PARTICULATE MATTER TSP AND PM_{10} LEVELS IN PUBLIC PARKS OF BANGKOK METROPOLITAN ADMINISTRATION

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ABSTRACT

The objectives of this research were to study levels of ambient TSP and PM_{10} concentrations at aerobic exercise sites in Public Parks of Bangkok Metropolitan Administration, Thailand and to study the influence of meteorological factors on the concentration levels of particulate matter. TSP and PM_{10} samples were collected during the rainy season from September to October 2009 and the winter season from January to February 2010 by using high volume air samplers. The samples were collected from 5 sampling sites in 4 Public Parks i.e. Lumphini (sites 1 and 2), Suan Luang Rama 9, Benchasiri and Saranrom.

The results showed that all 162 samples of 24-hour average TSP and PM_{10} concentrations were lower than ambient air quality standards. Levels of TSP at Lumphini1, Lumphini2, Suan Luang Rama 9, Benchasiri and Saranrom in rainy season varied from 34.1-55.6, 26.6-42.9, 33.7-78.2, 42.0-83.6 and 43.9-73.7 $\mu g/m^3$, respectively and in winter season varied from 81.8-124.2, 75.2-118.9, 36.9-113.0, 47.6-125.0 and 56.4-139.9 $\mu g/m^3$, respectively. Levels of PM_{10} in the rainy season varied from 17.5-28.1, 10.4-20.5, 23.4-55.2, 22.2-49.0 and 31.0-60.0 $\mu g/m^3$, respectively and in the winter season varied from 51.1-82.7, 42.0-71.2, 20.8-74.9, 27.3-90.6 and 37.0-110.2 $\mu g/m^3$, respectively. Furthermore, TSP and PM_{10} concentrations in 4 sampling sites had statistically significant correlation for both rainy and winter seasons ($p<0.05$), except Saranrom which showed no statistically significant correlation during the rainy season. In addition, the trend in 24-hour average TSP and PM_{10} concentrations on weekdays were higher than those on weekends. Levels of particulate matter at Lumphini in the winter season were significantly higher than in the rainy season, while at the other 3 parks, levels of particulate matter were not statistically significantly different between the rainy and winter seasons.

Meteorological factors (i.e. wind speed, wind direction and rain) can significantly influence the level of particulate matter. Wind speed was found to influence TSP and PM_{10} concentrations at Lumphini1, TSP concentration at Lumphini2 in the rainy season and TSP concentration at Benchasiri in the winter season. Wind direction was found to influence TSP and PM_{10} concentrations at Suan Luang Rama 9, Benchasiri and Saranrom in winter, while rain was found to influence TSP and PM_{10} concentrations at Benchasiri in winter.

KEY WORDS: PARTICULATE MATTER/ PM_{10}/ TSP/ PUBLIC PARK

98 pages

การศึกษาปริมาณฝุ่นละอองรวมและฝุ่นละอองขนาดไม่เกิน 10 ไมครอน ในสวนสาธารณะของกรุงเทพมหานคร

PARTICULATE MATTER TSP AND PM_{10} LEVELS IN PUBLIC PARKS OF BANGKOK METROPOLITAN ADMINISTRATION

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บทคัดย่อ

งานวิจัยนี้ มีวัตถุประสงค์เพื่อศึกษาปริมาณฝุ่นละอองรวม (TSP) และฝุ่นละอองที่มีขนาดเล็กกว่า 10 ไมครอน (PM_{10}) ในสวนสาธารณะของกรุงเทพมหานครบริเวณลานออกกำลังกาย รวมถึงศึกษาอิทธิพลของปัจจัยทางอุตุนิยมวิทยาที่มีผลต่อปริมาณฝุ่นละออง โดยเก็บตัวอย่างฝุ่นละอองด้วยเครื่องเก็บตัวอย่างอากาศปริมาตรสูงในช่วงฤดูฝน ตั้งแต่เดือนกันยายนถึงตุลาคม 2552 และช่วงฤดูหนาว ตั้งแต่เดือนมกราคมถึงกุมภาพันธ์ 2553 จากจุดเก็บตัวอย่าง 5 จุด ในสวนสาธารณะ 4 แห่ง ได้แก่ สวนลุมพินี (สถานี1 และ 2) สวนหลวง ร.9 อุทยานเบญจสิริ และสวนสราญรมย์

ผลการศึกษาปริมาณฝุ่นละออง TSP และ PM_{10} เฉลี่ย 24 ชั่วโมง จากตัวอย่างทั้งหมด 162 ตัวอย่าง พบว่าทุกตัวอย่างมีค่าต่ำกว่าค่ามาตรฐานคุณภาพอากาศในบรรยากาศทั่วไป โดย ปริมาณฝุ่นละออง TSP ของสถานีลุมพินี1 ลุมพินี2 สวนหลวง ร.9 อุทยานเบญจสิริ และสวนสราญรมย์ ในช่วงฤดูฝนมีค่าอยู่ในช่วง 34.1-55.6, 26.6-42.9, 33.7-78.2, 42.0-83.6 และ 43.9-73.7 มคก./ลบ.ม. ตามลำดับ ส่วนช่วงฤดูหนาวมีค่าอยู่ในช่วง 81.8-124.2, 75.2-118.9, 36.9-113.0, 47.6-125.0 และ 56.4-139.9 มคก./ลบ.ม. ตามลำดับ ปริมาณฝุ่นละออง PM_{10} ในช่วงฤดูฝนมีค่าอยู่ในช่วง 17.5-28.1, 10.4-20.5, 23.4-55.2, 22.2-49.0 และ 31.0-60.0 มคก./ลบ.ม. ตามลำดับ ส่วนช่วงฤดูหนาวมีค่าอยู่ในช่วง 51.1-82.7, 42.0-71.2, 20.8-74.9, 27.3-90.6 และ 37.0-110.2 มคก./ลบ.ม. ตามลำดับ นอกจากนี้ยังพบว่าปริมาณฝุ่นละออง TSP และ PM_{10} ใน 4 สถานีตรวจวัดมีความสัมพันธ์กันอย่างมีนัยสำคัญทางสถิติทั้งในช่วงฤดูฝนและฤดูหนาว ($p<0.05$) ส่วนสถานีสราญรมย์เฉพาะในช่วงฤดูฝน ไม่พบว่าปริมาณฝุ่นละออง TSP และ PM_{10} มีความสัมพันธ์กันอย่างมีนัยสำคัญ และปริมาณฝุ่นละออง TSP และ PM_{10} เฉลี่ย 24 ชั่วโมงในวันธรรมดาก็พบว่ามีแนวโน้มที่จะมีค่าสูงกว่าวันหยุด นอกจากนี้สวนลุมพินีมีปริมาณฝุ่นละอองในช่วงฤดูหนาวมากกว่าฤดูฝนอย่างมีนัยสำคัญทางสถิติ แต่ในอีก 3 สวน มีปริมาณฝุ่นละอองไม่แตกต่างกันอย่างมีนัยสำคัญทางสถิติระหว่างฤดูฝนและฤดูหนาว

ปัจจัยทางอุตุนิยมวิทยาที่มีผลต่อปริมาณฝุ่นละอองอย่างมีนัยสำคัญทางสถิติ ได้แก่ ความเร็วลม ทิศทางลม และปริมาณฝน โดยความเร็วลมมีผลต่อ ปริมาณฝุ่นละออง TSP และ PM_{10} ของสถานีลุมพินี1 ปริมาณฝุ่นละออง TSP ของสถานีลุมพินี2 ในช่วงฤดูฝน และ ปริมาณฝุ่นละออง TSP ของสถานีอุทยานเบญจสิริ ในช่วงฤดูหนาว ส่วนทิศทางลมมีผลต่อปริมาณฝุ่นละออง TSP และ PM_{10} ของสถานีสวนหลวง ร.9 อุทยานเบญจสิริ และสราญรมย์ ในช่วงฤดูหนาว ส่วนปริมาณฝนมีผลต่อปริมาณฝุ่นละออง TSP และ PM_{10} ของสถานีอุทยานเบญจสิริ ในช่วงฤดูหนาว

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CHAPTER I
INTRODUCTION

1.1 Statement of the problem and importance of the research

Nowadays, air pollution is a serious environmental problem because high concentration of many air pollutants can affect on human, animals, vegetation and materials. Main causes of air pollution are rapid increasing of population, economic expansion, industrialization, transportation and technology development. Most of air pollution problem experience in urban area is due to a large number of vehicles and one of the air pollutants that cause harm to human health is particulate matter.

Particulate matter in the atmosphere has range in size from approximately 0.005 to 100 microns in diameter. It can be classified as primary and secondary particles. Primary particles are emitted directly to the atmosphere from both natural and anthropogenic sources. Secondary particles are result of chemical process involving gases, aerosol particles and moisture form in the atmosphere. Large size particles (larger than 10 microns) can be easily removed by defense mechanisms of human respiratory system. It causes a nuisance, reduce visibility and damage to materials (Godish, 1997). Whereas small particles such as particulate matter less than 10 microns (PM_{10}) can enter and deposit deeper in the respiratory system, thereby causing a chronic bronchitis, emphysema and other lung diseases (Herman and Bisesi, 2003). Therefore, human health effect is associated mainly with small particles.

Bangkok is a capital city of Thailand. The registered population in 2009 is 5,702,595 (Department of Provincial Administration, 2009: online). Large number of people and high level of energy consumption are associated with air quality, especially particulate matter. Sources of particulate matter in Bangkok come from motor vehicles, construction activities and open burning. PM_{10} is part of particulate matter that can affect human health. The important sources of PM_{10} are automobiles and biomass burning (Chuersuwan et al., 2008). In accordance with data from the Department of Land Transportation (2010: online), total number of all registered vehicles in Bangkok up to March 2010 is 6,201,314. Thus increasing of PM_{10} is related with traffic congestion.

The Pollution Control Department (PCD) has been monitoring air quality in Bangkok since 1995. There are 7 permanent air quality monitoring stations and 21 temporary air quality monitoring stations for roadside locations (not exceed 10 meters from road). Moreover, there are 10 air quality monitoring stations for general areas (at least 50 meters away from road) (Air Quality and Noise Management Bureau, 2009: online). The results showed that annual average of PM_{10} at roadsides during 1995-2008 all exceeded the ambient air standard whereas about half of the results in general areas exceeded the ambient air standard (Figure 1.1). Based on results of PM_{10} concentrations obtained from three ambient monitoring stations and respiratory evaluation by using questionnaire, chronic effects of particulate matter to Bangkok children were investigated. The results indicated that respiratory symptoms of children living in the high and moderate pollution areas were significantly higher than those in the low pollution area (Langkulsen et al., 2006). The evaluation of death rate associated with particulate matter in Bangkok from 1996 to 2001 indicated that an increasing of PM_{10} by 1 $\mu g/m^3$ would increase the number of death by 0.05 % (Vichit-Vadakan, 2004). These data showed that particulate matter was a serious problem in Bangkok.

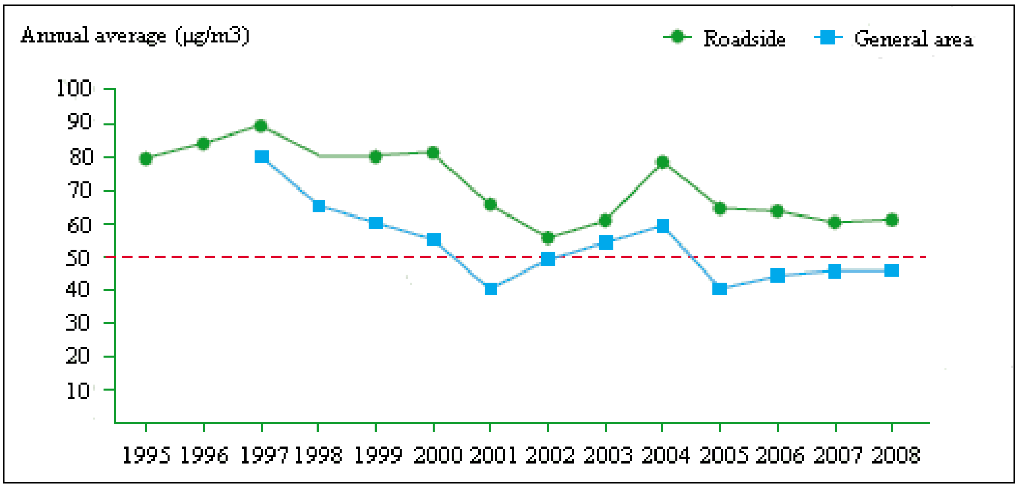


Figure 1.1 Annual average of PM_{10} at roadside and general area in Bangkok during 1995 – 2008

Source: Air Quality and Noise Management Bureau (2009: online)

Presently, Pollution Control Department established ambient air quality standards for particulate matter in three size ranges as shown in Table 1.1. This ambient air standards were aim to encourage air quality enhancement and conservation.

Table 1.1 Ambient air quality standards for particulate matter in Thailand

Particulate matter	**24-hour average (µg/m^3)**	**Annual average (µg/m^3)**
TSP	330	100
PM_{10}	120	50
$PM_{2.5}$	50	25

Source: Pollution Control Department (2010: online)

Thailand is under the influence of monsoon winds i.e. southwest monsoon (rainy season) and northeast monsoon (winter season). Rainy and winter seasons have difference of meteorological factors (Thai Meteorological Department, 2009: online). Studied from Chan et al. (2001) showed that meteorological factors (wind speed, wind direction, rainfall and relative humidity) can affect the concentration level of particulate matter. Thus, differences of meteorological factors between rainy and winter seasons are correlated with concentration levels of TSP and PM_{10}.

Bangkok Metropolitan Region has Public Park to improve people's quality of life and relief air pollution problems. All Public Parks in responsibility of Public Park Office have a total area of 19,431,988.24 square meters (Public Park Office, 2009: online). The Public Parks can be divided into 7 categories.

1. Pocket Park, Mini Park
2. Neighborhood Park
3. Community Park
4. District Park
5. City Park
6. Street Park
7. Special Purpose Park

Many people come to Public Parks for exercising. Public Park should have particulate matter not exceed ambient air quality standards. However, people exercising may be at risk because of exposure to automotive pollution in urban area (Sharman, 2005). Concentration levels of TSP and PM_{10} in Public Park may affect to health during exercises. In addition, most of the previous studies have mainly measured particulate matter on the roadside or general area. There is no study on air quality in any of Public Parks in Thailand. Consequently, this research intends to study TSP and PM_{10} concentration levels from 4 Public Parks in Bangkok, i.e. Suan Luang Rama 9 Park, Lumphini Park, Benchasiri Park and Saranrom Park. Moreover, the differences of meteorological factors between rainy and winter season are also investigated.

1.2 Research Objectives

1.2.1 To study concentration levels of TSP and PM_{10} in Public Park

1.2.2 To study the influence of meteorological factors on the concentration levels of TSP and PM_{10} in Public Park

1.3 Scope of research

This research study the ambient particulate matter TSP and PM_{10} concentration levels in aerobic exercise sites in Public Parks of Bangkok Metropolitan Administration.

1.3.1 Study area

Suan Luang Rama 9 Park, Lumphini Park, Benchasiri Park and Saranrom Park

1.3.2 Period

TSP and PM_{10} are measured in two seasons i.e. rainy season (September-October) and winter season (January-February).

1.4 Research benefits

1.4.1 The concentration levels of TSP and PM_{10} can be used as database to estimate the health risk of people exercising in Public Park.

1.4.2 The relationship between seasonal variation and concentration levels of TSP and PM_{10} can be shown.

1.5 Definitions

1.5.1 “Total suspended particulate matter (TSP)” is the suspended particulate matter up to approximately 35 micron in diameter (Colbeck, 2008).

1.5.2 “Particulate matter less than 10 micron (PM_{10})” is the particulate matter smaller than 10 micron in diameter (Colbeck, 2008).

1.5.3 “Particulate matter less than 2.5 micron ($PM_{2.5}$)” is the particulate matter smaller than 2.5 micron in diameter (Colbeck, 2008).

