black smoke concentration (3). Several studies on the concentration of PM_{2.5} and diesel exhaust particles on Harlem sidewalks in New York found that the spatial variations in concentrations were related to local diesel traffic density. Mean concentrations of PM_{2.5} exhibited 37 – 47 µg/m³, reflecting the importance of broader regional sources of PM_{2.5}. The results showed that the diesel exhaust particles concentration are influenced both by vehicular traffic and by point sources such as bus depots, where large number of diesel vehicles congregate (4).

According to the air pollution research conducted by Environment Department of Spain (5) which studied the influence of traffic on the PM₁₀ and PM_{2.5} in Madrid, Spain, PM₁₀ and PM_{2.5} concentrations show good agreement with traffic – related pollutants, such as nitrogen oxides and carbon monoxide, being time – correlated in

winter pollution episodes. The major source of the PM_{10} and $PM_{2.5}$ fractions was generated by the traffic emission.

In 2001, the recent work conducted by World Bank on the relationship between the exposure to particulate matter and the premature mortality and the respiratory symptoms (6) clearly indicates the relationship between particulate matter and health effect in Bangkok. The result showed that the air pollution directly affected people's health. 15% and 60% of people who lived in Bangkok area had a risk to be exposed to chronic respiratory illnesses and throat irritation with increasing tendency to such illness respectively. The World Bank study determined the economic (cost/benefit) due to air pollution. The results show that the residents of Bangkok spend about 12.5% of their total medical expenses on respiratory illnesses alone (about 131 baht per family per month). If $20 \mu/m^3$ annual average PM_{10} concentrations reduce, about 65 – 175 billion baht could be saved (based on 1995 prices and U.S. to baht exchange rate of 1 to 25) (6). The maximum 24 – hour average PM_{10} at roadside station observed in 2000 was about $240 \mu g/m^3$ (7). In 2002, the range of 24 – hour PM_{10} was about 9.3 – 268.6 $\mu g/m^3$ and 11.0 – 300.0 $\mu g/m^3$ at permanent stations and temporary stations respectively. While, the standard of PM_{10} 24 – hour average is regulated at 120 $\mu g/m^3$. There are seven roadside monitoring stations in Bangkok. They are operated by Pollution Control Department of Ministry of Natural Resources and Environment. The monitoring results at roadside stations show higher concentrations of air pollutions than the urban background station indicates that motor vehicles are the large emitters (8).

CO is a clear, odorless gas produced by the incomplete combustion of fossil fuels and organic substances. The natural degradation of plant matter can also contribute to the production of CO, but the vehicles are by far the largest man – made source. The highest ambient CO concentrations usually occur near congested transportation arteries and intersections. CO is not a respiratory irritant, but rather passes through lungs and interferes with the transfer of oxygen in blood. Symptoms of exposure include dizziness, headache and in extreme cases, loss of consciousness (9). Road transport is know to be one of the main sources of urban pollution, although

other sources also linked to combustion processes, such as domestic residential and institutional heating, also contribute to significant pollutant emissions in urban areas. In addition, a study on the relationship between the CO and PM₁₀ concentration in U.K. estimated the road traffic contribution to PM₁₀ within 10 U.K. urban areas used CO as a tracer of traffic emission. The relationship between the CO and PM₁₀ concentration calculated using linear regression analysis. In summer and winter particularly, the correlations between the two pollutants were found to be highly significant allowing a relationship to be identified. All emissions of CO within urban area arise from road traffic (10).

Nitrogen oxides (NO_x) from when fuel is burned at high temperature, as in a combustion process. Many of the nitrogen oxides are colorless and odorless. The primary sources of NO_x are motor vehicles, electric utilities and other industrial, commercial and residential sources that burn fuels. NO_x react with ammonia, moisture and other compounds to form nitric acid vapor and related particles. Human health concerns include effects on breathing and the respiratory system, damage to lung tissue and premature death. Small particles penetrate deeply into sensitive parts of the lungs and can cause or worsen respiratory disease such as emphysema and bronchitis and aggravate existing heart disease (11). In addition, a study on the relationship between particulate and NO_x concentration reflects to the exhaust emission. PM₁₀ concentrations are associated with high and are likely to arise from road traffic emissions. So that the comparison of the particulates, NO_x and CO concentrations indicates that traffic – induced resuspension is a significant source (10).

Particulate matter is emitted from a variety of sources besides fuel combustion, which increase the difficulty and uncertainty in quantifying their emission. Emissions from stationary combustion and road transport are certainly major sources, but there are also significant emissions from industrial processes, construction and quarrying and fugitive sources through mechanical break – up, abrasion and erosion (e.g. vehicle tyre and break wear). These sources are particularly difficult to quantify and vary both spatially and temporally, particularly construction. A particular problem arose suspension of road dust by traffic, which seems to be a major contribution. Non –

exhaust particles originate from wear and corrosion of road pavement and vehicle components like; tyre and brakes. Road maintenance, road equipment and particles originating in the road surroundings also contribute. This research identified the non – exhaust and exhaust particle that was emitted to the atmosphere in urban area by using the relationship between the concentrations of particulate and CO, and particulate and NO_x.

In U.S.A, EPA has set an air quality standard at 50 µg/m³ for long – term 1 – year average concentration of PM₁₀; for short – term 24 – hour, PM₁₀ concentration should not exceed 150 µg/m³ more than once a year. Long term (annual) PM_{2.5} concentrations should not exceed 15 µg/m³ more than once a year, and the short – term (daily) PM_{2.5} concentrations should not exceed 65 µg/m³ more than once a year. In Thailand, an air quality standard of 120 µg/m³ for short – term 24 – hour PM₁₀ concentrations has been set, and long – term 1 years average concentration should not exceed 50 µg/m³, but PM_{2.5} has not been set, so there is no official monitoring along with PM₁₀. Consequently, since the present situation of monitoring, controlling and abatement of these PM_{2.5} is not informed, measures to control PM_{2.5}, which affects health, cannot be established.

In order to study the relationship among PM₁₀, PM_{2.5} and PM_{coarse} concentration, the PM₁₀ concentration would be used to estimate PM_{2.5} and PM_{coarse} concentration and useful for air quality management in urban area. Because both of the particulate matters directly had an effect on people's health, especially those who reside in Bangkok area. Moreover, this study focuses on the relationship between particulate matter, CO and NO_x concentration on the roadside in Bangkok area in order to see the tendency and predict including to provide the management of the non – exhaust particle. Since the traffic has an effect on air quality and is also the major source of CO and NO_x.

1.2 Objectives

1. To study the correction of $PM_{10} - PM_{2.5}$, $PM_{10} - PM_{\text{coarse}}$ and $PM_{2.5} - PM_{\text{coarse}}$
2. To assess the non – exhaust particle near to roadside sites

1.3 Scopes of the study

Air quality data was obtained from three the roadside stations (Dindang station, Chokchai 4 station and Intrapitak station) and two urban background stations (Nonsiwitthaya school station and Klongjan station). These stations are operated by Pollution Control Department (PCD). Particulate matters in this study were PM_{10} , $PM_{2.5-10}$ and $PM_{2.5}$. PM_{10} and $PM_{2.5}$ were measured by the Gravimetric High Volume method. CO concentration in this study was measured by Non – Dispersive Infrared Detection method and NO_x concentration was measured by Chemiluminescence method. The particulate matter, CO and NO_x data of four – year period from January 2001 to October 2004 were used.

1.4 Expected Results

The relationship between the concentration of particulate matters and CO and NO_x can be used for

1. Realization the source of particulate matters is from the various vehicles on the roadside.
2. Prediction of the mass concentration of particulate matter from the roadside to plan of air quality control and management in Bangkok in the future years.

1.5 Conceptual Framework of the Study

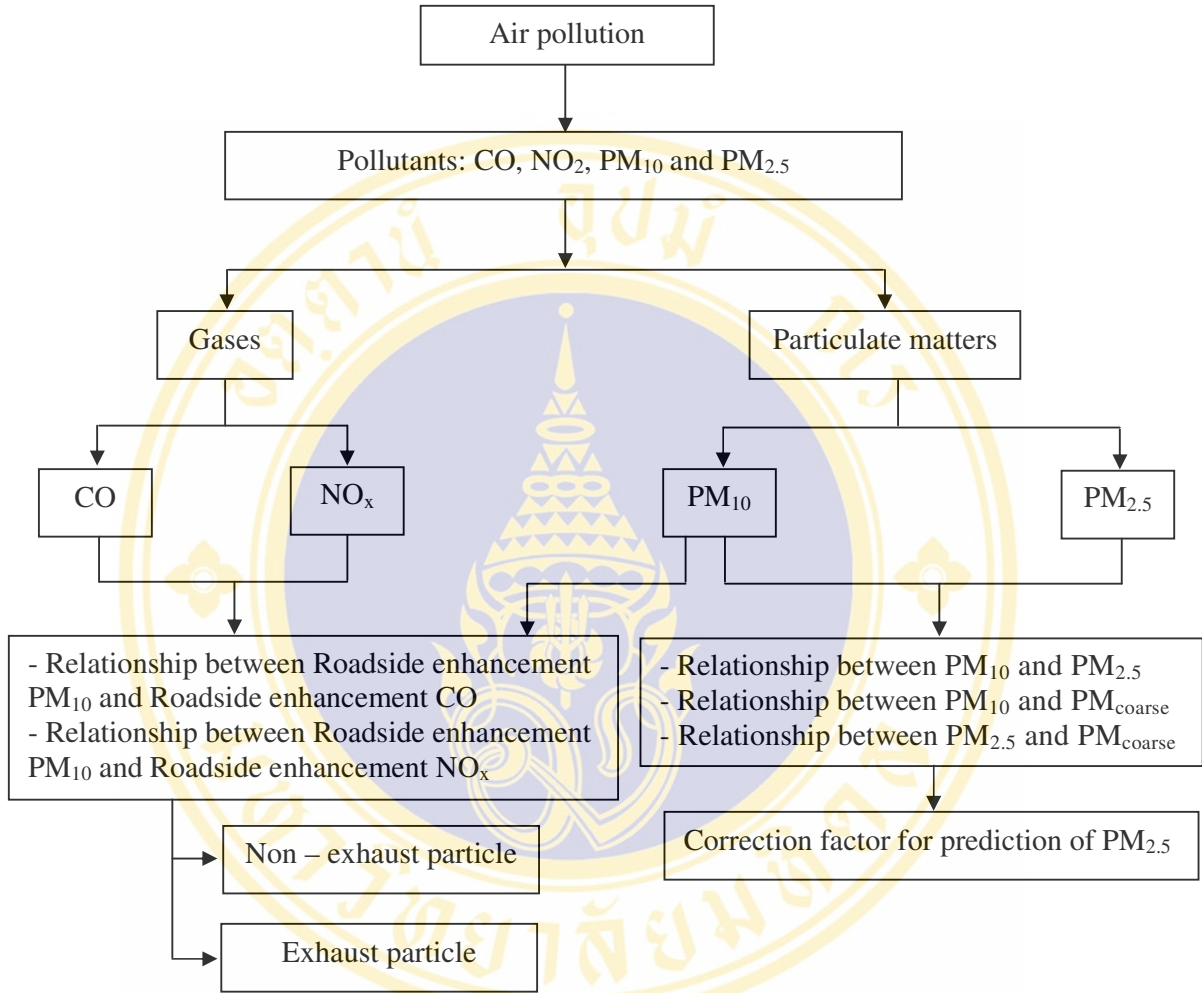


Figure 1 – 1 Conceptual Framework

1.6 Definition

Coarse particle (PM_{coarse}): the suspended particulate matter in size range of 2.5 – 10 micron.

CHAPTER II

LITERATURE REVIEW

This research studies about the relationships between the concentration of the particulate matter less than 10 micron (PM_{10}), 2.5 micron ($PM_{2.5}$) and PM_{coarse} ($PM_{2.5-10}$), CO and NO_x by studying the following:

- 2.1 Air pollution
- 2.2 Particulate matter
- 2.3 The major source of the fine particulate matter in Bangkok
- 2.4 Effect of particulate matter
- 2.5 Particulate matter measurement in the atmosphere
- 2.6 Carbon monoxide
- 2.7 Nitrogen Oxides
- 2.8 Air Pollution situation in Bangkok
- 2.9 Relevant researches

2.1 Air pollution

2.1.1 Definition of air pollution

Air is the composition of gaseous in the atmosphere. It consists of dry air. Its average by volume at sea level is 78.09% nitrogen, 20.95% oxygen, 0.93% argon, 0.03% carbon dioxide and other gases. Pure air occurs when the air has not enough pollutants to cause harm to human's or animal's health and other natural condition (12).

Air pollution refers to the open air condition which contains enough volume of contaminants such as dust, fumes, gases, mist, odor, smoke so as to cause harm to human's or animal's health or damage human wealth and other natural environment (12).

2.2 Particulate matter

2.2.1 Primary and secondary particle

Particles in the atmosphere may be liquid or solid. Their sizes range from 0.002 micron to less than 500 micron, which are minute singular molecules or combination of those minute singular molecules. Particles can occur in different ways as follow (9).

Aerosol: particulates formed by the coagulation of solid or liquid particles with gas which acts as the suspension medium. This term is a general term for most particulates in the atmosphere, which range in size from 0.001 micron to 100 micron.

Dust: a solid – particle aerosol, is formed by mechanical disintegration of parent material, such as by crushing or grinding. Particles range in size from submicrometer to visible size.

Smoke: particulates which can be seen by naked eyes, they can be caused by incomplete combustion and are usually either solid or liquid particles smaller than 1 micron.

Fume: a solid – particle aerosol, is produced by the condensation of vapors or gaseous combustion products. Its particle size is generally less than 1 micron. Note that this definition is different from the popular use of the term to refer to any noxious contaminant in the atmosphere.

Fly ash: non – combustible residue that results from burning fuels in an incinerator, boiler or furnace. It can include metal oxides, silicates and sulfur compounds, as well as many other chemical pollutants. It is fine ash carried along by flue gases that must be capture by some means before it reaches the mouth of the chimney.

Mist: a liquid – particle aerosol, is formed by condensation or atomization. Its particle size ranges from submicron to about 20 micron.

Spray: which is developed by making liquid to be sprayed out under pressure e.g. insecticide, herbicide which is larger in size than mist.

Respirable particle or inhalate particle: particulates smaller than 10 micron which can access to the human respiratory system.

Coarse particle: particulates matter is in the range of 2.5 – 10 micron.

Fine particle: particulates smaller than 2.5 micron.

The primary aerosol has particles that are introduced directly into the atmosphere, whereas a secondary aerosol has particles that are formed in the atmosphere by chemical reactions of gaseous components (gas – to particle conversion). Most secondary particles are formed from hydrocarbon, oxide of nitrogen and oxide of sulfur (13) or combined with solid particle by physical reaction or photochemical reaction. The particles formed from these reactions have different names depending on the characteristics of the formation (14).

2.2.2 Size and shape of particles

The shape of particles can be divided into two types: spherical particle and non - spherical such as cubical – quadrilateral particle and bar particle. The spherical particles are measured by diameter and non – spherical particles by using the spherical diameter which is equal cubic content's particle. The particulate matters in the atmosphere are mostly more than 10 micron to 0.001 micron. Most particles have the same size as the visible light 0.4 – 0.7 micron, so these particles has an effect on the light transmission. The particles that cause air pollution are generally 0.01 micron to 10 micron in size, particles which are less than 1 micron normally gradually fall to the ground. The industrial pollutants from some processes such as pulverized coal are normally 3 micron to 400 micron. Industrial pollutants, resulted from combustion processes, vaporization and condensation, are in miniature size between 0.01 micron to 1 micron, they are those particles of condensed hydrocarbon, gasoline and tars. Other particles sizes are between 0.01 micron to 100 micron such as metallurgical fumes, carbon black powdery, cement dust, fly ash and sulfuric acid mist. The particles sizes that are between 0.5 micron to 5 micron can harm the lungs. It was found the human body could eliminate the particles which are larger than 10 micron by the nose and the throat. Some particles could pass to the trachea. Most particles between 5 micron to 10 micron could be eliminated in the trachea so that they could

not pass into the lungs. The particles which are less than 2.5 micron could pass to the lungs (13).

2.2.3 Particles behavior in the atmosphere

Fine particles or particles with the diameter of about 0.005 micron to 0.1 micron can normally be in the atmosphere because of the hot vapor condensation from the combustion sources. When hours pass, each fine particle would agglomerate into the larger size. Sometime the agglomeration would occur in the gaseous state by the Brownian motion so the particles contact with each others. These agglomerations may occur in the fog or cloud. The larger particles, between 0.1 micron to 1 micron, can develop in two ways. First, the small particles are agglomerated, and second, the gases or vapor are chemically changed and become the particles in the atmosphere. These particles can become large enough that they can be eliminated from the atmosphere by rainout catchments in the cloud or rain washout. The particles between 2 micron to 100 micron can occur from many procedures e.g. the industrial sources, mist from the sea, volcano and plant particles. Most of these particles can be eliminated from the atmosphere by the gravity force with or without cloud and rain action (13). The large particles (diameter larger than 100 micron) may suspend in the atmosphere for 2 – 3 minutes, but those less than 0.5 micron can do so for many years because of the low rate of velocity (of falling). They can also suspend longer if the outside action such as the air ventilation and wind speed is involved (15).

2.2.4 Particulate matter less than 10 micron (16)

Particulate matters less than 10 micron, the important air pollutant, consist of solid and small semi – solid such as dust, smoke, fume and soot. The particles are formed from the combination of many kinds of substance and different chemical compounds. Moreover, they can be developed from many sources: natural sources and human activities. Those that are developed from natural sources are soils, sea spray, and those from human activities are (1) fuel combustion, especially from diesel engine vehicle, (2) open – combustion such as waste incineration, (3) agricultural waste

combustion such as grass and straw, (4) industrial processes such as stone crushing mill and cement works. PM₁₀ including fly ash from power plant, black smoke from vehicles or diesel engine vehicles and soot from kilns. The particles from these sources have high volume of both organic carbon and elemental carbon. These carbons affect health because they are respirable. The (respirable) particles can be divided into two sizes: coarse fraction particulate and fine fraction particulate. These two kinds of particles vary in sources, chemical compound and behavior.

Coarse fraction particulates are those between 2.5 micron to 10 micron. Most of the coarse fraction particles are from the combination of natural particles such as windblown soil dust, which are the primary particles that are directly emitted into the air. They cannot be changed by chemical reaction, so the particles can be easily classified by chemical compound sources as these compounds rarely change in the air. Some of particles is developed from mechanical process such as grinding, millstone, construction, demolition, stone explosion, cement industry, road dust and soil erosion by wind. These particles are normally from the earth surface. Their chemical compound is mostly crystalline oxide such as iron, aluminum, silicon, manganese and zinc. Their organic compound mostly consists of wax, fatty acid.

2.2.5 Particulate Matter less than 2.5 micron (16)

Fine particles with sizes less than 2.5 micron are solid and semi volatile particles. They mostly consist of secondary particulates from the combustion of gases such as SO₂, NO₂ and volatile organic compound (VOC). When the gases are in the combustion process, they are chemically and physically changed (gas to particle conversion). The fine fraction particles are firstly formed by combustion or secondary chemical reaction in the atmosphere.

Primary fine particulates are developed by the combustion process as follow:

1. Gas condensation or particle vaporization in high temperature condition.
2. Homogeneous Nucleation (only if the is properly high concentration of gas or vapour). The particle from combustion sources are directly released primary fine fraction particles to the atmosphere and secondary fine fraction particulates are formed by several reactions in the atmosphere.

PM_{2.5} is developed by three processes as follow:

1. The reaction between gaseous molecules which leads to a new kind of particles.
2. Coagulation of two particles which leads to large particles.
3. Interaction of gas particles and absorbable gas. This reaction relates to initial gas such as SO₂, NO₂ and volatile organic compound (VOC).

PM_{2.5} consists of primary fine particulate and secondary fine particulate. They can be in the air for a long period and also move to very long distance (100 – 1,000 km). The particulate tend to uniform dispersion in the urban area. It is very difficult to find out their sources.

The important source of PM_{2.5} is from (1) human activities such as fossil fuel combustion process from power plant, industry, (2) diesel engine vehicles such as trucks, (3) bio – fuel combustion such as straw and grass and coal burning. Furthermore, natural sources of bioaerosol such as bacteria, virus and endotoxin, release many kinds of chemical compounds which are the main compound of secondary fine particulates such as ammonium sulfate and ammonium nitrate. So, SO₂, NO₂ and NH₃ are important precursors of secondary particle (e.g. ammonium sulfate and ammonium nitrate). Fossil fuel from power plants, industry, vehicles, agricultural waste incineration and other combustion are important sources of sulfate compound, nitrate acid, organic carbon, element carbon, trace element, NH₃ and water.

2.3 The major sources of the fine particulate matter in Bangkok (17)

2.3.1 Reentrained dust emission.

The emission is caused almost exclusively by vehicle traffic due to dispersion. Emissions rates from this source depend upon vehicle traffic, weight, speed and the amount of dust deposited on the roads. The activities with the most significant contributions to total silt loading include:

- Wheel track out from construction sites

- Truck bed material loss
- Aggregate/debris piles
- Unpaved areas adjacent to roadways
- Areas disturbed during roadway construction.

A slight decline in uncontrolled reentrainment emission is expected over time, primarily due to the continued decreasing of average vehicle speeds as congestion increases. (As vehicle speeds decrease, so do emission rates.) This decrease occurs in spite of continued increases in distance, unless congestion is decreased by new roadway development.

Table 2 – 1 Uncontrolled Reentrainment Emission (Tons per year PM₁₀)

Uncontrolled Reentrainment Emission	1996	2000	2005
Reentrained Dust Emission	20,378	18,971	15,436

Source: (17)

2.3.2 Mobile sources.

These sources of PM_{2.5} are from incomplete combustion. PM_{2.5 -10} are inorganic materials from grinding coarse particulates. The dispersion mostly are running vehicles and compaction of the particulate matters on the road surface.

Table 2 – 2 PM₁₀ split between coarse and fine fraction and estimated contributions by source type at four Bangkok monitoring sites

Average coarse and fine PM ₁₀ fractions from Anderson Cascade 24 - hr average				
	Bansomdej	EGAT South	Odeon Cir	Pratunam
PM – 2.5 (µg/m ³)	31.0	35.3	95.7	119.4
PM 10 – 2.5 (µg/m ³)	60.9	30.8	87.6	132.0
PM – 10 (µg/m ³)	91.9	66.1	183.3	251.4
%PM – 2.5	33.7 %	53.3 %	52.2 %	47.5 %
%PM 10 – 2.5	66.3 %	46.7 %	47.8 %	52.5 %

Source: (17)

From Table 2 – 3, the mobile source inventory is dominated by heavy duty diesel vehicles and two – stoke motorcycles. In addition, emission falls dramatically, over time for all vehicle classes except for the heavy duty diesel. This fall is due to the retirement of older, higher polluting vehicles and their replacement with new vehicles meeting tighter emissions standard. The emission reduction in this replacement was more than the increase in emission resulted from increasing vehicles.

Table 2 – 3 Uncontrolled Mobile Source PM₁₀ Inventory (Ton per year)

Vehicle Class	1996	2000	2005
Heavy Diesel*	8,319	7,313	4,920
Motorcycles	2,882	3,262	2,507
Gasoline Cars	1,489	1,382	1,326
Light Diesel Trucks	1,353	1,362	1,392
Total	14,043	13,319	10,145

*Includes buses, city truck and long – haul trucks

Source: (17)

2.3.3 Construction activities.

Construction emissions is estimated from standard emission factors and Bangkok Metropolitan Administration construction permit data.

Table 2 – 4 Uncontrolled Construction Source PM₁₀ Emission (Ton per year)

Activities by phase	% of Total Emission	1996 Emission	2000* Emission	2005* Emission
Phase I: Demolition, Debris Removal	25	438	476	514
Phase II: Site Preparation (land clearing, soil scraping)	25	438	476	514
Phase III: General Construction (materials handing, cement/ concrete work, reentrainment)	50	876	952	1,028
Total Emissions	100	1,752	1,904	2,056

* 2% per year growth factor assumed.

Source: (17)

2.3.4 Industrial and commercial boiler.

According to the inventory indented by Chulalongkorn University, there are 424 industrial plants and 804 individual fuel oil combustion sources.

Table 2 – 5 Uncontrolled Industrial Boiler PM₁₀ Emission (Ton per year)*

Location	1996	2000	2005
Bangkok	15,028	15,028	15,028
Samut Prakan	2,411	2,411	2,411
Nonthaburi	677	677	677
Total	18,115	18,115	18,115

* Sulfur level fixed at 2% from 1996 forward.

Source: (17)

2.3.5 Utility boiler.

There are two power plants serving the BMR, a relatively small one in Nonthaburi (North Bangkok), and the main plant in Samut Prakan (South Bangkok). All boilers at these facilities burn the equivalent of US#6 (residual) fuel oil, with 1.7% sulfur. The standard emission factor equation is modified to account for the effects of the high asphaltene levels found in some of the fuels. Given the fuel consumption values for the two plants and the emission factors, the uncontrolled emissions levels are estimated and summarized in Table 2 – 6.

Table 2 – 6 Uncontrolled Power Plant PM₁₀ Emissions (Ton per year)*

Plant	1996	2000	2005
North Bangkok	803	803	803
South Bangkok	6,388	6,388	6,388
Total	7,191	7,191	7,191

* sulfur levels at 1.7% in 1996 and thereafter, as per the government mitigation plan.

Source: (17)

In 1996, it was estimated that there was 20,378 tons of PM₁₀ dust, which accounted for 33.2% of the dust from all sources, emitted from this source category.

Another source was industrial and commercial boilers, which produced 18,115 tons of PM₁₀ or 29.5%, from burning of fossil fuel. Automobile dust, from burning fuel in automobile engines, also produced a large amount of PM₁₀ dust, 14,043 tons/year or 22.8%. Power plants and construction activities especially transportation of construction materials added more PM₁₀ 7,191 tons/year or 11.7% and 1,752 tons/year or 2.9%, respectively.

Table 2 – 7 PM₁₀ Emission in Bangkok in 1996 (Ton per year)

Sources	Emission	%
Reentrained Dust	20,378	33.2
Industrial and Commercial Boiler	18,115	29.5
Mobile Sources	14,043	22.8
Utility Boiler	7,191	11.7
Construction Activities	1,752	2.9

Source: (17)

2.4 Effect of particulate matter

2.4.1 Effect on the ambient air

Particulate matters can reduce the visibility because they are solid particles and they are able to absorb, reflect and scatter light. The size, intensity and chemical compositions also influence how well the visibility is (18).

2.4.2 Effect on the object and construction

Particulate matters can be harmful to materials and construction such as metal corrosion, surface demolition from construction and art work deterioration. The important processes that have such effects are as follow:

- **Abrasion.** The suitable size of solid particles that move quickly can cause material abrasion, which depends on size, velocity, shape and sharp and pointed edge of the particle.

- **Deposition and removal.** The particles do not directly destroy the object but dirty the object, thus making it hard to clean. Because of this, the cleaning can erode the object.

- **Electrochemical corrosion.** Many metals such as iron can be destroyed by electrochemical process. When metals contact the air, the iron rust can occur. The rust thus can destroy the iron.

Other processes which cause particulate pollutant are as follow:

- **Moisture** is the major factor that accelerates the corrosion by aerosol. Especially rough materials are easier to break than smooth materials. The destruction is support by acidic gas such as SO_2 . When SO_2 combines with moisture in the air, H_2SO_4 occurred and that is a powerful erosive.

- **Temperature.** If temperature is high, it helps accelerate the chemical reaction. This causes more damage.

- **Sunlight.** The more photochemical reaction, the more the material and construction can be damaged.

- **Air movement.** Wind current is an important factor to disperse the particulate matter onto the surface of an object. The particulates then abrade the material causing the abrasiveness of the surface of the object.

2.4.3 Effect on indoor air quality

The air quality is important for people who normally spend their time indoor more than outdoor. This includes in office, vehicle, school and other places. The important factors influencing indoor air quality are as follow:

- **Outdoor air quality.** The particulate matters can spread inside the building by open entrances, leakage such as doors, windows and vent hole.

- **Indoor particle.** This occurs from activities inside the building such as cooking, cleaning and painting.

- **Building construction appearance.** Particle ventilation between outside and inside the building depends on the characteristic of the building such as open or close building, the numbers of windows and doors and other ventilation.

- **Ventilation system and air – conditioning system of the building.** Close systems ventilate the air to outside by the ventilators and air – conditioning system move the air inside by air filter system. The indoor particle will be from only indoor activities.

- **Meteorological and geographical air conditions.** The difference of the temperature inside the building and that outside the building, air pressure, air movement and wind current can influence the particles from outside into inside of the building.

- **Building location** can determine the quality of outdoor particles such as the building on the side of the street can get more indoor particles.

2.4.4 Effect on plant

The particles, such as tar, on the leaves, stems, flowers and fruits in dry condition can turn them yellow and withered or inhibit growing rate of plants. Moreover, the particles can also increase the sun radiations ranging between 400 – 760 nm, decreasing the photosynthesis process and causing the increase in the plants' absorbing the sun radiation ranging between 1,750 – 1,850 nm, which in turn increasing the heat in the leaves (9).

2.4.5 Effect on human health

The large particles irritate the upper respiratory system. PM_{10} can penetrate to the respiratory system and damage the organic tissue such as lung tissue. If the tissue get high volume of the particles or get it for a long period of time, the particles can be trapped in lung tissue and causes wound and asthma. This effect can finally cause of the respiratory diseases.

2.4.5.1 The process of left over particle in respiratory system

1. Inertial impaction

The 5 – 10 micron particles have inertia in crashing with posterior pharyngeal wall. When people breathe in, the particles flow to nasopharynx, causing 90° of them sticking in the nostril and the nasopharynx. Only little of them is in upper trachea. Those that flow down normally are in the bifurcation of the trachea.

2. Sedimentation

The 0.5 – 5 micron particle can pass through the long and may stick in trachea. For the particle of 2 – 5 micron, they often stick at central or proximal airway because the airway is larger than 2 mm. The particles of 0.5 – 2 micron can still be in peripheral airway because the airway is smaller than 2 mm.

3. Diffusion

For the particles smaller than 0.5 micron, it is as if gas passes through alveolar unit in the manner of Brownian movement which very small particles can be breathed out, with only a small amount still in the air sac.

4. Gravitational setting. Gravimetric setting is the drop of the particles by gravitation.

5. Electrostatic attraction.

Electrostatic attraction is the drop or form of the particles depending on the difference of the electric charge of the particles.

2.4.5.2 A left over particle position

1. Upper respiratory tract

Nose and nasopharynx are the first gate of preventive mechanic of respiratory system. Nose can filter the particle that is larger than 5

micron, so the particle that is large than 10 micron can still stick in the nose. Moreover, nose can trap very small particles, Radon substances, Hydro – dissolvable gas such as SO₂. However, inhaling while exercising and inhaling by using the mouth can draw more pollutant to lower trachea.

2. Lower respiratory tract

The 2 – 5 micron particles are often stuck at central airway by impaction and 2 micron particles are often stuck at peripheral airway by sedimentation. Alveolar deposition depends on particle sizes, respiration characteristic and the size and shape of trachea. Hygroscopic particles are those that absorb water to be large so they often stuck at central airway such as sodium chloride.

2.4.5.3 Danger mechanism of particle (19)

1. Alveolar inflammation

The inflammation results from the accumulation of small particles and chemical reaction response. These causes the increase the white blood cell.

2. Clotting pathway

White blood cells are stimulated and silted by protein in plasma. Plasma protein is then changed to be protein (fibrinogen) which relates to blood solidification and releasing from pneumatocytes. This is the cause heart attack.

3. Plasma viscosity

A case study in Germany found that the relationship between plasma intensity and air pollution level alternation in non – smoking men and women group. The study of change in blood circulation resulted from inflamed of air

sac in the lungs, which leads to the immediate reaction by the pathology, that is used to explain the relationship between the level of the particles in the air and the sudden death.

4. Airway reactivity

The muscle shrinks when trachea and large bronchial tube are stimulated by cold weather, smoke and air pollution. Allergy substance will be released, causing suffocated symptom and bronchial asthma.

2.4.5.4 Particle Preventive Mechanism

Hair in a nostril is the particle trap. Nasal mucus and throat mucus can trap small particle that passed nostril. Cilia, which cannot be seen, in the respiratory tube, blows the mucus to the neck as phlegm 12 times per second. The filtration varies as follow:

1. Coarse filtration. The kind of filtration is for small particles (diameter size < 15 micron) which can see. This kind of particles is released by sneezing, blowing the nose or gulping down the saliva.

2. Fine filtration. This kind of filtration is for small particle (diameter size 5 – 15 micron). This kind of particles can pass though nose and throat to trachea. Then, the respiratory mucus traps particles and blow them to the upper respiratory tract, and in about 20 minutes, by sneezing, blowing the nose or gulping down the saliva.

3. Cellular level defense. The kind of filtration is for particles with diameter size less than 5 micron. Some particles are breathed in and breathed out, some are destroyed by macrophage. Those that cannot be destroyed can damage the macrophage cell and penetrate to the lung tissue. The destroyed particles will be released by sneezing or blowing the nose though the lymph tube.

The level of danger of particles to respiratory system depends on the factors as follow:

1. Type of particles involved which yields different chemical and physical results.
2. Particle number concentration which is > 5 mppcf (1 million particle per 1 ft³ air) can be dangerous to the respiratory system. However, toxic particles can be less than 1 mppcf.
3. Particle size. Particles between 2 – 10 micron may cause the disease because they can pass through respiratory more. For the particles larger than 10 micron, they can often stick in the nose, mouth and throat.
4. Length of exposure. It may take about 10 years of exposure for the disease to reveal the symptom.
5. Hypersensitivity. Healthy people and unhealthy people can resist the disease differently.

Table 2 – 8 Particle Effect to Human Health

Diameter	Source	Effect
0.01 – 0.05 μm	Traffic congestion, exhaust pipe	When particle are mixed with gas, white blood cells will be produced a lot of more. Toxic substances will be released causing the lung to be swollen. Left – over particles at lung tissue can causes pneumoconiosis. Whoever get the particles and SO ₂ of 150 – 200 μm/m ³ concentration in a very short time or receive 100 – 200 μm/m ³ and 60 – 140 μm/m ³ concentration in long period of time tend to get lung disease and respiratory system disease.
0.01 – 2 μm	Exhaust pipe in urban area	0.01 – 2 μm particle mixed with SO ₂ or NO ₂ can be stuck at the trachea, causing respiratory way swell.
< 3 μm	Fuel combustion	Pass to the middle and lower respiratory tract in lungs and air sacs. If it is dissolvable, the lymph system and blood can absorb defects.
> 5 μm	Crowed urban area	Trapped and left over in upper respiratory tract. Cilia can be blown through the throat and released as phlegm or be swallowed.
> 10 μm	Construction and traffic congestion area	Trapped in the nose and the upper respiratory tract that affects vision.

Source: (20)

2.5 Particulate Matter Measurement

2.5.1 Air Quality Measurement

The measurement is the important procedure to control air pollution. It needs to be corresponded with technology or law procedure as well. Air quality measurement has many objectives and the measure planning needs to be corresponded to the following objectives (21).

1. To study the effect of air pollution on the environment and human health.
2. To study the effect of air pollution sources.
3. To be used in urban planning.
4. To identify the causes of air pollution.
5. To study the behavior of air pollution distribution.
6. To study the tendency of air pollution in a long period.
7. To study preliminary data for planning air quality measurement.

2.5.2 Air Quality Standard

Air quality standard refers to the determination of the highest level allowance of pollutant in the air. These prevent the danger to people and ecological system; and it depends on the objectives of the laws on:

1. Human health and welfare
2. Plants and animals
3. Property and other resources
4. Water and air transportation

According to the National Environmental Board announcement in 1995, standard level of the particles in the ambient air was determined by using gravimetric high volume at pressure 1 atmosphere, 25 °C for the average particulate size less than 100 micron (Total Suspended Particulates). In the air, the 24 hour average does not exceed 0.33 mg/m³ and geometric mean in 1 year does not exceed 0.1 mg/m³. The

average of those less than 10 μm (PM_{10}) in 24 hour is not more than 0.12 mg/m^3 and geometric mean in 1 year does not exceed 0.05 mg/m^3

Table 2 – 9 International Air Quality Standards on CO in comparison to Thai standard

Country	CO	
	1 hr (ppm)	8 hr (ppm)
USA	35	9
California	20	9
Netherlands	40	6
Australia	-	9
Europe Union	25	10
Canada	15	6
New Zealand	30	10
WHO	30	10
Thailand	30	9

Source: (22)

Table 2 – 10 International Air Quality Standards on PM_{10} and $\text{PM}_{2.5}$ in comparison to Thai standard

Country	PM_{10} ($\mu\text{g}/\text{m}^3$)		$\text{PM}_{2.5}$ ($\mu\text{g}/\text{m}^3$)	
	24 hr	Annual	24 hr	Annual
USA	150	50	65	15
California	50	30	-	-
Japan	-	-	-	-
Netherlands	-	-	-	-
Australia	-	-	-	-
Europe Union	50	-	-	-
Canada	-	-	-	-
New Zealand	120	50	-	-
WHO	-	20 – 50	55	-
Thailand	120	50	-	-

Source: (22)

Table 2 – 11 International Air Quality Standards on NO₂ in comparison to Thai standard

Country	NO ₂		
	1 hr (ppm)	24 hr (ppm)	Annual (ppm)
USA	-	-	0.053
California	0.26	-	-
Japan	-	-	-
Netherlands	-	-	-
Australia	0.16	-	-
Europe Union	0.026	-	-
Canada	-	-	-
New Zealand	0.15	-	-
WHO	0.11	-	0.021 – 0.026
Thailand	0.17	-	-

Source: (22)

2.5.3 Particulate matter measurement

The particulate matters in the ambient air are the pollutants which have unstable form. The characteristic of size, weight, surface area, volume, density and chemical composition are varied. These characteristics determine the particulate sampling and measurement. The measurement of the particulate matters in the ambient air can be divided into:

2.5.3.1 Microscopic measurement of Particle Size

Microscopic measurement of the particle size is the direct measurement of separation of particle size (14)

1. Optical microscopy. The optical microscopy is used in the general science for counting and separating the 0.3 – 20 micron particle collected on the slide plate and observe through the different expanding lens.

2. Electron microscopy. The electron microscopy is used to count and separate the invisible particle by the general microscopy. The measurement can be classified into two types; Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM)

3. Electron microprobe. This analyzer has been developed from SEM and can be used to classify and measure particulates automatically. The method is based on the use of X-ray beam to detect particulate matter in atmosphere.

2.5.3.2 Direct – reading instrument

Continuously automatic instruments are used in direct – reading measurement. This method measures the physical characteristic of the particle instead of directly weighting measurement so as to weight the light – weight particle (23). This method is divided into:

1. Spot optical density measurement. Spot optical density measurement such as beta – ray absorption method is the method of collecting the particle on the filter paper and measuring the spot optical density of the filter paper by radiating the beta – radiation through the particles. The particle could adsorb the beta – ray and the amount of the particles directly in proportion to the ratio of the beta – ray adsorption rate. This method can be used to measure the particle less than 10 micron.

2. Light – scattering photometry. Light – scattering photometry is the instrument which is based on the scattering principle. The amount of the light scattered by the particles is proportionately varied on the quantity of the particulate matters. It can measure and separate the particulate matter of 0.1 micron. The instruments based on this principle are:

- Owl instrument. Owl instrument is the basic instrument used to measure the monodispersed aerosols by using the light deviation at 90°. It can be used to measure the particulate matter of 0.1 – 0.4 micron and the light deviation which causes the color band which can be used to measure the particulate matter of 0.4 – 2 micron.

- Photometer. Photometer is the instrument used to measure the scattering of light caused by the particulate matters by setting the reflection angle at 90, 45 and 30°. It can also measure the particulate matter of $1 \mu\text{m}/\text{m}^3$ – $100 \text{mg}/\text{m}^3$.

- Integrating nephelometers. Integrating nephelometer is the instrument used to measure suspended particulates in liquid or gas form. Each particle

passes through the light focus and then the angle of the reflection is measured. The instrument can also measure the particulate matters of 0.1 – 100 micron.

- Electrical mobility analyzer. Electrical mobility analyzer is the instrument using the electrical voltage to measure the quantity and size of the particles. The air loaded with the particles is passed through to the diameter of the electric plate with the anode and cathode on the parallel position. The instrument is installed at the entrance and the exit of the air. When the particles turn to either the anode and cathode and pass through the instrument. The charged particles are attracted and bound to the opposite electrical palette.

2.5.3.3 The Inertial and impacted particle measurement

This measurement is the system of inertial dust collection by relying on the particle inert force from the change of the air speed. In this manner, the particle clings or falls down on the receptor. The measurements relying on this principle are (14):

1. Single stage impactor. Single stage impactor is the instrument that change the speed or the rate of the particle flow by using the jet or orifice that has one part for collecting particles and a pump on a side.

2. Cascade impactor. Cascade impactor is the instrument that uses the impactor theory which consists of 2 – 4 particle collectors. Each the collector collects the particles of different size. The impactor can separate the particles in two size: 2 – 10 micron and larger than 10 micron.

3. Andersen samplers. Andersen samplers are the instruments that have multiple layers of particle collectors. Each layer has a silt for the air of the different size to flow through and fall on.

4. Multiple – silt high volume cascade impactor. This is the instrument which had four silts, each silt has a part for collecting particles. The fifth silt collects the particles of tiny size. Each silt has a jet running in size.

5. Lundgren sample. This is the instrument which has four jets where the particles ranging in size are collected in each layer. The air flow rate is about 0.014 – 0.23 m³ per minute.

2.5.3.4 Measurement of particulates by centrifugal force

This detection method is based on the separation of particulates from the air flow by centrifugal force which makes particulates in the samples flow rapidly in circle along with the path through the instrument. The detection instruments based on this principle are:

1. Cyclone samplers. These instruments have no moving parts but are designed to direct air to flow in circle path. The circulation path of particulates is decreased and then strike to the wall in the instrument and go into the lower collecting part. Most of these instruments are designed to collect particulates less than one micron.

2. Air centrifuges. These instruments are designed to direct the air samples to flow through two conical shafts. The inner shaft spun by a motor sucks the air to the open at the upper part and exit at the large open on the conical shaft. These instruments can be used to measure particulates within the size range of 0.03 micron.

2.5.3.5 Virtual impactors – Dichotomous samplers

These instruments use slow air flow rate to collect particulate samples on the filter below. The instruments working on this principle developed by US. EPA are called Dichotomous samplers which can be used to collect particulate matter less than 10 micron.

2.5.3.6 Respirable dust samplers

These instruments are designed to measure particulate matter in the size range that is harmful to human health.

2.5.3.7 Analysis of particulate matter in air by gravimetric method with high volume air samplers

Air sample analysis by gravimetric method works by collecting particulate matter by suckling air sample through a filter. This method can collect particulates with the size of 0.3 micron at 99% efficiency. The amount of particulate matter is then determined by analyzing the weight of particulate sample collected from filter.

The gravimetric high volume method is the reference method that US.EPA approved for measuring particulate matter in air, including TSP, PM₁₀ and PM_{2.5}. The principle of this technique is based on the collecting of high volume air, from 1,600 – 2,400 m³ (57,000 – 86,000 cubic feet) through a filter paper with a high-efficient air suckling instrument. The weight of the filter paper is then determined and compared to the total air volume for analyzing the total amount of particulate matter in air. In addition, the filter paper containing particulate sample can also be used for quantitative determination and identification of inorganic metals in the sample (24).

The gravimetric high volume method is widely used in USA for determination of a wide size-range of particulate matter from big particles to small particulates that are harmful to human health. In this method, dry particulate samples are collected in the study area, usually for 24 hours, every six days. This makes the method not practical for continuous particulate matter analysis (25). However, this method still has many advantages including easy instrumental operation and ability to collect high amount of particulate matter. The filter paper containing particulate sample can also be used for chemical analysis to determine contaminated substances in air (26).

2.6 Carbon Monoxide

2.6.1 Physical and Chemical Properties

Carbon monoxide (CO) is a colorless, odorless and tasteless gas which is commonly formed during the incomplete combustion of carbonaceous material. It is slightly lighter than air and only slightly soluble in water. Carbon monoxide absorbs electromagnetic radiation in the infrared region with the main absorption band centered at 4.67 μm: this property is used for the measurement of carbon monoxide concentration in the air (27).

While carbon monoxide is chemically inert under normal conditions of temperature and pressure (25 °C; 1 atm (101 kPa)), it becomes reactive at higher temperatures and can act as a strong reducing agent. At 90 ° C, it reacts with iodine pentoxide to produce iodine vapour. At 150 ° C, it also releases mercury vapour from mercury(II)oxide. Both reactions are used in the analytical chemistry of carbon

monoxide. The oxidation of carbon monoxide to carbon dioxide (CO₂) is accelerated by metallic catalysts such as palladium on silica gel or by a mixture of manganese and copper oxides (Hopcalite) (27).

In forming carboxyhaemoglobin (HbCO), carbon monoxide reacts with the iron in protohaem – a constituent of haemoglobin – and forms strong coordination bonds. Thus carboxyhaemoglobin is toxic because it is about 200 times more stable than oxyhaemoglobin (HbO₂). Carbon monoxide also combines reversibly with myoglobin and cytochromes, including P – 450 (27).

2.6.2 Sources of Carbon Monoxide in the Environment

2.6.2.1 Natural Occurrence

The natural sources of carbon monoxide are forest and grass fires, volcanoes, marsh gases and electric storms. Some carbon monoxide is also formed in the upper atmosphere (above 75 km) by the photodissociation of carbon dioxide. Another natural source of carbon monoxide is rainwater, where production of carbon monoxide in the clouds is tentatively attributed to the photochemical oxidation of organic matter or the slight dissociation of carbon monoxide induced by electrical discharge or both. Some carbon monoxide is also formed during germination of seeds and seedling growth, by the action of microorganism on plant flavonoids and in higher plants (27).

2.6.2.2 Man – made Sources

According to Jaffe (28), global emissions of man – made carbon monoxide in 1970 amounted to 360 million tons. Seiler (29) calculated the carbon monoxide emissions for 1973 as 600 million tons. A breakdown of Jaffe's estimate according to the type of source is shown in Table 2 – 12. The motor vehicle was by far the largest contributor accounting for 55% of total emissions. Other transportation sources, certain industrial processes, waste disposal and miscellaneous burning activities were responsible for the remaining carbon monoxide emissions.

Any industrial process or operation, where incomplete combustion of carbonaceous material occurs, may easily be of importance as far as occupational exposure to carbon monoxide is concerned. Smelting of iron ore, gas production works, gasworks and coke ovens, distribution and use of natural gas and coal gas, automobile manufacturing, garages and service station are among the most important sources for occupational exposure to carbon monoxide.

2.6.4 Exposure

The acute toxicity of carbon monoxide has long been recognized. Such concentrations are those commonly found in urban air (caused almost wholly by traffic pollution) and indoors (caused by faulty ventilation of heating or cooking appliances). Since the main source of carbon monoxide as an urban pollutant is the petrol engine, the problems posed by the inhalation of relatively low concentrations of the gas are likely to grow rather than diminish, as traffic becomes denser and more widespread.

Natural sources of carbon monoxide are of considerable magnitude but are diffuse and ambient air concentrations at locations removed from man – made source range from 0.01 to 0.9 mg/m³. The most important sources of carbon monoxide at breathing level are petrol engine vehicle exhausts. The diesel engine (compression ignition), when properly adjusted, emits little carbon monoxide. The density, distribution and mode of operation of vehicles vary greatly and these and other factors, the most important of which is the weather, produce great variation in the concentrations of pollutants produced by traffic concentrations steeply with distance from the street. However, distinct patterns are often discernible. In garage and tunnels, being in effect closed streets, pollution by carbon monoxide can reach high levels. However, since transit time in tunnels is relatively short, higher concentrations than those found in streets are tolerable. Usually, there are monitoring instruments that control ventilation and sound alarms if concentrations exceed agreed values, which may vary from 115 to 570 mg/m³ depending on the use and length of the tunnel. High concentration of carbon monoxide may accumulate inside motor vehicles because of fractures in exhaust systems or other mechanical defects.

2.7 Nitrogen Oxides

Nitrogen oxides are produced by combustion processes and are emitted to the air mainly as NO together with some NO₂. Natural biological processes and lightning also emit NO and NO₂. In the atmosphere nitrogen oxides undergo complex chemical and photochemical reactions; NO is oxidized to NO₂ and other products and eventually to HNO₃ and nitrates. Nitrogenous species are removed from the air to the ground by wet and dry deposition processes. Oxidized nitrogen compounds can have impacts on human health and the environment and are important to the formation of photochemical smog and tropospheric ozone (30).

2.7.1 Sources of Nitrogen Oxides

Combustion systems emit NO and NO₂ and together these species are usually denoted as NO_x. When NO_x emissions are expressed in mass units, the mass is expressed as if all the NO had been converted to NO₂.

2.7.1.1 Fuel combustion

Annual production of NO_x from combustion of fossil fuels is typically estimated from emission factors for various combustion processes, combined with worldwide consumption data for coal, oil and natural gas.

2.7.1.2 Biomass burning

In natural fires and the burning of wood, temperatures are rarely high enough to cause oxidation of nitrogen molecule of the air. The emissions are thereby more closely related to the fixed nitrogen content of the fuel. Biomass burning is mainly associated with agricultural practices in the tropics, which include plant, slash and shift practices as well as natural or intentional burning of savanna vegetation at the end of the dry season. Forest wildfires and use of wood as fuel make a lesser contribution.

2.7.1.3 Lightning

Thunderstorm activity is a major NO_x source. Electrical discharges in air generate NO_x by thermal dissociation of nitrogen molecules due to ohmic heating inside the discharge channel and shockwave heating of the surroundings.

2.7.1.4 Soil

The release of NO_x from soil depends critically on the temperature and moisture content of the soil. Skiba et al.(30) estimated for the United Kingdom the NO and N_2O emissions from agricultural land to be 2 – 6 % of the nationwide NO_x emissions and 16 – 64 % of the N_2O emissions, respectively.

2.7.1.5 Ocean

There have been few measurements of NO_x , N_2O or NH_3 fluxes over the ocean and current literature suggests that the sea is a negligible source of NO . Zafiriou and McFarland (30) observed a supersaturation of seawater with regard to NO in regions of relatively high concentrations of nitrite, owing to upwelling conditions. The excess NO must arise from photochemical decomposition of nitrite by sunlight.

2.7.2 Exposure

Human and environment exposure to nitrogen oxides varies greatly from cities to the countryside and with time of day and season. The concentrations of NO and NO_2 typically present outdoors in a range of urban situations are relatively well established. The concentrations encountered indoors depend on the nature of combustion appliances, chimneys and ventilation. When unvented combustion appliances are used for cooking or heating, indoor concentrations of nitrogen oxides typically greatly exceed those existing outside. In assessing human exposure to NO_2 (and other oxides of nitrogen), averaging times chosen should account for the type of effect to be expected. With regard to NO_2 , the principal biological responses include a) relatively transient effects on respiratory function associate with acute, short – term (< 1 hour) exposure and b) the likelihood of increased risk for respiratory disease in

children associated with frequently repeated short – term peak exposures and/or lower level long – term exposures (30).

2.8 Air Pollution Situation in Bangkok

Bangkok, like many other mega cities in the world, has serious problems associated with the use of energy in the transport sector. Several factors, including population growth and rapid economic expansion are fundamental factors requiring consideration for long – term planning. Rapid industrialization and urbanization, coupled with the lack of the land – use planning in the past, has contributed to the atmospheric pollution associated with the transport sector. This problem has been intensified by road infrastructures incapable of absorbing the rapidly growing vehicle population which causes congestion.

At present, there are three government agencies maintaining the measurement of the air pollutants in Bangkok (31).

1. The Air Quality and Noise Management Bureau, Pollution Control Department of Ministry of Natural Resources and Environment
2. The Bureau of Environmental Health, Department of Health of Ministry of Public Health
3. Bangkok Metropolitan Administration (BMA)

In 2002, PM_{10} remain important the air pollution problem in Bangkok due to the measurement were measured still over the standard especially on the roadside. There amount of the vehicles that is the major source are more problem than the resident area (7).

Ambient air is defined as areas which are more than 50 meters from major roads. In these areas, Pollution Control Department of Ministry of Natural Resources and Environment has set up 10 monitoring stations. Particulate matter less than 10 micron (PM_{10}) exceed the standard value some of the time but nitrogen dioxide and carbon monoxide were found to be within the standard values (7).

There are 7 monitoring stations near the roadside in Bangkok and 21 temporary stations operated by Pollution Control Department of Ministry of Natural Resources and Environment. The monitoring results show high concentrations of air pollutants than the ambient air as motor vehicles are large emitters. In the 2002, particulate matter was still the most important problem and at some stations carbon monoxide and nitrogen dioxide occasionally exceeded the standard (7).

Bangkok Metropolitan Administration (BMA) maintains one air quality monitoring station in front of Ratchatavee District Office and one mobile unit. The results from these stations indicate that in 2002 the highest level of particulate matter less than 10 micron (PM_{10}) was observed in January (an average of $103.44 \mu\text{g}/\text{m}^3$) due to the dry condition, which was similar to previous year. Other pollutants were found to be within the standard values. The mobile unit's results showed that particulate matter less than 10 micron (PM_{10}) and carbon monoxide were at health threatening level, especially on Ratchaprarob Road with high volume of traffic. The 24 hour average PM_{10} concentration on Ratchaprarob Road was $149.68 - 276.69 \mu\text{g}/\text{m}^3$, which was much higher than the standard ($120 \mu\text{g}/\text{m}^3$). For carbon monoxide (8 hour average) only Ratchadapisek Road had it over the standard of 9 ppm (found at $0.44 - 21.99$ ppm) (7).

Carbon monoxide and nitrogen dioxide did not exceed the standard. However, nitrogen dioxide along with the particles in the air can often be seen as a reddish – brown layer over many urban areas. NO_x is one of the main ingredients involved the formation of ground level ozone, which can trigger serious respiratory problems.

Table 2 - 13 Concentration of PM₁₀ at urban background area in Bangkok during 1996 – 2002

Year	PM ₁₀	
	Daily mean (µg/m ³)	No. over standard/Total No. of measurement (percentage)
1996	101.94	175/586 (29.8)
1997	80.64	235/1,783 (13.18)
1998	66.4	108/1,692 (6.38)
1999	60.6	67/1,586 (4.2)
2000	56.1	37/1,725 (2.1)
2001	40.5	2/1,550 (0.13)
2002	49.4	7/1,775 (0.39)

Source: Air Quality and Noise Management Bureau, Pollution Control Department (PCD), in 1998, 1999, 2000, 2001, 2002 and 2003

Table 2 – 14 Concentration of PM₁₀ at roadside area in Bangkok during 1996 – 2002

Year	PM ₁₀	
	Daily mean (µg/m ³)	No. over standard/Total No. of measurement (percentage)
1996	151.33	270/412 (65.53)
1997	117.7	385/1,016 (37.89)
1998	81.6	156/1,304 (12)
1999	80.1	145/1,724 (8.4)
2000	82.6	206/1,613 (12.8)
2001	67.9	161/1,614 (9.98)
2002	57.8	69/1,814 (3.8)

Source: Air Quality and Noise Management Bureau, Pollution Control Department (PCD), in 1998, 1999, 2000, 2001, 2002 and 2003

Table 2 - 15 Concentration of CO at urban background area in Bangkok during 1998 – 2002

Year	1 hr CO		8 hr CO	
	Daily mean (ppm)	No. over standard/ Total No. of measurement (percentage)	Daily mean (ppm)	No. over standard/ Total No. of measurement (percentage)
1998	0.9	0/65,174 (0)	0.9	0/62,295 (0)
1999	1.23	0/54,172 (0)	1.25	74/59,741 (0.12)
2000	0.96	0/70,186 (0)	0.97	0/71,609 (0)
2001	0.94	0/67,368 (0)	0.94	0/68,654 (0)
2002	0.85	0/81,379 (0)	0.90	0/83,928 (0)

Source: Air Quality and Noise Management Bureau, Pollution Control Department (PCD), in 1998, 1999, 2000, 2001, 2002 and 2003

Table 2 - 16 Concentration of CO at roadside area in Bangkok during 1998 – 2002

Year	1 hr CO		8 hr CO	
	Daily mean (ppm)	No. over standard/ Total No. of measurement (percentage)	Daily mean (ppm)	No. over standard/ Total No. of measurement (percentage)
1998	1.98	3/40,749 (0.01)	2.23	299/42,345 (0.71)
1999	2.29	0/49,282 (0)	2.29	196/49,197 (0.4)
2000	2.20	0/41,879 (0)	2.19	34/42,452 (0.08)
2001	2.03	0/51,243 (0)	2.03	39/51,762 (0.08)
2002	1.90	0/56,815 (0)	1.86	9/57,144 (0.015)

Source: Air Quality and Noise Management Bureau, Pollution Control Department (PCD), in 1998, 1999, 2000, 2001, 2002 and 2003

Table 2 - 17 Concentration of NO₂ at urban background area in Bangkok during 1996 – 2002

Year	NO ₂	
	Daily mean (ppb)	No. over standard/ Total No. of measurement (percentage)
1998	21	0/55,660 (0)
1999	22.8	0/44,907 (0)
2000	22.8	0/67,094 (0)
2001	22.5	0/73,290 (0)
2002	23.9	0/79,930 (0)

Source: Air Quality and Noise Management Bureau, Pollution Control Department (PCD), in 1998, 1999, 2000, 2001, 2002 and 2003

Table 2 – 18 Concentration of NO₂ at roadside area in Bangkok during 1996 – 2002

Year	NO ₂	
	Daily mean (ppb)	No. over standard/Total No. of measurement (percentage)
1998	32.9	1/18,272 (0.005)
1999	32.2	1/10,434 (0.01)
2000	35.4	0/22,962 (0)
2001	35.2	10/23,728 (0.04)
2002	36.74	1/23,914 (0.004)

Source: Air Quality and Noise Management Bureau, Pollution Control Department (PCD), in 1998, 1999, 2000, 2001, 2002 and 2003

2.9 Relevant Research

Artinano, et al (5) studied the influence of traffic on the PM₁₀ and PM_{2.5} urban aerosol fractions in Madrid, Spain. An experimental study, based on the chemical characterization of PM₁₀ and PM_{2.5} fractions sampled at a representative urban site, provides the major mass contents of these two fractions. These were mainly related to two different particle sources: combustion processes including traffic emissions and mineral – origin particles. PM₁₀ and PM_{2.5} concentrations showed good agreement with traffic – related pollutants such as nitrogen oxides and CO, being time – correlated in winter pollution episodes.

Siriwan Kaewgnam (33) studied the morphology and elemental composition of PM₁₀ in Bangkok by using two air sampling instruments which were a high volume air sampler and a personal air sampler. The relationship between the TSP and PM₁₀ was obtained by using Pearson rank correlation coefficient and linear regression as a statistical method for data analysis at 95% confidence. From SPSS program, the linear regression equation was $y = 0.588x$ when y is the amount of PM₁₀ and x is TSP while the relationship coefficient is 0.955. As the coefficient is very near to one, this indicated that amount of PM₁₀ is highly related to the amount of TSP. Therefore, the work suggested that it was possible to use the amount of TSP for the prediction of PM₁₀.

Harrison, et al (34) studied the sources and processes affecting concentrations of PM_{10} and $PM_{2.5}$ particulate matter in Birmingham, U.K. Analysis of the data indicates a marked difference between summer and winter periods. In the winter months $PM_{2.5}$ comprises about 80% of PM_{10} and is strongly correlated with NO_x indicating the importance of road traffic as a source. In the summer months, coarse particles ($PM_{2.5-10}$) account for almost 50% of PM_{10} and the influence of resuspended surface dust and soil and of secondary particulate matter was evident. The chemical analysis data were also found consistent with three sources dominating the PM_{10} composition: vehicle exhaust emissions, secondary ammonium salts and resuspended surface dust.

Chaloulakou, et al (35) studied $PM_{2.5}$ and PM_{10} during 1 June 1999 through 31 May 2000 in downtown Athens, Greece. $PM_{2.5}$ and PM_{10} concentrations were highly correlated with carbon monoxide, black carbon. The results of the analysis underlined the importance of local emission sources, mostly from traffic, which were responsible for the high PM_{10} and $PM_{2.5}$ concentration levels observed during this one – year – sampling period.

Querol, et al (36) studied the speciation and origin of $PM_{2.5}$ and PM_{10} during 1999 to 2000 in Spain by using gravimetric high volume method. Wide variations in particulate matter levels were found among the different geographical areas. These variations also depended on the type of monitoring site i.e. rural background, sub – urban or industrial background and curb – side stations. PM_{10} levels ranged from 15 – 20 $\mu\text{g}/\text{m}^3$ in rural areas, 45 – 50 $\mu\text{g}/\text{m}^3$ at curb – site stations. $PM_{2.5}$ levels ranged from 9 – 14 $\mu\text{g}/\text{m}^3$ at rural background station, 25 – 35 $\mu\text{g}/\text{m}^3$ at curb – side sites.