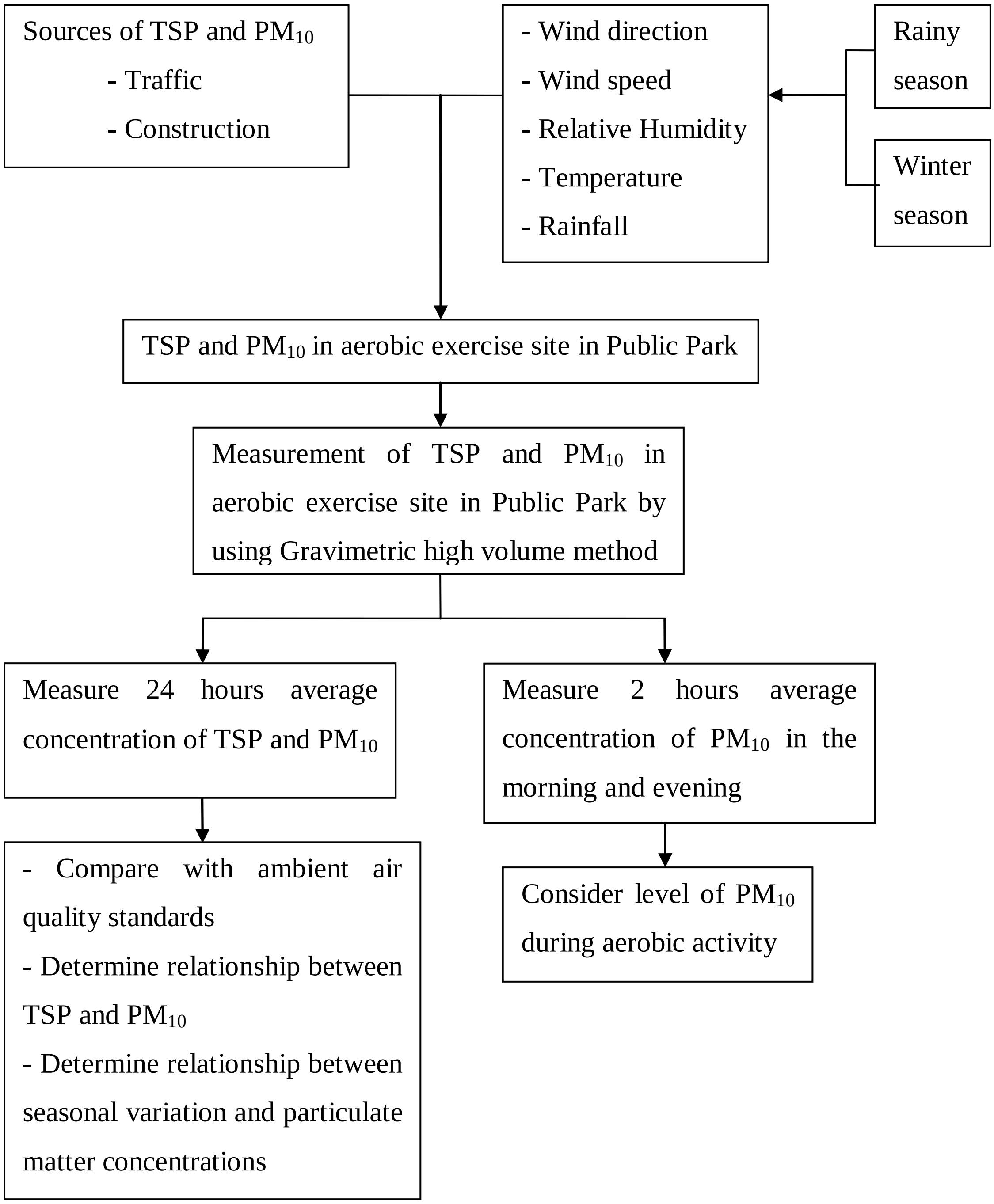
1.5.4 “Ambient air quality standards” is a legal limit on concentrations of a regulated pollutant which can occur in the atmosphere (Godish, 1997).

1.5.5 “Public Park” is a green space in the city for objectives of environment protection, physical activity and recreation of people in community (Iamtrakul, 2005).

1.5.6 “Aerobic exercise” is any form of exercise such as running and cycling (Weil, 2002).

1.5.7 “Health effect” is a change on human health resulting from exposure to pollutant (Kampa and Castanas, 2008).

1.6 Conceptual framework



CHAPTER II
LITERATURE REVIEW

This chapter is divided into eight sections as the following:

2.1 Particulate matter

2.2 Effects of ambient suspended particulate matter

2.3 Meteorological factors influencing the particulate matter

2.4 Weather in Bangkok

2.5 Public Park

2.6 Measurement of particulate matter

2.7 Ambient air quality standard

2.8 Related researches

2.1 Particulate matter

Particulate matter (PM) is often used synonymously with aerosol. It can be a suspension of solid, liquid in air or both. Sources of particles can be divided into natural and anthropogenic sources. In the former case, include volcanic eruption, forest fire, sea spray, biologic sources (mold, fungi, algae, pollen, bacteria, decaying plant and animal life) and meteoric debris; the latter includes transportation, fuel combustion in stationary sources such as factories, power plants and open burning (Vallero, 2008).

A typical size distribution of ambient particulate matter is a log normal distribution and can be represented by two distinct modes (Figure 2.1). There are two modes (coarse and fine mode) with an overlap in the range of 1-3 µm in diameter. Coarse mode is particles larger than 1-3 µm and usually formed by mechanical processes e.g. soil dust, sea spray and many industrial dusts. Fine mode is particles smaller than 1-3 µm; these particles are generated in combustion or formed from gases. The fine mode includes the accumulation and the nuclei mode. Accumulation mode is particles in the range 0.1-2 µm and grows by coagulation or condensation; commonly these particles do not grow to coarse mode. Nuclei mode is particles smaller than 0.1 µm. These particles formed by gas to new particle conversion (nucleation) or emitted from processes involving condensation of vapor (Colbeck, 2008; Wilson et al., 2002).

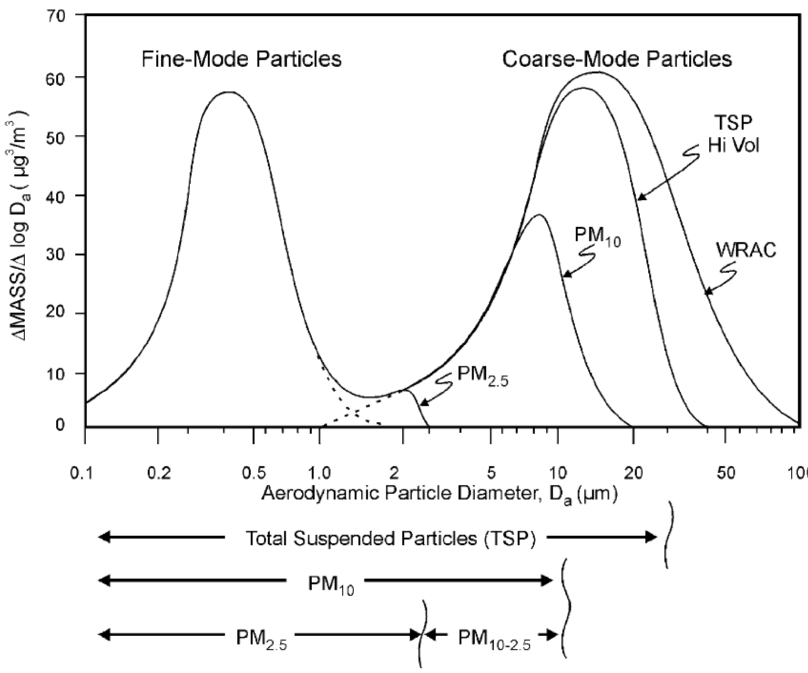


Figure 2.1 An idealized distribution of ambient particulate matter.
Source: Wilson et al. (2002)

Another classification of particles by size is regulatory size cuts. Total Suspended Particulate matter (TSP) is a particles ranging in size from 0.1 – 35 µm in diameter. TSP is described by the design of the high volume sampler which collects all of the fine particles but only part of the coarse particles (Wilson et al., 2002). Particulate matter equal to or less than 10 µm in diameter (PM_{10}) are described as "inhalable". These particles selected based on health considerations, they can penetrate into the respiratory system (Herman and Bisesi, 2003). Particles less than 2.5 µm in diameter are called "respirable", they can enter and be deposited in pulmonary tissue (Godish, 1997). An ultrafine particle is a particle less than 0.1 µm (Heinrich and Slama, 2007).

Terminologies of atmospheric particles are defined as follows (Seinfeld, 1986):

Aerosol – Tiny particles dispersed in gases.

Dust – Suspensions of solid particles produced by mechanical disintegration of material such as crushing, grinding and blasting. Particles size is larger than 1 µm.

Coarse particle – A particles larger than 2.5 µm in diameter.

Fine particle – A particles less than 2.5 µm in diameter.

Fog – A visible aerosols. Usually is a dispersion of water or ice.

Fume – A solid particles generated by condensation from the vapor state, generally after volatilization from melted substances and often accompanied by a chemical reaction. Particles size is smaller than 1 µm.

Haze – An aerosol include a combination of water droplets, pollutants and dust. Particles size is smaller than 1 µm.

Mist – A liquid particles, water in form of particles suspended in the atmosphere.

Smog – A term is derived from smoke and fog, applied to extensive contamination by aerosol.

Smoke – Small gas-borne particles resulting from incomplete combustion.

Sources of particulate matter may be emitted from mobile sources such as automobiles, trains, airplanes etc.; and stationary sources such as industrial process, electricity generating plants (Godish, 1997). The major sources of particulate matter in Bangkok include traffic, secondary particles, biomass burning and road dust (Oanh et al., 2006; Chuersuwan et al., 2008). Especially, large numbers of vehicles and traffic congestion have caused severe impact on air quality in Bangkok.

2.2 Effects of ambient suspended particulate matter

Particulate matter in atmosphere can cause adverse effects on human health and environment as follows:

2.2.1 Effects on human health

The effects of particulate matter on human health are damage to the respiratory system and cardiovascular system, especially aggravation of existing respiratory diseases and increases in lung cancer mortality. Health effects of particulate matter not consider only the concentration and characteristics of particle, but they also related to several factors (Olson and Boison, 2005).

In general, human can protect particulate matter by defense mechanism in respiratory system. Large particles are filtered and trapped in the upper airways then these particles are removed by sneezing, coughing and swallowing. The respiratory system may be divided into three regions (Vallero, 2008; Seinfeld, 1986).

- Nasal region consists of nose mouth and throat.
- Tracheobronchial region consists of trachea and bronchial tube.
- Pulmonary region consists of terminal bronchi and alveolar sacs.

Deposition of particulate matter in respiratory system is described in several physical mechanisms (Seinfeld, 1986).

- Interception occurs when the trajectory of a particle bring it close to a surface.
- Inertial impaction occurs when the air stream changes direction but the particle tends to hold the same trajectory, causing large particles greater than 5 µm to impact on bends and bifurcations.
- Sedimentation occurs in the area which airways are small and air velocity is low i.e. bronchioles and alveolar spaces. This mechanism occurs due to action of gravity and effect for particles approximately 0.5 – 1 µm in diameter.
- Diffusion or Brownian motion occurs in the small airways and alveoli. If particle size decreases, Brownian motion increases and this become an effective mechanism for deposition in the small air spaces. This mechanism is most important for particle sizes below 0.5 µm in diameter.

Particulate matter less than 10 µm in diameter is penetrated deeply into the respiratory system. They cause acute and chronic symptoms. Acute symptoms are restricted activity, respiratory illnesses and exacerbations of asthma. Chronic diseases are lung cancer, chronic bronchitis, asthma and emphysema (Herman and Bisesi, 2003). Fine particle (particles with aerodynamic diameter of less than 2.5 µm) is deposit in pulmonary region more than coarse particle. Furthermore, sensitive people, elderly and children are susceptible to the effect of fine particle (Lee et al., 2007; Heinrich and Slama, 2007).

2.2.2 Effects on animals

Previous studies of air pollution affects indicate that besides of death and illness to the human, domesticated animals such as dogs and cats were also affected (Godish, 1997).

Bettini et al. (2009) investigated the relationship between the accumulation of black dust matter in lungs (anthracosis) and primary lung cancer in dogs. The result showed that pulmonary anthracosis cause by inhalation of polluted air was associated with a high frequency of lung cancer in dogs.

Few studies focused on the effect of particulate matter to experimental animals such as rat. Studies by Mohallem et al. (2005) indicated that moderate level of air pollution in Sao Paulo city may affect the reproductive health of female mice. Campbell et al. (2005) examined the effect of particulate matter to inflammation in mouse brain. The result indicated that components of inhaled particulate matter may trigger a proinflammatory response in nervous tissue that could contribute to the pathophysiology of neurodegenerative diseases.

2.2.3 Effects on vegetation

Atmospheric particulate matter may affect vegetation both direct and indirect. The direct effect is particulate matter deposition on leaf surface. Indirect effect is occurring by changing soil chemistry or decrease radiation for photosynthetic. However, indirect effects in soil are important due to they can alter nutrient cycling and inhibit plant nutrient uptake.

Deposition of particulate matter on vegetation depends on size and chemical composition. Moreover, particles can be deposit to vegetation by wet and dry processes (Grantz et al., 2003).

2.2.4 Effects on materials

Particulate matter can affect materials by physical mechanism i.e. soiling effect of passive dust deposition and wind driven particle impact on surface. Furthermore, chemical reactions may result when pollutant contact with materials. This chemical effect usually results in irreversible changes. Thus, chemical effect on materials by particulate matter is a more serious problem than the physical changes (Godish, 1997).

Stefanis et al. (2009) investigated the dry deposition of marine aerosol for evaluate impact to the building stone. The result indicated that marine aerosol can be deposited on the stone surface, leading to the pore fracture and stone decay. Furthermore, marine aerosol is easily deposited on surface even through at high wind speed or at distant building.

2.2.5 Effects on atmospheric properties

Visibility is the ability to detect contrast between an object and its surroundings. If contrast decreases, ability to see object will be reduces. The threshold contrast is mean to the lowest limit of contrast for human observers. This value influences the maximum distance at which an object or the various components of an observed scene can be discerned (Godish, 1997; Vallero, 2008).

Reduction in visibility is caused by two processes in the atmosphere: scattering and absorption of light (Seinfeld, 1986). Light scattering process is the most important cause of visibility reduction; concern the interaction of light with particles. This phenomenon is altering the direction or frequency of the light and dependent on the size of the particles suspended in the atmosphere. Light absorption occurs when the electromagnetic radiation interacts with particles and is transferred internally to the gas or particle (Vallero, 2008).

Kim et al. (2001) studied visibility reduction during yellow sand periods in Kwangju city, Korea. The result indicated that when hourly average PM_{10} concentration varied from 32.9 – 601.8 µg/m^3, the hourly averaged visual range will be decreasing from 61.7 – 1.9 km. Moreover, the data showed that fine particle were relatively lower than coarse particle.

2.3 Meteorological factors influencing the particulate matter

The atmosphere can be divided into regions according to its vertical temperature profile. From the surface up to about 11 km is called the troposphere, which is an atmospheric region where the air temperature decreases with height and is a region that contains almost all of the weather (Ahrens, 2008).

Weather is comprised of several factors such as air temperature, air pressure, humidity, precipitation and wind (Ahrens, 2008). Many studies indicated that meteorological factors can affect the mass concentration of TSP and PM_{10} (Chan and Kwok, 2001; Karar et al., 2006). The meteorological factors that affect to the particulate matter are as follows:

2.3.1 Precipitation

Precipitation is liquid or solid water particle that falls from the atmosphere to the ground. It has several forms such as rain, snow, sleet, freezing rain and hail (Ackerman and Knox, 2007). Water vapor is the first step of the precipitation cycle with condenses onto a particle that finally grows large enough to fall out of a cloud and reaches the ground (Spellman, 1999; Ackerman and Knox, 2007).

Rain is particles melt into liquid droplets, occur when temperature remains above 0°C from the cloud base to the surface. Raindrops are not teardrop-shaped, they are spheres flattened by the pressure of the wind as they fall. They are at least 500 µm in diameter.

Previous works on particulate matter indicated that rainfall is correlated with level of particulate matter in the atmosphere. The concentration of TSP and PM_{10} decrease if the rainfall increases (Chan and Kwok, 2001). The removals of particulate matter take place by the process of impaction and entrapment by falling raindrops (Shukla et al., 2008).

2.3.2 Wind

Wind is the horizontal movement of air along surface of the earth (Spellman, 1999). Wind is air in motion that arises from a combination of forces. There are five different forces combine to move air: the gravitational force, the pressure gradient force, the coriolis force, friction and centrifugal forces (Ackerman and Knox, 2007).