Lirong, et al (37) studied the volatile organic compounds, PM_{10} and CO on the roadsides in Guangzhou, China. Volatile organic compounds (VOCs) were collected with sorbent tubes, PM_{10} and CO were measured simultaneously with portable analyzers. The results showed that pedestrian exposure to PM_{10} and benzene was high. The good correlations between BTEX, PM_{10} and CO in the streets indicated that automotive emission might be their major source.

Samara, et al (38) studied the chemical mass balance source apportionment of PM_{10} in an industrialized urban area of Northern Greece during June 1997 – June 1998. The chemical source profiles consisting of the particulate matter components were obtained for a number of industrial activities, non – catalyst and catalyst – equipped passenger cars, diesel fuelled taxis and buses as well as for geological fugitive sources (paved road dust and soil from open lands). Ambient and source data were used in a chemical mass balance (CMB) receptor model for source identification and apportionment. Results of CMB modeling showed that major source of ambient PM_{10} was diesel vehicle exhaust.

Jumpol (39) studied a comparison of measuring techniques for ambient suspended particulate matter and PM_{10} by high volume air sampler at 3 different locations in Bangkok Metropolitan Area. The areas were classified as residential area, commercial area and industrial area. The average ratio of respirable suspended matter (PM_{10}) to TSP is 0.66 with a best fit equation obtained from linear regression as $Y = 1.03X + 40.2$ ($Y = TSP$, $X = PM_{10}$) and $r = 0.75$. Concentration of respirable suspended particulate matter are not different significantly at 95% confident level. The average ratio of PM_{10} to TSP is 0.66 or this equation could use to estimate the level of the particle airborne problem that affect to public health.

Neville S.(40) studied the air quality on Marylebone Road in London. The maximum contribution to the total emissions of NO_x from traffic was from cars, which contribute 28%. The maximum contribution to the total emissions of PM_{10} from traffic was from cars, which contribute 37%. Therefore any reduction in emissions from buses, taxis and other diesel vehicles might still make a useful contributions in busy roadside pollution levels.

Airborne Particles Expert Group (10) studied the relationships between PM_{10} , $PM_{2.5}$ and NO_x at the Birmingham Hodge Hill site. The results were highly consistent with the earlier analysis of a single winter' data indicating a strong correlation between $PM_{2.5}$ and NO_x consistent with a road traffic source. A clear indication was

showed that at this site the high NO_x and are likely to arise from road traffic emissions.



CHAPTER III

METHODOLOGY

3.1 Study site

The study areas were three roadside stations (Dindang station, Chokchai 4 station and Intrapitak station) and two urban background stations (Nonsiwitthaya school station and Klongjan station). The stations were operated by Pollution Control Department (PCD). This study was the analytical research focusing on the relationship of PM₁₀, CO and NO_x concentrations from five stations. Dindang station was the only air quality monitoring station which focuses on the relationship between PM₁₀, PM_{2.5} and PM_{coarse}.

Particulate matters in this study are PM₁₀ and PM_{2.5} that were measured by the Gravimetric High Volume method. CO concentration in this study is measured by Non – Dispersive Infrared Detection method. NO_x concentration is measured by Chemiluminescence method.

3.2 Data collection

The data of the study consist of

1. PM₁₀ were obtained from the measurements at Dindang station, Chokchai 4 station, Intrapitak station, Nonsiwitthaya school station and Klongjan station during 2001 – 2004.
2. PM_{2.5} levels were measured from Dindang station during 2001 – 2004.
3. CO concentration were measured from Dindang station, Chokchai 4 station, Intrapitak station, Nonsiwitthaya school station and Klongjan station during 2001 – 2004.

4. NO_x concentration were measured from Dindang station, Chokchai 4 station, Intrapitak station, Nonsiwitthaya school station and Klongjan station during 2001 – 2004.

3.3 Data processing

The collected data were paired of $\text{PM}_{10} - \text{PM}_{2.5}$, $\text{PM}_{10} - \text{PM}_{\text{coarse}}$, $\text{PM}_{2.5} - \text{PM}_{\text{coarse}}$, $\text{PM}_{10} - \text{CO}$ concentration and $\text{PM}_{10} - \text{NO}_x$ concentration. The data were also grouped into two seasons; wet season (June – October) and dry season (November – May).

In this study, the data were analyzed based on whole period, annual, season (dry season and wet season) and single season as showed in Table 3 – 1.

Table 3 – 1 Pattern of data analysis

Pattern	During time
Whole period	1/01/2001 – 31/10/2004
Annual	1/01/2001 – 31/12/2001
	1/01/2002 – 31/12/2002
	1/01/2003 – 31/12/2003
	1/01/2004 – 31/10/2004
Aggregation whole period	Wet season (2001,2002, 2003, 2004)
	Dry season (2002, 2003, 2004)
Single season	Wet season (1/06/2001 – 31/10/2001)
	Dry season (1/11/2001- 31/05/2002)
	Wet season (1/06/2002 – 31/10/2002)
	Dry season (1/11/2002 – 31/05/2003)
	Wet season (1/06/2003 – 31/10/2003)
	Dry season (1/11/2003 – 31/05/2004)
	Wet season (1/06/2004 – 31/10/2004)

3.4 Data analysis

3.4.1 The relationship between PM_{10} and $PM_{2.5}$ was interpreted from the equation of linear regression between PM_{10} and $PM_{2.5}$ concentration as shown below.

$$y = ax + b$$

when $y = PM_{2.5}$ concentration ($\mu g/m^3$)

$x = PM_{10}$ concentration ($\mu g/m^3$)

$a =$ slope or regression coefficient

$b =$ intercept.

3.4.2 The relationship of $PM_{10} - PM_{coarse}$, and $PM_{2.5} - PM_{coarse}$

PM_{coarse} was calculated from the subtraction of PM_{10} and $PM_{2.5}$ concentration ($PM_{10} - PM_{2.5}$). And then, PM_{coarse} and PM_{10} or $PM_{2.5}$ was analyzed to obtain the relationship of $PM_{10} - PM_{coarse}$, and $PM_{2.5} - PM_{coarse}$. The equation of linear regression is shown below.

$$y = ax + b$$

when $y = PM_{coarse}$ concentration ($\mu g/m^3$)

$x = PM_{10}$ or $PM_{2.5}$ concentration ($\mu g/m^3$)

$a =$ slope or regression coefficient

$b =$ intercept.

3.4.3 The relationship of Roadside enhancement PM_{10} – Roadside enhancement CO, and Roadside enhancement PM_{10} – Roadside enhancement NO_x

The PM_{10} , CO and NO_x data of 5 stations were pooled. Daily mean roadside concentrations of PM_{10} , CO and NO_x have been calculated for three stations; Dindang station, Chokchai 4 station, Intrapitak station. Daily mean urban background concentrations from two stations; Nonsiwitthaya school station and Klongjan station, were then subtracted to give the daily roadside enhancement of the concentration of each species.

$$\text{Roadside enhancement} = \text{Road measurement} - \text{Urban background measurement}$$

The relationship of Roadside enhancement PM_{10} , Roadside enhancement CO and Roadside enhancement NO_x can be interpreted from the equation of linear regression as shown below.

$$y = ax + b$$

when $y =$ Roadside enhancement PM_{10} concentration ($\mu g/m^3$)

$x =$ Roadside enhancement CO or NO_x concentration (ppm/ppb)

$a =$ slope or regression coefficient

$b =$ intercept.

The values of intercept from relationships of Roadside enhancement PM_{10} , Roadside enhancement CO and Roadside enhancement NO_x were used to determine the fraction of non – exhaust PM_{10} . The methodology of Non – exhaust particle was shown in Figure 3 – 1.

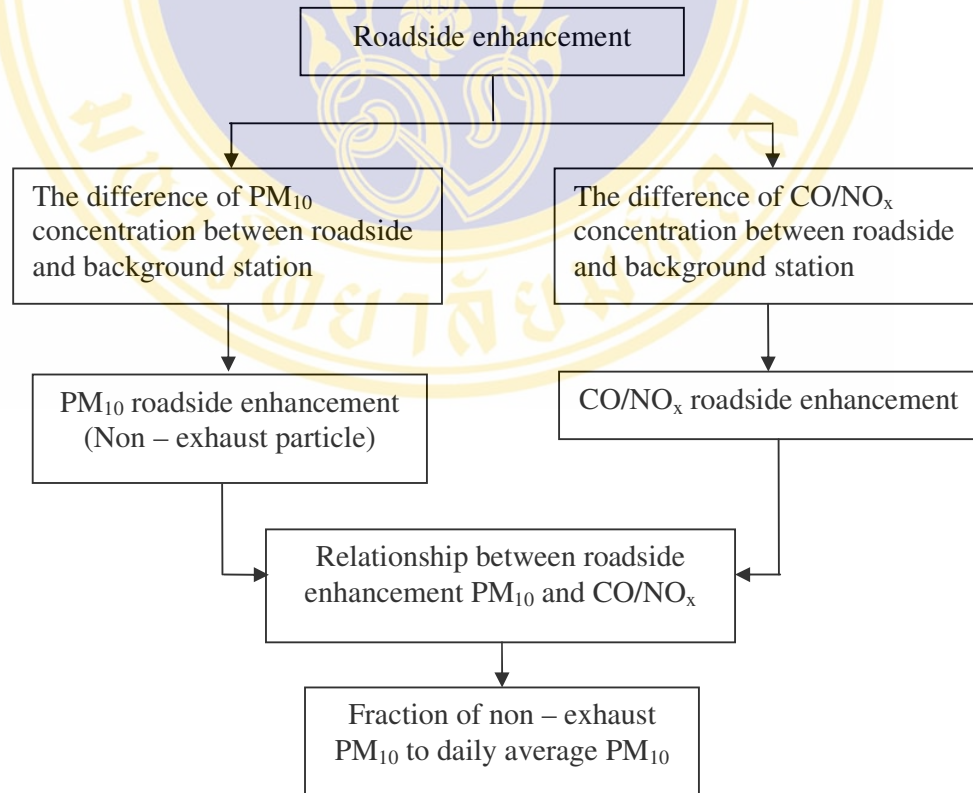


Figure 3 – 1 Methodology of non – exhaust particle

CHAPTER IV

RESULTS AND DISCUSSIONS

Chapter IV presents results and discussions as the following:

4.1 Relationship of PM_{10} , $PM_{2.5}$ and PM_{coarse}

4.2 Relationship between Roadside enhancement PM_{10} and Roadside enhancement CO

4.3 Relationship between Roadside enhancement PM_{10} and Roadside enhancement NO_x

4.1 Relationship of PM_{10} , $PM_{2.5}$ and PM_{coarse}

4.1.1 Relationship between PM_{10} and $PM_{2.5}$

Time series of the atmospheric particulate matter both PM_{10} and $PM_{2.5}$ were studied at Dindang station during 1 January 2002 to 31 October 2004 and all the data were collected by the gravimetric high volume method.

The average PM_{10} concentrations were $93.38 \mu\text{g}/\text{m}^3$ in the range of 40.4 to $196.2 \mu\text{g}/\text{m}^3$ during the whole period. In 2002, the daily average PM_{10} concentration was $94.08 \mu\text{g}/\text{m}^3$ in the daily range of 44.0 to $196.2 \mu\text{g}/\text{m}^3$. In 2003, the concentrations of daily PM_{10} were 49.5 to $151.7 \mu\text{g}/\text{m}^3$ with an average of $87.39 \mu\text{g}/\text{m}^3$. The range of daily average concentrations during 1 January to 31 October 2004 was 40.4 to $177.0 \mu\text{g}/\text{m}^3$ with an average of $104.76 \mu\text{g}/\text{m}^3$. The ambient air quality standard of annual average PM_{10} concentration was $50 \mu\text{g}/\text{m}^3$ (22). The annual PM_{10} concentration measured at Dindang station were above the annual standard of $50 \mu\text{g}/\text{m}^3$ except the annual average PM_{10} in 2002. The average annual concentration of PM_{10} at Dindang station, 2002 - 2004 was shown in Figure 4 – 1.

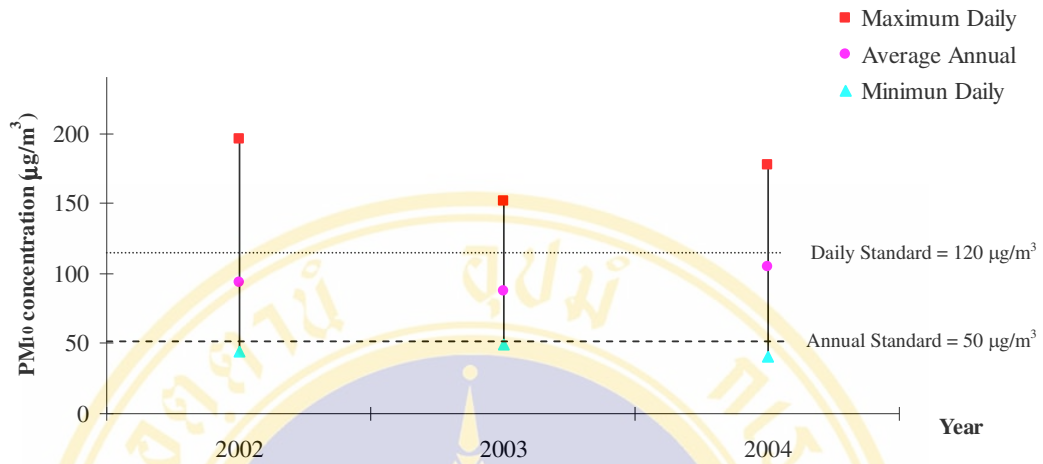


Figure 4 – 1 Concentration of PM₁₀ at Dindang station during 2002 – 2004

The average of daily PM_{2.5} concentrations was 56.82 µg/m³ in the range of 21.4 to 127.6 µg/m³ during the whole period. Daily PM_{2.5} concentrations at 2002 were in the range of 24.6 to 127.6 µg/m³ with the average of 57.5 µg/m³. In 2003, the range of daily PM_{2.5} was 24.2 to 94.9 µg/m³ with an average of 51.73 µg/m³. The range daily PM_{2.5} during 1 January to 31 October 2004 was 21.7 to 119.98 µg/m³ with an average of 66.29 µg/m³. In Thailand, the ambient air quality standard of annual average PM_{2.5} is not established. For this study, the US.EPA annual standard PM_{2.5} of 15 µg/m³ was used (22). The average PM_{2.5} concentration was considerably higher than the US.EPA annual PM_{2.5} standard. The range and average annual concentration of PM_{2.5} at Dindang station 2002 - 2004 was shown in Figure 4 – 2.

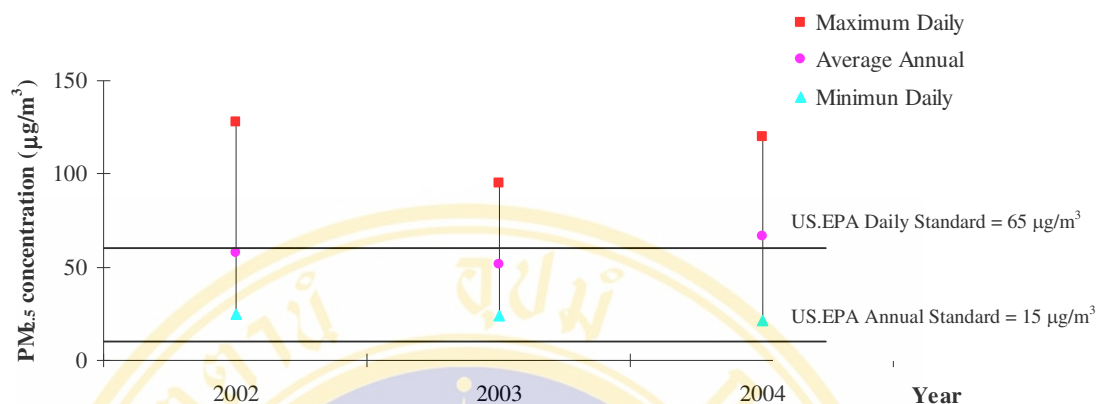


Figure 4 – 2 Range and average Concentration of PM_{2.5} at Dindang station during 2002 – 2004

Table 4 – 1 showed the best – fit equation of relationship between PM₁₀ and PM_{2.5} for prediction PM_{2.5} concentration of Dindang station. When X values were PM₁₀ concentrations and Y values were PM_{2.5} concentrations. Linear equations from Table 4 – 1 indicated highly correlation of PM₁₀ and PM_{2.5} concentrations.

Table 4 – 1 The best – fit equation of relationship between PM₁₀ and PM_{2.5} for prediction PM_{2.5} concentration of Dindang station

Period	PM ₁₀ and PM _{2.5}		
	Equation	r ²	n
Whole period (2002 – 2004)	PM _{2.5} = 0.622 PM ₁₀	r ² = 0.903	n = 94
Annual			
2002	PM _{2.5} = 0.624 PM ₁₀	r ² = 0.936	n = 40
2003	PM _{2.5} = 0.603 PM ₁₀	r ² = 0.860	n = 37
2004 (1 January – 31 October)	PM _{2.5} = 0.645 PM ₁₀	r ² = 0.893	n = 17
Aggregation whole period			
Dry season 2002-2004	PM _{2.5} = 0.635 PM ₁₀	r ² = 0.907	n = 64
Wet season 2002-2004	PM _{2.5} = 0.569 PM ₁₀	r ² = 0.837	n = 30
Single season			
Dry season 2002	PM _{2.5} = 0.629 PM ₁₀	r ² = 0.898	n = 26
Dry season 2003	PM _{2.5} = 0.622 PM ₁₀	r ² = 0.883	n = 22
Dry season 2004	PM _{2.5} = 0.644 PM ₁₀	r ² = 0.842	n = 12
Wet season 2002	PM _{2.5} = 0.599 PM ₁₀	r ² = 0.908	n = 15
Wet season 2003	PM _{2.5} = 0.524 PM ₁₀	r ² = 0.498	n = 13
Wet season 2004	PM _{2.5} = 0.957 PM ₁₀	r ² = 1	n = 2

Table 4 – 1 showed that the best – fit equation of Dindang station (when $y = PM_{2.5}$ and $x = PM_{10}$). According to regression analysis, the r^2 of equation which had trend line pass through origin's point (short equation) and the r^2 of equation which had normal trend line (long equation) were appeared to be closed each other, thus the short equation can be useful for the prediction of $PM_{2.5}$ from the concentration of PM_{10} . Moreover, PM_{10} concentration comprises $PM_{2.5}$ concentration, PM_{10} concentrations were $0 \mu\text{g}/\text{m}^3$, so that $PM_{2.5}$ concentrations were $0 \mu\text{g}/\text{m}^3$ as well.

The results in Table 4 – 1 showed that the mass concentrations of the particulate matter are obviously varied in the season. It appears that the fraction of $PM_{2.5}$ in PM_{10} concentrations during the dry season was higher than the wet season. The coefficients of determination (r^2) for the prediction of $PM_{2.5}$ from PM_{10} had a very high value (42).

This result was in agreement with the relationship between PM_{10} and $PM_{2.5}$ concentrations studied in the other countries. For example, the study conducted by Charron and Harrison indicated that the ratio of $PM_{2.5}/PM_{10}$ was about 0.67 for the whole period, i.e. on average two – third of the mass of PM_{10} was within $PM_{2.5}$ fraction (43). Harrison et al. and Chaloulakou et al., found that the ratio of $PM_{2.5}/PM_{10}$ of the winter season was higher than the other seasons (34, 35). Janssen et al., performed the ratio between $PM_{2.5}$ and PM_{10} in the Netherlands for a year period. The $PM_{2.5}/PM_{10}$ ratios were found in range of 0.21 to 0.79 (32).

From the results, it could be concluded that it was possible to use a correction factor for explaining relationship between concentrations of PM_{10} and $PM_{2.5}$ in Bangkok. The constant correction factor useful for the prediction of $PM_{2.5}$ from PM_{10} concentration during the study period was approximately 0.622.

4.1.2 Relationship between PM_{10} and PM_{coarse}

From PM_{10} and $PM_{2.5}$ measurements PM_{coarse} fraction corresponding to the mass of particles between 2.5 and $10 \mu\text{m}$ had been calculated by difference from subtraction. The average PM_{coarse} concentrations were $36.56 \mu\text{g}/\text{m}^3$ in the range of 12.37 to $83.02 \mu\text{g}/\text{m}^3$ during the whole period. In 2002, the average PM_{coarse} concentrations were $36.59 \mu\text{g}/\text{m}^3$ in the range of 19.4 to $70.1 \mu\text{g}/\text{m}^3$. In 2003, the range

of PM_{coarse} was from 15.4 to $67.3 \mu\text{g}/\text{m}^3$ with an average of $35.66 \mu\text{g}/\text{m}^3$. The range during 1 January to 31 October 2004 was 12.37 to $83.02 \mu\text{g}/\text{m}^3$ with an average of $38.47 \mu\text{g}/\text{m}^3$. The range and average concentration of PM_{coarse} at Dindang station from 2002 to 2004 was shown in Figure 4 – 3.

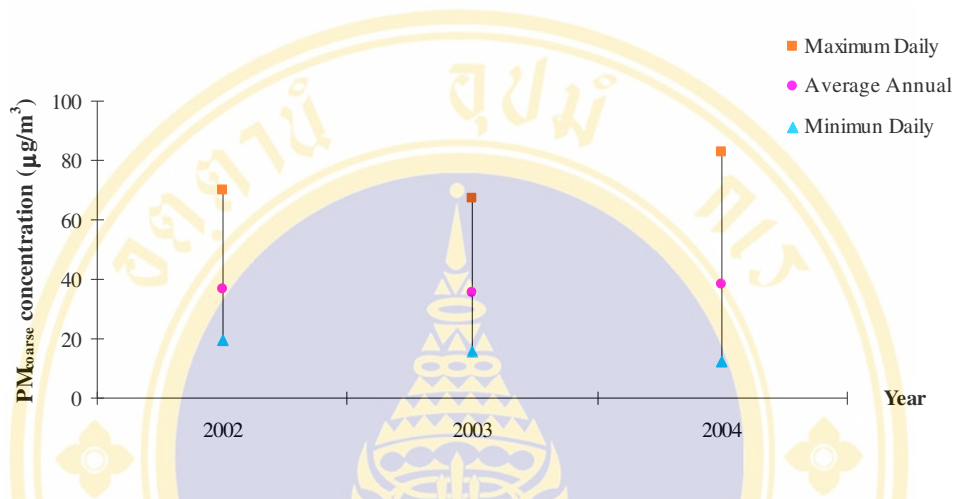


Figure 4 – 3 Range and average Concentration of PM_{coarse} at Dindang station during 2002 – 2004

Table 4 – 2 showed the best – fit equation of relationship between PM_{10} and PM_{coarse} for prediction PM_{coarse} concentration of Dindang station. When X values were PM_{10} concentrations and Y values were PM_{coarse} concentrations.

Table 4 – 2 The best – fit equation of relationship between PM_{10} and PM_{coarse} for prediction PM_{coarse} concentration of Dindang station

Period	PM_{10} and PM_{coarse}		
Whole period (2002 – 2004)	$PM_{coarse} = 0.378 PM_{10}$	$r^2 = 0.539$	n = 94
Annual			
2002	$PM_{coarse} = 0.378 PM_{10}$	$r^2 = 0.666$	n = 40
2003	$PM_{coarse} = 0.397 PM_{10}$	$r^2 = 0.435$	n = 37
2004 (1 January – 31 October)	$PM_{coarse} = 0.355 PM_{10}$	$r^2 = 0.526$	n = 17
Aggregation whole period			
Dry season 2002-2004	$PM_{coarse} = 0.365 PM_{10}$	$r^2 = 0.616$	n = 64
Wet season 2002-2004	$PM_{coarse} = 0.431 PM_{10}$	$r^2 = 0.293$	n = 30
Single season			
Dry season 2002	$PM_{coarse} = 0.370 PM_{10}$	$r^2 = 0.565$	n = 26
Dry season 2003	$PM_{coarse} = 0.378 PM_{10}$	$r^2 = 0.582$	n = 22
Dry season 2004	$PM_{coarse} = 0.356 PM_{10}$	$r^2 = 0.455$	n = 12
Wet season 2002	$PM_{coarse} = 0.401 PM_{10}$	$r^2 = 0.521$	n = 15
Wet season 2003	$PM_{coarse} = 0.476 PM_{10}$	$r^2 = 0.284$	n = 13
Wet season 2004	$PM_{coarse} = 0.043 PM_{10}$	$r^2 = 1$	n = 2

In this study, the short equations were used for the prediction of $PM_{2.5}$ from the concentration of PM_{10} . Then PM_{10} concentrations were $0 \mu\text{g}/\text{m}^3$, so that PM_{coarse} concentrations were $0 \mu\text{g}/\text{m}^3$ as well. Because of PM_{10} concentration comprised PM_{coarse} concentration. The short equations were used for the prediction of PM_{coarse} from the concentration of PM_{10} .

According, to regression analysis, the r^2 of equation which had trend line pass through the origin's point (short equation) and the r^2 of equation which had normal trend line (long equation) were appeared to be close to each other, thus the short equation can be useful for the prediction of PM_{coarse} from the concentration of PM_{10} . The results from Table 4 – 2 displayed the coefficients of determination (r^2) of whole period were 0.539 indicating that the relationship between PM_{10} and PM_{coarse} had moderate correlation (42).

This result was in agreement with the relationship between PM_{10} and PM_{coarse} concentrations studied in the other countries. For example, the study conducted by Harrison et al., indicated that in summer months, PM_{coarse} account for almost 50% of PM_{10} and the influence of resuspended surface dusts and soils and of secondary

particulate matter was evident (34). Charron and Harrison indicated that the ratio of PM_{coarse}/PM_{10} was about 0.33 for the whole period. Construction and demolition activities were responsible for occasional large PM_{coarse} concentrations than traffic (43).

From the results, it could be concluded that it was possible to use a constant correction factor for explaining relationship between concentrations of PM_{10} and PM_{coarse} in Bangkok. The constant correction factor useful for the prediction of PM_{coarse} from PM_{10} concentration during the study period was approximately 0.378.

4.1.3 Relationship between $PM_{2.5}$ and PM_{coarse}

The relationship between $PM_{2.5}$ and PM_{coarse} were shown in Table 4 – 3. X values were $PM_{2.5}$ concentrations and Y values were PM_{coarse} concentrations. In this study, the short equation was used to the prediction of PM_{coarse} from the concentration of $PM_{2.5}$. The results were shown in Table 4 – 3.

Table 4 – 3 The best – fit equation of relationship between $PM_{2.5}$ and PM_{coarse} for prediction PM_{coarse} concentration of Dindang station

Period	$PM_{2.5}$ and PM_{coarse}		
	$PM_{coarse} =$	$r^2 =$	n
Whole period (2002 – 2004)	$0.568 PM_{2.5}$	0.374	92
Annual			
2002	$0.572 PM_{2.5}$	0.196	39
2003	$0.626 PM_{2.5}$	0.525	37
2004 (1 January – 31 October)	$0.48 PM_{2.5}$	0.714	16
Aggregation whole period			
Dry season 2002-2004	$0.540 PM_{2.5}$	0.360	58
Wet season 2002-2004	$0.718 PM_{2.5}$	0.132	30
Single season			
Dry season 2002	$0.545 PM_{2.5}$	0.199	25
Dry season 2003	$0.585 PM_{2.5}$	0.065	22
Dry season 2004	$0.475 PM_{2.5}$	0.407	11
Wet season 2002	$0.652 PM_{2.5}$	0.320	15
Wet season 2003	$0.845 PM_{2.5}$	0.519	13
Wet season 2004	$0.5 PM_{2.5}$	0.998	2

The result in Table 4 – 3 displayed the coefficients of determination (r^2) during this study period were 0.374 indicating that the relationship between $PM_{2.5}$ and PM_{coarse} had weak correlation.

The linear regression equation was insignificant for the substitution $PM_{2.5}$ and PM_{coarse} . The coefficients of determination (r^2) for the prediction of PM_{coarse} from $PM_{2.5}$ had a very low value. It could be concluded that there was no suitable constant correction factor useful for the prediction of PM_{coarse} from $PM_{2.5}$.

4.2 Relationship between Roadside enhancement PM_{10} and Roadside enhancement CO

4.2.1 Relationship between roadside enhancement PM_{10} and roadside enhancement CO of Dindang station and Nonsiwitthaya school station

According to the study, it was found that roadside enhancement of Dindang was the difference of roadside enhancement PM_{10} and roadside enhancement CO between Dindang station and Nonsiwitthaya school station. The PM_{10} roadside enhancements of Dindang over the period of the study were $36.6 \mu\text{g}/\text{m}^3$ in the range of 2.5 to $83.1 \mu\text{g}/\text{m}^3$. In 2001, the range of roadside enhancements was 11.0 to $81.0 \mu\text{g}/\text{m}^3$ with the average of $49.35 \mu\text{g}/\text{m}^3$. In 2002, PM_{10} roadside enhancements were in the range of 2.5 to $83.1 \mu\text{g}/\text{m}^3$ with an average of $56.4 \mu\text{g}/\text{m}^3$. In 2003, the range was 2.6 to $43.1 \mu\text{g}/\text{m}^3$ with an average of $24.78 \mu\text{g}/\text{m}^3$. The roadside enhancement PM_{10} of Dindang station and Nonsiwitthaya school station from 2001 to 2003 was shown in Figure 4 – 4.