Wind speed and wind direction are associated with transport and dilution of pollutants. However, wind speed over smooth surfaces e.g. lakes, cultivated field and rural area are higher than wind speed over rougher surfaces e.g. mountains and buildings. Therefore, in urban area with high buildings, wind speed is significantly reduced. Furthermore, variety in wind direction is significant affect on pollutant dispersion. If wind moves to the same direction, the pollutant will not disperse to surrounding area. Actually wind direction is shifting, pollutant will be dispersed over a larger area and level of pollutant in each areas are lower (Godish, 1997).

Kim et al. (2005) studied on influence of wind speed on the relationships between different size ranges of airborne particle. The result showed that changes wind speed in term of increase or decrease, can exert significant influences on relative particulate matter distribution patterns among different particle fractions.

Hussein et al. (2006) utilized a long term data of particle concentrations both ultra-fine particles and the fraction of fine particles and examined their dependencies on the relevant meteorological parameters. The results showed that ambient temperature, local wind speed and direction were found to be the important factors that control the number concentrations of fine particle.

2.3.3 Relative humidity

Relative humidity describes how close the air is to being saturated with water vapor. The ratio of water vapor pressure and saturation water vapor pressure at the same temperature is called the saturation ratio. Multiplying the saturation ratio by 100% yields the relative humidity.

Relative humidity is correlates with ambient air temperature. The saturation vapor pressure decreases when the temperature decreases. Thus, a decrease in temperature ensues in an increase in the relative humidity, and increasing the temperature decreases the relative humidity (Ackerman and Knox, 2007).

Wang et al. (2009) studied on relative humidity that influences the level of particulate matter and variations of particulate matter concentrations with different sizes. The result showed that relative humidity affects the concentration of coarse particles and fine particles differently and their correlation shows the seasonal difference. In spring, autumn and winter, relative humidity is negatively correlated with TSP and PM_{10} concentrations but positively correlated with $PM_{2.5}$ and $PM_{1.0}$ concentrations whereas in summer, relative humidity is positively correlated with PM_{10}, $PM_{2.5}$ and $PM_{1.0}$. It indicates that high relative humidity in summer is depresses the diffusion of particles and depressing effect is more significant for small particles.

2.3.4 Temperature

In the troposphere, temperature decreases with increasing altitude at a rate of 6.5 °C per kilometer. This is the normal lapse rate. The environmental lapse rate is a change of temperature with altitude at any particular time and location. These values demonstrate the atmospheric stability and affect vertical air motion with associate the dispersion of particulate matter.

Superadiabatic lapse rate (Figure 2.2A) occurs when a parcel of warm air is released into an environment where the temperature decrease with height is greater than the adiabatic lapse rate. Therefore, the atmosphere will be unstable and proper for the vertical dispersion of particulate matter. If a warm parcel of air is released into an environment where the lapse rate approaches the adiabatic lapse rate (Figure 2.2B), the temperature is still decrease with height and the atmosphere would be neutrally stable. This condition is good for the vertical dispersion of particulate matter. If the temperature remained constant with height (Figure 2.2C) the atmosphere tends to be more stable and the dispersion of particulate matter becomes limited or moderate. If the temperature increases with height (Figure 2.2D) the atmospheric conditions are very stable. This are called temperature inversions. Dispersion potential in vertical motion under inversion conditions is very poor (Godish, 1997).

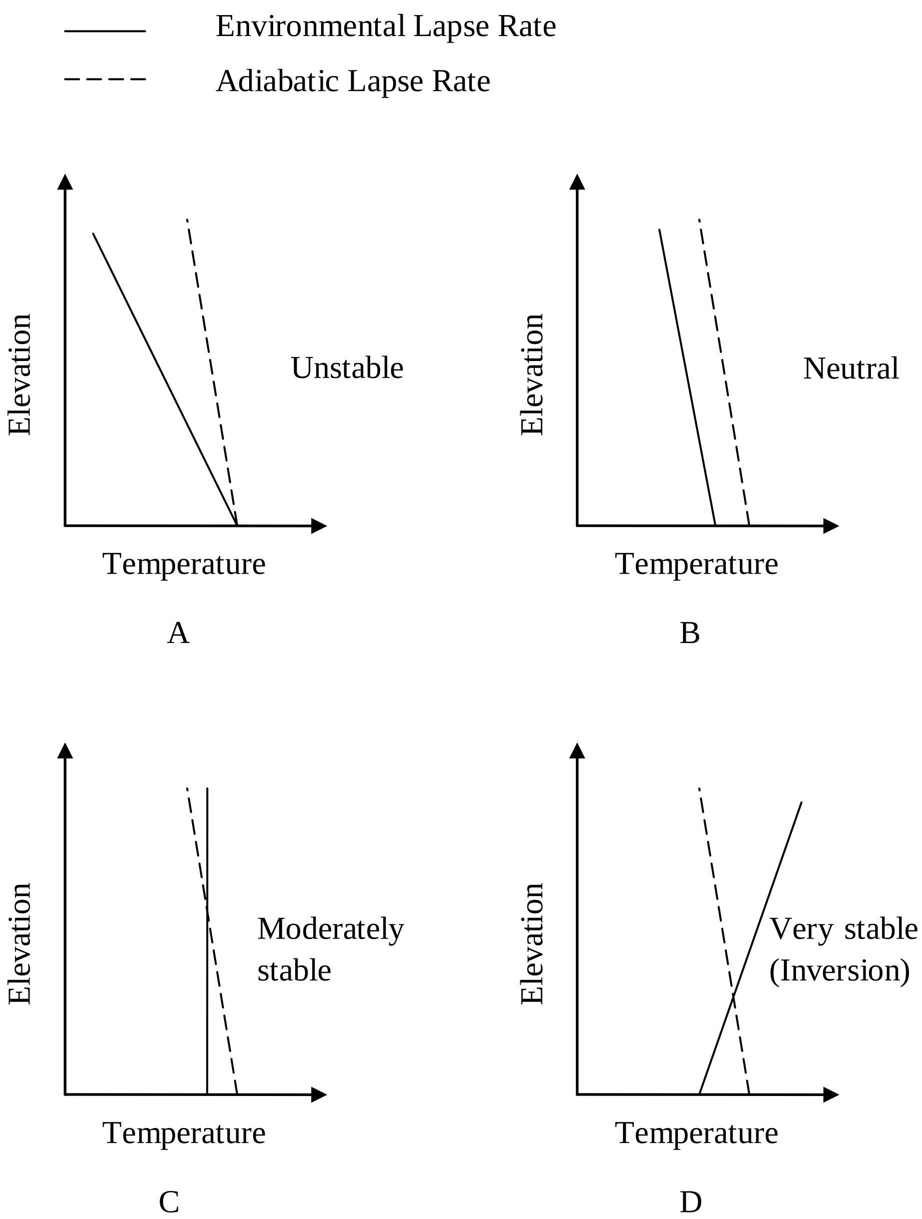


Figure 2.2 Relationship of environmental lapse rate to atmospheric stability.
Source: Godish (1997)

Janhäll et al. (2006) studied on evaluation of urban aerosol during winter days with morning inversion by using meteorological data and vertical back scattering profiles indicated that particles increased during temperature inversion in the morning rush hours. When the morning inversion broke up and the polluted ground-level air was mixed with the residual layer, the number of particles decreased more rapidly than mass of particles.

2.4 Weather in Bangkok

Bangkok is located on latitudes 13° 45’N and longitudes 100° 30’E, is in the central part of Thailand. The climate is under influence of monsoon winds i.e. southwest and northeast monsoon (Thai Meteorological Department, 2009: online).

2.4.1 Season

Climate in Bangkok can be divided into three seasons.

1) Rainy season

The influencing of southwest monsoon brings a moist air from the Indian Ocean toward Thailand and causing abundant rain in Bangkok. This season is longest period of the year, approximately 6 months, start in mid-May to mid-October. The wettest month of the year is September with a value of 345.3 mm. (average during 1971-2000).

2) Winter season

The influencing of northeast monsoon brings the cold and dry air from China toward Thailand. This season is cold period than those other seasons of the year. Winter season start in mid-October to mid-February. The coldest month of the year is December with a value of 25.9 °C (average during 1971-2000).

3) Summer season

This season is the transitional period from northeast to southwest monsoon. Summer season start in mid-February to mid-May and this is hot period than those other seasons of the year. The hottest month of the year is April with a value of 30.1 °C (average during 1971-2000).

2.4.2 Temperature

Bangkok is located in tropical latitude zone, thus the weather is quite warm. Average temperature of Bangkok in rainy, winter and summer season are 28.6, 26.8 and 29.6 °C, respectively (average during 1971-2000).

2.4.3 Rainfall

Average rainfall of Bangkok in rainy, winter and summer season are 1358.3, 79.7 and 105.2 mm, respectively. A number of annual rainy day is 127 days (average during 1971-2000).

2.4.4 Relative Humidity

Average relative humidity of Bangkok in rainy, winter and summer season are 77.5, 71.5 and 74 %, respectively (average during 1971-2000).

2.4.5 Wind

Predominant winds in rainy, winter and summer season are southwest, northeast and south, respectively. Furthermore, wind speed in rainy, winter and summer season are 2.9, 2.7 and 4.4 knots, respectively (average during 1971-2000).

2.5 Public Park

It is widely known that Public Park can improve urban air quality (Lam et al., 2005). Trees in urban green area can remove particulate matter by dry deposition on plant surface through gravity sedimentation or impaction (Jim and Chen, 2008).

Bangkok has been improving structure of agency that responsible in park and tree. At present, Public Park is in responsibility of Public Park Office, Environment Bureau, Bangkok Metropolitan Administration. The obligation of Public Park Office is including plan and develop green area in Bangkok. Bangkok has a Public Park with the area of 19,431,988.24 square meters. The 25 main Public Parks have a total area of 4,246,158 square meters (Table 2.1) and the rest is many small Public Parks (Public Park Office, 2009: online). A per capita Public Park in Bangkok was approximately 1.82 square meters (Thaiutsa et al., 2008)

Table 2.1 The 25 main Public Parks in Bangkok Metropolitan Area

Public Park	District	Area (m^2)	Number of visiting people / week
Lumphini Park	Pathum Wan	576,000	83,135
Chatuchak Park	Chatuchak	248,226	35,000
Phra Nakhon Park	Lat Krabang	80,000	8,300
Saranrom Park	Phra Nakhon	36,800	28,250
Thonburirom Park	Thung Khru	101,280	8,000
Suan Luang Rama 9	Prawet	800,000	5,186
Seri Thai Park	Bueng Kum	560,000	37,000
Nong Chok Park	Nong Chok	56,800	3,000
Benchasiri Park	Khlong Toei	46,400	22,000
Rommaninat Park	Phra Nakhon	47,888	15,000
Queen Sirikit Park	Chatuchak	315,060	7,520
Santiphap Park	Ratchathewi	32,320	28,000
Wachirabenchatat Park	Chatuchak	600,000	23,500
The Public Park in commemoration of H.M. the king’s 6th Cycle Birthday	Bang Kho Laem	46,400	20,000
Rommani Tungsikan Park	Don Mueang	25,096	1,732
Tawiwanarom Park	Thawi Watthana	86,400	4,100
50th Birthday Maha Chakri Sirindhorn Park	Prawet	32,196	4,710
Ramindra Sport Park	Bang Khen	94,400	9,550
Kiakkai Chaloemprakiet Park	Dusit	16,000	-
Rama 8 Park	Bang Phlat	38,400	-
Panpirom Park	Huai Khwang	22,400	-
Wanadharma Park	Prawet	76,892	493
60th Birthday of H.M. Queen Sirikit Park	Lat Krabang	83,200	25,005
Benjakiti Park	Khlong Toei	208,000	5,650
Santichaiprakarn Park	Phra Nakhon	16,000	-

Source: Public Park Office (2009: online)

The Public Park in Bangkok can be classified as the following

1) Pocket Park, Mini Park has an area not exceeding 3,200 square meters. This park is serving people around 1 kilometer and use for playground, exercise and relaxes. There are large number of Pocket Park such as park near the King Rama V Equestrian Monument and park in front of the City Law Enforcement Department.

2) Neighborhood Park has an area 3,200 – 40,000 square meters. This park is serving people around 1 - 3 kilometer and have facility more than Pocket Park. There are large number of Neighborhood Park such as Saranrom Park and Santiphap Park.

3) Community Park has an area 40,000 – 200,000 square meters. This park is serving people around 3 - 8 kilometer and have facility more than Pocket Park and Neighborhood Park. There are large number of Community Park such as Benchasiri Park and Thonburirom Park.

4) District Park has an area 200,000 – 800,000 square meters. This park is serving people around more than 8 kilometer. This park has a picnic area, multipurpose area and special feature area such as pond and flower garden. There are five parks in District Park i.e. Lumphini Park, Chatuchak Park, Seri Thai Park, Wachirabenchatat Park and Queen Sirikit Park.

5) City Park has an area more than 800,000 square meters. This park has many activity and be able to service all people of city. Suan Luang Rama 9 is only City Park in Bangkok.

6) Street Park may be divided into three types i.e. Linear Park, Island Park and Junction Park.

7) Special Purpose Park is unlimited area such as park around Victory Monument and Democracy Monument.

2.6 Measurement of particulate matter

2.6.1 Total Suspended Particulate (TSP)

2.6.1.1 High volume method

The high volume air sampling method is usable to all measurements of ambient suspended particulate matter. It is appropriate for measuring total suspended particulate matter (TSP) and particulate matter less than 10 micron (PM_{10}). Principle of this method, air is flow through a size selective inlet and filter at a flow rate of 40 ft^3/min. Particles with aerodynamic diameters less than the cut-point of the inlet are collected on the filter. The mass of these particles is determined by the difference in filter weights before and after sampling. The particulate matter concentration is calculated by dividing the mass of particles with a volume of air sampled (Lodge, 1988). Apparatus of this method can be classified as the following:

1) Sampler consists of an inlet, filter holder, air mover, flow controller and timer.

2) Size selective inlet for TSP sampling is using Peaked Roof Inlet which consists of triangular structure to protect the filter from dustfall.

3) Flow controller

- Manual volume flow control. Desire flow rate can be adjusted by increasing or decreasing the voltage. The flow rate decreases when particles deposited increases but normally less than 10%.

- Automatic volume flow control by Critical Throat. Flow is limited in a throat section between filter and blower.

- Automatic mass flow control. Air pass through the sensing probe. A feedback signal is sent to the blower to increase or decrease the flow and keeping the heat transfer constant at the sensing element.

4) Laboratory equipment consists of a numbering machine, desiccator and analytical balance.

5) Calibration equipment consists of an orifice transfer standard, manometer, barometer and thermometer.

6) Filter media. A 20.3 x 25.4 cm filter is used to collect particles. The appropriate filter media for high volume air sampling are cellulose fiber, glass fiber, quartz fiber, Teflon coated glass fiber and Teflon membrane filter.

2.6.2 Particulate Matter less than 10 micron (PM_{10})

2.6.2.1 High volume method

Principle of PM_{10} sampling by high volume method is similar with previously described TSP sampling, but difference on the size selective inlet as following:

- Opposed jet inertial separation. Sampled air pass through opposed jets, particles larger than 10 µm in diameter are trapped in the inlet while smaller particles are deposit on the filter.

- Cyclonic flow inlet. Sampled air pass through vertical cylinder with a swirling motion. Particles larger than 10 µm in diameter are deposited on the inner surface of the cylinder.

2.6.2.2 Tapered element oscillating microbalance (TEOM)

The particle mass of PM_{10} or $PM_{2.5}$ that measure with TEOM is determined by continuous weighing of particle deposited on a filter. The filter is attached to a vibrating hollow tapered glass tube. The frequency of mechanical oscillation of this tube is a function of its mass. Deposition of particles on the filter leads to changes in the mass of the system and results in changes of its frequency of oscillation. A microprocessor directly converts the vibration frequency to mass concentration. Thermal mass flow controller is used to control flow rate and is automatically measured to determine the mass concentration. Air passes through the sampling head at flow rate 16.67 l/min and divided between the filter flow (3 l/min) and an auxiliary flow (13.67 l/min) (Charron et al., 2004).

2.6.2.3 Partisol Sampler

The partisol sampler is gravimetric method for the collection of PM_{10} or $PM_{2.5}$. The partisol has an automatic filter exchange mechanism which provides unattended monitoring for up to 16 consecutive days. Temperature and pressure sensors are controlled by internal regulators to maintain the temperature within ±5 °C of ambient temperature. A microprocessor is use to record the total volume of air sampled, total measuring time, average temperature and pressure. Sample is collect on filter 47 mm in diameter with 0.6 µm pore size (Charron et al., 2004).

2.6.2.4 Dichotomous Air Sampler

Dichotomous air sampler is use to collect particulate matter less than 10 micron; separating the sample to coarse ($PM_{10-2.5}$) and fine particle ($PM_{2.5}$). The total flow rate of the dichotomous sampler is 16.71 l/min. A virtual impactor split the airflow into flow rate of 1.7 l/min for $PM_{10-2.5}$ sample and 15.0 l/min for $PM_{2.5}$ onto 47 mm diameter PTFE filters (Poor et al., 2002).

2.6.3 Particulate Matter less than 2.5 micron ($PM_{2.5}$)

2.6.3.1 TEOM

$PM_{2.5}$ sampling by Tapered element oscillating microbalance is similar with previously described in PM_{10} sampling.

2.6.3.2 Partisol Sampler

$PM_{2.5}$ sampling by Partisol Sampler is similar with previously described in PM_{10} sampling.

2.6.4 Micro Orifice Uniform Deposit Impactor (MOUDI)

The MOUDI is a 12 stages cascade impactor with all stages having 50% cut-points ranging from 0.056 to 18 µm in aerodynamic diameter. Thus, all the MOUDI stage collections is a true measure of TSP due to particles of all sizes are collected between the inlet stage and the back up filter stage. Sample is collect on filters 47 mm in diameter with 0.4 µm pore size for the first 11 stages. While filter 37 mm in diameter with 1 µm pore size is used for the final back-up filter (Keywood et al., 1999).

2.6.5 Particle fallout

This method is useable to area surveys for measure particle fallout nuisances. Large solid and liquid particles (normally larger than 10 µm in diameter) are collected by gravitational settling in an open-mouth container for a designated period of time. The mass of insoluble particles is determined by the weight-gain of the filter after filtration. The mass of soluble particles is determined by the weight gain of a crucible after evaporation. Insoluble, soluble and total dustfall rates are calculated by normalizing the mass measurements by the collection area of the container and the sampling time (Lodge, 1988).

2.7 Ambient air quality standard

The basic for air quality management is setting up target of ambient air quality standards. It is a legal limit on concentrations of a regulated pollutant that occur in the atmosphere. Setting ambient air quality standards is a difficult process. The promulgation of an ambient air quality standard is considered by intensive review of the scientific evidence associated with pollutant levels and their effects and the level of protection necessary, finally decision making by a regulatory authority (Godish, 1997)

The ambient air quality standards in Thailand were set up according to notification of Office of the National Environment Board No.10, B.E.2538 (1995) under the Enhancement and Conservation of National Environmental Quality Act B.E.2535 (1992). Pollution Control Department set up ambient air quality standard for particulate matter in these size ranges as TSP, PM_{10} and $PM_{2.5}$ (Table 2.2). In addition, Table 2.2 also provides air quality standards of WHO and other countries.

Table 2.2 Ambient air quality standards of particulate matter in Thailand, WHO and other countries

Country	TSP (µg/m^3)		PM_{10} (µg/m^3)		$PM_{2.5}$ (µg/m^3)	
	24 h	1 year	24 h	1 year	24 h	1 year
Thailand[1]	330	100	120	50	50	25
USA[2]			150	50	35	15
Hong Kong[3]	260	80	180	55		
India[4]			100	60	60	40
Republic of Korea[5]			100	50		
United Kingdom[6]			50	40		
WHO[7]			50	20	25	10

Sources: 1. Pollution Control Department (2010: online)
2. U.S. Environmental Protection Agency (2009: online)
3. Environmental Protection Department (2004: online)
4. Ministry of Environment and Forests (2009: online)
5. Ministry of Environment (2007: online)
6. UK Department for Environment (2007: online)
7. WHO (2010: online)

2.8 Related researches

Lam et al. (2005) studied the concentrations of respirable suspended particulates in Hong Kong urban parks and open spaces. The results showed that average concentration of RSP in urban parks was 56.4 µg/m^3 whereas the park edge and park center were 58.2 and 53.9 µg/m^3, respectively. A number of one-way analyses of variance (ANOVA) were used to determine any significant difference in air quality among different districts and among park types. The results indicate that RSP concentration differed significantly among districts ($p < 0.01$) but not among different park types. Furthermore, this study was compare the result of air quality at a particular park with nearest continuous monitoring station that operated by government. These monitoring stations have two types, i.e. roadside stations situated on busy roads and ambient stations situated on roof tops of buildings. These comparisons indicated that while RSP concentrations in urban parks were lower than those at roadsides, they were similar to the ambient levels. This study proposes that air quality in urban parks is significantly better than those in the roadsides area. However, it is not significantly better than the ambient levels in a city.

Chuersuwan et al. (2008) studied the concentration levels and major sources of $PM_{2.5}$ and PM_{10} in Bangkok Metropolitan Region during February 2002 – January 2003. Four sampling sites were selected from the monitoring stations of Pollution Control Department. Din Daeng station represents a high traffic impact site. Jan Krasem and Bann Somdej stations represent a residential site. Bang Na station represents an urban low impact site. Each site was equipped with two low volume air samplers and collected on 47 mm stretch PTFE filters or quartz fiber filters for gravimetric and chemical analyses. The results show that Din Daeng station had 24-hour average PM_{10} and $PM_{2.5}$ concentrations higher than those other stations, 108.1 ± 35.5 µg/m^3 and 69.0 ± 28.8 µg/m^3, respectively. Jan Krasem and Bann Somdej stations had similar 24-hour average PM_{10} concentrations, 61.1 ± 25.2 µg/m^3 and 62.1 ± 30.7 µg/m^3, respectively. Similarly, 24-hour average $PM_{2.5}$ concentrations are 40.9 ± 21.4 µg/m^3 and 41.5 ± 24.6 µg/m^3, respectively. Bang Na station had lower concentrations of both PM_{10} and $PM_{2.5}$ than those other stations, 57.6 ± 23.9 µg/m^3 and 37.9 ± 18.9 µg/m^3, respectively. Statistical analysis indicated that daily means of both PM_{10} and $PM_{2.5}$ were significantly different among sites ($p < 0.05$).

Shan et al. (2007) studied the particle removal by vegetation in urban green space. TSP samples were collected once per season (January, April, July and October) by KB6120 Middle Flux Air Sampler. Four sampling sites were selected at 0,5,10 and 15 m away from the roadside. The results show that TSP concentration decrease with distance further away from the street. This purification effects are especially prominent within 10 m from the roadside. The TSP removal are higher in summer and autumn because flourished leaves and large trees are able to slow down the airflow and to hold up particulate matter. In spring and winter the deciduous trees without leaves effect to high TSP concentration.

Karar et al. (2006) studied the seasonal and spatial variations of TSP and PM_{10} in urban area of Kolkata, India. The residential and industrial sites have been chosen based on the major activities of the local area. Mean of daily average concentrations of TSP and PM_{10} during the study period in residential area are 268.4 and 140.1 µg/m^3, respectively; while industrial area are 363.5 and 196.6 µg/m^3, respectively. The 24 hours average PM_{10}/TSP ratios at residential and industrial area are 0.52 and 0.54, respectively. A result over a study period shows the seasonal variations of TSP and PM_{10}. The maximum daily average TSP and PM_{10} concentrations are 732.1 and 401.2 µg/m^3, respectively, that found during winter in industrial area. The minimum daily average TSP and PM_{10} concentrations are 125.7 and 62.4 µg/m^3, respectively, that found during monsoon in industrial area. Furthermore, daily average TSP and PM_{10} concentrations in residential area ranged between 139.3-580.3 µg/m^3 and 68.2-280.6 µg/m^3, respectively. TSP and PM_{10} concentrations of both monitoring sites showed inverse relationship with wind speed, temperature and relative humidity.

Krerkkaiwal (2004) studied levels of coarse particle (2.5-10 µm) and fine particle ($PM_{2.5}$) in Bangkok. Airborne particulates were sampling by using Dichotomous air sampler. Two monitoring sites were selected from the monitoring station of Pollution Control Department. Din Daeng site represented the roadside area. Phayathai site represented the general area. Moreover, Phuttamonthol Sai 2 represented the control area. The results in 3 sites show that winter season had higher particulate matter than those in rainy season. Din Daeng site had the highest concentrations for both PM_{10} and $PM_{2.5}$ than the other two sites. Coefficient of relation between $PM_{2.5}$ and PM_{10} was 0.979. It indicated that level of PM_{10} can be used to reflect the trend of $PM_{2.5}$.

Lin et al. (2008) studied the TSP and PM_{10} concentration in Taiwan on the weekends and weekdays during four consecutive seasons. Two sites were selected at a distance far from the main road 3 m. (site 1) and 50 m. (site 2), respectively. Roadside suspended particles were collected with a high-volume sampler. TSP and PM_{10} were consecutively sampled for 12 h, with daytime samples from 7:00 am to 7:00 pm and nighttime samples from 7:00 pm to 7:00 am. The results show that TSP and PM_{10} concentrations at site 2 were lower than those at site 1. This may imply that suspended particles measured at site 1 mainly came from traffic emissions, while suspended particles measured at site 2 involve with long-distance transportation. TSP and PM_{10} concentrations in the daytime were higher than those at nighttime. Moreover, TSP and PM_{10} concentrations on weekdays were generally higher than at weekends.

Shah and Shaheen (2008) studied levels of Total Suspended Particulate matter (TSP) in Islamabad, Pakistan during June 2004-May 2005. A total of 214 TSP samples were collected by using high volume samplers at flow rate 1.13 m^3/min. The results showed that TSP varied from 41.8-977 µg/m^3, with a mean value of 164±108 µg/m^3. Highest mean TSP was found during spring at 212 µg/m^3 while the lowest mean TSP was found during summer and winter because of the excessive precipitation during monsoon of summer. The TSP concentration was significantly and positively correlated with maximum and average temperature at r = 0.34 and r = 0.28, respectively.

Chan and Kwok (2001) studied the seasonal variation of particulate matter in heavily traffic urban area of Hong Kong. TSP, PM_{10} and $PM_{2.5}$ were collected from June 1998 to May 1999. The results show that average PM_{10}/TSP, $PM_{2.5}$/TSP and $PM_{2.5}$/PM10 ratios are 0.64, 0.53 and 0.76, respectively. Both TSP and PM_{10} were increasing from summer to reach maximum in February of the winter while $PM_{2.5}$ had less apparent variation. Correlation between TSP, PM_{10} and $PM_{2.5}$ are quite high, value of r^2 between PM_{10} and $PM_{2.5}$, TSP and PM_{10}, $PM_{2.5}$ and TSP are 0.78, 0.71 and 0.61, respectively. Large size particles (TSP and PM_{10}) were affected by meteorological factors such as relative humidity, wind direction and rainfall.

CHAPTER III
METHODOLOGY

This research is to determine concentration levels of ambient suspended particulate matter (TSP and PM_{10}) from 4 selected Public Parks in Bangkok, i.e. Suan Luang Rama 9, Lumphini, Benchasiri and Saranrom.

3.1 Materials and methods

3.1.1 Study area

Referring to the seven categories of Public Park that has been divided by Public Park Office, this research chose four categories according to their popularity as follows: City Park, District Park, Community Park and Neighborhood Park. It is decided to choose the representative Public Park that is most often used in each category. These are Suan Luang Rama 9, Lumphini, Benchasiri and Saranrom, respectively (Figure 3.1).

Figure 3.1 Map shows location of the four selected Public Parks in Bangkok

Source: adapted from Raktrip (2009: online)

Four Public Parks were selected as following:

1. Suan Luang Rama 9 Park is classified as a City Park with a size of 500 rai. It locates on Sukhumvit 103 road, Prawet district. This park situate in the outskirt of Bangkok with a residential area and low traffic. The weekly average number of people using this park in 2009 is 5,186 (Public Park Office, 2009). Monitoring site is nearby aerobic exercise site and car park (Figure 3.2).

Figure 3.2 Suan Luang Rama 9 Park

Source: Google (2010: online)

2. Lumphini Park is classified as District Park with a size of 360 rai. It locates on Rama 4 road, Pathum Wan district. This park situate in the inner city with a commercial, residential area and high traffic during working hours. The weekly average number of people using this park in 2009 is 83,135 (Public Park Office, 2009). Two monitoring sites are selected in this park. The first monitoring site is on aerobic exercise site near the Royal monument of King Rama 6 (Lumphini1), approximately 150 m away from Rama 4 and Rajadamri roads. The second monitoring site is on aerobic exercise site near Lumphini discovery learning library (Lumphini2), approximately 300 m away from Rama 4 and Rajadamri roads (Figure 3.3).

Figure 3.3 Lumphini Park

Source: Google (2010: online)

3. Benchasiri Park is classified as Community Park with a size of 29 rai. It locates on Sukhumvit road, Khlong Toei district. This park situate in the commercial, shopping area and high traffic during working hours. The weekly average number of people using this park in 2009 is 22,000 (Public Park Office, 2009). Monitoring site is nearby aerobic exercise site and car park, approximately 260 m away from sukhumvit road (Figure 3.4)

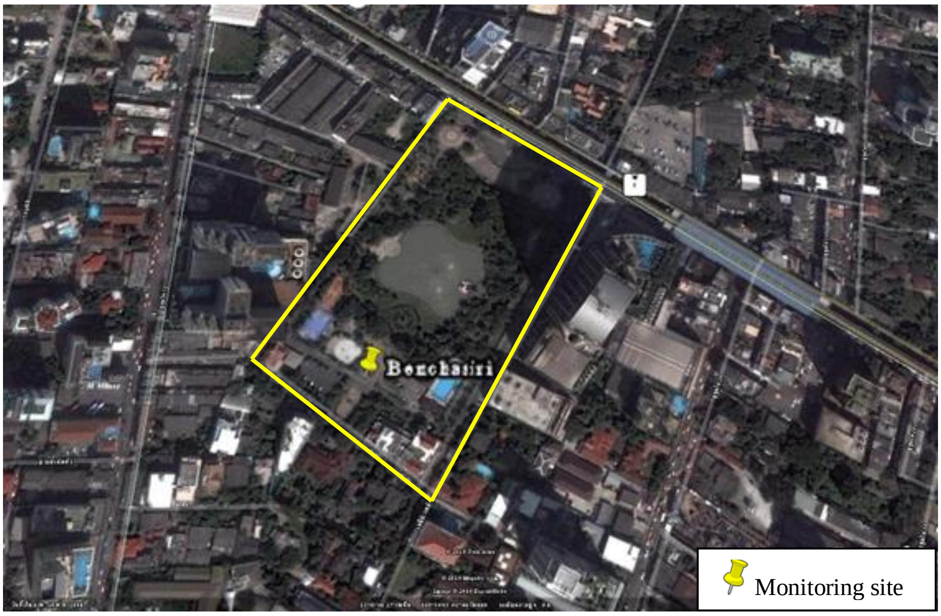


Figure 3.4 Benchasiri Park

Source: Google (2010: online)

4. Saranrom Park is classified as Neighborhood Park which a size of 23 rai. It locates on Charoenkrung road, Phra Nakhon district. This park situate in the residential area and moderate traffic. The weekly average number of people using this park in 2009 is 28,250 (Public Park Office, 2009). Monitoring site is nearby aerobic exercise site, approximately 5 m away from Charoenkrung road (Figure 3.5).

Figure 3.5 Saranrom Park

Source: Google (2010: online)

3.1.2 Measurements of TSP and PM_{10}

TSP and PM_{10} samples were collected during rainy and winter seasons at the 5 previously described monitoring sites (Figure A-1 to Figure A-5, Appendix A). The samplings duration is 24 hours and sampling every other day for 2 weeks period. However, monitoring TSP and PM_{10} concentrations levels in 24 hours and compare with the ambient air quality standard are not enough. Because people do not stay in Public Park throughout the day. Most of people are exercising only in the morning and evening (before and after working hours). Thus, concentration levels of particulate matter during exercise are also important to be considered for health effect. Aim of this sampling is to determine 2 hours average of PM_{10} levels during the time that people come to exercise in the morning and evening. This sampling chose only one weekday and one weekend and collected 2 hours samples during 24 hours collection. However, these samplings were collected only during winter season.