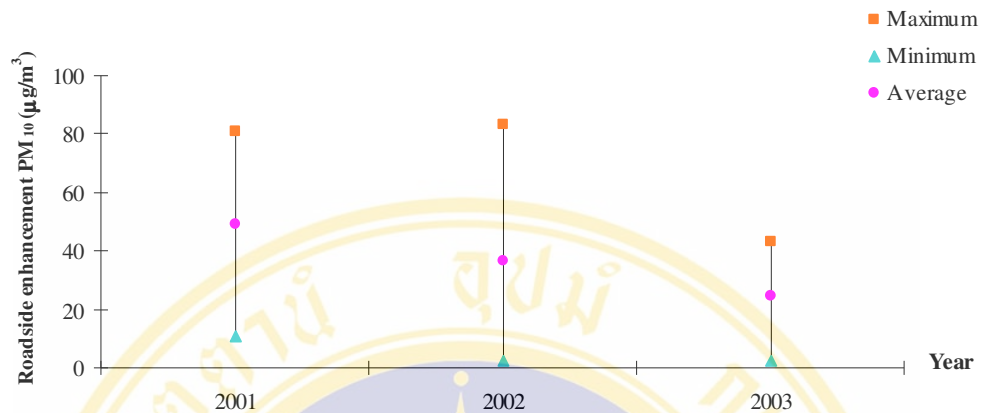


Figure 4 – 4 Roadside enhancement PM_{10} of Dindang station and Nonsiwitthaya school station during 2001 – 2003

The CO roadside enhancement of Dindang was the difference between the CO roadside enhancement of Dindang station and Nonsiwitthaya school station. The CO roadside enhancements of Dindang over the period of the study were 1.56 ppm in the range of 0.33 to 3.85 ppm. In 2001, the range of roadside enhancements was 0.33 to 3.55 ppm with the average of 1.98 ppm. In 2002, CO roadside enhancements were in the range of 0.57 to 3.85 ppm with an average of 1.71 ppm. In 2003, the range was 0.37 to 1.68 ppm with an average of 0.96 ppm. The roadside enhancement CO of Dindang station and Nonsiwitthaya school station from 2001 to 2003 was shown in Figure 4 – 5

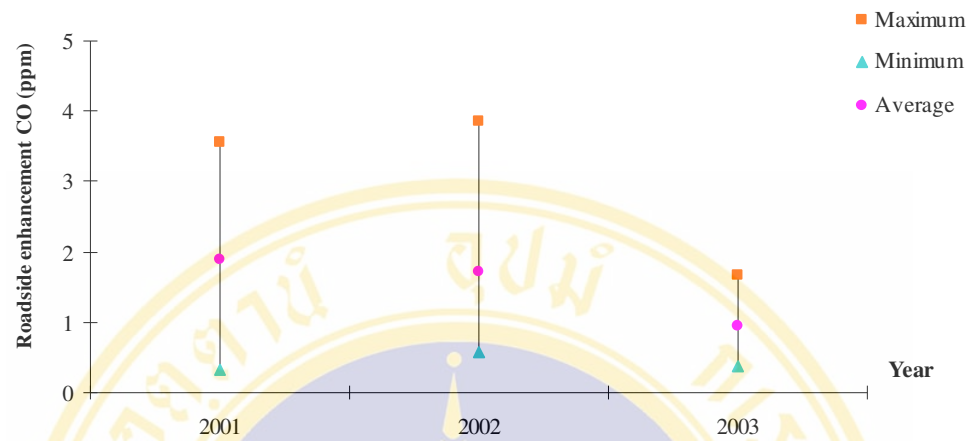


Figure 4 – 5 Roadside enhancement CO of Dindang station and Nonsiwitthaya school station during 2001 – 2003

Figures 4 – 4 and 4 – 5 showed the roadside enhancement PM_{10} and roadside enhancement CO between the measurement at the roadside station (Dindang station) and urban background station (Nonsiwitthaya school station). The roadside enhancements PM_{10} and CO during 2001 – 2003 had trended to decreasing because of Nonsiwitthaya school station were not ideal background station. It was probably that the background station became the roadside station or increasing the other sources including many activities in this area.

According to regression analysis, the relationships between PM_{10} and CO of Dindang station and Nonsiwitthaya school station were shown in Table 4 – 4.

Table 4 – 4 Result of regression analyses of PM₁₀ and CO of Dindang station and Nonsiwitthaya school station, 2001 – 2003

Period	Regression analyses of PM ₁₀ and CO of Dindang station and Nonsiwitthaya school station		
Whole period (2001 – 2003)	PM ₁₀ = 16.292 CO + 11.157	r ² = 0.476	n = 93
Annual			
2001	PM ₁₀ = 12.190 CO + 26.303	r ² = 0.336	n = 23
2002	PM ₁₀ = 16.986 CO + 7.298	r ² = 0.494	n = 46
2003	PM ₁₀ = 10.028 CO + 15.186	r ² = 0.060	n = 24
2004	ND		
Aggregation whole period			
Dry season 2001-2004	PM ₁₀ = 17.065 CO + 7.865	r ² = 0.557	n = 49
Wet season 2001-2004	PM ₁₀ = 16.407 CO + 13.202	r ² = 0.396	n = 44
Single season			
Dry season 2001	PM ₁₀ = 7.316 CO + 36.029	r ² = 0.335	n = 12
Dry season 2002	PM ₁₀ = 18.505 CO + 2.411	r ² = 0.559	n = 27
Dry season 2003	PM ₁₀ = 23.101 CO + 1.723	r ² = 0.362	n = 10
Dry season 2004	ND		
Wet season 2001	PM ₁₀ = 16.103 CO + 19.035	r ² = 0.309	n = 14
Wet season 2002	PM ₁₀ = 17.046 CO + 8.096	r ² = 0.315	n = 18
Wet season 2003	PM ₁₀ = 8.291 CO + 19.712	r ² = 0.044	n = 12
Wet season 2004	ND		

The results in Table 4 – 4 showed that the coefficients of determination (r²) of whole period were 0.476 indicating that the relationship between concentrations of PM₁₀ and CO had moderate correlation (42).

4.2.2 Relationship between Roadside enhancement PM₁₀ and Roadside enhancement CO of Intrapitak station and Nonsiwitthaya school station

According to the study, it was found that roadside enhancement of Intrapitak was the difference of roadside enhancement PM₁₀ and roadside enhancement CO between Intrapitak station and Nonsiwitthaya school station. The PM₁₀ roadside enhancements of Intrapitak over the period of the study were 10.38 µg/m³ in the range of 0.8 to 24.3 µg/m³. In 2001, the range of roadside enhancements was 2.0 to 20.0 µg/m³ with the average of 10.4 µg/m³. In 2002, PM₁₀ roadside enhancements were in the range of 2.5 to 21.7 µg/m³ with an average of 11.97 µg/m³. In 2003, the range was 1.0 to 24.3 µg/m³ with an average of 12.65 µg/m³. In 2004, the range of was 0.8 to 17.1 µg/m³ with the average of 9.09 µg/m³. The roadside enhancement PM₁₀ of Intrapitak station and Nonsiwitthaya school station from 2001 to 2004 was shown in Figure 4 – 6.

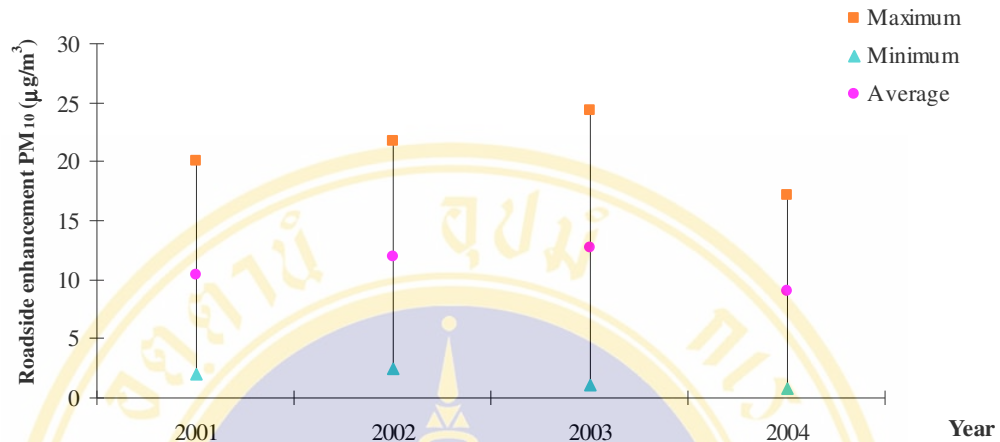


Figure 4 – 6 Roadside enhancement PM₁₀ of Intrapitak station and Nonsiwitthaya school station during 2001 – 2004

The CO roadside enhancement of Intrapitak was the difference between the CO roadside enhancement of Intrapitak station and Nonsiwitthaya school station. The CO roadside enhancements of Intrapitak over the period of the study were 0.49 ppm in the range of 0.06 to 1.21 ppm. In 2001, the range of roadside enhancements was 0.06 to 0.79 ppm with the average of 0.38 ppm. In 2002, CO roadside enhancements were in the range of 0.15 to 0.61 ppm with an average of 0.37 ppm. In 2003, the range of road enhancement was 0.45 to 1.21 ppm with an average of 0.83 ppm. In 2004, the roadside enhancement was 0.31 to 0.76 ppm with an average of 0.55. The roadside enhancement CO of Intrapitak station and Nonsiwitthaya school station from 2001 to 2004 was shown in Figure 4 – 7.

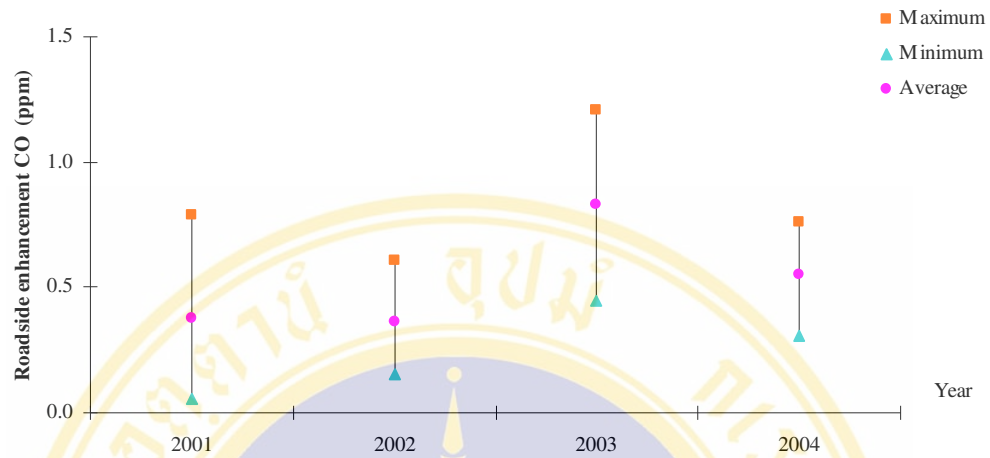


Figure 4 – 7 Roadside enhancement CO of Intrapitak station and Nonsiwitthaya school station during 2001 – 2004

Figures 4 – 6 and 4 – 7 showed the roadside enhancement PM_{10} and roadside enhancement CO between the measurement at the roadside station (Intrapitak station) and urban background station (Nonsiwitthaya school station). The roadside enhancements PM_{10} and CO during 2001 – 2004 had trended to decreasing because of Nonsiwitthaya school station were not ideal background station. It was probably that this background station became the roadside station or increasing the other sources including many activities in this area.

According to regression analysis, the relationships between PM_{10} and CO of Intrapitak station and Nonsiwitthaya school station were shown in Table 4 – 5.

Table 4 – 5 Result of regression analyses of PM₁₀ and CO of Intrapitak station and Nonsiwitthaya school station, 2001 – 2004

Period	Regression analyses of PM ₁₀ and CO of Intrapitak station and Nonsiwitthaya school station		
	PM ₁₀ =	r ² =	n =
Whole period (2001 – 2004)	PM ₁₀ = 6.760 CO +7.041	r ² = 0.023	n = 24
Annual			
2001	PM ₁₀ = 6.736 CO +7.827	r ² = 0.092	n = 5
2002	PM ₁₀ = -10.441 CO +15.795	r ² = 0.069	n = 6
2003	PM ₁₀ = 30.658 CO -12.796	r ² = 1	n = 2
2004	PM ₁₀ = 5.218 CO +6.207	r ² = 0.025	n = 11
Aggregation whole period			
Dry season 2001-2004	PM ₁₀ = 7.085 CO +8.983	r ² = 0.088	n = 12
Wet season 2001-2004	PM ₁₀ = 6.379CO + 5.731	r ² = 0.032	n = 10
Single season			
Dry season 2001	PM ₁₀ = 1.867 CO + 10.988	r ² = 0.007	n = 4
Dry season 2002	PM ₁₀ = 2.324 CO +12.907	r ² = 0.003	n = 5
Dry season 2003	PM ₁₀ = 30.850 CO - 13.208	r ² = 0.997	n = 3
Dry season 2004		ND	
Wet season 2001		ND	
Wet season 2002		ND	
Wet season 2003		ND	
Wet season 2004	PM ₁₀ = 6.379 CO + 5.731	r ² = 0.032	n = 10

Table 4 – 5 showed that the number of data in this study period was too small for precisely analyses. The coefficients of determination (r²) during this study period were low value indicating that the relationship between concentration of PM₁₀ and CO of Intrapitak station and Nonsiwitthaya school station had weak correlation (42).

4.2.3 Relationship between Roadside enhancement PM₁₀ and Roadside enhancement CO of Chokchai 4 station and Klongjan station

According to the study, it was found that roadside enhancement of Chokchai 4 was the difference of roadside enhancement PM₁₀ and roadside enhancement CO between Chokchai 4 station and Klongjan station. The PM₁₀ roadside enhancements of Chokchai 4 over the period of the study were 15.72 µg/m³ in the range of 1.8 to 42.7 µg/m³. In 2002, PM₁₀ roadside enhancements were in the range of 1.8 to 42.7 µg/m³ with an average of 17.97 µg/m³. In 2003, the range of the road enhancement was 4.0 to 21.2 µg/m³ with an average of 12.8 µg/m³. In 2004, the range of road enhancement was 14.4 µg/m³ in the range of 3.8 to 33.9 µg/m³. The roadside enhancement PM₁₀ of Chokchai 4 station and Klongjan station from 2002 to 2004 was shown in Figure 4 – 8.

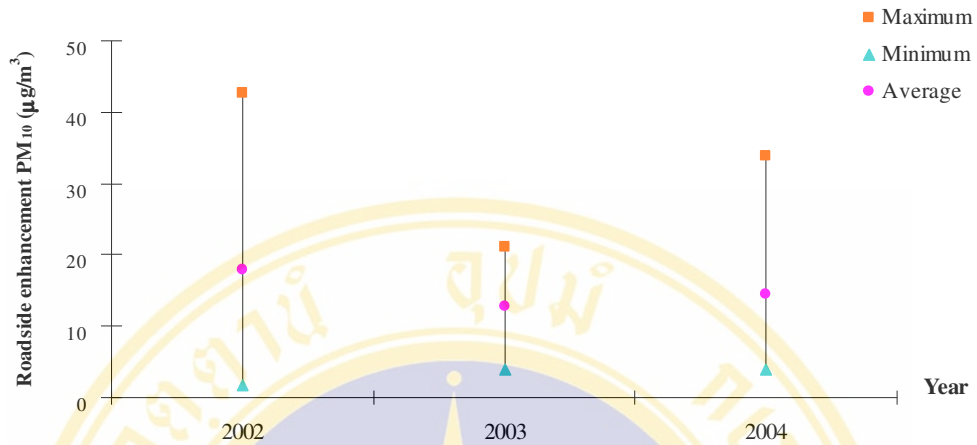


Figure 4 – 8 Roadside enhancement PM₁₀ of Chokchai 4 station and Klongjan station during 2002 – 2004

The CO roadside enhancement of Chokchai 4 was the difference between the CO roadside enhancement of Chokchai 4 station and Klongjan station. The CO roadside enhancements of Chokchai 4 over the period of the study were 0.59 ppm in the range of 0.04 to 1.17 ppm. In 2002, CO roadside enhancements were in the range of 0.29 to 1.13 ppm with an average of 0.67 ppm. In 2003, the range was 0.20 to 1.13 ppm with an average of 0.58 ppm. In 2004, the range of roadside enhancement was 0.04 to 1.17 ppm with an average of 0.50. The roadside enhancement CO of Chokchai 4 station and Klongjan station from 2002 to 2004 was shown in Figure 4 – 9.

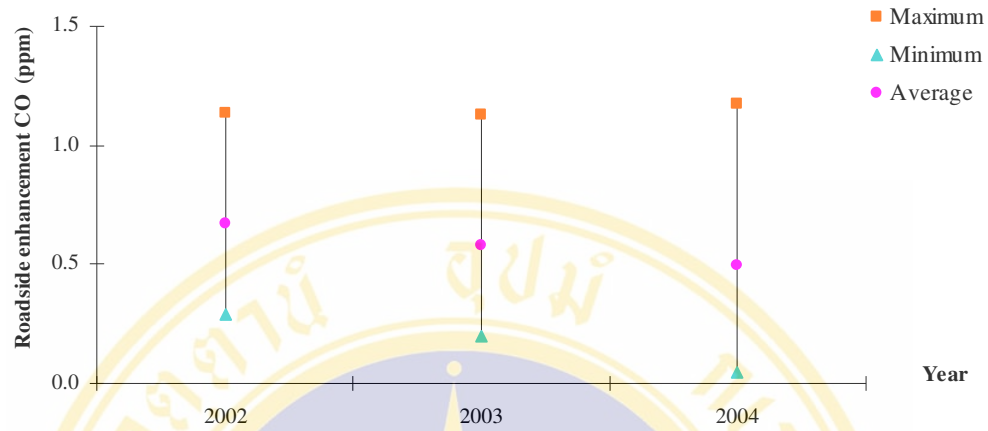


Figure 4 – 9 Roadside enhancement CO of Chokchai 4 station and Klongjan station during 2002 – 2004

Figures 4 – 8 and 4 – 9 showed the roadside enhancement PM_{10} and roadside enhancement CO between the measurement at the roadside station (Chokchai 4 station) and urban background station (Klongjan station). The roadside enhancements PM_{10} and CO during 2002 – 2004 had trended to decreasing because of Klongjan station was not ideal background station. It was probably that this station became the roadside station or increasing the other sources including many activities in this area.

According to regression analysis, the relationships between concentration of PM_{10} and CO of Chokchai 4 station and Klongjan station were shown in Table 4 – 6.

Table 4 – 6 Result of regression analyses of PM₁₀ and CO of Chokchai 4 station and Klongjan station, 2002 – 2004

Period	Regression analyses of PM ₁₀ and CO of Chokchai 4 station and Klongjan station		
Whole period (2002 – 2004)	PM ₁₀ =8.270 CO+10.871	r ² = 0.064	
Annual			
2001	ND		
2002	PM ₁₀ = 17.626 CO +6.227	r ² = 0.154	n = 24
2003	PM ₁₀ = 10.905 CO +6.475	r ² = 0.410	n = 9
2004	PM ₁₀ = -0.482 CO +14.645	r ² = 0	n = 21
Aggregation whole period			
Dry season 2001-2004	PM ₁₀ = 12.681 CO +12.639	r ² = 0.153	n = 30
Wet season 2001-2004	PM ₁₀ = 12.687 CO + 12.732	r ² = 0.153	n = 24
Single season			
Dry season 2001	PM ₁₀ = -8.183 CO + 19.185	r ² = 0.017	n = 4
Dry season 2002	PM ₁₀ = 17.554 CO + 3.732	r ² = 0.512	n = 9
Dry season 2003	PM ₁₀ = 13.351 CO + 3.378	r ² = 0.584	n = 7
Dry season 2004	PM ₁₀ = -4.784 CO +19.278	r ² = 0.023	n = 10
Wet season 2001	ND		
Wet season 2002	PM ₁₀ = 18.496 CO + 8.252	r ² = 0.163	n = 16
Wet season 2003	ND		
Wet season 2004	PM ₁₀ = -41.462 CO +23.688	r ² = 0.201	n = 8

Table 4 – 6 showed that the number of data in this study period was too small for precisely analyses. The coefficients of determination (r²) during this study period were low value indicating that the relationship between concentration of PM₁₀ and CO of Chokchai 4 station and Klongjan station had weak correlation (42).

Results of the relationship between PM₁₀ and CO of three areas indicated that the roadside enhancement of Dindang station and Nonsiwitthaya school station was suitable for the estimation of the non – exhaust particle at Dindang area. Because of the data number of PM₁₀ and CO concentrations between Intrapitak, Chokchai 4 and Klongjan station were little for analyses including the coefficients of determination (r²) during this study period were low value indicating the relationship between concentration of PM₁₀ and CO had weak correlation. The data should be collected to increase the reliability. The non – exhaust particle could be estimated by the relationship between PM₁₀ and CO at Dindang station. The result was shown in Table 4 – 7.

Table 4 – 7 The fraction of non – exhaust particle to average PM₁₀ concentrations of PM₁₀ and CO at Dindang station, 2001 – 2004

Period	Daily Average PM ₁₀ at Dindang station (µg/m ³)	Fraction
Whole period	89.61	0.40
Annual		
2001	104.78	0.48
2002	89.49	0.40
2003	75.30	0.32
2004	ND	ND
Aggregation whole period		
Dry season 2001-2003	98.50	0.36
Wet season 2002-2003	79.71	0.44

The results of Table 4 – 7 showed that the ratio of non – exhaust particle to average PM₁₀ concentration during 2001 was highest than those ratios. The fractions of non – exhaust particle to average PM₁₀ concentration were in range of 0.32 to 0.48.

4.3 Relationship between Roadside enhancement PM₁₀ and Roadside enhancement NO_x

4.3.1 Relationship between Roadside enhancement PM₁₀ and Roadside enhancement NO_x of Dindang station and Nonsiwitthaya school station

According to the study, it was found that roadside enhancement of Dindang was the difference of roadside enhancement PM₁₀ and roadside enhancement NO_x between Dindang station and Nonsiwitthaya school station. The PM₁₀ roadside enhancements of Dindang over the period of the study were 33.26 µg/m³ in the range of 2.4 to 83.1 µg/m³. In 2001, the range of roadside enhancements was 11.0 to 71.0 µg/m³ with the average of 45.3 µg/m³. In 2002, PM₁₀ roadside enhancements were in the range of 2.5 to 83.1 µg/m³ with an average of 35.83 µg/m³. In 2003, the range was 2.6 to 46.2 µg/m³ with an average of 25.26 µg/m³. In 2004, PM₁₀ roadside enhancements were in the range of 2.4 to 49.3 µg/m³ with an average of 27.26 µg/m³. The roadside enhancement PM₁₀ of Dindang station and Nonsiwitthaya school station from 2001 to 2004 was shown in Figure 4 – 10.

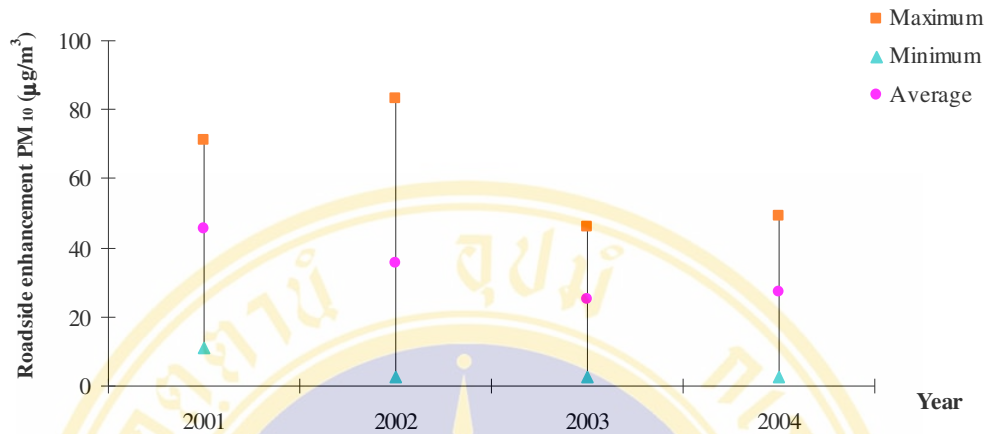


Figure 4 – 10 Roadside enhancement PM₁₀ of Dindang station and Nonsiwitthaya school station during 2001 – 2004

The NO_x roadside enhancement of Dindang was the difference between the NO_x roadside enhancement of Dindang station and Nonsiwitthaya school station. The NO_x roadside enhancements of Dindang over the period of the study were 122.99 ppb in the range of 7.87 to 322.98 ppb. In 2001, the range of roadside enhancements was 41.58 to 322.98 ppb with the average of 173.92 ppb. In 2002, NO_x roadside enhancements were in the range of 30.85 to 298.04 ppb with an average of 119.77 ppb. In 2003, the range of roadside enhancement was 23.0 to 260.94 ppb with an average of 103.5 ppb. In 2004, NO_x roadside enhancements were in the range of 7.87 to 237.86 ppb with an average of 106.49 ppb. The roadside enhancement NO_x of Dindang station and Nonsiwitthaya school station from 2001 to 2004 was shown in Figure 4 – 11.

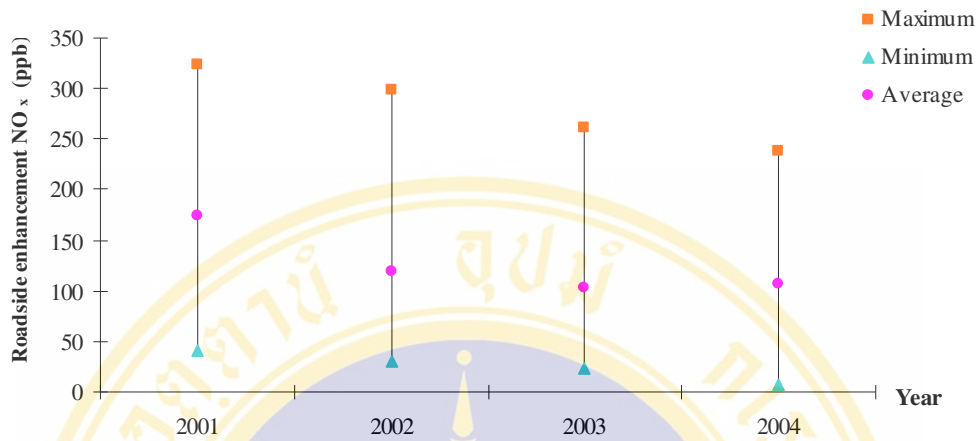


Figure 4 – 11 Roadside enhancement NO_x of Dindang station and Nonsiwitthaya school station during 2001 – 2004

Figures 4 – 10 and 4 – 11 showed that the roadside enhancement PM₁₀ and roadside enhancement CO between the measurement at the roadside station (Dindang station) and urban background station (Nonsiwitthaya school station). The roadside enhancements PM₁₀ and CO during 2001 – 2004 had trended to decreasing. It was probably that this station became the roadside station or increasing the other sources including many activities in this area.

According to regression analysis, the relationships between concentration of PM₁₀ and NO_x of Dindang station and Nonsiwitthaya school station were shown in Table 4 – 8.

Table 4 – 8 Result of regression analyses of PM₁₀ and NO_x of Dindang station and Nonsiwitthaya school station, 2001 – 2004

Period	Regression analyses of PM ₁₀ and NO _x of Dindang station and Nonsiwitthaya school station		
Whole period (2001 – 2004)	PM ₁₀ = 0.182 NO _x + 10.832	r ² = 0.494	n = 110
Annual			
2001	PM ₁₀ = 0.174 NO _x + 15.085	r ² = 0.535	n = 20
2002	PM ₁₀ = 0.207 NO _x + 11.028	r ² = 0.467	n = 43
2003	PM ₁₀ = 0.102 NO _x + 14.679	r ² = 0.219	n = 35
2004	PM ₁₀ = 0.163 NO _x + 9.899	r ² = 0.562	n = 12
Aggregation whole period			
Dry season 2001-2004	PM ₁₀ = 0.186 NO _x + 9.391	r ² = 0.540	n = 58
Wet season 2001-2004	PM ₁₀ = 0.179 NO _x + 12.256	r ² = 0.422	n = 52
Single season			
Dry season 2001	PM ₁₀ = 0.141 NO _x + 22.089	r ² = 0.342	n = 8
Dry season 2002	PM ₁₀ = 0.199 NO _x + 9.732	r ² = 0.398	n = 25
Dry season 2003	PM ₁₀ = 0.122 NO _x + 12.712	r ² = 0.450	n = 20
Dry season 2004	PM ₁₀ = 0.233 NO _x + 5.659	r ² = 0.505	n = 5
Wet season 2001	PM ₁₀ = 0.194 NO _x + 12.286	r ² = 0.451	n = 13
Wet season 2002	PM ₁₀ = 0.269 NO _x + 4.877	r ² = 0.563	n = 19
Wet season 2003	PM ₁₀ = 0.240 NO _x + 25.562	r ² = 0.015	n = 13
Wet season 2004	PM ₁₀ = 0.138 NO _x + 12.077	r ² = 0.586	n = 7

The results in Table 4 – 8 showed that the coefficients of determination (r²) of whole period were 0.499 indicating that the relationship between concentrations of PM₁₀ and NO_x had moderate correlation (42).

4.3.2 Relationship between Roadside enhancement PM₁₀ and Roadside enhancement NO_x of Intrapitak station and Nonsiwitthaya school station

According to the study, it was found that roadside enhancement of Intrapitak was the difference of roadside enhancement PM₁₀ and roadside enhancement NO_x between Intrapitak station and Nonsiwitthaya school station. The PM₁₀ roadside enhancements of Intrapitak over the period of the study were 15.28 µg/m³ in the range of 0.80 to 36.7 µg/m³. In 2001, the range of roadside enhancements was 2.0 to 27.0 µg/m³ with the average of 16.55 µg/m³. In 2002, PM₁₀ roadside enhancements were in the range of 1.5 to 31.1 µg/m³ with an average of 16.66 µg/m³. In 2003, the range of PM₁₀ roadside enhancements was 0.8 to 36.7 µg/m³ with an average of 12.64 µg/m³. The roadside enhancement PM₁₀ of Intrapitak station and Nonsiwitthaya school station from 2001 to 2003 was shown in Figure 4 – 12.

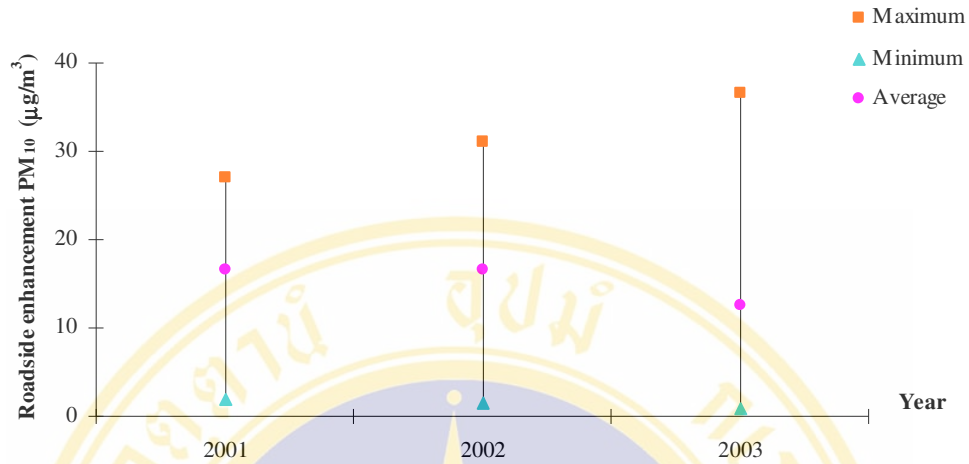


Figure 4 – 12 Roadside enhancement PM₁₀ of Intrapitak station and Nonsiwitthaya school station during 2001 – 2003

The NO_x roadside enhancement of Intrapitak was the difference between the NO_x roadside enhancement of Intrapitak station and Nonsiwitthaya school station. The NO_x roadside enhancements of Intrapitak over the period of the study were 19.38 ppb in the range of 0.14 to 57.09 ppb. In 2001, the range of roadside enhancements was 1.67 to 57.09 ppb with the average of 27.96 ppb. In 2002, NO_x roadside enhancements were in the range of 0.14 to 25.57 ppb with an average of 12.59 ppb. In 2003, the range of roadside enhancement was 2.0 to 46.26 ppb with an average of 17.6 ppb. The roadside enhancement NO_x of Intrapitak station and Nonsiwitthaya school station from 2001 to 2003 was shown on Figure 4 – 13.

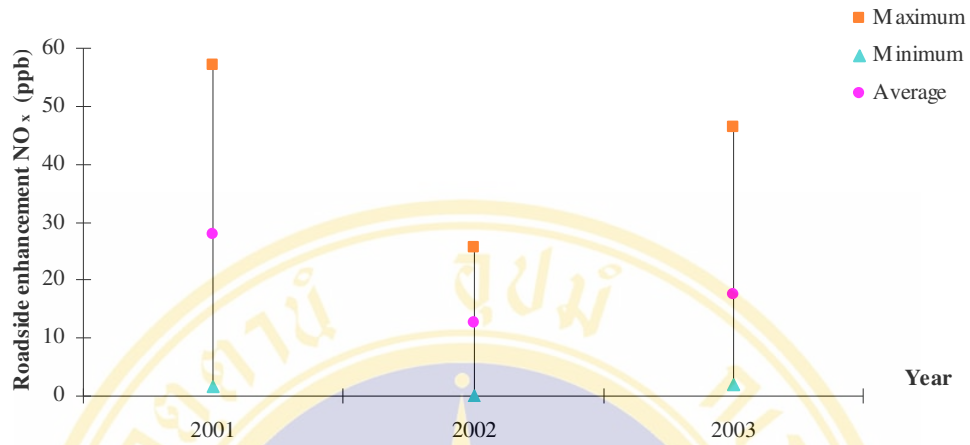


Figure 4 – 13 Roadside enhancement NO_x of Intrapitak station and Nonsiwitthaya school station during 2001 – 2003

Figures 4 – 12 and 4 – 13 showed that the roadside enhancement PM_{10} and roadside enhancement CO between the measurement at the roadside station (Intrapitak station) and urban background station (Nonsiwitthaya school station). The roadside enhancements PM_{10} and CO during 2001 – 2003 had trended to decreasing. It was probably that this station became the roadside station or increasing the other sources including many activities in this area.

According to regression analysis, the relationships between concentration of PM_{10} and NO_x of Intrapitak station and Nonsiwitthaya school station were shown in Table 4 – 9.

Table 4 – 9 Result of regression analyses of PM₁₀ and NO_x of Intrapitak station and Nonsiwitthaya school station, 2001 – 2003

Period	Regression analyses of PM ₁₀ and NO _x of Intrapitak station and Nonsiwitthaya school station		
Whole period (2001 – 2003)	PM ₁₀ = 0.209 NO _x + 11.237	r ² = 0.084	n = 33
Annual			
2001	PM ₁₀ = 0.145 NO _x + 12.497	r ² = 0.065	n = 11
2002	PM ₁₀ = 0.464 NO _x + 10.817	r ² = 0.062	n = 11
2003	PM ₁₀ = 0.355 NO _x + 6.389	r ² = 0.093	n = 11
2004	ND		
Aggregation whole period			
Dry season 2001-2004	PM ₁₀ = -0.143 NO _x + 28.532	r ² = 0.066	n = 5
Wet season 2001-2004	PM ₁₀ = 0.234 NO _x + 10.555	r ² = 0.110	n = 28
Single season			
Dry season 2001	PM ₁₀ = 0.196 NO _x + 10.156	r ² = 1	n = 2
Dry season 2002	ND		
Dry season 2003	PM ₁₀ = -0.431 NO _x + 44.231	r ² = 1	n = 2
Dry season 2004	ND		
Wet season 2001	PM ₁₀ = 0.153 NO _x + 14.258	r ² = 0.247	n = 8
Wet season 2002	PM ₁₀ = 0.464 NO _x + 10.817	r ² = 0.062	n = 11
Wet season 2003	PM ₁₀ = 0.161 NO _x + 6.343	r ² = 0.082	n = 9
Wet season 2004	ND		

Table 4 – 9 showed that the data number of this study period too little for precisely analyses. The coefficients of determination (r²) during this study period were low value (0.113) indicating that the relationship between concentration of PM₁₀ and NO_x of Intrapitak station and Nonsiwitthaya school station had weak correlation (42).

4.3.3 Relationship between Roadside enhancement PM₁₀ and Roadside enhancement NO_x of Chokchai 4 station and Klongjan station

According to the study, it was found that roadside enhancement of Chokchai 4 was the difference of roadside enhancement PM₁₀ and roadside enhancement NO_x between Chokchai 4 station and Klongjan station. The PM₁₀ roadside enhancements of Chokchai 4 over the period of the study were 15.79 µg/m³ in the range of 3.80 to 36.0 µg/m³. In 2001, the range of roadside enhancements was 5.0 to 36.0 µg/m³ with the average of 18.57 µg/m³. In 2002, PM₁₀ roadside enhancements were in the range of 7.3 to 19.2 µg/m³ with an average of 11.35 µg/m³. In 2003, the range of PM₁₀ roadside enhancements was 4.0 to 34.8 µg/m³ with an average of 16.96 µg/m³. In 2004, the range of roadside enhancements was 3.8 to 22.4 µg/m³ with the average of 11.91

$\mu\text{g}/\text{m}^3$. The roadside enhancement PM_{10} of Chokchai 4 station and Klongjan station from 2001 to 2004 was shown in Figure 4 – 14.

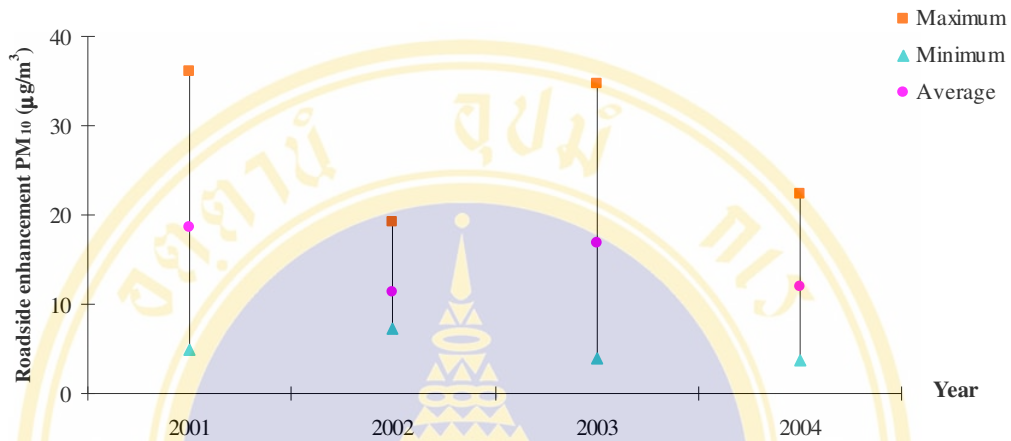


Figure 4 – 14 Roadside enhancement PM_{10} of Chokchai 4 station and Klongjan station during 2001 – 2004

The NO_x roadside enhancement of Chokchai 4 was the difference between the NO_x roadside enhancement of Chokchai 4 station and Klongjan station. The NO_x roadside enhancements of Chokchai 4 over the period of the study were 53.41 ppb in the range of 2.61 to 101.0 ppb. In 2001, the range of roadside enhancements was 6.52 to 101.0 ppb with the average of 56.38 ppb. In 2002, NO_x roadside enhancements were in the range of 34.22 to 89.35 ppb with an average of 58.92 ppb. In 2003, the range of roadside enhancement was 12.39 to 89.04 ppb with an average of 52.9 ppb. In 2004, the range of roadside enhancement was 2.61 to 81.57 ppb with the average of 49.48 ppb. The roadside enhancement NO_x of Chokchai 4 station and Klongjan station from 2001 to 2004 was shown in Figure 4 – 15.

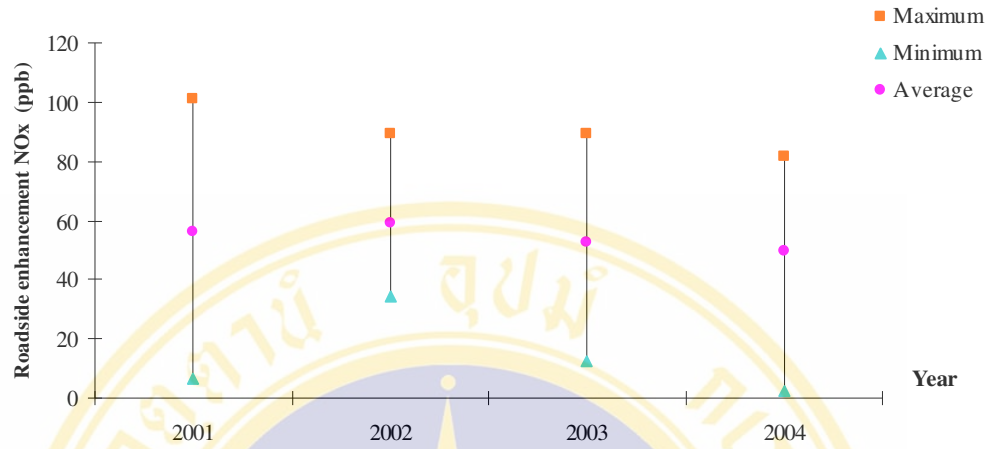


Figure 4 – 15 Roadside enhancement NO_x of Chokchai 4 station and Klongjan station during 2001 – 2004

Figures 4 – 14 and 4 – 15 showed that the roadside enhancement PM₁₀ and roadside enhancement CO between the measurement at the roadside station (Chokchai 4 station) and urban background station (Klongjan station). The roadside enhancements PM₁₀ and CO during 2001 – 2004 had trended to decreasing. It was probably that this station became the roadside station or increasing the other sources including many activities in this area.

According to regression analysis, the relationships between concentration of PM₁₀ and NO_x of Chokchai 4 station and Klongjan station were shown in Table 4 – 10.

Table 4 – 10 Result of regression analyses of PM₁₀ and NO_x of Chokchai 4 station and Klongjan station, 2001 – 2004

Period	Regression analyses of PM ₁₀ and NO _x of Chokchai 4 station and Klongjan station		
Whole period (2001 – 2004)	PM ₁₀ = 0.076 NO _x + 11.727	r ² = 0.044	n = 56
Annual			
2001	PM ₁₀ = 0.034 NO _x + 16.659	r ² = 0.016	n = 14
2002	PM ₁₀ = 0.035 NO _x + 9.301	r ² = 0.030	n = 4
2003	PM ₁₀ = 0.117 NO _x + 10.771	r ² = 0.055	n = 25
2004	PM ₁₀ = 0.075 NO _x + 8.197	r ² = 0.088	n = 13
Aggregation whole period			
Dry season 2001-2004	PM ₁₀ = 0.033 NO _x + 12.329	r ² = 0.023	n = 22
Wet season 2001-2004	PM ₁₀ = 0.148 NO _x + 7.356	r ² = 0.081	n = 34
Single season			
Dry season 2001	PM ₁₀ = -0.156 NO _x + 16.020	r ² = 1	n = 2
Dry season 2002	PM ₁₀ = 0.005 NO _x + 13.786	r ² = 0	n = 10
Dry season 2003	PM ₁₀ = 0.073 NO _x + 10.784	r ² = 0.103	n = 10
Dry season 2004	ND		
Wet season 2001	PM ₁₀ = 0.117 NO _x + 10.694	r ² = 0.065	n = 8
Wet season 2002	ND		
Wet season 2003	PM ₁₀ = 0.130 NO _x + 10.290	r ² = 0.045	n = 12
Wet season 2004	PM ₁₀ = 0.104 NO _x + 6.785	r ² = 0.139	n = 10

Table 4 – 10 showed that the data number of this study period too little for precisely analyses. The coefficients of determination (r²) during this study period were low value (0.044) indicating that the relationship between concentration of PM₁₀ and NO_x of Chokchai 4 station and Klongjan station had weak correlation (42).

As results of the relationship between PM₁₀ and NO_x of three areas indicated that the roadside enhancement of Dindang station and Nonsiwitthaya school station was suitable for the estimation of the non – exhaust particle at Dindang area. Because of the number data of PM₁₀ and NO_x concentrations between Intrapitak, Chokchai 4 and Klongjan station were little for analyses including the coefficients of determination (r²) during this study period were low value indicating the relationship between concentration of PM₁₀ and NO_x had weak correlation (38). The data should be collected to increase the reliability. The non – exhaust particle could be estimated by the relationship between PM₁₀ and NO_x at Dindang station. The result was shown in Table 4 – 11.

Table 4 – 11 The fraction of non – exhaust particle to PM₁₀ from concentrations of PM₁₀ and NO_x at Dindang station, 2001 – 2004

Period	Daily Average PM ₁₀ at Dindang station (µg/m ³)	Fraction
Whole period	87.96	0.37
Annual		
2001	96.05	0.46
2002	86.95	0.40
2003	83.96	0.30
2004	89.75	0.31
Aggregation whole period		
Dry season 2001-2004	100.19	0.34
Wet season 2001-2004	76.99	0.40

From the results of Table 4 – 11 showed that the ratio of non – exhaust particle to average PM₁₀ concentration during 2001 was highest than those ratios. The fraction of non – exhaust particle to average PM₁₀ concentration were in range of 0.30 to 0.46.

The fractions of non – exhaust particle in PM₁₀ observed at Dindang station during 2001 – 2004 were shown in Table 4 – 12.

Table 4 – 12 Comparison of the fraction of non – exhaust particle to average PM₁₀ at Dindang station, 2001 – 2004

Period	Under Relationship between PM ₁₀ and CO		Under Relationship between PM ₁₀ and NO _x	
	Daily Average PM ₁₀ at Dindang station (µg/m ³)	Fraction	Daily Average PM ₁₀ at Dindang station (µg/m ³)	Fraction
Whole period	89.61	0.40	87.96	0.37
Annual				
2001	104.78	0.48	96.05	0.46
2002	89.49	0.40	86.95	0.40
2003	75.30	0.30	83.96	0.30
2004	ND	ND	89.75	0.31
Aggregation whole period				
Dry season 2001-2004	98.50	0.36	100.19	0.34
Wet season 2001-2004	79.71	0.44	76.99	0.40

The results from Table 4 – 12 showed the estimation of the non – exhaust particle from the relationship between PM₁₀ and CO and the relationship between PM₁₀ and NO_x. The fraction of the non – exhaust particle and average PM₁₀ were close to each other. In 2001, the fraction of the non – exhaust particle and average PM₁₀ was highest.

This result was in agreement with the study of the non – exhaust particle in the other countries. For example, the study conducted by Lenschow et al., indicated that about 25% of the traffic influence was exhaust emission and tyre abrasion and 75% was resuspension of soil particles in the street (44). Harrison et al., studied the relationships of PM_{10} and NO_x . PM_{coarse} account one – fifth of PM_{10} concentration over the winter period that arise in part from wear of tyre and road surfaces and resuspended of dust by passing traffic (34). Charron and Harrison indicated that 31.4% of PM_{10} was from the non – exhaust emissions (43).

According to the result of the relationship between the particulate matter concentrations, the particle size distribution of PM_{10} can be classified into two types. Firstly, particles are with an aerodynamic diameter of 2.5 microns or less. The second is particles with an aerodynamic diameter of between 2.5 and 10 microns or coarse particles. It was found that $PM_{2.5}$ was the major contributor to the PM_{10} concentration at Dindang station. About 70% of PM_{10} concentration comprised of $PM_{2.5}$ concentration and strongly correlate with the dry season. $PM_{2.5}$ was widely regarded as the result of in complete combustion like; mobile sources whereas PM_{coarse} were more typically associated with geologic origin and grinding of larger particles (reentrainment). Reentrainment of particulate was for the most part related to vehicle grinding of particulate deposited on the road surfaces. From the study by Pollution Control Department, a source apportionment of PM_{10} in Bangkok and suburban areas, were observed from four monitoring sites during November 1995 to January 1996. It indicated that PM_{10} levels were higher especially at Pratunam and Odean sites. These sites were localized traffic and road dust could be expected to be the main contributors to the high level of PM_{10} . Moreover, the mobile sources were a contributing factor to the high PM_{10} level on the roadside area. Another source apportionment that were regarded such as road dust, steel mill, utility/industrial boilers secondary sulfate and marine (17).

The concentrations of $PM_{2.5}$ in dry season were higher than wet season accounting for 70 % of PM_{10} . The influence was regional and independent of the site location like; local construction activities and dust transport. Frequent raining and cold temperature reduce outdoor activities and particle resuspension, leading to low vehicular emissions and particle concentrations in the atmosphere.

The relationships between the particulate matter, CO and NO_x of Dindang station and Nonsiwitthaya school station were significant. The roadside enhancements were used to estimate of the non – exhaust particle at Dindang station. The relationships showed that about 40% of the non – exhaust particle comprise of the total particle is non – exhaust. The non – exhaust emissions would become more important as exhaust emissions in Bangkok area. The non – exhaust emissions could be a significant emission source in urban areas. The estimation of the non – exhaust emission were less than the measurement. The methods like; the air pollution abatement though reduction of particle and other air pollutants from vehicle, industry, construction and sweeping and cleaning roads, were used to removing the particle from the road surface. These methods were to maintain continuous efforts and reduced the particle to the air. Moreover, the particulate on the road may be an agglomerate of fine dust from the neighboring soil due to wind erosion, settlement of dust from tail pipe emissions or erosion of tires. Road dust emissions are resuspended particulate matter entrained in the urban street canopies due to wind erosion and movement of vehicles on the road.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Relationship of PM_{10} , $PM_{2.5}$ and PM_{coarse}

1) The results of regression relationship between the concentrations of PM_{10} and $PM_{2.5}$ indicate that there is a relationship between PM_{10} and $PM_{2.5}$ with 1% level of significance. The $PM_{2.5}/PM_{10}$ ratio of Dindang station is approximately to 0.622 with coefficient of determination (r^2) of 0.903. So it is possible to use it as the correction factor, which is 0.622, for the prediction of $PM_{2.5}$ from PM_{10} concentration. In addition, the relationship between PM_{10} and PM_{coarse} with 1% level of significance is 0.378 of the ratio PM_{coarse}/PM_{10} with r^2 of 0.539. We can use the concentration of PM_{10} to predict the concentration of PM_{coarse} . While, the $PM_{2.5}/PM_{coarse}$ ratio is 0.568 with r^2 of 0.374, it could be concluded that there are not relationship between the concentrations of $PM_{2.5}$ and PM_{coarse} .

2) The seasonal variation influence to the concentration of PM_{10} and $PM_{2.5}$ especially, the dry season because of adverse dispersion conditions and temperature inversions.

5.1.2 Relationship between Roadside enhancement PM_{10} and Roadside enhancement CO

The relationship between PM_{10} and CO at Dindang station and Nonsiwitthaya school station show that the coefficients of determination (r^2) of whole period are 0.476 indicating that the relationship between concentrations of PM_{10} and CO has moderate correlation. The results based on the relationship between road enhancement PM_{10} and road enhancement CO exhibit that the non – exhaust particle near to Dindang station is about 40% of average daily PM_{10} .

5.1.3 Relationship between Roadside enhancement PM₁₀ and Roadside enhancement NO_x

The relationship between PM₁₀ and NO_x of Dindang station and Nonsiwitthaya school station show that the coefficients of determination (r^2) of whole period are 0.494 indicating that the relationship between concentrations of PM₁₀ and NO_x has moderate correlation. The results based on the relationship between road enhancement PM₁₀ and road enhancement NO_x exhibit that the non – exhaust particle near to Dindang station is about 37% of average daily PM₁₀.

5.2 Recommendations for Further Study

1) Further study should be focused on continuous long term data set of PM_{2.5} to get more information including all the air quality monitoring stations.

2) Road traffic is a major source of the particulate matter in urban area. Development of a better understanding of the non – exhaust emissions from road vehicles including the level of non – exhaust emissions, measurement of the particle size distributions, number concentration of each size range or investigation into the distinct chemical characteristic of particles from brake wear, tyre wear and road dust resuspension may allow them to be identified and quantified.

3) Due to change of emission sources e.g. amount of vehicles and constructions, the study of the correction factor for predicting PM_{2.5} from PM₁₀ or vice versa should be re – study at least every three years based on this study's results which show similar values over the study period of three years.

4) It should be noticed that the level of non – exhaust particle observed in wet season was greater than dry season. The solution of this issue need more study.

REFERENCES

- 1.กรมควบคุมมลพิษ, สำนักจัดการคุณภาพอากาศและเสียง, กระทรวงทรัพยากรธรรมชาติและสิ่งแวดล้อม. สถานการณ์และการจัดการปัญหาหมอกพิษทางอากาศและเสียง ปี 2545. กรุงเทพฯ, 2546.
- 2.Bascom R, Bromberg, PA, Costa DA. et al. Health effect of outdoor air pollution. Am J Respir Crit Care Med. [Online] 1996. Oct; 13. Available from: <http://www.jhu.edu> [accessed 2004 Sep 24]
- 3.Brunekreef B, Janssen NA, Hartog J, Hassema H, Knape M, Vliet P. Air pollution from truck traffic and lung function in children living near motorways. Epidemiology 1997; 8:298 – 303.
- 4.Kinney L, Aggarwal, Northridge E, Janssen A.H. and Shepard. Airborne concentrations of PM_{2.5} and diesel exhaust particles on Harlem sidewalks. Environ Health Perspect. [Online] 2000. Jan; 21. Available from: <http://ehpnet1.niehs.nih.gov/docs/2000/108p213-218kinney/abstract.html> [accessed 2004 Jan 13]
- 5.Artinano B, Salvador P, Alonso DG, Querol X and Alastuey A. Influence of traffic on the PM₁₀ and PM_{2.5} urban aerosol fractions in Madrid (Spain). Sciencedirect journal of the Total Environment. [Online] 2004. Apr; 1. Available from: <http://sciencedirect.com> [accessed 2004 Oct 17]
- 6.กรมควบคุมมลพิษ, กองจัดการคุณภาพอากาศและเสียง, กระทรวงวิทยาศาสตร์ เทคโนโลยี และสิ่งแวดล้อม. โครงการศึกษาผลกระทบของฝุ่นละอองต่อสุขภาพอนามัยของประชาชนในเขตกรุงเทพมหานคร. กรุงเทพฯ, 2544.
- 7.สำนักปลัดกรุงเทพมหานคร, กองควบคุมและจัดการคุณภาพสิ่งแวดล้อม. รายงานสถานการณ์คุณภาพสิ่งแวดล้อมของกรุงเทพมหานคร 2544. กรุงเทพฯ, 2545.
- 8.สำนักปลัดกรุงเทพมหานคร, กองควบคุมและจัดการคุณภาพสิ่งแวดล้อม. รายงานสถานการณ์คุณภาพสิ่งแวดล้อมของกรุงเทพมหานคร 2546. กรุงเทพฯ, 2547.

- 9.วงศ์พันธ์ ลิ้มปเสนีย์, นิตยา มหาผล, ชีระ เกรอด. มลภาวะอากาศ. พิมพ์ครั้งที่ 6. กรุงเทพฯ:
โรงพิมพ์จุฬาลงกรณ์มหาวิทยาลัย, 2543.
10. Airborne Particles Expert Group, Department of the environment, transport and the regions, the Welsh office, the Scottish office and the department of the environment (Northern Ireland). Source apportionment of airborne particulate matter in the United Kingdom. London, 1999.
11. US. EPA., 1998. NO_x How nitrogen oxides affect the way we live and breath.
12. พัฒนา มูลพฤกษ์. การป้องกันและควบคุมมลพิษ. พิมพ์ครั้งที่ 1. กรุงเทพฯ: หจก. เอ็น.เอส.
แอล.พรีนติ้ง, 2539.
13. พิศิษฐ์ วัฒนสมบูรณ์. หลักมลพิษทางอากาศ เล่ม 1. พิมพ์ครั้งที่ 1. กรุงเทพฯ: มหาวิทยาลัยมหิดล;
2544.
14. Hinds and William C. Aerosol Technology: Properties, behavior and measurement of airborne particles. John Wiley & Sons, Inc., U.S.A. 1982.
15. Suess M.J. and Thomas K. Ambient air pollution from industrial source. Health & Environment. New York: Elsevier Inc; 1985.
16. รพีพัฒน์ เกริกโกวิท. องค์ประกอบธาตุในฝุ่นละอองขนาดเล็กกว่า 2.5 ไมครอนในเขต
กรุงเทพมหานคร [วิทยานิพนธ์ปริญญาวิทยาศาสตรมหาบัณฑิต สาขาวิทยาศาสตร์
สภาวะแวดล้อม]. กรุงเทพฯ: บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย; 2543.
17. กรมควบคุมมลพิษ. การจัดทำยุทธศาสตร์ในการแก้ไขปัญหาฝุ่นละอองในกรุงเทพมหานคร
(Particulate Matter Abatement Strategy for the Bangkok Metropolitan Area). กรุงเทพฯ, 2544.
18. น้อม งามนิสัย. ปัญหานุษย์กับภาวะแวดล้อม. กรุงเทพฯ: สำนักพิมพ์อักษรวัฒนา, 2523.
19. วนิตา ทรัพย์สุข. ผลของฝุ่นละอองขนาดเล็กและก๊าซไนโตรเจนไดออกไซด์ภายในที่พักอาศัยต่อ
สุขภาพของแม่บ้านและเด็กในกรุงเทพมหานคร กรุงเทพมหานคร [วิทยานิพนธ์
ปริญญาวิทยาศาสตรมหาบัณฑิต สาขาวิทยาศาสตร์สภาวะแวดล้อม]. กรุงเทพฯ:
บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย; 2543.

- 20.ธวัช สุนทรจารย์ และประภาวัลย์ เพียรธรรม. ผู้ดูแลห้อง: ปัญหาจากการจราจรที่มีผลกระทบต่อสุขภาพอนามัย. ความปลอดภัยและสิ่งแวดล้อม 2539; 4: 61 – 67.
- 21.นิตยา มหาผล. เอกสารการสอนชุดวิชากฎหมายสิ่งแวดล้อม หน่วยที่ 8 สาขานิติศาสตร์ มหาวิทยาลัยสุโขทัยธรรมาธิราช. พิมพ์ครั้งที่ 4. กรุงเทพฯ: โรงพิมพ์มหาวิทยาลัยสุโขทัยธรรมาธิราช, 2533.
- 22.นพภาพร พานิช และแสงสันต์ พานิช. แบบจำลองทางคณิตศาสตร์ด้านคุณภาพอากาศ. พิมพ์ครั้งที่ 1. กรุงเทพฯ: สำนักพิมพ์จุฬาลงกรณ์มหาวิทยาลัย, 2544.
- 23.ศิริกัลยา สุวจิตตานนท์, วิวัฒน์ ตัณฑะพานิชกุล, ชิกาโอะ คานาโอะกะ, จุฑามาศ เกตุทัต. มลภาวะอากาศ. พิมพ์ครั้งที่ 2. กรุงเทพฯ: สำนักพิมพ์มหาวิทยาลัยเกษตรศาสตร์, 2544.
- 24.US. EPA., 1999. Compendium Method IO – 2.1: Sampling of ambient air for total suspended particulate matter (SPM) and PM using high volume (HV) sampler. [Online] 1999: [78 screens] Available from: URL: <http://www.epa.gov/ttn/amtic/files/ambient/inorganic/mthod-2-1.pdf>. [access 2004 Mar 30].
- 25.World Health Organization. Environmental health criteria & sulfur oxides and suspended particulate matter. Geneva: WHO offset Publication; 1979.
- 26.World Health Organization. Selected methods of Measuring air pollutions. Geneva: WHO offset Publication; 1976.
- 27.World Health Organization. Environmental health criteria & carbon monoxide. Geneva: WHO offset Publication; 1979.
28. Jaffe LS. Carbon monoxide in the biosphere: sources, distributions and concentrations. J geophys. Page 5293 – 5305; 1973.
- 29.Seiler, W. The cycle of carbon monoxide in the atmosphere. In:International Conference on Environmental Sensing and Assessment, Las Vegas, NV, 14 – 19 September, New York, Institute of Electrical and Electronics Engineers, Vol.2, 6 pp. 1975.
- 30.World Health Organization. Environmental health criteria & nitrogen oxides. Geneva: WHO offset Publication; 1997.