Each site was equipped with 2 high volume air samplers one for TSP and another one for PM_{10} at flow rate of 1.13 m^3/min. Both TSP and PM_{10} samples were collected on 20.3 x 25.4 cm Whatman glass fiber filters. Each filter was equilibrated in desiccator and determined gravimetrically using an analytical balance with a sensitivity of 0.1 mg. Powder-free vinyl gloves were used for filter handling.

3.1.2.1 Filter preparation (Lodge, 2000)

1) Inspect each filter for pinholes, tears, creases, etc. If the filter is defect, it should not be used.

2) Assign an identification number to the right hand corner on smoothest side of each filter.

3) Equilibrate a filter in the desiccator (Relative humidity = 50 ± 5 % and Temperature = 30 ± 3 °C) for at least 24 hours.

4) Calibrate an analytical balance before weigh filter and recalibrate every ten filters.

5) Adjust the balance tare to read zero without filter in weighing chamber.

6) Weigh each filter and record pre-sampling weight. Place each filter in 8 x 10 square inches plastic bag, seal and take it to field.

3.1.2.2 Field sampling (Lodge, 2000)

1) Select appropriate monitoring location by considering near the aerobic exercise site and availability of electricity power source.

2) Calibrate the high volume air sampler flow rate and set flow rate at 1.13 m^3/min.

3) Place a filter on the support screen with the rough side upward.

4) Put the chart paper in the flow recorder.

5) For PM_{10} sampler, Dow Corning Silicone #316 was used to spray on the shim plate every sampling.

6) Set the timer to start and stop the sampler for 24 or 2 hours.

7) Record the sampling information such as site location, sampling date, starting time, filter identification number, initial meter reading, initial flow rate, ambient temperature and barometric pressure.

8) After sampling is completed, carefully fold the filter in half lengthwise and place in its plastic bag.

9) Record the elapsed time, final meter reading and final flow rate.

3.1.2.3 Post-sampling weighing (Lodge, 2000)

1) Equilibrate a filter in the conditioning environment (Relative humidity = 50 ± 5 % and Temperature = 30 ± 3 °C) for at least 24 hours.

2) Adjust the balance tare to read zero before weighing.

3) Weigh each filter and record post-sampling weight.

4) Calculate the mass concentration of TSP and PM_{10}.

3.1.3 Sampling period

TSP and PM_{10} samplings were collected in two seasons, i.e. rainy season (September-October 2009) and winter season (January-February 2010) as shown in Table 3.1

Table 3.1 Ambient air sampling schedule

Sampling site	Season	
	Rainy	Winter
Lumphini 1, Lumphini 2	14/9/09 - 26/9/09	10/1/10 - 22/1/10
Suan Luang Rama 9, Benchasiri, Saranrom	5/10/09 - 21/10/09	25/1/10 - 12/2/10

3.1.4 Calibration of high volume air sampler

The calibration of flow rate will always be performed whenever monitoring site is changed. Criteria for calibrate flow rate must be met with a minimum of 5 calibration points within the allowable variance range of 1.02-1.24 m^3/min (36-44 ft^3/min) and correlation coefficient must be equal to or better than 0.990. The procedures of calibration are as follows:

1) Disconnect the motor from the mass flow controller and directly connect the motor to an electricity power source.

2) Install the calibration orifice and top loading adapter plate to the sampler. Tighten the top loading adapter hold-down nuts securely and assure that no air leak.

3) Warm up the motor to normal operating temperature.

4) Examine an air leak by covering the hole on top of the calibration orifice and pressure tap on the side of the orifice with your hands.

5) Connect a rubber vacuum tube from one valve of the

manometer to the pressure tap on the side of the calibration orifice. Another valve of the manometer opens to the atmosphere. Before calibrate the water level must be at the same level.

6) Five resistance plates were used for five calibration points. Record the continuous flow recorder and manometer reading.

7) Record the information i.e. current date, start time of calibration, monitoring site, air temperature and barometric pressure.

8) Calculate a sampler set point to the target operating flow rate of 1.13 m^3/min.

3.1.5 Quality assurance and quality control (QA/QC)

3.1.5.1 Internal QA/QC

To assure the quality of TSP and PM_{10} measurement, the methodology for sampling and analysis were based on Reference method of 40 CFR 50, Appendix B and J (U.S. Environmental Protection Agency, 2009). The QA/QC of the monitoring was implemented as follows:

- The flow rate of air sampler will be re-calibrated when monitoring site is change.
- TSP and PM_{10} samples were collected for 24 ± 1 hours
- Flow rate was set at 1.13 ± 0.11 m^3/min
- Use a powder-free vinyl gloves for handling filters in field sampling and laboratory
- Filter equilibration was controlled for at least 24 hours before weigh a filters
- Re-spray the shim plate in PM_{10} sampler with a Dow Corning Silicone #316
- Blank samples were used to determine the actual weight of field samples.

3.1.5.2 Interlaboratory Comparison

In order to demonstrate that results from this study are compatible with those from PCD, which is a government agency that responsible for monitoring the ambient air quality in Thailand. Two PM_{10} high-volume air samplers (one from this study and another one from PCD) were compared at the same sampling site simultaneously. Sampling location was selected from temporary air quality monitoring station of PCD at Land Development Department site which is located on Phahonyothin road with a relatively heavy traffic (Figure A-6, Appendix A). The comparing sampling duration was 24-hour average for one week.

3.2 Meteorological data

Because this research measured only TSP and PM_{10} concentration levels. Therefore, the meteorological data such as wind speed, wind direction, rainfall, relative humidity and temperature were obtained from Thai Meteorological Department (Appendix C).

Suan Luang Rama 9 was used meteorological data from Bangna station while Lumphini1, Lumphini2, Benchasiri and Saranrom were used meteorological data from Bangkok station.

3.3 Data analysis

3.3.1 Calculation of TSP and PM_{10} concentration levels

3.3.1.1 Calculate the flow rate at standard conditions

$Q_{std} = P_a V_a T_{std} / 35.31 T_a P_{std}$

Where Q_{std} = flow rate (m^3/min) at 25°C, 760 mmHg

P_a = Ambient barometric pressure (mmHg)

V_a = flow rate from recorder chart (CFM)

T_a = Ambient temperature (°K = 273 + °C)

T_{std} = standard reference temperature (298 °K)

P_{std} = standard reference barometric pressure (760 mmHg)

35.31 = conversion for cubic feet to cubic meters

3.3.1.2 Calculate the standard sample volume

$V_{std} = Q_{std} \times t$

Where V_{std} = volume of air sampled (m^3) at 25°C, 760 mmHg

t = sampling time (min)

3.3.1.3 Calculate the TSP or PM_{10} concentrations

TSP or $PM_{10} = (W_f - W_i) \times 10^6 / V_{std}$

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

W_f = final weights of filter (g)

W_i = initial weights of filter (g)

10^6 = conversion for grams to micrograms

3.3.2 Statistical analysis

To analyze the relationship between TSP and PM_{10} and between seasonal variation and particulate matter concentration levels, the SPSS for window version 11.5 programs was used in the study.

Simple linear regression and correlation coefficient analysis was used to analyze the relationship between TSP and PM_{10} concentrations.

Independent samples test was used to analyze the relationship of TSP and PM_{10} concentrations between weekday and weekend. Furthermore, the relationship of TSP and PM_{10} concentrations between rainy and winter season was also used this analysis.

A paired t-test was used to analyze the relationship of TSP and PM_{10} concentrations between monitoring site which near and far from road (Lumphini1 and Lumphini2).

Stepwise multiple regression analysis was used to analyze the relationship between level of particulate matter and meteorological factors.

A paired t-test was used to analyze the interlaboratory comparison between this study and PCD.

CHAPTER IV
RESULTS AND DISCUSSION

This chapter presents results and discussion as the following:

4.1 Concentrations of TSP and PM_{10} in 4 selected public parks

4.2 Relationship between TSP and PM_{10} in each sampling site

4.3 Influence of seasonal variation on TSP and PM_{10}

4.4 Interlaboratory comparison between the PM_{10} high volume air sampler used by this study and that used by the PCD

4.1 Concentrations of TSP and PM_{10} in 4 selected public parks

A total of 162 samples were collected for 24-hour average TSP and PM_{10} and another 18 samples for 2-hour average PM_{10} (as shown in Table 4.1). These samples were collected from 5 sampling sites in the 4 Public Parks (Appendix B).

Table 4.1 Number of samples collected for TSP and PM_{10} from 5 sampling sites

Sampling site	Total number of 24-hour TSP samples	Total number of 24-hour PM_{10} samples	Total number of 2-hour PM_{10} samples
Lumphini1	14	14	4
Lumphini2	14	14	2
Suan Luang Rama 9	19	19	4
Benchasiri	17	17	4
Saranrom	17	17	4
Total	81	81	18

4.1.1 Lumphini1

The results of 24-hour average concentrations of PM_{10} and TSP, and its ratio at Lumphini1 are shown in Table 4.2 and Figure 4.1. Moreover, the 24-hour and 2-hour average PM_{10} concentrations are compared and illustrated in Figure 4.2.

Table 4.2 Concentrations of PM_{10} and TSP (24-hour average), and PM_{10}/TSP ratios at Lumphini1

Season	Day	PM_{10} (μg/m^3)	TSP (μg/m^3)	PM_{10}/TSP
Rainy	Monday (14/9/09)	28.1	55.6	0.51
	Tuesday (22/9/09)	27.2	50.5	0.54
	Wednesday (16/9/09)	27.5	48.9	0.56
	Thursday (24/9/09)	17.5	36.5	0.48
	Friday (18/9/09)	20.8	40.8	0.51
	Saturday (26/9/09)	21.0	42.6	0.49
	Sunday (20/9/09)	18.6	34.1	0.54
	Range	17.5-28.1	34.1-55.6	0.48-0.56
Winter	Monday (18/1/10)	82.7	124.2	0.67
	Tuesday (12/1/10)	73.9	109.6	0.67
	Wednesday (20/1/10)	52.5	83.6	0.63
	Thursday (14/1/10)	67.9	106.8	0.64
	Friday (22/1/10)	63.8	93.5	0.68
	Saturday (16 1/10)	51.1	81.8	0.62
	Sunday (10/1/10)	82.7	118.2	0.70
	Range	51.1-82.7	81.8-124.2	0.62-0.70
Ambient Air Quality Standard		120	330	

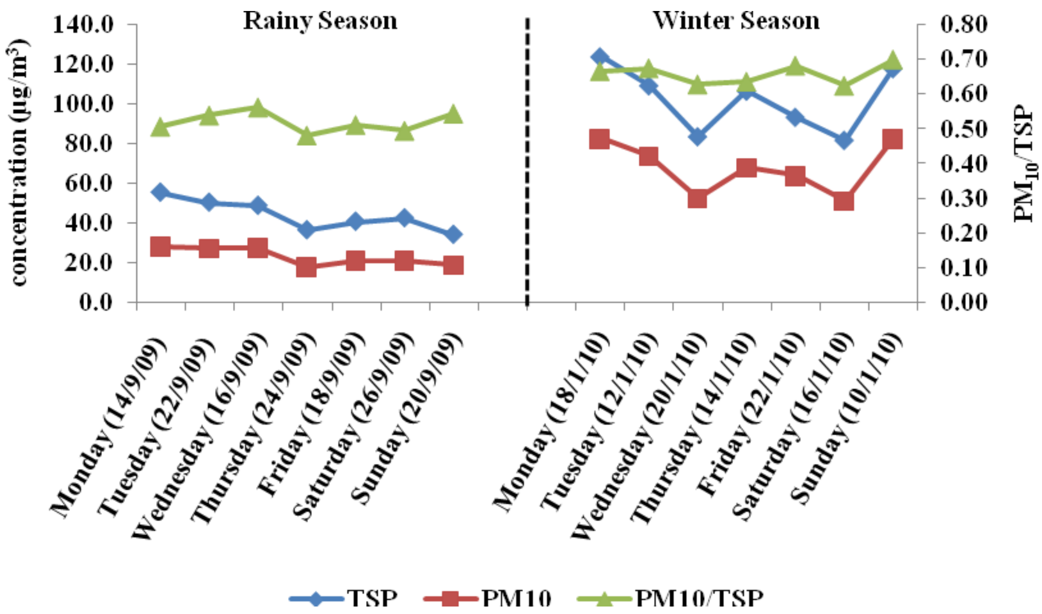


Figure 4.1 Concentrations of PM_{10} and TSP (24-hour average), and PM_{10}/TSP ratios at Lumphini1

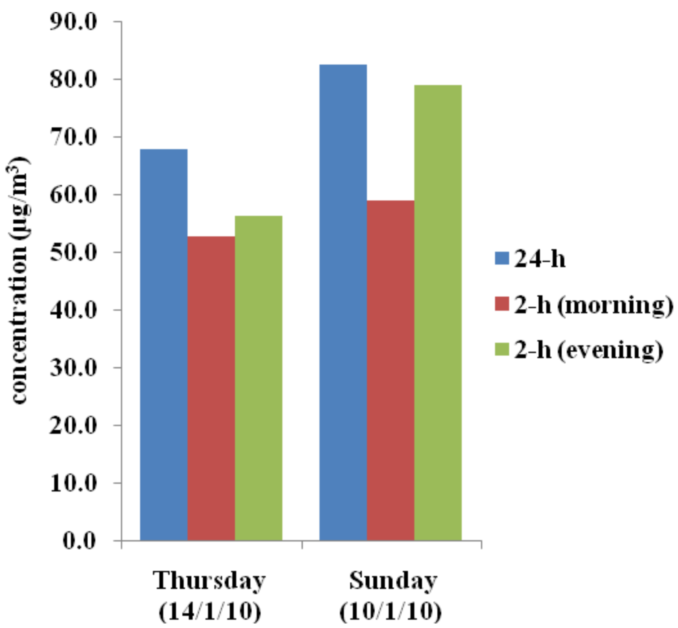


Figure 4.2 Comparisons of PM_{10} concentrations between 24-hour average and 2-hour average (morning and evening) at Lumphini1

Table 4.2 and Figure 4.1 reveal that concentration levels of PM_{10} and TSP in rainy season are lower than those in winter. The 24-hour average concentrations of PM_{10} and TSP in rainy season varied from 17.5 to 28.1 µg/m^3 and 34.1 to 55.6 µg/m^3, respectively, whereas the 24-hour average concentrations of PM_{10} and TSP in winter season varied from 51.1 to 82.7 µg/m^3 and 81.8 to 124.2 µg/m^3, respectively. The PM_{10}/TSP ratios appears to be lower in rainy season than in winter season, i.e. it varied from 0.48 to 0.56 and 0.62 to 0.70, respectively.

Figure 4.2 shows that the 24-hour average PM_{10} concentrations are relatively higher than those for 2-hour average by 4 to 29 %.

4.1.2 Lumphini2

The results of 24-hour average concentrations of PM_{10} and TSP, and its ratio at Lumphini2 are shown in Table 4.3 and Figure 4.3. In addition, the 24-hour and 2-hour average PM_{10} concentrations are compared as shown in Figure 4.4.