31. กองอนามัยสิ่งแวดล้อม. ปัญหามลพิษทางอากาศผลกระทบต่อสุขภาพอนามัยและแนวทางแก้ไข.
กรุงเทพฯ: กระทรวงสาธารณสุข; 2542.
32. Janssen AH., Van Mansom, Der J, Harssema H and Hoek G. Mass concentration and elemental composition of airborne particulate matter at street and background locations. *Scienedirect journal of Atmospheric Environment*. [Online] 1996. Sep;9. page 1185 – 1193. Available from: <http://sciencedirect.com> [accessed 2004 Oct 17]
33. ศิริวรรณ แก้วงาม. สันฐานและองค์ประกอบธาตุของฝุ่นที่มีขนาดเล็กกว่า 10 ไมครอนในเขตกรุงเทพมหานคร [วิทยานิพนธ์ปริญญาวิทยาศาสตรมหาบัณฑิต สาขาวิทยาศาสตร์สภาวะแวดล้อม]. กรุงเทพฯ: บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย; 2543.
34. Harrison, R.M, Deacon R and Jones R. Sources and processes affecting concentrations of PM₁₀ and PM_{2.5} particulate matter in Birmingham (U.K). *Scienedirect journal of Atmospheric Environment*. [Online] 1997. Jun;13. page 4103 – 4117. Available from: <http://sciencedirect.com> [accessed 2004 Oct 17]
35. Chaloulakou A, Kassomenos P, Spyrellis N, Demokritou P and Koutrakis P. Measurements of PM₁₀ and PM_{2.5} particle concentrations in Athens, Greece. *Scienedirect journal of Atmospheric Environment*. [Online] 2002. Oct;17. page 649 – 660. Available from: <http://sciencedirect.com> [accessed 2004 Oct 25]
36. Querol X, Alastuey A, Viana M.M. et al. Speciation and origin of PM₁₀ and PM_{2.5} in Spain. *Scienedirect journal of Aerosol Science*. [Online] 2004. Apr;20. Available from: <http://sciencedirect.com> [accessed 2004 Nov 13]
37. Zhao Lirong, Wang Xinming, He Qiusheng. et al. Exposure to hazardous volatile organic compounds, PM₁₀ and CO while walking along streets in urban Guangzhou, China. *Scienedirect journal of Aerosol Science*. [Online] 2004. Jul;14. Available from: <http://sciencedirect.com> [accessed 2004 Nov 13]

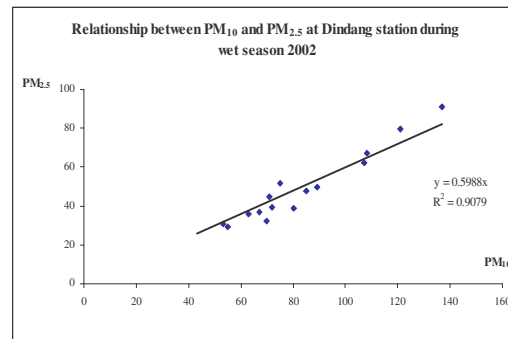
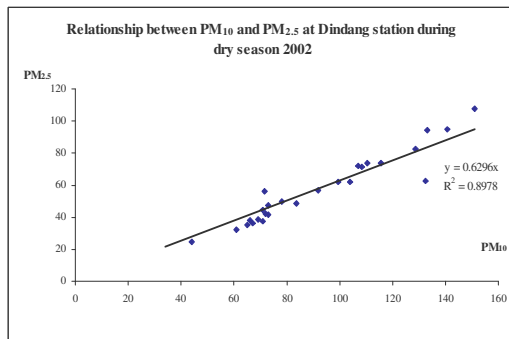
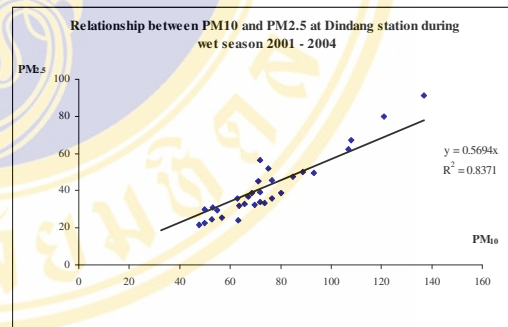
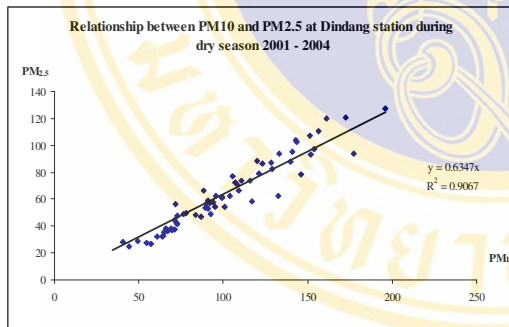
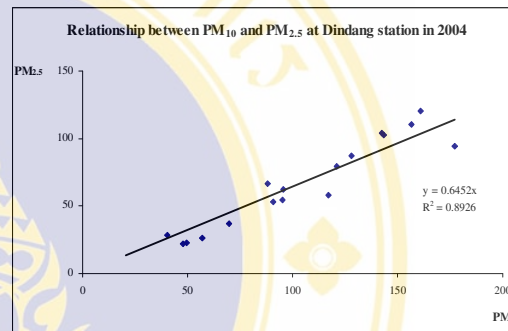
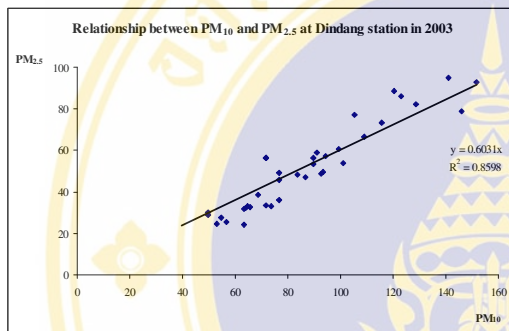
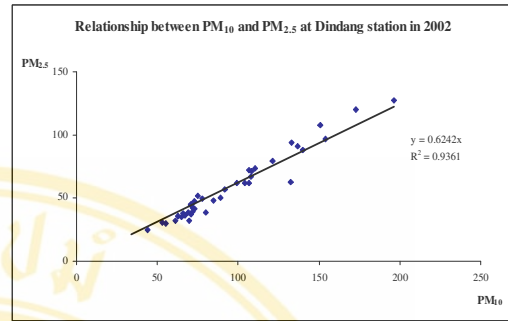
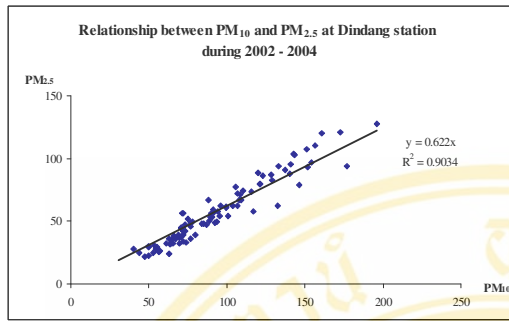
- 38.Samara C, Kouimtzis, Tsitouridou R, Kaninas G and Simeonov V. Chemical mass balance source apportionment of PM₁₀ in an industrialized urban area of Northern Greece. Sciencedirect journal of Atmospheric Environment. [Online] 2002.Sep;11. Available from: <http://sciencedirect.com> [accessed 2004 Jun 29]
- 39.จุมพล ศิริสวัสดิ์. การศึกษาเปรียบเทียบเทคนิคการตรวจวัดฝุ่นละอองในบรรยากาศ
(วิทยานิพนธ์ปริญญาวิทยาศาสตรมหาบัณฑิต (สาธารณสุขศาสตร์) สาขาวิชาเอก
อนามัยสิ่งแวดล้อม. กรุงเทพฯ: บัณฑิตวิทยาลัย มหาวิทยาลัยมหิดล; 2535.
- 40.Neville S. Air Quality Review and Assessment. Westminster City Council, 2000.
- 41.สำนักอุตุนิยมวิทยา. กลุ่มภูมิอากาศ. ภูมิอากาศในประเทศไทย. กรุงเทพฯ: กรมอุตุนิยมวิทยา;
2545.
42. กัลยา วานิชย์บัญชา. สถิติสำหรับงานวิจัย. พิมพ์ครั้งที่1. โรงพิมพ์จุฬาลงกรณ์มหาวิทยาลัย,
2548.
- 43.Charron A and Harrison, R.M. Fine (PM_{2.5}) and Coarse (PM_{2.5-10}) Particulate matter on a heavily trafficked London highway: sources and processes, Division of environmental health and risk management, School of geography, earth and environment sciences, University of Birmingham, 2000.
- 44.Lenschow P, Abraham H-J, Kutzner K, Lutz M, Preuß J-D and Reichenbacher W. Some ideas about the sources of PM₁₀. Sciencedirect journal of Atmospheric Environment. [Online] 2001.Jan;24. Available from: <http://sciencedirect.com> [accessed 2005 May 12]



Appendix A: PM concentrations at Dindang station**Table A – 1** Pairs data of PM₁₀ and PM_{2.5} concentrations

Date	PM ₁₀ (µg/m ³)	PM _{2.5} (µg/m ³)	Date	PM ₁₀ (µg/m ³)	PM _{2.5} (µg/m ³)
11 Jan 02	196.2	127.6	13 Mar 03	109.1	66.5
17 Jan 02	172.7	120.5	19 Mar 03	64.6	32.9
23 Jan 02	140	87.9	25 Mar 03	99.3	60.8
29 Jan 02	153.8	96.9	31 Mar 03	100.9	54
22 Feb 02	71	37.5	6 Apr 03	64.1	32.2
28 Feb 02	66	38	30 Apr 03	76.6	49.1
12 Mar 02	67	36.3	6 May 03	86.7	46.9
5 Apr 02	78	49.6	12 May 03	89.5	53.6
11 Apr 02	72	42.2	18 May 03	54.5	27.5
29 Apr 02	73	41.7	11 Jun 03	63.4	31.7
5 May 02	104	62	17 Jun 03	76.5	45.6
11 May 02	71	44.2	23 Jun 03	49.8	29.9
17 May 02	44	24.6	29 Jun 03	68.8	38.7
23 May 02	65	35.3	5 Jul 03	93.3	49.5
29 May 02	61	32.4	11 Jul 03	65.6	32.6
4 Jun 02	63	35.9	17 Jul 03	71.8	56.4
10 Jun 02	55	29.5	23 Jul 03	56.6	25.4
16 Jun 02	72	39.1	29 Jul 03	73.7	33.2
22 Jun 02	67	36.7	10 Aug 03	63.2	24.2
28 Jun 02	75	51.8	16 Aug 03	71.8	33.6
4 Jul 02	71	44.9	22 Aug 03	76.7	36
10 Jul 02	80	38.7	9 Sep 03	52.9	24.5
27 Aug 02	89	49.9	27 Oct 03	105.3	77.3
8 Sep 02	53.1	30.9	2 Nov 03	120.2	88.4
14 Sep 02	69.7	32.2	8 Nov 03	123.1	86.2
20 Sep 02	108.1	67.1	20 Nov 03	91.1	58.9
26 Sep 02	85	47.7	26 Nov 03	89.7	56.5
2 Oct 02	121	79.7	14 Dec 03	94.2	57.4
8 Oct 02	107	62.1	20 Dec 03	146	78.7
14 Oct 02	137	91.1	26 Dec 03	151.7	92.8
26 Oct 02	69	38.5	7 Jan 04	142.7	103.68
1 Nov 02	110.5	73.9	19 Jan 04	40.4	28.03
7 Nov 02	99.3	61.8	25 Jan 04	95.3	54.36
13 Nov 02	132.6	62.5	18 Feb 04	177	93.98
19 Nov 02	108.3	71.3	7 Mar 04	117	58.05
7 Dec 02	107	72.1	13 Mar 04	69.8	36.86
13 Dec 02	92	56.9	24 Apr 04	57.1	26.53
19 Dec 02	151	107.5	6 May 04	95.8	62.35
25 Dec 02	133	94	11 Jul 04	49.7	22.75
31 Dec 02	73	47.4	29 Jul 04	47.6	21.7
6 Jan 03	128.8	82.3	3 Sep 04	90.7	53.22
12 Jan 03	115.7	73.5	21 Sep 04	120.9	79.3
18 Jan 03	140.9	94.9	27 Sep 04	128.2	86.83
5 Feb 03	83.7	48.3	7 Oct 04	88.1	66.45
11 Feb 03	71.6	56.2	15 Oct 04	143.3	102.46
17 Feb 03	49.5	28.9	21 Oct 04	156.4	110.41
1 Mar 03	92.6	48.9	27 Oct 04	160.9	119.98

Relationship between PM₁₀ and PM_{2.5} at Dindang station



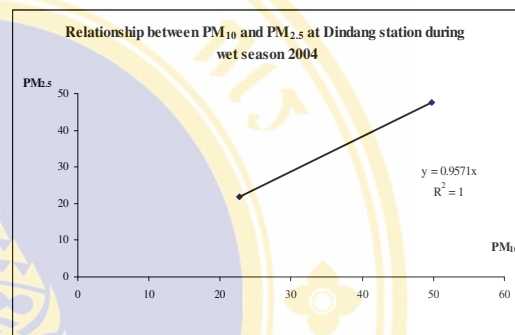
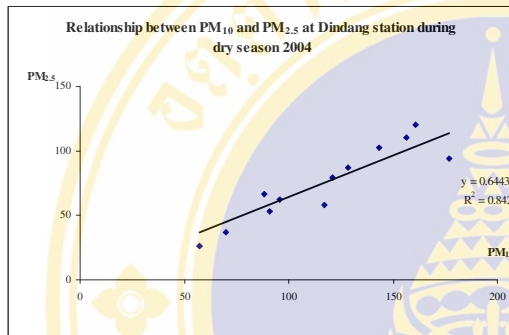
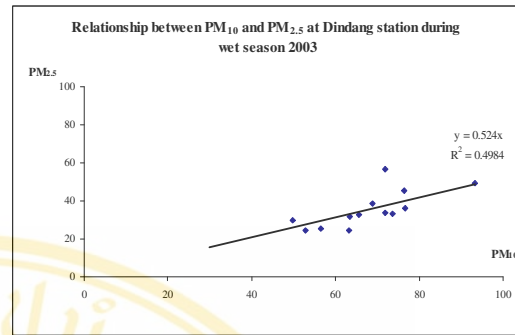
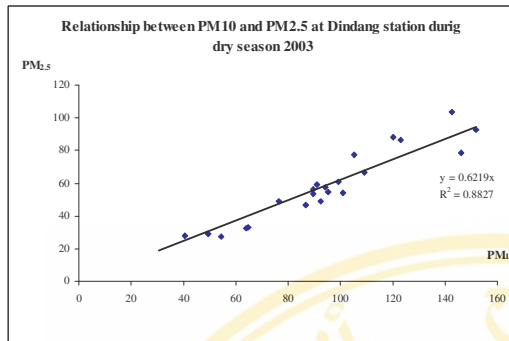
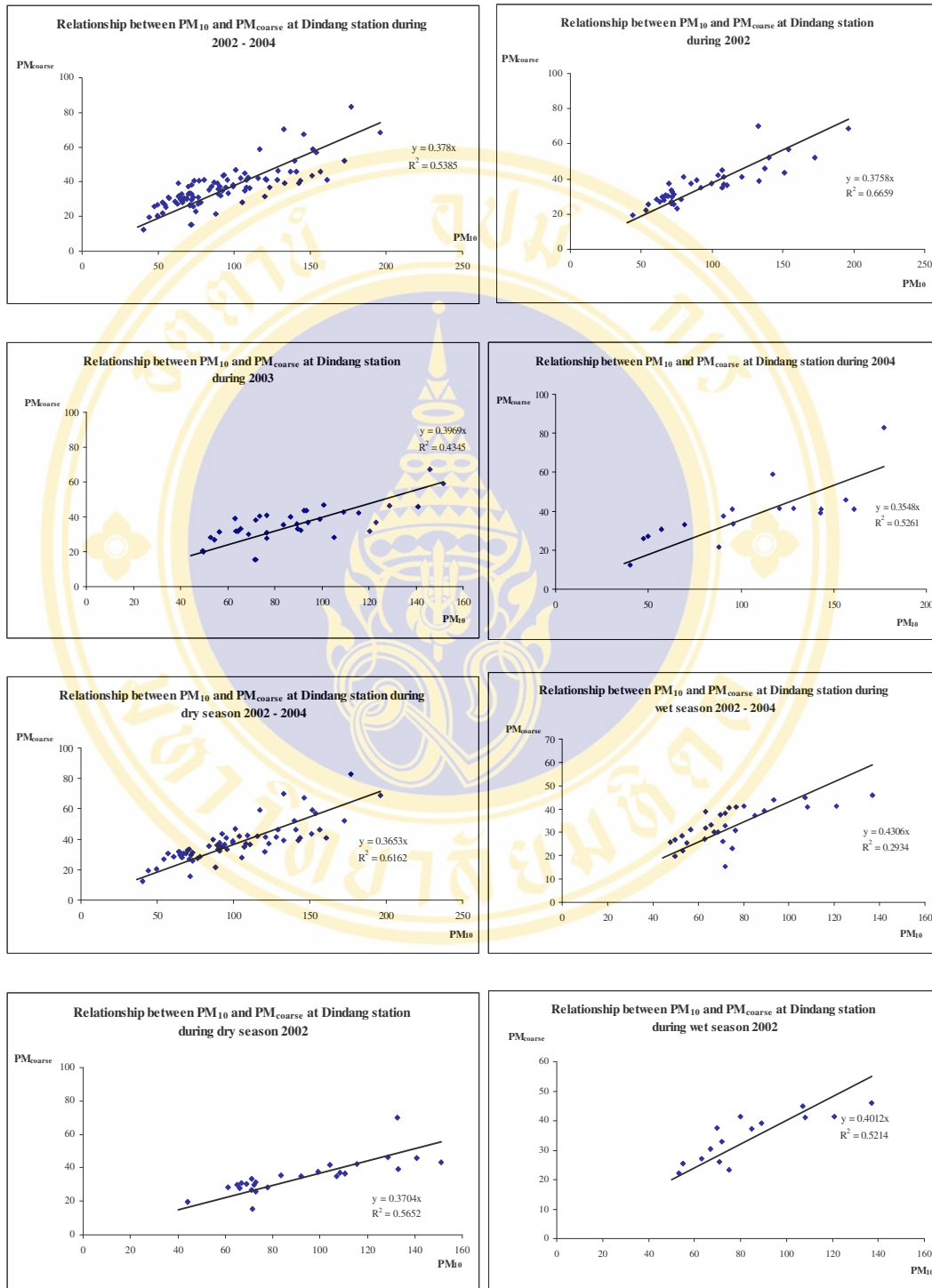


Table A – 2 Pairs data of PM₁₀ and PM_{coarse} concentrations

Date	PM ₁₀ (µg/m ³)	PM _{coarse} (µg/m ³)	Date	PM ₁₀ (µg/m ³)	PM _{coarse} (µg/m ³)
11 Jan 02	196.2	68.6	13 Mar 03	109.1	42.6
17 Jan 02	172.7	52.2	19 Mar 03	64.6	31.7
23 Jan 02	140	52.1	25 Mar 03	99.3	38.5
29 Jan 02	153.8	56.9	31 Mar 03	100.9	46.9
22 Feb 02	71	33.5	6 Apr 03	64.1	31.9
28 Feb 02	66	28	30 Apr 03	76.6	27.5
12 Mar 02	67	30.7	6 May 03	86.7	39.8
5 Apr 02	78	28.4	12 May 03	89.5	35.9
11 Apr 02	72	29.8	18 May 03	54.5	27
29 Apr 02	73	31.3	11 Jun 03	63.4	31.7
5 May 02	104	42	17 Jun 03	76.5	30.9
11 May 02	71	26.8	23 Jun 03	49.8	19.9
17 May 02	44	19.4	29 Jun 03	68.8	30.1
23 May 02	65	29.7	5 Jul 03	93.3	43.8
29 May 02	61	28.6	11 Jul 03	65.6	33
4 Jun 02	63	27.1	17 Jul 03	71.8	15.4
10 Jun 02	55	25.5	23 Jul 03	56.6	31.2
16 Jun 02	72	32.9	29 Jul 03	73.7	40.5
22 Jun 02	67	30.3	10 Aug 03	63.2	39
28 Jun 02	75	23.2	16 Aug 03	71.8	38.2
4 Jul 02	71	26.1	22 Aug 03	76.7	40.7
10 Jul 02	80	41.3	9 Sep 03	52.9	28.4
27 Aug 02	89	39.1	27 Oct 03	105.3	28
8 Sep 02	53.1	22.2	2 Nov 03	120.2	31.8
14 Sep 02	69.7	37.5	8 Nov 03	123.1	36.9
20 Sep 02	108.1	41	20 Nov 03	91.1	32.2
26 Sep 02	85	37.3	26 Nov 03	89.7	33.2
2 Oct 02	121	41.3	14 Dec 03	94.2	36.8
8 Oct 02	107	44.9	20 Dec 03	146	67.3
14 Oct 02	137	45.9	26 Dec 03	151.7	58.9
26 Oct 02	69	30.5	7 Jan 04	142.7	39.02
1 Nov 02	110.5	36.6	19 Jan 04	40.4	12.37
7 Nov 02	99.3	37.5	25 Jan 04	95.3	40.94
13 Nov 02	132.6	70.1	18 Feb 04	177	83.02
19 Nov 02	108.3	37	7 Mar 04	117	58.95
7 Dec 02	107	34.9	13 Mar 04	69.8	32.94
13 Dec 02	92	35.1	24 Apr 04	57.1	30.57
19 Dec 02	151	43.5	6 May 04	95.8	33.45
25 Dec 02	133	39	11 Jul 04	49.7	26.95
31 Dec 02	73	25.6	29 Jul 04	47.6	25.9
6 Jan 03	128.8	46.5	3 Sep 04	90.7	37.48
12 Jan 03	115.7	42.2	21 Sep 04	120.9	41.6
18 Jan 03	140.9	46	27 Sep 04	128.2	41.37
5 Feb 03	83.7	35.4	7 Oct 04	88.1	21.65
11 Feb 03	71.6	15.4	15 Oct 04	143.3	40.84
17 Feb 03	49.5	20.6	21 Oct 04	156.4	45.99
1 Mar 03	92.6	43.7	27 Oct 04	160.9	40.92

Relationship between PM₁₀ and PM_{coarse} at Dindang station



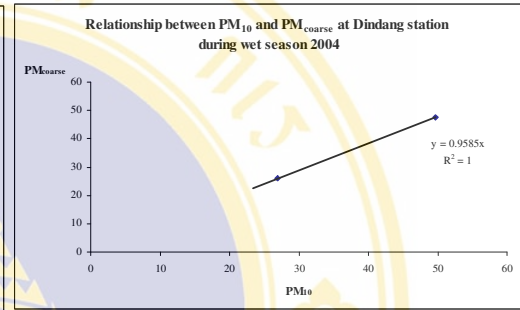
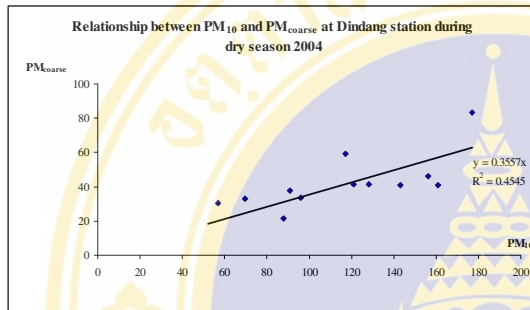
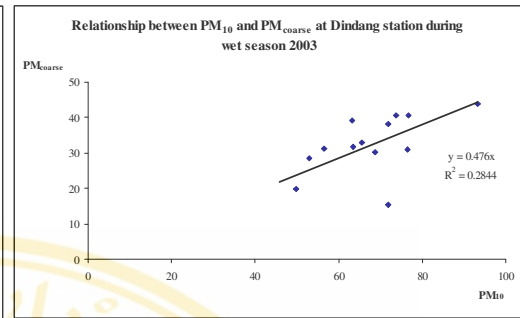
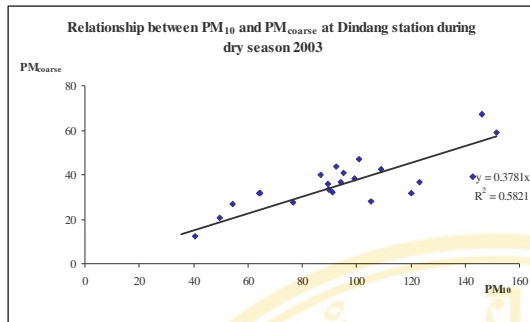
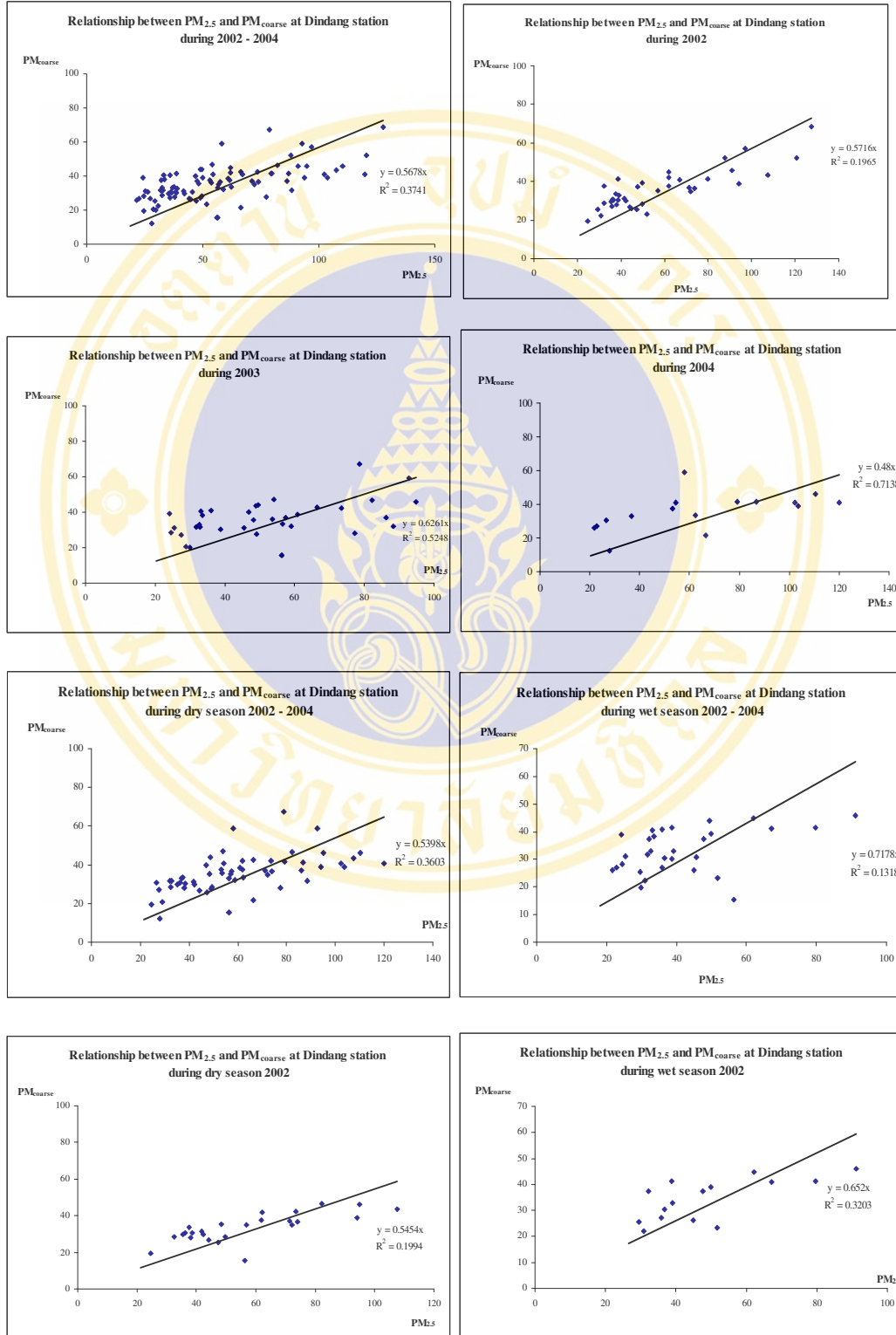


Table A – 3 Pairs data of PM_{2.5} and PM_{coarse} concentrations

Date	PM _{2.5} (µg/m ³)	PM _{coarse} (µg/m ³)	Date	PM _{2.5} (µg/m ³)	PM _{coarse} (µg/m ³)
11 Jan 02	127.6	68.6	13 Mar 03	66.5	42.6
17 Jan 02	120.5	52.2	19 Mar 03	32.9	31.7
23 Jan 02	87.9	52.1	25 Mar 03	60.8	38.5
29 Jan 02	96.9	56.9	31 Mar 03	54	46.9
22 Feb 02	37.5	33.5	6 Apr 03	32.2	31.9
28 Feb 02	38	28	30 Apr 03	49.1	27.5
12 Mar 02	36.3	30.7	6 May 03	46.9	39.8
5 Apr 02	49.6	28.4	12 May 03	53.6	35.9
11 Apr 02	42.2	29.8	18 May 03	27.5	27
29 Apr 02	41.7	31.3	11 Jun 03	31.7	31.7
5 May 02	62	42	17 Jun 03	45.6	30.9
11 May 02	44.2	26.8	23 Jun 03	29.9	19.9
17 May 02	24.6	19.4	29 Jun 03	38.7	30.1
23 May 02	35.3	29.7	5 Jul 03	49.5	43.8
29 May 02	32.4	28.6	11 Jul 03	32.6	33
4 Jun 02	35.9	27.1	17 Jul 03	56.4	15.4
10 Jun 02	29.5	25.5	23 Jul 03	25.4	31.2
16 Jun 02	39.1	32.9	29 Jul 03	33.2	40.5
22 Jun 02	36.7	30.3	10 Aug 03	24.2	39
28 Jun 02	51.8	23.2	16 Aug 03	33.6	38.2
4 Jul 02	44.9	26.1	22 Aug 03	36	40.7
10 Jul 02	38.7	41.3	9 Sep 03	24.5	28.4
27 Aug 02	49.9	39.1	27 Oct 03	77.3	28
8 Sep 02	30.9	22.2	2 Nov 03	88.4	31.8
14 Sep 02	32.2	37.5	8 Nov 03	86.2	36.9
20 Sep 02	67.1	41	20 Nov 03	58.9	32.2
26 Sep 02	47.7	37.3	26 Nov 03	56.5	33.2
2 Oct 02	79.7	41.3	14 Dec 03	57.4	36.8
8 Oct 02	62.1	44.9	20 Dec 03	78.7	67.3
14 Oct 02	91.1	45.9	26 Dec 03	92.8	58.9
26 Oct 02	38.5	30.5	7 Jan 04	103.68	39.02
1 Nov 02	73.9	36.6	19 Jan 04	28.03	12.37
7 Nov 02	61.8	37.5	25 Jan 04	54.36	40.94
19 Nov 02	71.3	37	7 Mar 04	58.05	58.95
7 Dec 02	72.1	34.9	13 Mar 04	36.86	32.94
13 Dec 02	56.9	35.1	24 Apr 04	26.53	30.57
19 Dec 02	107.5	43.5	6 May 04	62.35	33.45
25 Dec 02	94	39	11 Jul 04	22.75	26.95
31 Dec 02	47.4	25.6	29 Jul 04	21.7	25.9
6 Jan 03	82.3	46.5	3 Sep 04	53.22	37.48
12 Jan 03	73.5	42.2	21 Sep 04	79.3	41.6
18 Jan 03	94.9	46	27 Sep 04	86.83	41.37
5 Feb 03	48.3	35.4	7 Oct 04	66.45	21.65
11 Feb 03	56.2	15.4	15 Oct 04	102.46	40.84
17 Feb 03	28.9	20.6	21 Oct 04	110.41	45.99
1 Mar 03	48.9	43.7	27 Oct 04	119.98	40.92

Relationship between PM_{2.5} and PM_{coarse} at Dindang station



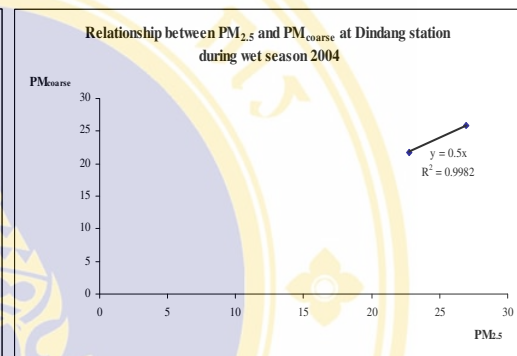
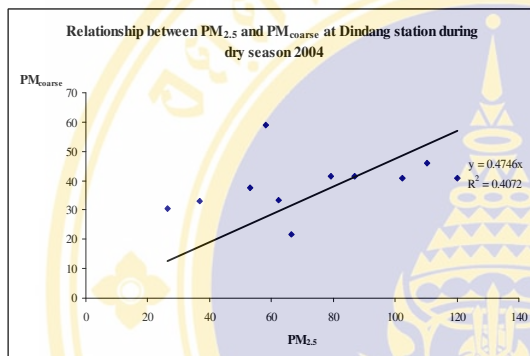
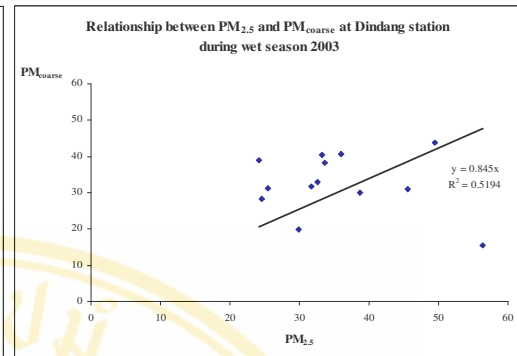
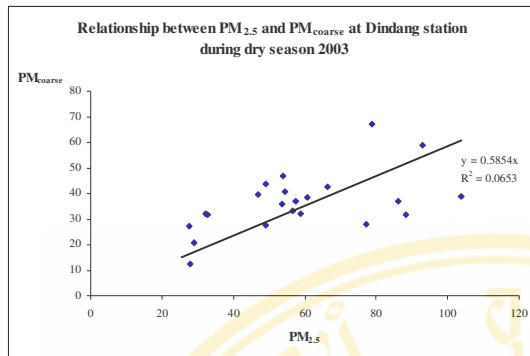
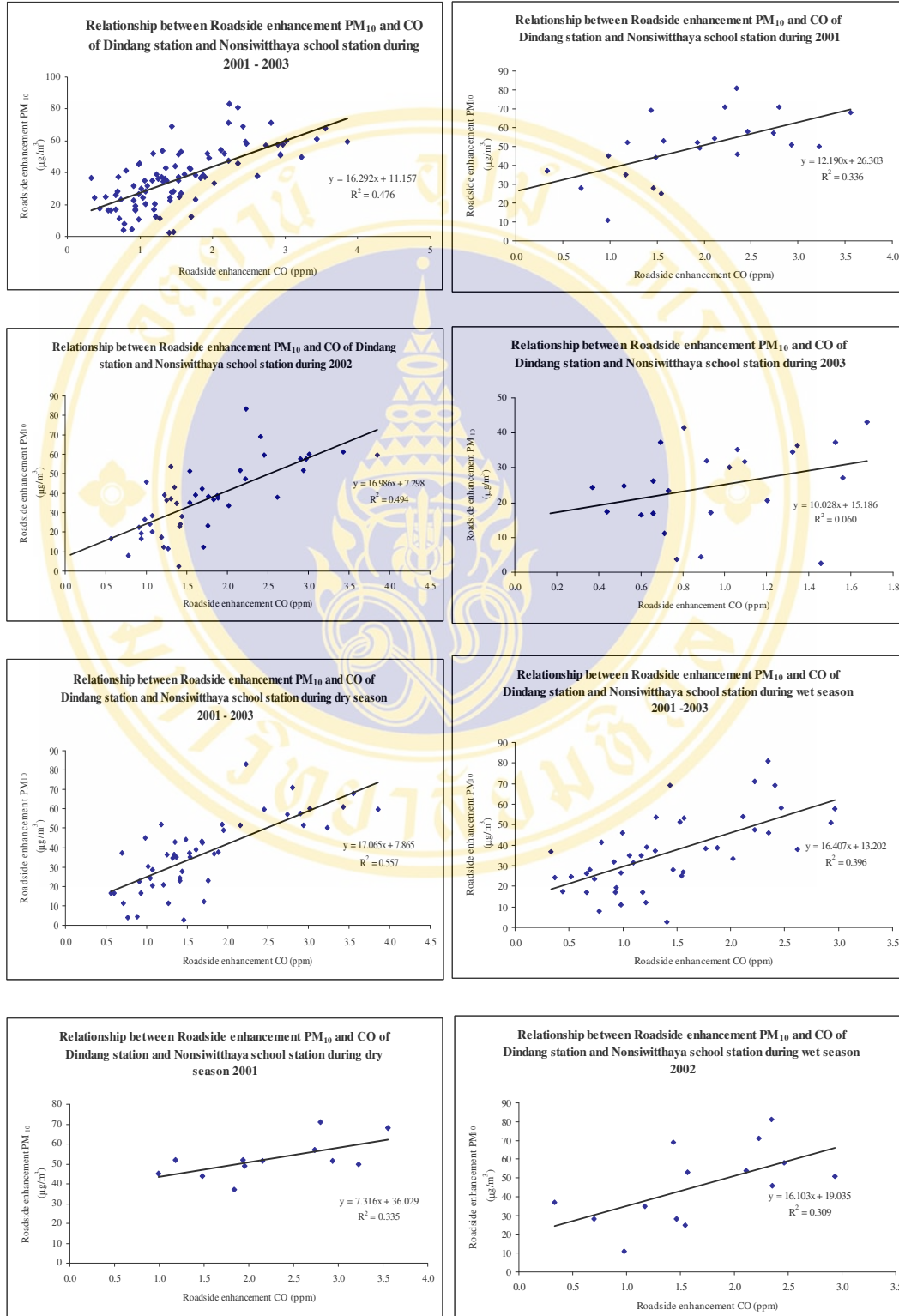


Table A – 4 Roadside enhancement PM₁₀ and Roadside enhancement CO of Dindang station and Nonsiwitthaya school station

Date	Roadside enhancement CO (ppm)	Roadside enhancement PM ₁₀ (µg/m ³)	Date	Roadside enhancement CO (ppm)	Roadside enhancement PM ₁₀ (µg/m ³)
3 Jun 01	2.93	51	9 Aug 02	1.77	38.3
15 Jun 01	1.47	28	21 Aug 02	1.21	12.2
21 Jun 01	0.98	11	27 Aug 02	2.22	47.5
27 Jun 01	1.57	53	14 Sep 02	1.22	39.1
2 Aug 01	0.70	28	20 Sep 02	2.97	57.8
20 Aug 01	1.17	35	26 Sep 02	1.30	37.1
26 Aug 01	0.33	37	2 Oct 02	2.62	37.9
7 Sep 01	1.54	25	8 Oct 02	1.53	51.2
13 Sep 01	2.35	46	14 Oct 02	2.41	69.2
19 Sep 01	2.34	81	20 Oct 02	1.25	36.2
25 Sep 01	2.23	71	26 Oct 02	1.53	35.2
1 Oct 01	1.44	69	1 Nov 02	3.01	60.1
7 Oct 01	2.11	54	7 Nov 02	1.37	34.9
13 Oct 01	2.47	58	13 Nov 02	2.23	83.1
19 Oct 01	2.80	71	19 Nov 02	3.85	59.6
6 Nov 01	0.99	45	25 Nov 02	2.45	59.5
12 Nov 01	1.48	44	1 Dec 02	1.69	42.4
18 Nov 01	2.74	57	7 Dec 02	1.89	37.5
24 Nov 01	3.55	68	13 Dec 02	1.61	39
30 Nov 01	3.23	50	19 Dec 02	2.90	57.5
6 Dec 01	1.95	49	25 Dec 02	3.43	61
12 Dec 01	1.93	52	31 Dec 02	1.44	27.9
18 Dec 01	1.18	52	5 Feb 03	0.77	3.7
17 Jan 02	2.93	51.6	11 Feb 03	1.46	2.6
23 Jan 02	1.83	36.9	17 Feb 03	0.89	4.3
29 Jan 02	2.16	51.7	1 Mar 03	1.32	34.4
22 Feb 02	1.07	20.3	13 Mar 03	1.53	37.3
28 Feb 02	0.93	16.4	19 Mar 03	0.71	11.2
6 Mar 02	1.41	22.8	25 Mar 03	1.68	43.1
12 Mar 02	0.57	16.6	30 Apr 03	1.20	20.6
5 Apr 02	1.71	12.3	6 May 03	1.02	30.1
11 Apr 02	0.91	22.4	12 May 03	1.34	36.4
29 Apr 02	1.76	23.1	18 May 03	0.60	16.4
5 May 02	1.35	43	11 Jun 03	0.44	17.4
11 May 02	1.42	24.1	17 Jun 03	1.10	31.7
17 May 02	1.27	11.4	29 Jun 03	0.52	24.7
23 May 02	1.07	28.4	5 Jul 03	0.91	31.9
29 May 02	1.05	24.2	17 Jul 03	1.56	27.1
4 Jun 02	0.98	26.5	23 Jul 03	0.66	16.9
10 Jun 02	0.93	19.4	29 Jul 03	1.06	35.1
16 Jun 02	1.87	38.7	5 Aug 03	0.66	26.1
22 Jun 02	1.40	2.5	10 Aug 03	0.37	24.4
28 Jun 02	2.02	33.4	16 Aug 03	0.80	41.4
16 Jul 02	0.78	8	9 Sep 03	0.93	17.2
22 Jul 02	1.00	45.8	15 Oct 03	0.73	23.4
28 Jul 02	1.19	17.2	27 Oct 03	0.70	37.3
3 Aug 02	1.30	53.5			

Relationship between Roadside enhancement PM₁₀ and CO of Dindang station and Nonsiwitthaya school station



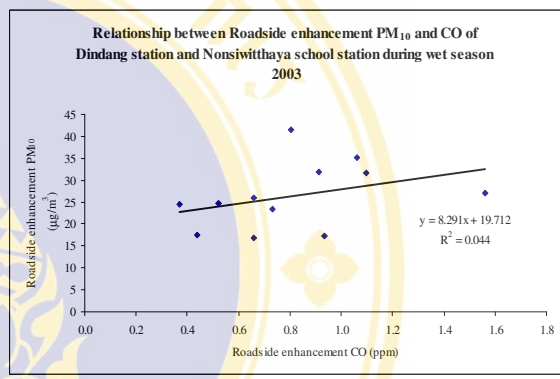
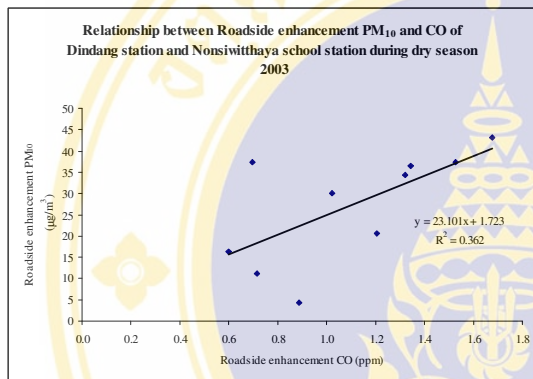
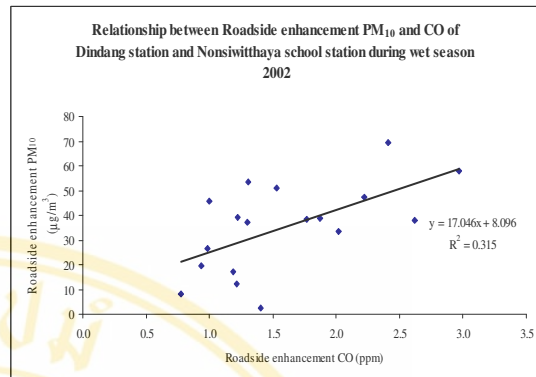
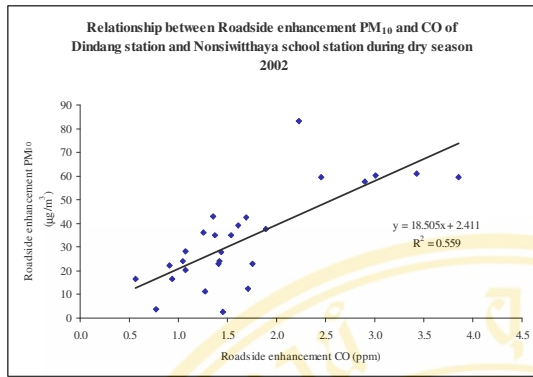
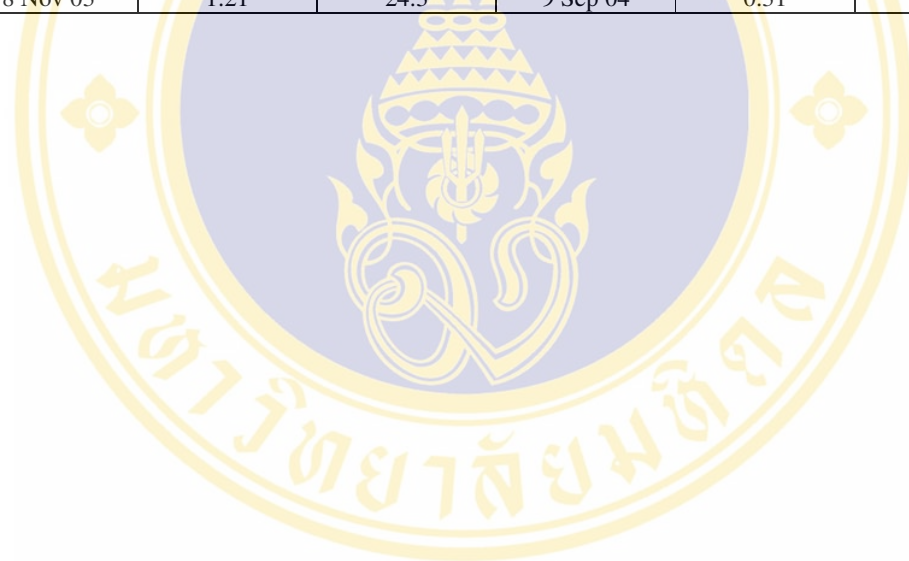
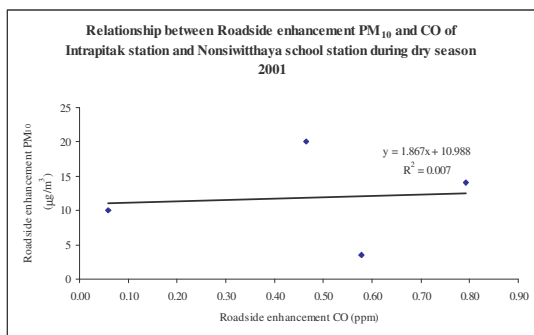
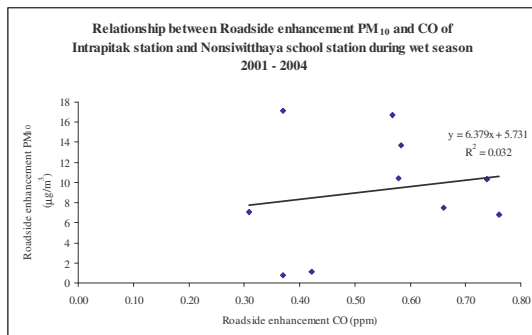
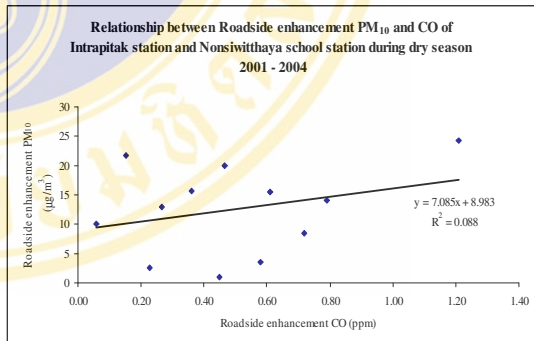
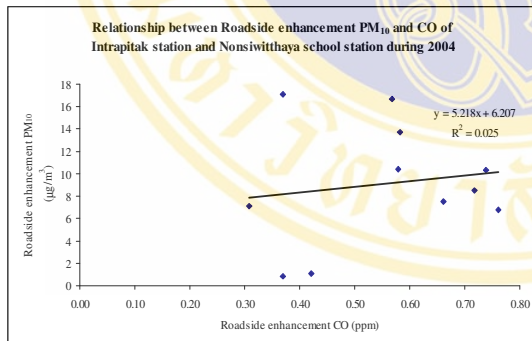
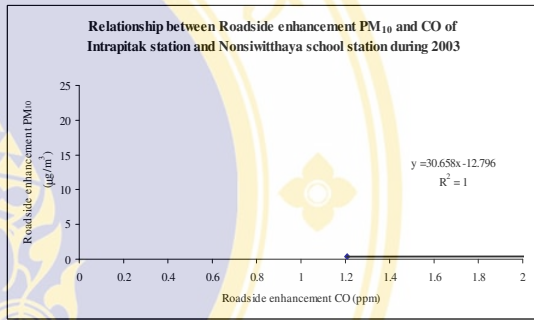
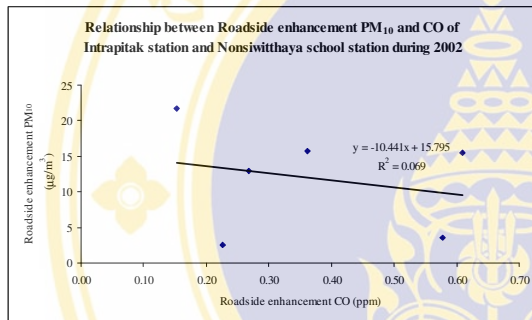
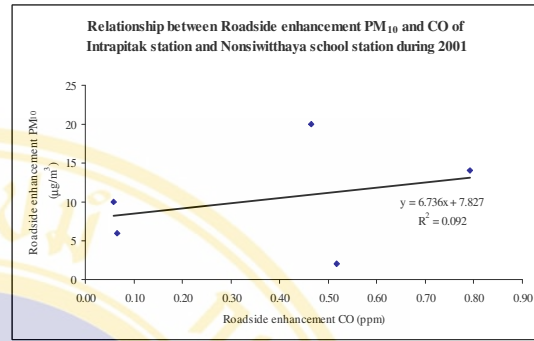
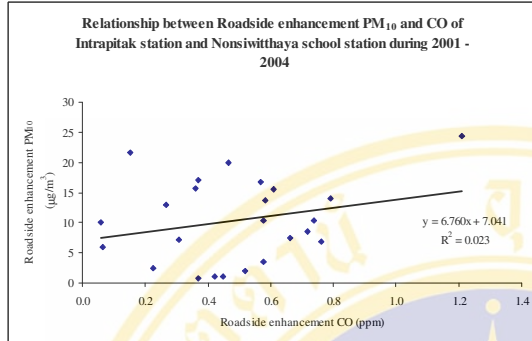


Table A – 5 Roadside enhancement PM₁₀ and Roadside enhancement CO of Intrapitak station and Nonsiwitthaya school station

Date	Roadside enhancement CO (ppm)	Roadside enhancement PM ₁₀ (µg/m ³)	Date	Roadside enhancement CO (ppm)	Roadside enhancement PM ₁₀ (µg/m ³)
3 Feb 01	0.07	6	2 Dec 03	0.45	1
9 Feb 01	0.52	2	12 Feb 04	0.72	8.5
19 Oct 01	0.79	14	29 Jun 04	0.58	13.7
30 Nov 01	0.47	20	17 Jul 04	0.37	0.8
12 Dec 01	0.06	10	23 Jul 04	0.42	1.1
4 Feb 02	0.58	3.5	29 Jul 04	0.37	17.1
16 Feb 02	0.61	15.5	4 Aug 04	0.74	10.3
22 Feb 02	0.23	2.5	10 Aug 04	0.57	16.7
11 Apr 02	0.36	15.7	16 Aug 04	0.66	7.5
29 Apr 02	0.27	12.9	22 Aug 04	0.58	10.4
5 May 02	0.15	21.7	28 Aug 04	0.76	6.8
8 Nov 03	1.21	24.3	9 Sep 04	0.31	7.1



Relationship between Roadside enhancement PM₁₀ and CO of Intrapitak station and Nonsiwitthaya school station



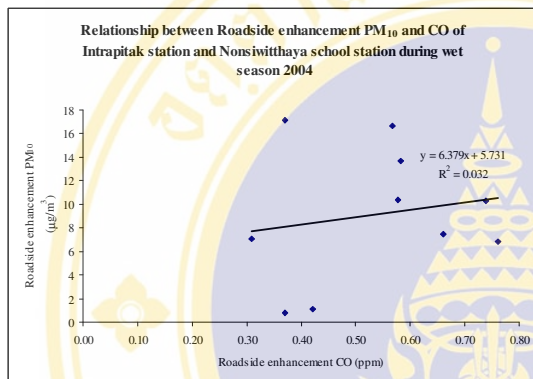
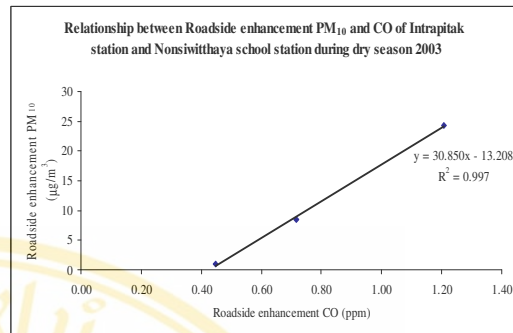
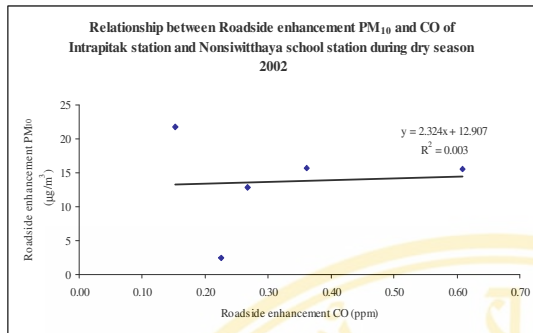
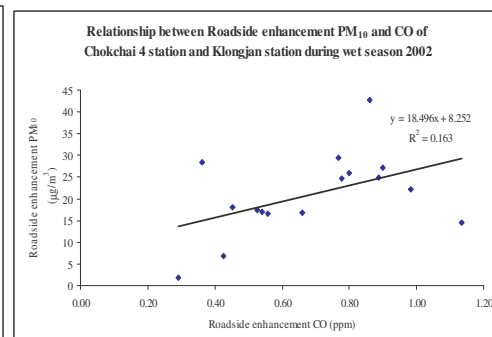
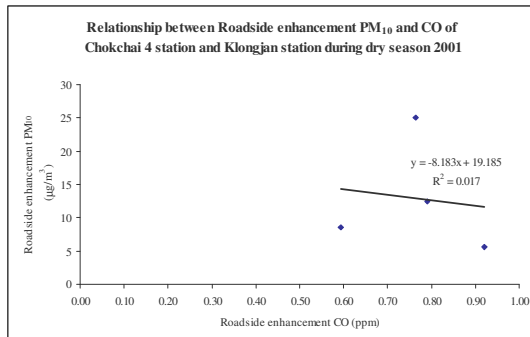
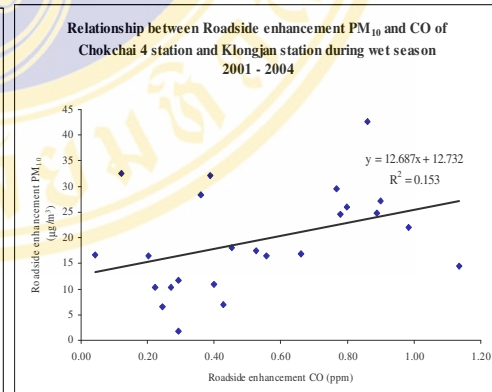
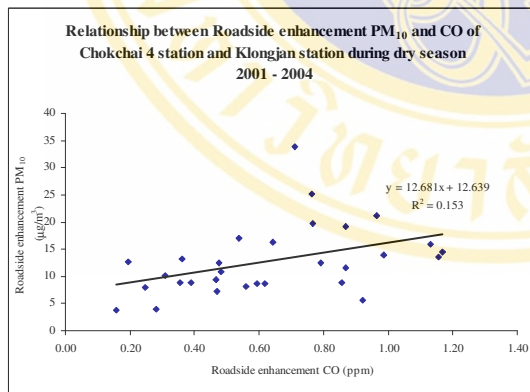
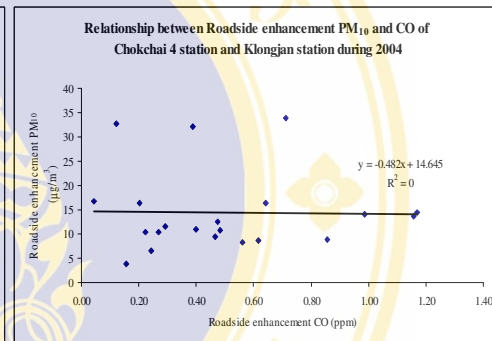
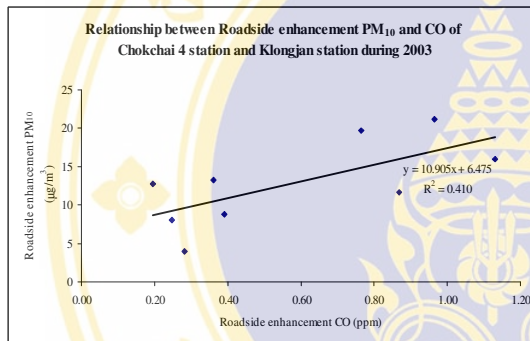
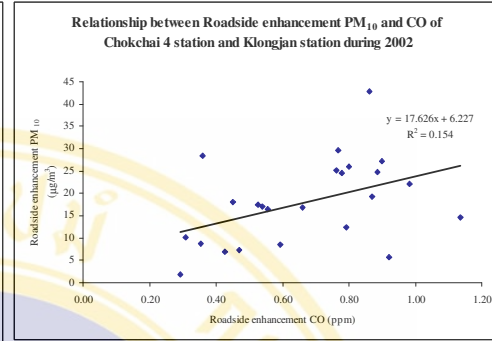
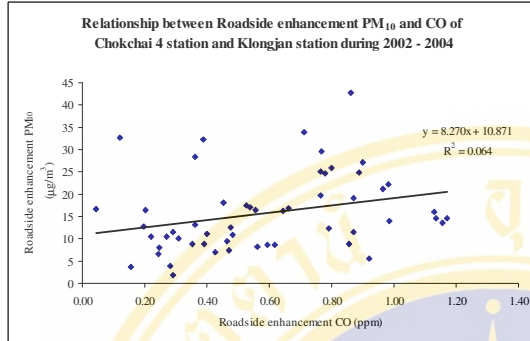


Table A – 6 Roadside enhancement PM₁₀ and Roadside enhancement CO of Chokchai 4 station and Klongjan station

Date	Roadside enhancement CO (ppm)	Roadside enhancement PM ₁₀ (µg/m ³)	Date	Roadside enhancement CO (ppm)	Roadside enhancement PM ₁₀ (µg/m ³)
17 Jan 02	0.92	5.6	21 Oct 03	0.36	13.2
23 Jan 02	0.59	8.6	27 Oct 03	0.39	8.8
4 Feb 02	0.76	25.1	26 Nov 03	0.87	11.6
10 Feb 02	0.79	12.4	2 Dec 03	0.25	8
17 May 02	0.54	17.1	20 Dec 03	0.97	21.2
5 Jun 02	0.53	17.4	26 Dec 03	1.13	16
10 Jun 02	0.78	24.6	1 Jan 04	0.64	16.3
16 Jun 02	0.43	6.9	31 Jan 04	0.62	8.7
27 Jun 02	0.77	29.5	12 Feb 04	0.16	3.8
4 Jul 02	0.90	27.1	18 Feb 04	0.48	10.8
10 Jul 02	0.80	25.9	24 Feb 04	1.16	13.6
16 Jul 02	0.36	28.4	1 Mar 04	0.86	8.8
28 Jul 02	1.13	14.5	19 Mar 04	0.47	9.5
3 Aug 02	0.66	16.9	31 Mar 04	1.17	14.5
15 Aug 02	0.86	42.7	12 Apr 04	0.71	33.9
21 Aug 02	0.45	18	24 Apr 04	0.56	8.2
2 Sep 02	0.98	22.1	30 Apr 04	0.48	12.5
8 Sep 02	0.56	16.5	6 May 04	0.99	14
2 Oct 02	0.89	24.8	30 May 04	0.39	32.2
14 Oct 02	0.29	1.8	17 Jun 04	0.29	11.6
26 Oct 02	0.31	10.1	29 Jun 04	0.40	11
7 Dec 02	0.47	7.3	5 Jul 04	0.27	10.4
13 Dec 02	0.35	8.8	17 Jul 04	0.04	16.7
19 Dec 02	0.87	19.2	4 Aug 04	0.12	32.6
6 Jan 03	0.77	19.7	10 Aug 04	0.20	16.4
5 Feb 03	0.20	12.7	9 Sep 04	0.24	6.6
11 Feb 03	0.28	4	9 Oct 04	0.22	10.4

Relationship between Roadside enhancement PM₁₀ and CO of Chokchai 4 station and Klongjan station



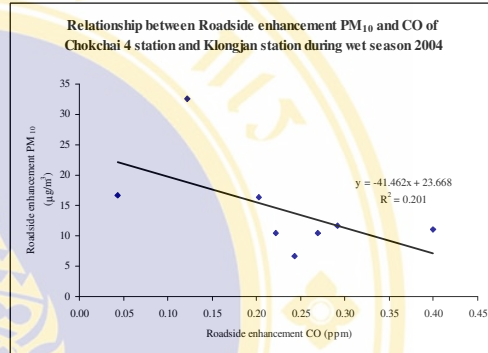
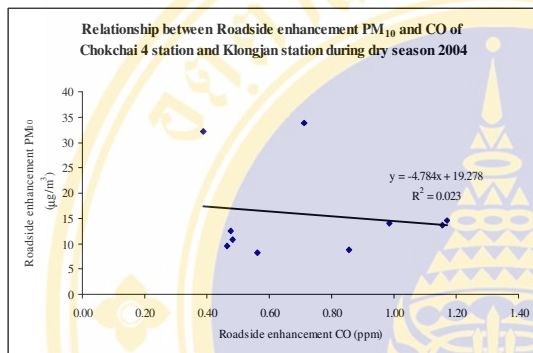
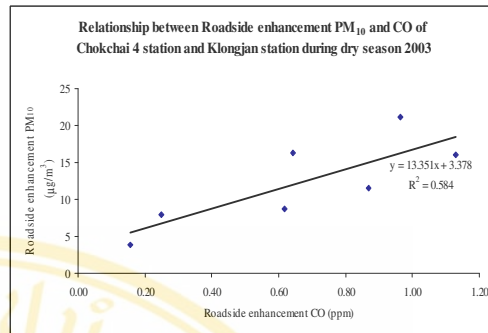
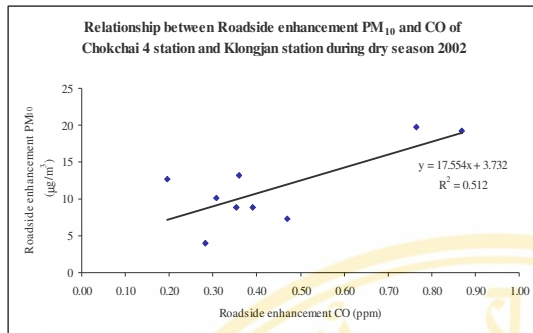