Table 4.3 Concentrations of PM_{10} and TSP (24-hour average), and PM_{10}/TSP ratios at Lumphini2

Season	Day	PM_{10} (µg/m^3)	TSP (µg/m^3)	PM_{10}/TSP
Rainy	Monday (14/9/09)	20.5	42.9	0.48
	Tuesday (22/9/09)	18.0	40.1	0.45
	Wednesday (16/9/09)	18.9	41.8	0.45
	Thursday (24/9/09)	10.9	30.0	0.36
	Friday (18/9/09)	11.7	32.2	0.36
	Saturday (26/9/09)	13.5	32.4	0.41
	Sunday (20/9/09)	10.4	26.6	0.39
	Range	10.4-20.5	26.6-42.9	0.36-0.48
Winter	Monday (18/1/10)	71.2	118.9	0.60
	Tuesday (12/1/10)	66.7	104.2	0.64
	Wednesday (20/1/10)	42.0	80.5	0.52
	Thursday (14/1/10)	61.1	101.0	0.61
	Friday (22/1/10)	53.2	87.0	0.61
	Saturday (16/1/10)	43.7	75.2	0.58
	Sunday (10/1/10)	64.2	116.1	0.55
	Range	42.0-71.2	75.2-118.9	0.52-0.64
Ambient Air Quality Standard		120	330	

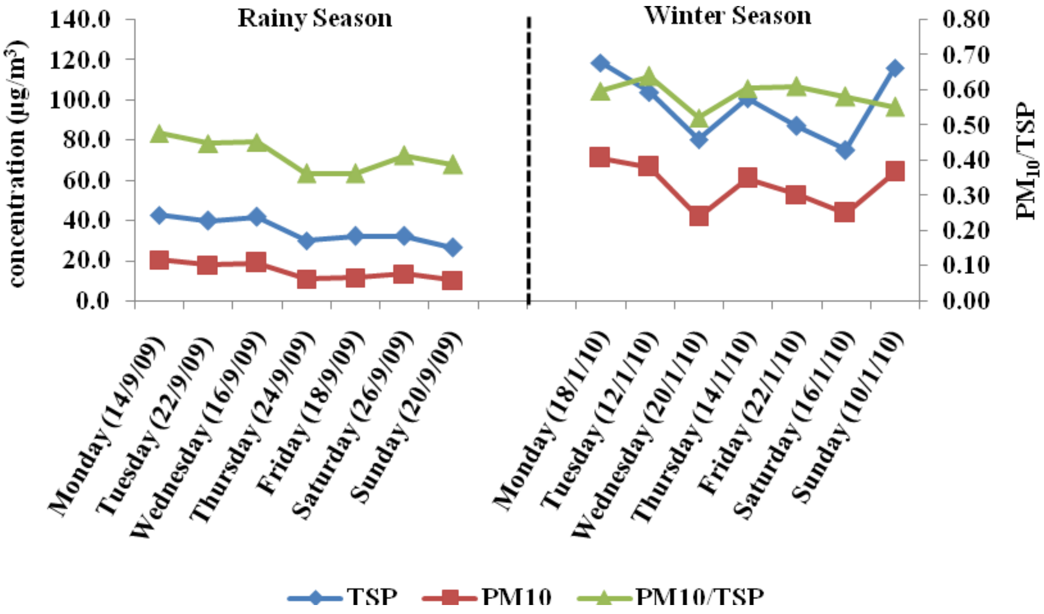


Figure 4.3 Concentrations of PM_{10} and TSP (24-hour average), and PM_{10}/TSP ratios at Lumphini2

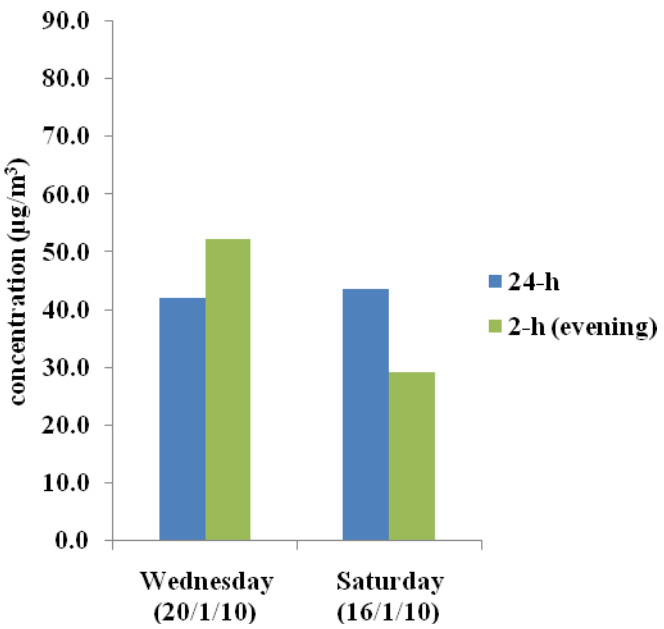


Figure 4.4 Comparisons of PM_{10} concentrations between 24-hour average and 2-hour average (evening) at Lumphini2

Table 4.3 and Figure 4.3 show that concentration levels of PM_{10} and TSP in rainy season are lower than those in winter season. The 24-hour average concentrations of PM_{10} and TSP in rainy season varied from 10.4 to 20.5 $\mu g/m^3$ and 26.6 to 42.9 $\mu g/m^3$, respectively, whereas the 24-hour average concentrations of PM_{10} and TSP in winter season varied from 42.0 to 71.2 $\mu g/m^3$ and 75.2 to 118.9 $\mu g/m^3$, respectively. The PM_{10}/TSP ratios are a little lower in rainy season than in winter season, i.e. it varied from 0.36 to 0.48 and 0.52 to 0.64, respectively.

At Lumphini2 site, two samples were collected for 2-hour average only in the evening because there is no aerobic activity in the morning. Figure 4.4 reveals that at Lumphini2 site, 24-hour average PM_{10} concentration is lower than that of 2-hour average on weekday (Wednesday, 20/1/10) but is higher on weekend (Saturday, 16/1/10). The difference between 24-hour average and 2-hour average PM_{10} concentrations are varied in the range of 24-33 %.

There are 2 monitoring sites at Lumphini Park. Lumphini1 and Lumphini2 are far from Rama 4 and Rajadamri road at approximately 150 and 300 m, respectively. All of the overall mean 24-hour average TSP and PM_{10} concentrations for both rainy and winter seasons at Lumphini1 were higher than those of Lumphini2 (Figure 4.5). It appears that automobile is a major source of particulate matter in Bangkok. Because the particulate matter can be removed by trees (Jim and Chen, 2008), therefore, levels of TSP and PM_{10} at Lumphini2 site that is at the center of the park were lower than those at Lumphini1 site that locates near the road. This result coincides with other studies, e.g. Lam et al. (2005) founded that PM_{10} levels on the park edge were higher than those in the park center.

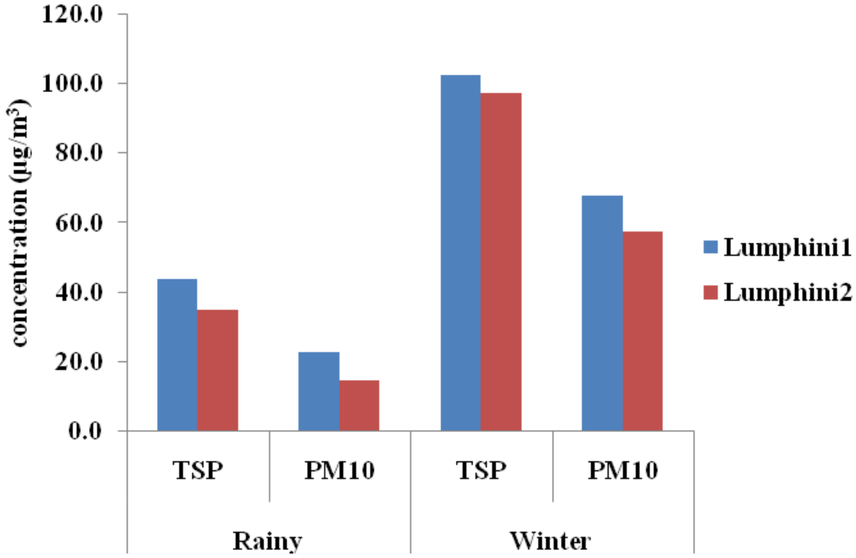


Figure 4.5 Means of 24-hour average TSP and PM_{10} concentrations between Lumphini1 and Lumphini2

The results of paired t-test (Table 4.4), which is determined at 0.05 level of significant, show that TSP and PM_{10} in both rainy and winter seasons at Lumphini1 were significantly higher than those at Lumphini2.

Table 4.4 Results of paired t-test of TSP and PM_{10} concentrations between Lumphini1 and Lumphini2

Season	PM	Site	Mean	n	SD	Correlation	t	Sig.(2-tailed)
Rainy	TSP	Lumphini1	44.1	7	7.82	0.972	10.764	0.000
		Lumphini2	35.2	7	6.38			
	PM_{10}	Lumphini1	23.0	7	4.51	0.979	22.781	0.000
		Lumphini2	14.8	7	4.19			
Winter	TSP	Lumphini1	102.6	7	16.60	0.995	7.655	0.000
		Lumphini2	97.6	7	17.11			
	PM_{10}	Lumphini1	67.8	7	12.98	0.953	6.744	0.001
		Lumphini2	57.4	7	11.40			

4.1.3 Suan Luang Rama 9

The results of 24-hour average concentrations of PM_{10} and TSP, and its ratio at Suan Luang Rama 9 are shown in Table 4.5 and Figure 4.6. In addition, the 24-hour and 2-hour average PM_{10} concentrations are compared and illustrated in Figure 4.7.

Table 4.5 Concentrations of PM_{10} and TSP (24-hour average), and PM_{10}/TSP ratios at Suan Luang Rama 9

Season	Day	PM_{10} (µg/m^3)	TSP (µg/m^3)	PM_{10}/TSP
Rainy	Monday (5/10/09)	48.3	75.7	0.64
	Tuesday (13/10/09)	23.4	33.7	0.70
	Wednesday (7/10/09)	51.9	70.4	0.74
	Thursday (15/10/09)	55.2	71.5	0.77
	Friday (9/10/09)	51.6	78.2	0.66
	Saturday (17/10/09)	46.4	67.2	0.69
	Sunday (11/10/09)	26.2	41.4	0.63
	Monday (19/10/09)	38.0	59.0	0.64
	Wednesday (21/10/09)	36.1	47.6	0.76
	Range	23.4-55.2	33.7-78.2	0.63-0.77
Winter	Monday (25/1/10)	57.7	99.35	0.58
	Tuesday (2/2/10)	36.6	59.7	0.61
	Wednesday (27/1/10)	74.9	113.0	0.66
	Thursday (4/2/10)	20.8	36.9	0.56
	Friday (29/1/10)	46.2	71.5	0.65
	Saturday (6/2/10)	32.0	51.2	0.62
	Sunday (31/1/10)	29.8	50.4	0.59
	Monday (8/2/10)	26.7	42.8	0.63
	Wednesday (10/2/10)	37.0	56.6	0.65
	Friday (12/2/10)	37.6	58.8	0.64
	Range	20.8-74.9	36.9-113.0	0.56-0.66
Ambient Air Quality Standard		120	330	

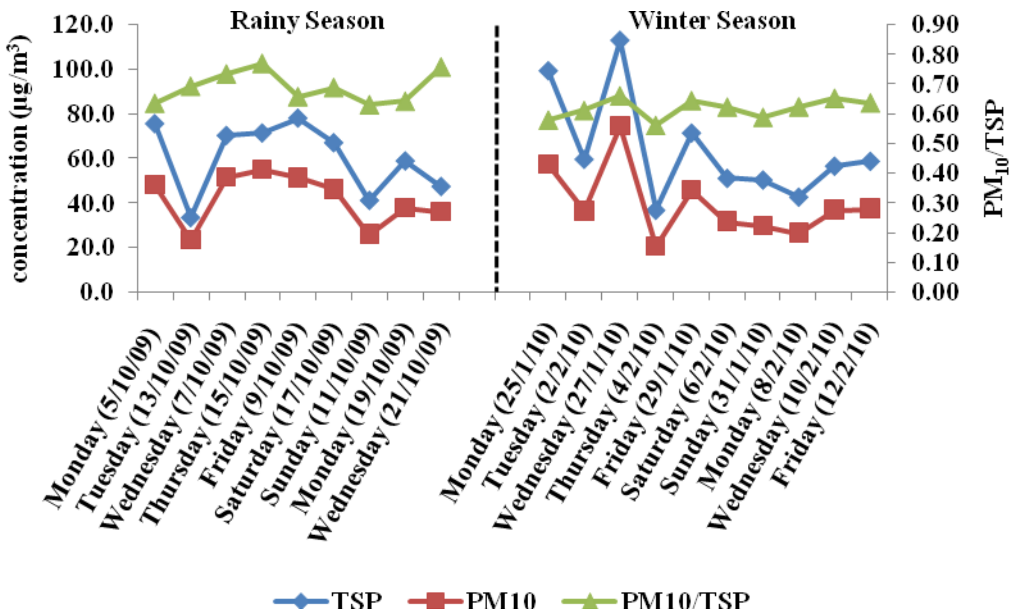


Figure 4.6 Concentrations of PM_{10} and TSP (24-hour average), and PM_{10}/TSP at Suan Luang Rama 9

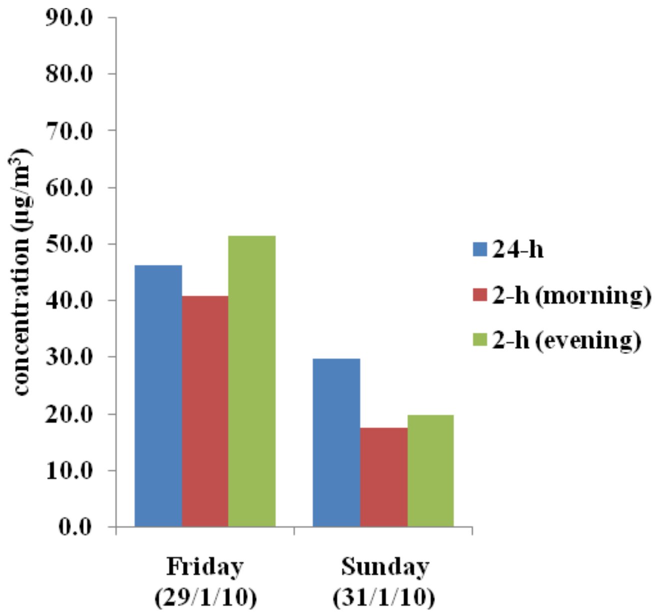


Figure 4.7 Comparisons of PM_{10} concentrations between 24-hour average and 2-hour average (morning and evening) at Suan Luang Rama 9

Table 4.5 and Figure 4.6 show that concentration levels of PM_{10} and TSP appear to be not much difference between rainy and winter seasons. The 24-hour average concentrations of PM_{10} and TSP in rainy season varied from 23.4 to 55.2 $\mu g/m^3$ and 33.7 to 78.2 $\mu g/m^3$, respectively, whereas the 24-hour average concentrations of PM_{10} and TSP in winter season varied from 20.8 to 74.9 $\mu g/m^3$ and 36.9 to 113.0 $\mu g/m^3$, respectively. The PM_{10}/TSP ratios in rainy and winter season varied from 0.63 to 0.77 and 0.56 to 0.66, respectively.

Figure 4.7 reveals that the 24-hour average PM_{10} concentrations are relatively higher than those in 2-hour average, except for the 2-hour average PM_{10} concentration on Friday (29/1/10) in the evening which is higher than the 24-hour average. The 24-hour average PM_{10} concentrations are different from the 2-hour average PM_{10} concentrations in a range of 11-41 %.

4.1.4 Benchasiri

The results of 24-hour average concentrations of PM_{10} and TSP, and its ratio at Benchasiri are shown in Table 4.6 and Figure 4.8. Moreover, the 24-hour and 2-hour average PM_{10} concentrations are compared and illustrated in Figure 4.9.