Table A – 7 Roadside enhancement PM₁₀ and Roadside enhancement NO_x of Dindang station and Nonsiwitthaya school station

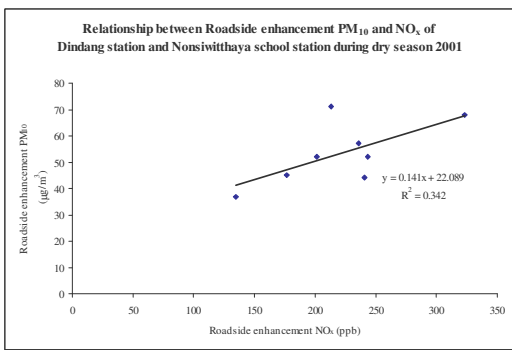
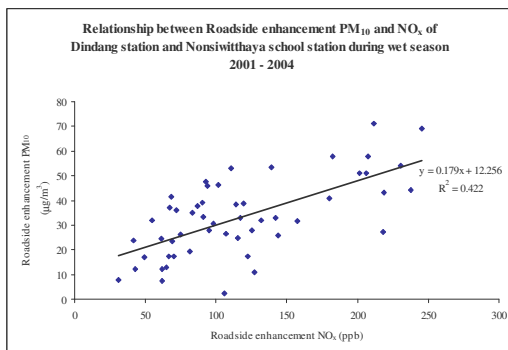
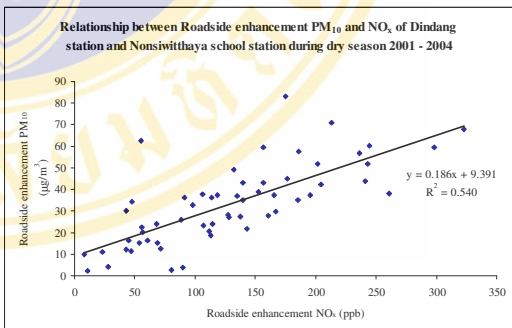
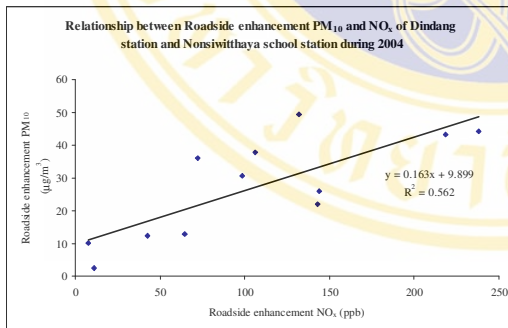
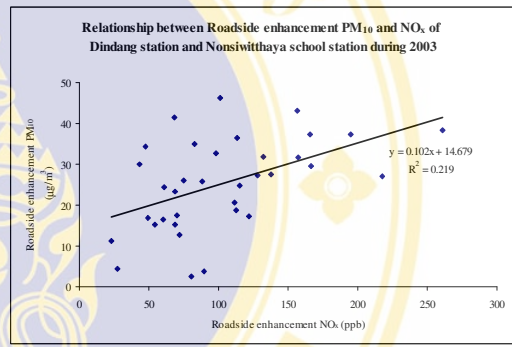
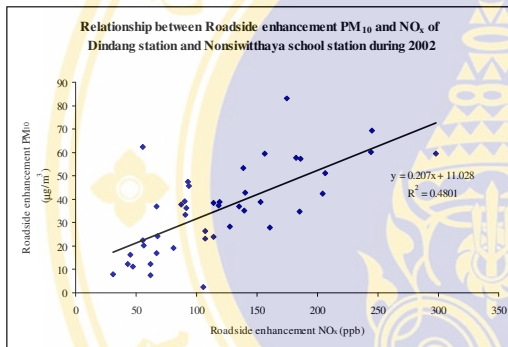
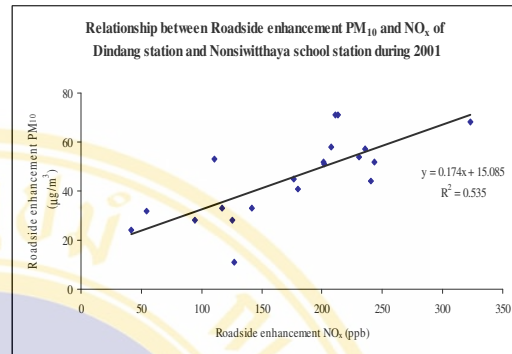
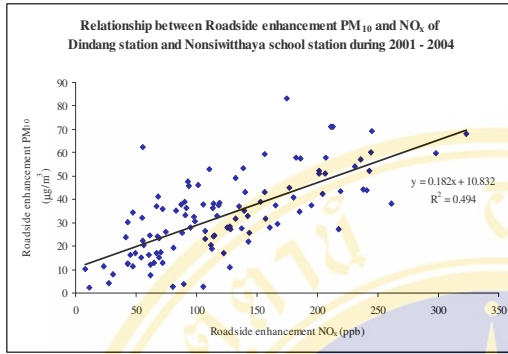
Date	Roadside enhancement NO _x (ppb)	Roadside enhancement PM ₁₀ (µg/m ³)	Date	Roadside enhancement NO _x (ppb)	Roadside enhancement PM ₁₀ (µg/m ³)
3 Jun 01	201.52	51	13 Nov 02	174.77	83.1
9 Jun 01	142.14	33	19 Nov 02	298.04	59.6
15 Jun 01	125.45	28	25 Nov 02	156.59	59.5
21 Jun 01	127.30	11	1 Dec 02	204.09	42.4
27 Jun 01	110.54	53	7 Dec 02	118.57	37.5
9 Jul 01	180.12	41	13 Dec 02	152.65	39
15 Jul 01	54.61	32	19 Dec 02	186.21	57.5
21 Jul 01	117.09	33	31 Dec 02	160.61	27.9
27 Jul 01	41.58	24	5 Feb 03	89.65	3.7
2 Aug 01	94.88	28	11 Feb 03	80.35	2.6
25 Sep 01	211.26	71	17 Feb 03	27.61	4.3
7 Oct 01	230.78	54	1 Mar 03	47.39	34.4
13 Oct 01	207.26	58	13 Mar 03	165.64	37.3
19 Oct 01	212.99	71	19 Mar 03	23.00	11.2
6 Nov 01	176.53	45	25 Mar 03	156.48	43.1
12 Nov 01	240.84	44	6 Apr 03	54.09	15.3
18 Nov 01	236.01	57	30 Apr 03	111.73	20.6
24 Nov 01	322.98	68	6 May 03	43.17	30.1
12 Dec 01	243.16	52	12 May 03	113.57	36.4
18 Dec 01	201.30	52	18 May 03	60.30	16.4
23 Jan 02	135.11	36.9	24 May 03	71.70	12.7
22 Feb 02	56.57	20.3	30 May 03	128.16	27.2
28 Feb 02	45.13	16.4	11 Jun 03	70.22	17.4
5 Apr 02	42.65	12.3	17 Jun 03	157.37	31.7
11 Apr 02	55.91	22.4	29 Jun 03	114.96	24.7
17 Apr 02	55.30	62.5	5 Jul 03	132.13	31.9
29 Apr 02	107.00	23.1	17 Jul 03	217.91	27.1
5 May 02	139.81	43	23 Jul 03	49.22	16.9
11 May 02	114.25	24.1	29 Jul 03	82.90	35.1
17 May 02	46.95	11.4	5 Aug 03	74.70	26.1
23 May 02	127.52	28.4	10 Aug 03	60.96	24.4
29 May 02	67.77	24.2	16 Aug 03	68.44	41.4
4 Jun 02	107.22	26.5	9 Sep 03	122.25	17.2
10 Jun 02	81.22	19.4	15 Sep 03	101.32	46.2
16 Jun 02	119.30	38.7	15 Oct 03	69.14	23.4
22 Jun 02	105.52	2.5	27 Oct 03	195.35	37.3
28 Jun 02	91.02	33.4	2 Nov 03	260.94	38.3
4 Jul 02	61.86	7.6	8 Nov 03	137.52	27.6
16 Jul 02	30.85	8	20 Nov 03	68.80	15.2
22 Jul 02	93.95	45.8	26 Nov 03	166.57	29.6
28 Jul 02	66.65	17.2	14 Dec 03	112.71	18.8
3 Aug 02	138.78	53.5	20 Dec 03	88.22	25.9
9 Aug 02	114.35	38.3	26 Dec 03	98.09	32.7
21 Aug 02	61.70	12.2	18 Feb 04	132.13	49.3
27 Aug 02	92.83	47.5	7 Mar 04	105.95	37.9
14 Sep 02	90.22	39.1	13 Mar 04	7.87	10.1
20 Sep 02	182.27	57.8	24 Apr 04	11.13	2.4
26 Sep 02	67.17	37.1	6 May 04	143.07	21.9

Table A – 7 Roadside enhancement PM₁₀ and Roadside enhancement NO_x of Dindang station and Nonsiwitthaya school station (Continued)

Date	Roadside enhancement NO _x (ppb)	Roadside enhancement PM ₁₀ (µg/m ³)	Date	Roadside enhancement NO _x (ppb)	Roadside enhancement PM ₁₀ (µg/m ³)
2 Oct 02	86.98	37.9	11 Jul 04	72.13	36.1
8 Oct 02	206.17	51.2	23 Jul 04	98.27	30.7
14 Oct 02	245.33	69.2	29 Jul 04	64.48	12.9
20 Oct 02	91.58	36.2	9 Sep 04	42.61	12.3
26 Oct 02	139.78	35.2	15 Sep 04	143.74	25.9
1 Nov 02	244.31	60.1	9 Oct 04	237.86	44.3
7 Nov 02	185.40	34.9	15 Oct 04	218.67	43.3



Relationship between Roadside enhancement PM₁₀ and NO_x of Dindang station and Nonsiwitthaya school station



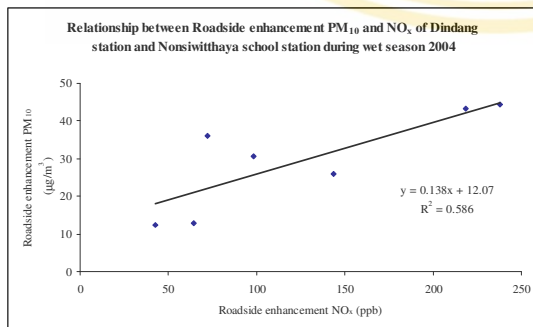
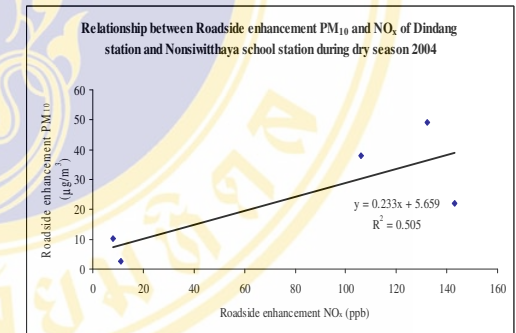
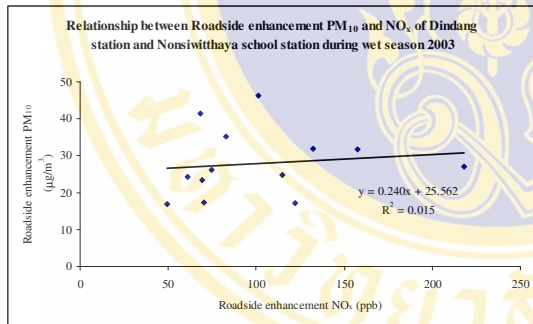
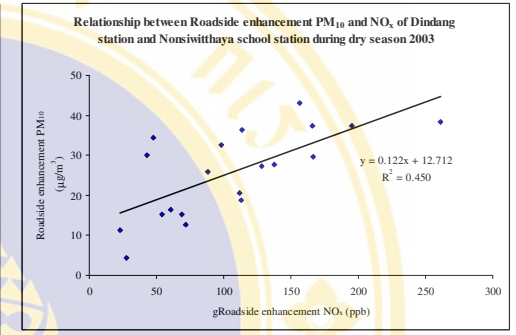
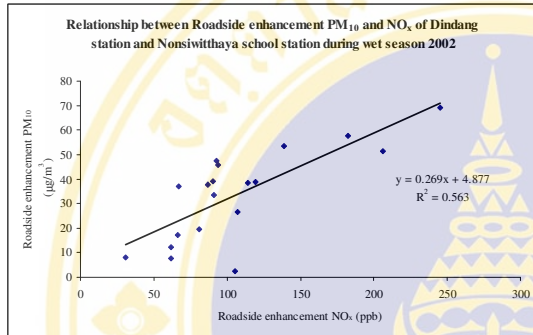
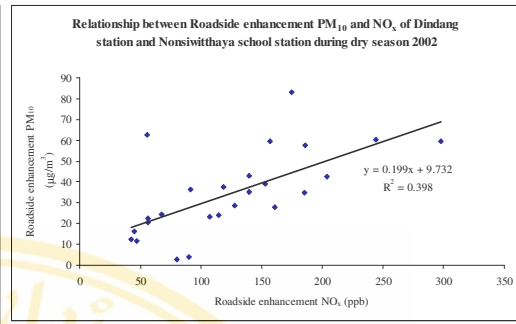
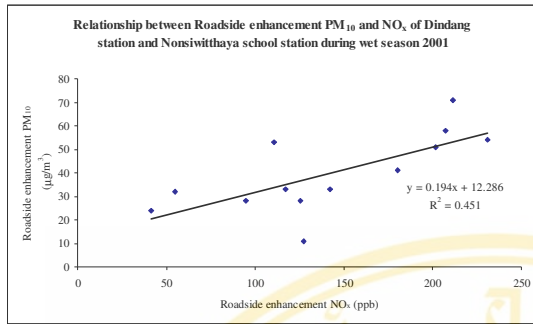
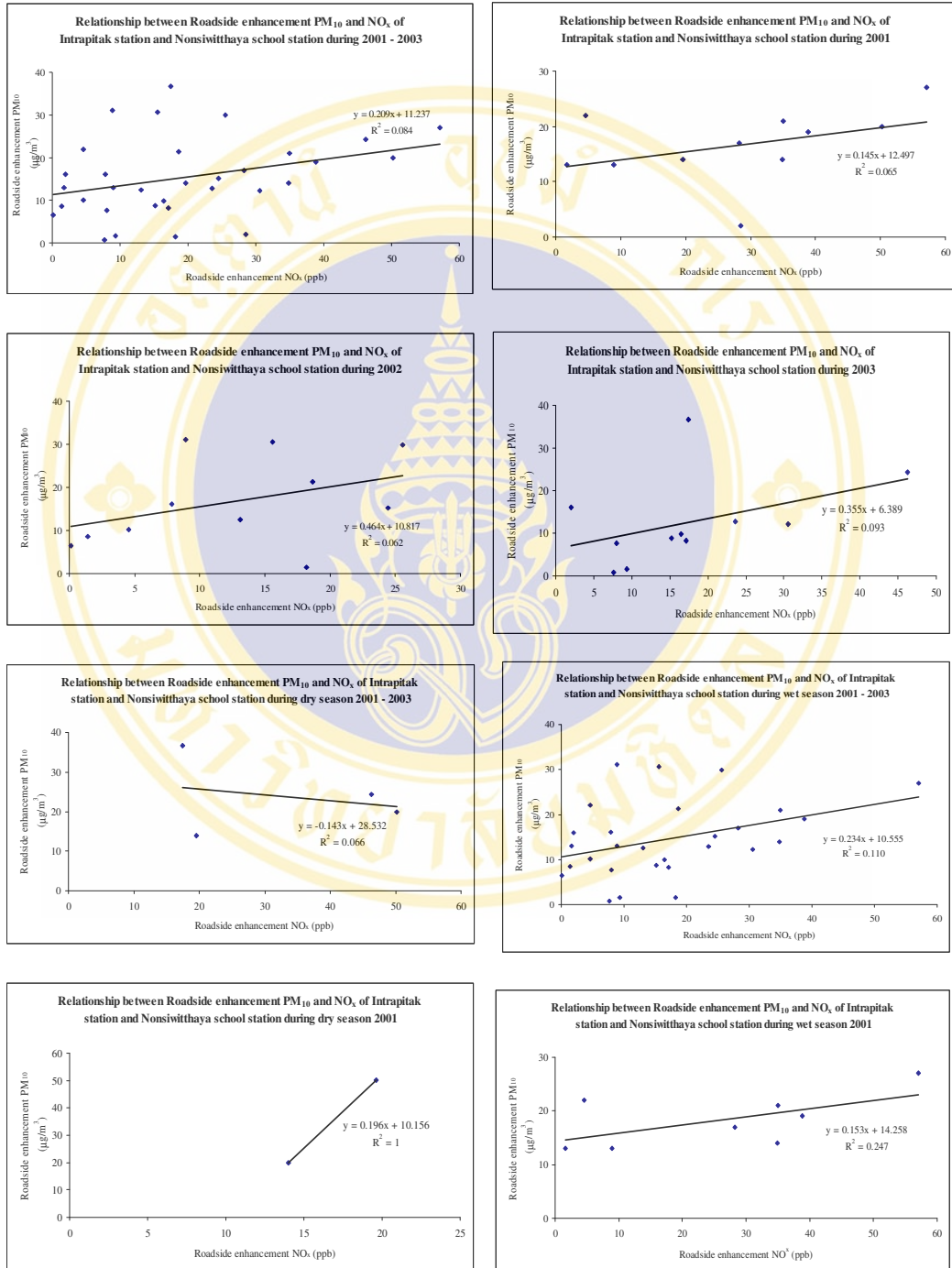


Table A – 8 Roadside enhancement PM₁₀ and Roadside enhancement NO_x of Intrapitak station and Nonsiwitthaya school station

Date	Roadside enhancement NO _x (ppb)	Roadside enhancement PM ₁₀ (µg/m ³)	Date	Roadside enhancement NO _x (ppb)	Roadside enhancement PM ₁₀ (µg/m ³)
9 Feb 01	28.55	2	28 Jul 02	4.57	10.1
9 Jun 01	34.88	14	2 Sep 02	24.48	15.2
15 Jun 01	34.97	21	14 Sep 02	13.09	12.5
9 Jul 01	38.83	19	8 Oct 02	1.43	8.5
15 Jul 01	4.57	22	14 Oct 02	7.87	16.1
27 Jul 01	1.67	13	18 May 03	8.00	7.7
2 Aug 01	28.27	17	24 May 03	15.17	8.8
25 Sep 01	8.91	13	17 Jun 03	30.57	12.2
7 Oct 01	57.09	27	29 Jun 03	7.65	0.8
19 Oct 01	19.61	14	17 Jul 03	9.35	1.6
30 Nov 01	50.22	20	23 Jul 03	17.17	8.2
17 May 02	0.14	6.5	29 Jul 03	23.57	12.8
23 May 02	18.65	21.3	10 Aug 03	16.43	9.9
4 Jun 02	25.57	29.9	16 Aug 03	2.00	16
10 Jun 02	15.57	30.6	8 Nov 03	46.26	24.3
22 Jun 02	18.22	1.5	14 Nov 03	17.48	36.7
28 Jun 02	8.90	31.1			

Relationship between Roadside enhancement PM₁₀ and NO_x of Intrapitak station and Nonsiwitthaya school station



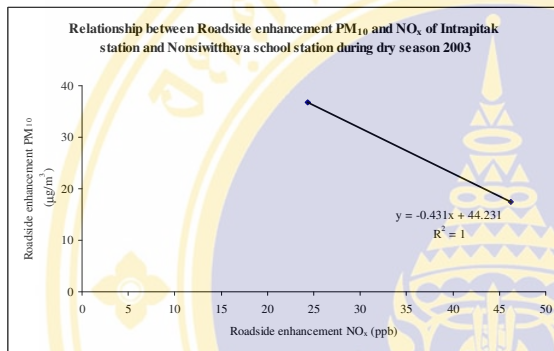
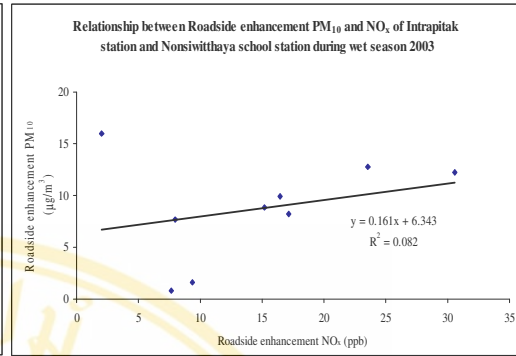
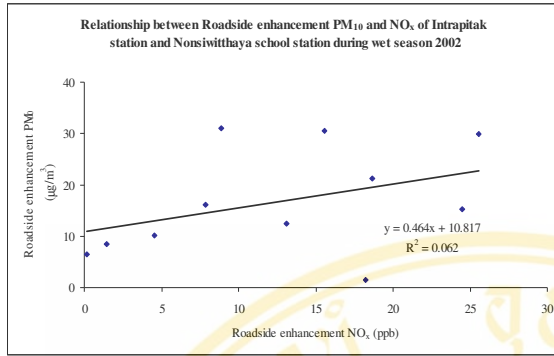
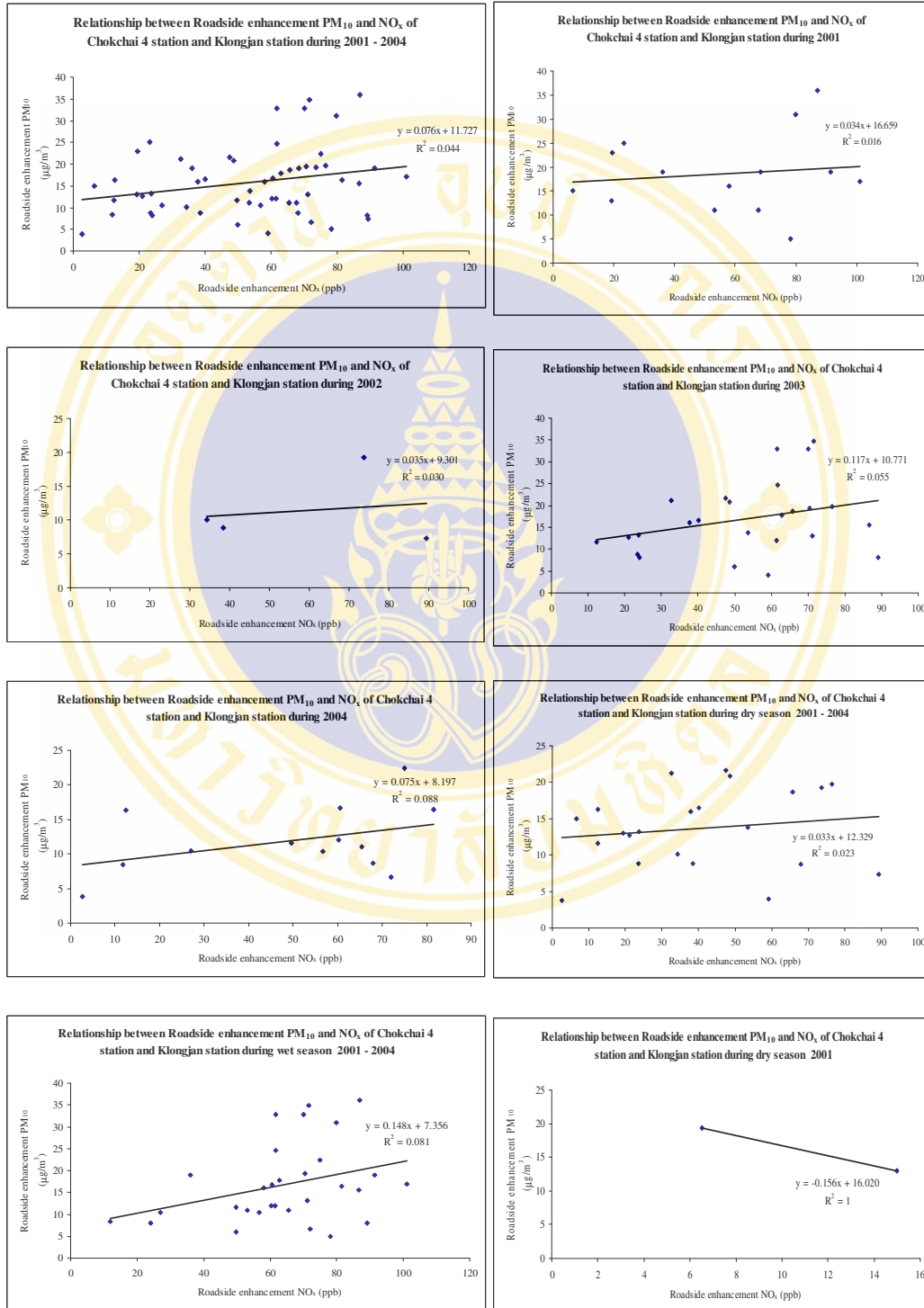
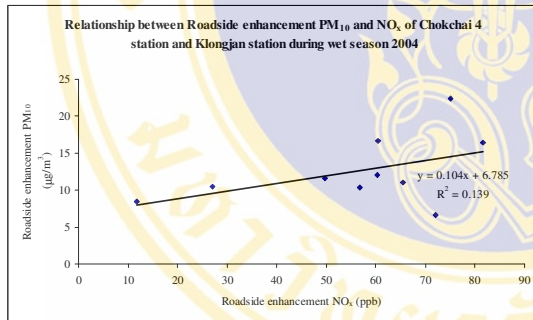
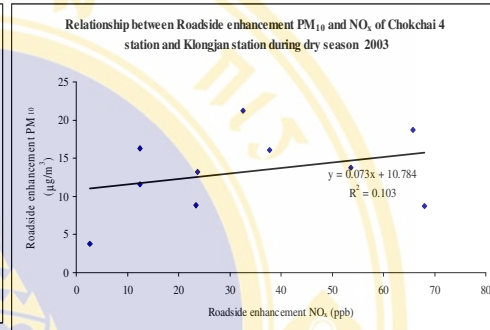
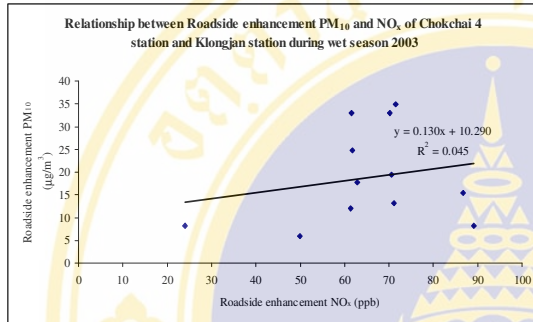
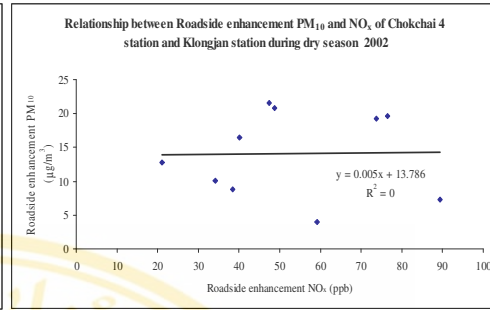
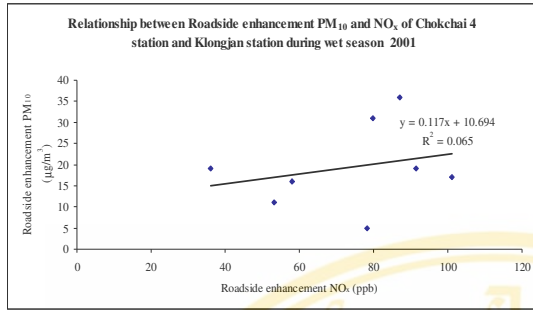


Table A – 9 Roadside enhancement PM₁₀ and Roadside enhancement NO_x of Chokchai 4 station and Klongjan station

Date	Roadside enhancement NO _x (ppb)	Roadside enhancement PM ₁₀ (µg/m ³)	Date	Roadside enhancement NO _x (ppb)	Roadside enhancement PM ₁₀ (µg/m ³)
4 Jan 01	23.30	25	11 Jul 03	49.83	6
10 Jan 01	67.67	11	17 Jul 03	61.36	12
16 Jan 01	19.51	23	23 Jul 03	70.13	32.9
3 Feb 01	68.30	19	29 Jul 03	62.85	17.8
15 Feb 01	6.52	15	16 Aug 03	61.74	24.7
4 May 01	19.30	13	15 Sep 03	61.61	32.9
21 Jun 01	53.21	11	9 Oct 03	71.53	34.8
26 Jun 01	79.82	31	15 Oct 03	24.04	8.1
3 Jul 01	78.17	5	21 Oct 03	23.76	13.2
9 Jul 01	101.00	17	27 Oct 03	23.46	8.8
15 Jul 01	91.43	19	8 Nov 03	53.56	13.8
8 Aug 01	36.13	19	20 Nov 03	65.72	18.7
7 Sep 01	86.98	36	26 Nov 03	12.39	11.6
19 Sep 01	58.01	16	20 Dec 03	32.65	21.2
26 Oct 02	34.22	10.1	26 Dec 03	37.79	16
7 Dec 02	89.35	7.3	1 Jan 04	12.48	16.3
13 Dec 02	38.46	8.8	31 Jan 04	68.04	8.7
19 Dec 02	73.66	19.2	12 Feb 04	2.61	3.8
6 Jan 03	76.43	19.7	17 Jun 04	49.65	11.6
12 Jan 03	47.43	21.6	29 Jun 04	65.43	11
5 Feb 03	21.00	12.7	5 Jul 04	56.70	10.4
11 Feb 03	59.13	4	17 Jul 04	60.48	16.7
24 May 03	48.61	20.8	10 Aug 04	81.57	16.4
30 May 03	40.09	16.5	22 Aug 04	60.29	12
11 Jun 03	71.17	13.1	28 Aug 04	75.04	22.4
23 Jun 03	89.04	8.1	9 Sep 04	72.04	6.6
29 Jun 03	70.51	19.4	21 Sep 04	27.04	10.5
5 Jul 03	86.65	15.5	3 Oct 04	11.83	8.4

Relationship between Roadside enhancement PM₁₀ and CO of Chokchai 4 station and Klongjan station





Appendix B Location of PCD Station

1. Dindang station



Figure B – 1 : Dindang station



Figure B – 2 : High volume air sampler for PM₁₀ measurement



Figure B – 3 : Partisol - Plus air sampler for PM_{2.5} measurement

2. Intrapitak station



Figure B – 4 :Intrapitak station

3. Nonsiwitthaya school station



Figure B – 5 : Nonsiwitthaya school station

4. Chokchai 4 station



Figure B – 6 : Chokchai 4 station

5. Klongjan station



Figure B – 7 : Klongjan station

BIOGRAPHY

NAME	Miss Supawan Intoon
DATE OF BIRTH	27 th January 1977
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