Table 4.6 Concentrations of PM_{10} and TSP (24-hour average), and PM_{10}/TSP ratios at Benchasiri

Season	Day	PM_{10} (μg/m^3)	TSP (μg/m^3)	PM_{10}/TSP
Rainy	Monday (5/10/09)	36.8	66.6	0.55
	Tuesday (13/10/09)	32.9	56.6	0.58
	Wednesday (21/10/09)	31.1	56.2	0.55
	Thursday (15/10/09)	49.0	83.6	0.59
	Friday (9/10/09)	44.2	74.8	0.59
	Saturday (17/10/09)	46.5	69.6	0.67
	Sunday (11/10/09)	22.2	42.0	0.53
	Monday (19/10/09)	24.3	46.4	0.52
	Range	22.2-49.0	42.0-83.6	0.52-0.67
Winter	Monday (25/1/10)	71.4	115.6	0.62
	Tuesday (2/2/10)	41.1	64.2	0.64
	Wednesday (27/1/10)	90.6	125.0	0.73
	Thursday (4/2/10)	27.3	47.6	0.57
	Friday (29/1/10)	55.8	76.6	0.73
	Sunday (31/1/10)	43.8	56.7	0.77
	Monday (8/2/10)	32.9	53.2	0.62
	Wednesday (10/2/10)	46.2	75.8	0.61
	Friday (12/2/10)	44.6	69.9	0.64
	Range	27.3-90.6	47.6-125.0	0.57-0.77
Ambient Air Quality Standard		120	330	

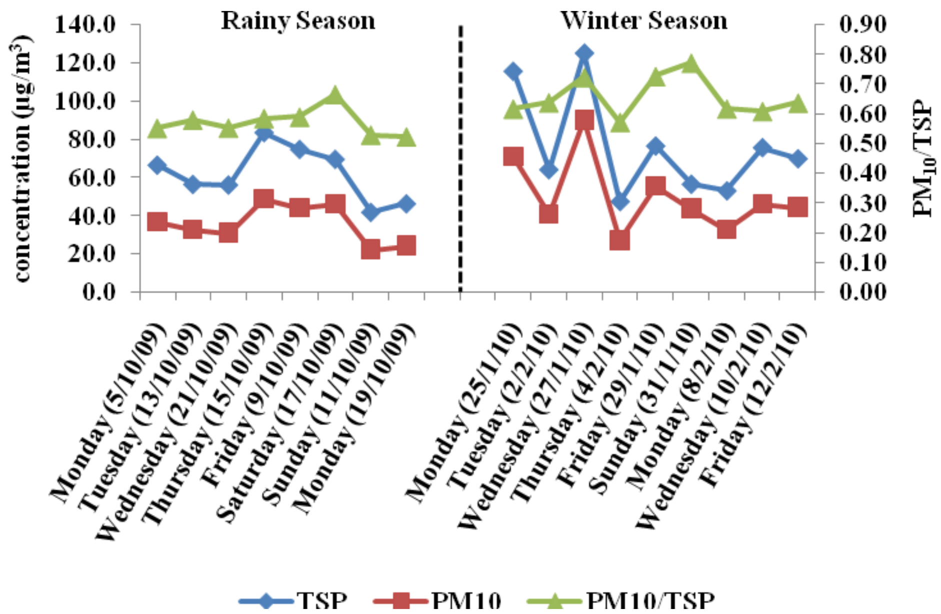


Figure 4.8 Concentrations of PM_{10} and TSP (24-hour average), and PM_{10}/TSP ratios at Benchasiri

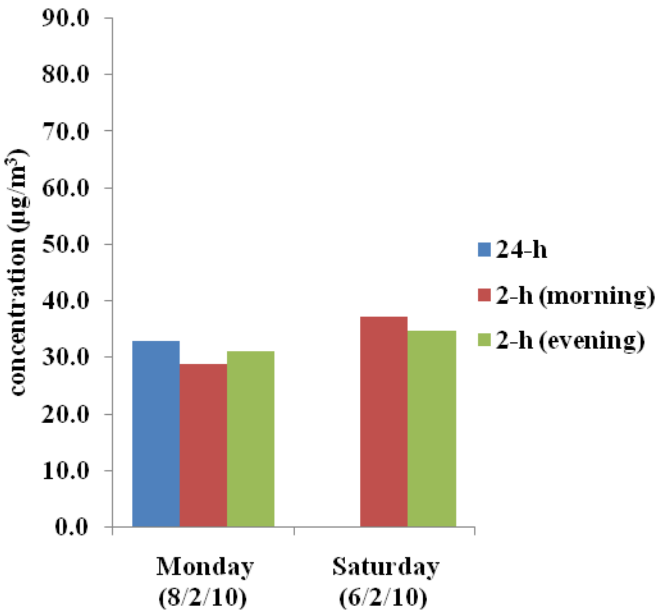


Figure 4.9 Comparisons of PM_{10} concentrations between 24-hour average and 2-hour average (morning and evening) at Benchasiri

Table 4.6 and Figure 4.8 show that concentration levels of PM_{10} and TSP in rainy season are slightly lower than those in winter season. The 24-hour average concentrations of PM_{10} and TSP in rainy season varied from 22.2 to 49.0 µg/m^3 and 42.0 to 83.6 µg/m^3, respectively, whereas the 24-hour average concentrations of PM_{10} and TSP in winter season varied from 27.3 to 90.6 µg/m^3 and 47.6 to 125.0 µg/m^3, respectively. The PM_{10}/TSP ratios are a little lower in rainy season than in winter season, i.e. it varied from 0.52 to 0.67 and 0.57 to 0.77, respectively.

Figure 4.9 reveals that at Benchasiri site, 24-hour average PM_{10} concentration on Saturday (6/2/10) was missing because of power failure. Thus, this day is unable to compare between 24-hour average and 2-hour average PM_{10} concentrations. The 24-hour average PM_{10} concentration on Monday (8/2/10) is higher than those of 2-hour average for both in the morning and in the evening. The 24-hour average PM_{10} concentration on Monday is different from the 2-hour average PM_{10} concentrations in a range of 5-12 %.

4.1.5 Saranrom

The results of 24-hour average concentrations of PM_{10} and TSP, and its ratio at Saranrom are shown in Table 4.7 and Figure 4.10. In addition, the 24-hour and 2-hour average PM_{10} concentrations are compared and illustrated in Figure 4.11.

Table 4.7 Concentrations of PM_{10} and TSP (24-hour average), and PM_{10}/TSP ratios at Saranrom

Season	Day	PM_{10} (μg/m^3)	TSP (μg/m^3)	PM_{10}/TSP
Rainy	Monday (5/10/09)	36.3	64.7	0.56
	Tuesday (13/10/09)	47.6	58.3	0.82
	Wednesday (7/10/09)	34.4	69.6	0.49
	Thursday (15/10/09)	60.0	73.7	0.81
	Friday (9/10/09)	39.2	71.9	0.54
	Sunday (11/10/09)	31.0	43.9	0.71
	Monday (19/10/09)	36.3	50.0	0.73
	Wednesday (21/10/09)	46.7	58.1	0.80
	Range	31.0-60.0	43.9-73.7	0.49-0.82
Winter	Monday (25/1/10)	81.4	97.7	0.83
	Tuesday (2/2/10)	41.8	66.4	0.63
	Wednesday (27/1/10)	110.2	139.9	0.79
	Friday (29/1/10)	58.1	80.9	0.72
	Saturday (6/2/10)	38.2	58.9	0.65
	Sunday (31/1/10)	39.7	61.0	0.65
	Monday (8/2/10)	37.0	56.4	0.66
	Wednesday (10/2/10)	40.7	60.1	0.68
	Friday (12/2/10)	40.8	63.2	0.65
	Range	37.0-110.2	56.4-139.9	0.63-0.83
Ambient Air Quality Standard		120	330	

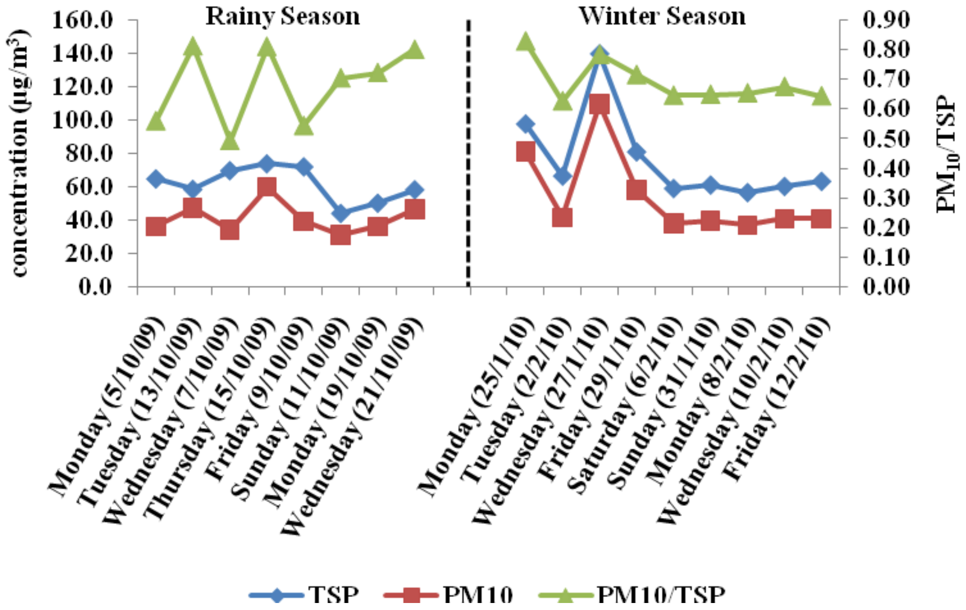


Figure 4.10 Concentrations of PM_{10} and TSP (24-hour average), and PM_{10}/TSP ratios at Saranrom

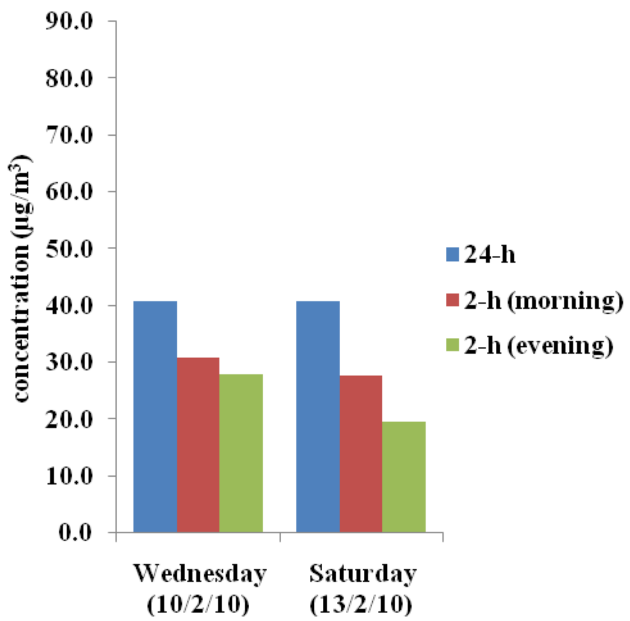


Figure 4.11 Comparisons of PM_{10} concentrations between 24-hour average and 2-hour average (morning and evening) at Saranrom

Table 4.7 and Figure 4.10 show that concentration levels of PM_{10} and TSP in rainy season are relatively lower than those in winter season. The 24-hour average concentrations of PM_{10} and TSP in rainy season varied from 31.0 to 60.0 µg/m^3 and 43.9 to 73.7 µg/m^3, respectively, whereas the 24-hour average concentrations of PM_{10} and TSP in winter season varied from 37.0 to 110.2 µg/m^3 and 56.4 to 139.9 µg/m^3, respectively. The PM_{10}/TSP ratios are varied more in rainy season than those in winter season, i.e. it varied from 0.49 to 0.82 and 0.63 to 0.83, respectively.

Figure 4.11 reveals that at Saranrom site, 24-hour average PM_{10} concentrations are higher than those in 2-hour average for both weekday and weekend. The 24-hour average PM_{10} concentrations are higher than those of 2-hour average in a range of 24-52 %.

The overall 24-hour average concentrations of TSP varied from 26.6 to 139.9 µg/m^3 (n=81). Whereas those of PM_{10} varied from 10.4 to 110.2 µg/m^3 (n=81). The PM_{10}/TSP ratios of all 24-hour average samples ranged from 0.36 to 0.83. The 2-hour average concentrations of PM_{10} varied from 17.6 to 79.0 µg/m^3 (n=18).

4.1.6 Comparison of TSP and PM_{10} concentrations with ambient air quality standards

The concentration levels of TSP and PM_{10} (24-hour average) obtained from this study were compared with the ambient air quality standards of 330 and 120 µg/m^3 for TSP and PM_{10}, respectively (Pollution Control Department, 2010). The results showed that all measured TSP and PM_{10} concentration levels from 5 sampling sites in 4 public parks did not exceed the TSP and PM_{10} (24-hour average) ambient air quality standards.

Although, sometimes there were air pollution problems in some areas of Bangkok due to PM_{10} concentration levels exceeded the ambient air quality standard (Air Quality and Noise Management Bureau, 2009). However, the results indicated that air quality of Public Parks in Bangkok area are still good and safe for those who come to visit or exercise. Anyway, the comparison among the 5 sampling sites of 4 public parks in term of air quality, it appeared that at sampling site Lumphini1, which located near heavy traffic road, had highest means of 24-hour average TSP and PM_{10} concentration levels. This is in agreement with the studied of Chan and Kwok (2001) which also found high concentration levels of particulate matter in the heavy traffic area during winter season.

Table 4.8 and Figure 4.12 show the means of 24-hour average TSP and PM_{10} concentrations in each sampling site. In addition, Table 4.8 also shows range of 24-hour average TSP and PM_{10} as well as ratios of mean ± SD (24-hour average) between winter and rainy seasons.

Table 4.8 Range, mean ± SD, and winter/rainy ratios of mean ± SD of 24-hour average TSP and PM_{10} concentrations on each sampling site

Sampling site	**PM**	**Winter**		**Rainy**		$\frac{(\mathrm{Mean}\pm\mathrm{SD})_{winter}}{(\mathrm{Mean}\pm\mathrm{SD})_{rainy}}$
		Range ($\mu g/m^3$)	**Mean ± SD ($\mu g/m^3$)**	**Range ($\mu g/m^3$)**	**Mean ± SD ($\mu g/m^3$)**	
Lumphini1	TSP	81.8-124.2	102.6±16.6	34.1-55.6	44.1±7.8	2.3±0.5
	PM_{10}	51.1-82.7	67.8±13.0	17.5-28.1	23.0±4.5	2.9±0.8
Lumphini2	TSP	75.2-118.9	97.6±17.1	26.6-42.9	35.2±6.4	2.8±0.7
	PM_{10}	42.0-71.2	57.4±11.4	10.4-20.5	14.8±4.2	3.9±1.3
Suan Luang Rama 9	TSP	36.9-113.0	64.0±24.4	33.7-78.2	60.5±16.1	1.1±0.5
	PM_{10}	20.8-74.9	39.9±16.0	23.4-55.2	41.9±11.6	0.9±0.5
Benchasiri	TSP	47.6-125.0	76.1±27.0	42.0-83.6	62.0±14.2	1.2±0.5
	PM_{10}	27.3-90.6	50.4±19.7	22.2-49.0	35.9±10.0	1.4±0.7
Saranrom	TSP	56.4-139.9	76.1±27.4	43.9-73.7	61.3±10.7	1.2±0.5
	PM_{10}	37.0-110.2	54.2±25.4	31.0-60.0	41.4±9.5	1.3±0.7

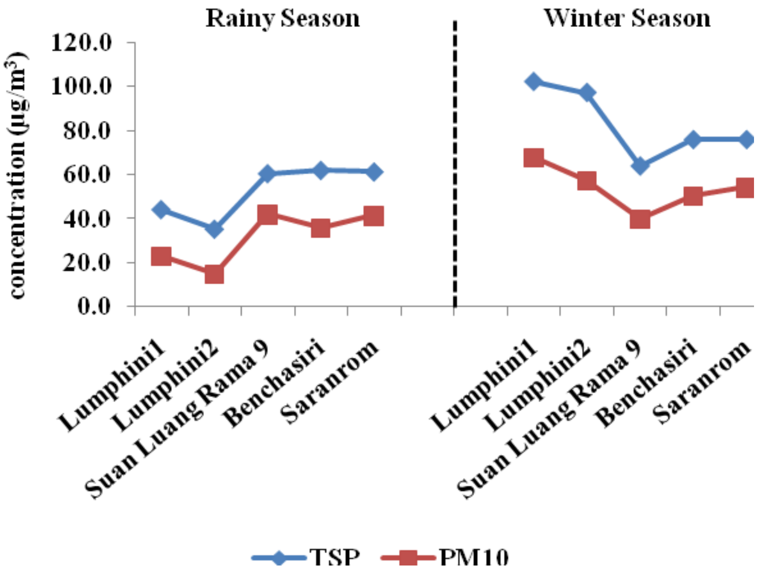


Figure 4.12 Means of 24-hour average TSP and PM_{10} concentrations on each sampling site

Table 4.8 and Figure 4.12 indicate that, in winter season, the means of 24-hour average TSP and PM_{10} concentrations at Lumphini1, Lumphini2, Suan Luang Rama 9, Benchasiri and Saranrom were 102.6, 97.6, 64.0, 76.1, 76.1 µg/m^3 and 67.8, 57.4, 39.9, 50.4, 54.2 µg/m^3, respectively. In rainy season, the means of 24-hour average TSP and PM_{10} concentrations at Lumphini1, Lumphini2, Suan Luang Rama 9, Benchasiri and Saranrom were 44.1, 35.2, 60.5, 62.0, 61.3 µg/m^3 and 23.0, 14.8, 41.9, 35.9, 41.4 µg/m^3, respectively.

Table 4.8 indicates that almost all of the overall mean of 24-hour average TSP and PM_{10} concentrations in winter season are higher than those in rainy season, except the PM_{10} concentrations at Suan Luang Rama 9 which shows higher PM_{10} concentrations in winter than those in rainy season. In addition, these ratios can be divided in 3 groups as follows:

1) Winter/rainy ratios that ranging from 2.3 – 3.9. This group has large difference of TSP and PM_{10} concentrations between winter and rainy seasons. It indicates that means of 24-hour average TSP and PM_{10} concentrations at Lumphini1 and Lumphini2 in winter are certainly higher than those in rainy season.

2) Winter/rainy ratios that ranging from 1.1 – 1.4. This group has slightly difference of TSP and PM_{10} concentrations between winter and rainy seasons. It

indicates that means of 24-hour average TSP and PM_{10} concentrations at Benchasiri, Saranrom and Suan Luang Rama 9 (TSP only) in winter are slightly higher than those in rainy season.

3) Winter/rainy ratio that less than 1. Only the winter/rainy ratio of PM_{10} at Suan Luang Rama 9 belongs to this group. This group has slightly difference of PM_{10} concentration between winter and rainy season. It indicates that mean of 24-hour average PM_{10} concentration at Suan Luang Rama 9 in winter are slightly lower than those in rainy season.

Table 4.9 and Figure 4.13 show the range and mean ± SD of 24-hour average PM_{10}/TSP ratio on each site. It reveals that in rainy season, the means of 24-hour average concentrations of PM_{10}/TSP ratios at Lumphini1, Lumphini2, Suan Luang Rama 9, Benchasiri and Saranrom were 0.52, 0.42, 0.69, 0.57 and 0.68, respectively. In winter season, the means of 24-hour average concentrations of PM_{10}/TSP ratios were 0.66, 0.59, 0.62, 0.66 and 0.69, respectively. Due to PM_{10}/TSP ratio indicates the proportion of particulate matter in two size range, the result shows means of 24-hour average concentrations of PM_{10}/TSP ratios at all sampling site in both seasons were higher than 0.5, indicating that proportion of PM_{10} was quite high, except at Lumphini2 which shows the ratio in rainy season was lower than 0.5.

Table 4.9 Range and mean ± SD of 24-hour average concentrations of PM_{10}/TSP ratio on each sampling site

Sampling site	Rainy		Winter	
	Range	Mean ± SD	Range	Mean ± SD
Lumphini1	0.48-0.56	0.52±0.03	0.62-0.70	0.66±0.03
Lumphini2	0.36-0.48	0.42±0.05	0.52-0.64	0.59±0.04
Suan Luang Rama 9	0.63-0.77	0.69±0.05	0.56-0.66	0.62±0.03
Benchasiri	0.52-0.67	0.57±0.05	0.57-0.77	0.66±0.07
Saranrom	0.49-0.82	0.68±0.13	0.63-0.83	0.69±0.07

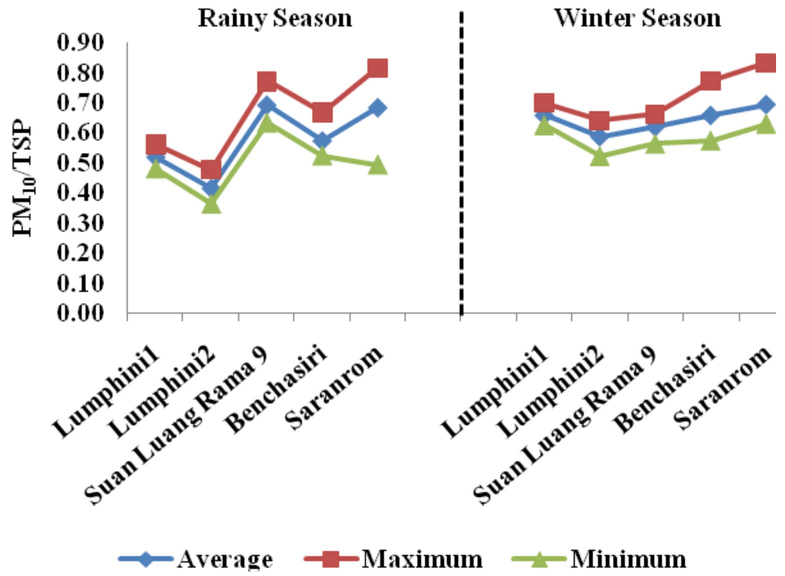


Figure 4.13 Means of 24-hour average PM_{10}/TSP ratio on each sampling site

The results from this study suggest that levels of particulate matter in Public Parks are relatively low. In Table 4.10, it shows the results obtained from this study and the data from air quality monitoring stations of the PCD in 2009 (Air Quality and Noise Management Bureau, 2010: online). It indicates that the maximum concentrations of both TSP and PM_{10} concentrations in Public Parks are lower than the maximum concentrations obtained from the PCD's roadside and ambient stations.

Table 4.10 Range of 24-hour average TSP and PM_{10} concentrations of this study and the PCD's monitoring stations

	TSP		**PM_{10}**	
	Range (μg/m^3)	**n[a] / N[b]**	**Range (μg/m^3)**	**n / N**
This study	26.6-139.9	0 / 81	10.4-110.2	0 / 81
Roadside station[c]	20-350	1 / 379	15.5-183.0	109 / 2043
Ambient station[d]	20-320	0 / 533	5.9-193.4	31 / 3171

Note : [a] Number of samples (exceed the ambient air quality standards)

[b] Total number of samples

[c] Data of TSP and PM_{10} (24-hour average concentrations) in 2009 from 7 roadside air quality monitoring stations of the PCD

[d] Data of TSP and PM_{10} (24-hour average concentrations) in 2009 from 10 ambient air quality monitoring stations of the PCD

Furthermore, results of the 24-hour average PM_{10} concentrations from Lumphini1 site are compared with those from Chulalongkorn Hospital station which is the PCD's roadside air quality monitoring station (Air Quality and Noise Management Bureau, 2010: online) as shown in Table 4.11. The Chulalongkorn Hospital station is located approximately 240 m from the Lumphini1 site. It indicates that PM_{10} concentrations from Lumphini1 site are relatively lower than those obtained from the Chulalongkorn Hospital station.

Table 4.11 Comparison of 24-hour average PM_{10} concentrations between Lumphini1 site and Chulalongkorn Hospital air quality monitoring station

	September 2009		**January 2010**	
	Range (μg/m^3)	**Number of samples**	**Range (μg/m^3)**	**Number of samples**
Lumphini1	17.5-28.1	7	51.1-82.7	7
Chulalongkorn Hospital	36.7-77.1	26	56.5-137.5	31

4.2 Relationship between TSP and PM_{10} in each sampling site

4.2.1 Relationship between TSP and PM_{10}

Relationships between TSP and PM_{10} at each sampling site in both rainy and winter seasons were analyzed by using linear regression (Table 4.12), which is determined at $\alpha = 0.05$ (when Y = TSP as the dependent variable and X = PM_{10} as the independent variable). The results revealed that the TSP and PM_{10} are all significant correlated at $\alpha = 0.05$ and the coefficient of determination (r^2) were relatively high, ranging from 0.897 to 0.985. Similarly, Chan and Kwok (2001) showed a good correlation between TSP and PM_{10} in Hong Kong, i.e. value of r^2 between TSP and PM_{10} in winter, summer and whole year were 0.64, 0.79 and 0.71, respectively. However, Saranrom site in rainy season (n = 8) displayed r^2 quite lower than other sites (r^2 = 0.225), indicates that the relationship between TSP and PM_{10} has a weak correlation. The reason for a weak correlation between TSP and PM_{10} at Saranrom site was probably due to the high TSP concentrations and low PM_{10}/TSP ratios obtained on the first three days (5, 7 and 9 October 2009) of air sampling. Therefore, if the results obtained from those three days were excluded from the analysis, then the relationship between TSP and PM_{10} at Saranrom site will be comparable with the other 4 sampling sites with the r^2 equal to 0.985.

Table 4.12 Results of linear regression analysis of relationship between TSP and PM_{10} in 5 sampling sites

Site	Season	Equation	r^2	n	F	t	Sig.
Lumphini1	Rainy	Y = 6.011 + 1.661X	0.919	7	56.983	7.549	0.001
	Winter	Y = 17.169 + 1.259X	0.969	7	154.827	12.443	0.000
Lumphini2	Rainy	Y = 12.933 + 1.496X	0.964	7	135.654	11.647	0.000
	Winter	Y = 15.856 + 1.422X	0.897	7	43.546	6.599	0.001
Suan Luang Rama 9	Rainy	Y = 4.875 + 1.328X	0.916	9	76.329	8.737	0.000
	Winter	Y = 3.936 + 1.505X	0.979	10	373.199	19.318	0.000
Benchasiri	Rainy	Y = 12.674 + 1.374X	0.945	8	102.202	10.109	0.000
	Winter	Y = 9.017 + 1.330X	0.941	9	110.669	10.520	0.000
Saranrom	Rainy	Y = 39.123 + 0.535X	0.225	8	1.740	1.319	0.235
	Rainy	Y = 12.890 + 0.991X	0.985*	5	199.365	14.120	0.001
	Winter	Y = 18.148 + 1.068X	0.985	9	454.733	21.324	0.000

Note: * High correlation when analyzed by using only five days data (11, 13, 15, 19 and 21 October 2009)

4.2.2 Relationship between weekday and weekend of TSP and PM_{10} concentrations

The results of this study show that means of 24-hour average TSP and PM_{10} concentrations on weekday are relatively higher than weekend in both rainy and winter seasons as shown in Figures 4.14 and 4.15. Likewise, the studies from DeGaetano and Doherty (2004) and Chan et al. (2001), show that weekly variation of particulate matter on weekday is higher than weekend. These results indicate that weekday with a heavy traffic is influenced on particulate matter concentration. While a light traffic on weekend is coinciding with a low level of particulate matter (Pey et al., 2008).

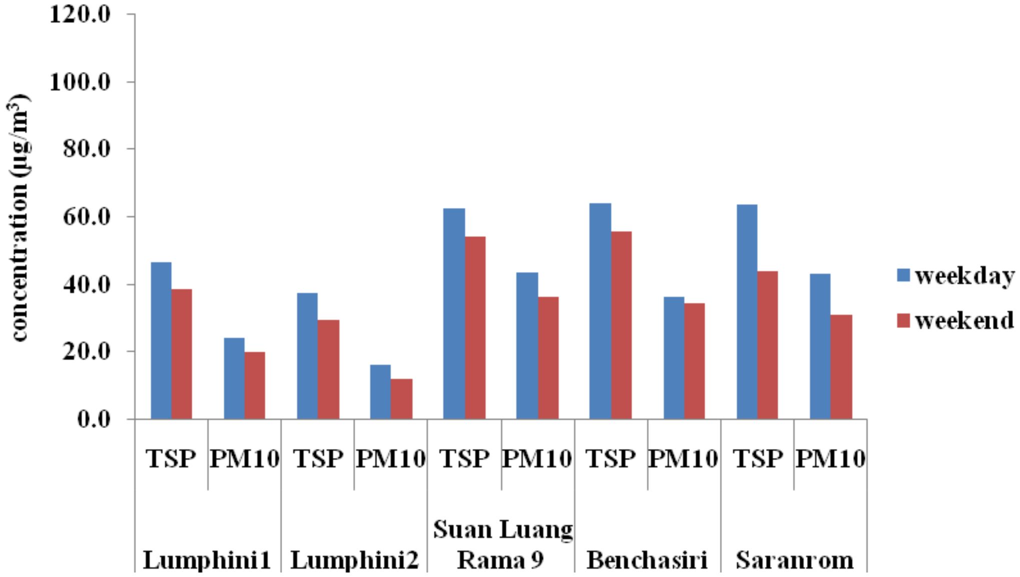


Figure 4.14 Means of 24-hour average TSP and PM_{10} concentrations between weekday and weekend in rainy season

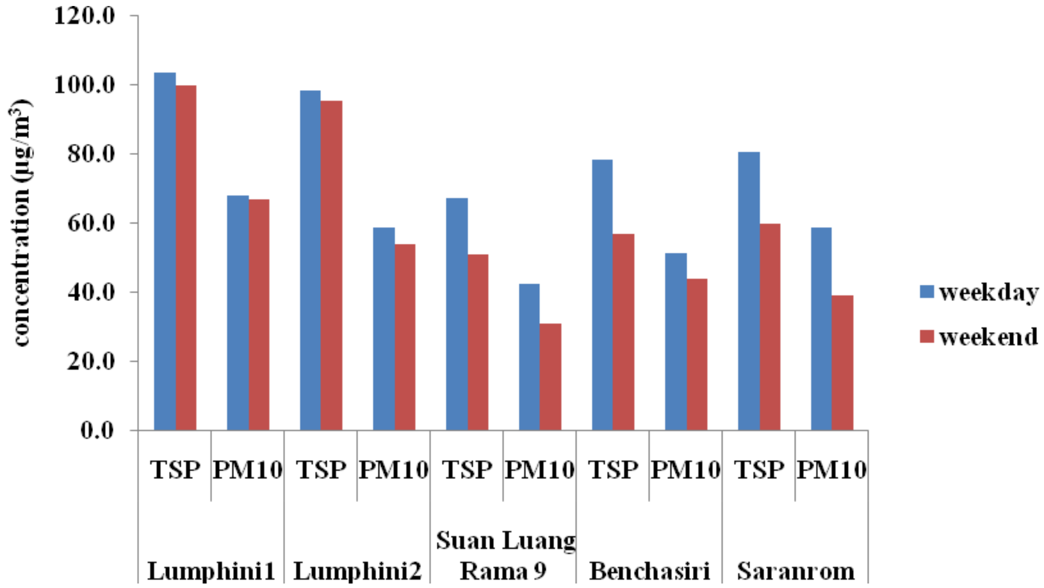


Figure 4.15 Means of 24-hour average TSP and PM_{10} concentrations between weekday and weekend in winter season

According to Figures 4.14 and 4.15, the weekday means of 24-hour average TSP and PM_{10} concentrations at all monitoring sites in both rainy and winter seasons are higher than weekend. However, in winter season at Lumphini1 and Lumphini2, means of 24-hour average TSP and PM_{10} concentrations are not much different between weekday and weekend. Moreover, the results of independent samples test (Table 4.13), which is determined at $\alpha = 0.05$ show the probability Sig. (2-tailed) is higher than the determined statistical significant. It means that the TSP and PM_{10} concentrations are not statistically significant difference between weekday and weekend.

Table 4.13 Results of independent samples test of TSP and PM_{10} concentrations between weekday and weekend

Season	Site	PM	Day	Mean	n	SD	t	Sig. (2-tailed)
Rainy	Lumphini1	TSP	Weekday	46.4	5	7.69	1.311	0.247
			Weekend	38.3	2	6.01		
		PM_{10}	Weekday	24.2	5	4.78	1.216	0.278
			Weekend	19.8	2	1.70		
	Lumphini2	TSP	Weekday	37.4	5	5.89	1.693	0.151
			Weekend	29.5	2	4.10		
		PM_{10}	Weekday	16.0	5	4.39	1.196	0.285
			Weekend	11.9	2	2.19		
	Suan Luang Rama 9	TSP	Weekday	62.3	7	16.47	0.596	0.570
			Weekend	54.3	2	18.24		
		PM_{10}	Weekday	43.5	7	11.44	0.755	0.475
			Weekend	36.3	2	14.28		
	Benchasiri	TSP	Weekday	64.0	6	13.66	0.681	0.521
			Weekend	55.8	2	19.52		
		PM_{10}	Weekday	36.4	6	9.02	0.230	0.826
			Weekend	34.4	2	17.18		
	Saranrom	TSP	Weekday	63.8	7	8.67	2.142	0.076
			Weekend	43.9	1	-		
		PM_{10}	Weekday	42.9	7	9.15	1.220	0.268
			Weekend	31.0	1	-		

Table 4.13 Results of independent samples test of TSP and PM_{10} concentrations between weekday and weekend (cont.)

Season	Site	PM	Day	Mean	n	SD	t	Sig. (2-tailed)
Winter	Lumphini1	TSP	Weekday	103.5	5	15.59	0.234	0.824
			Weekend	100.0	2	25.74		
		PM_{10}	Weekday	68.2	5	11.28	0.106	0.920
			Weekend	66.9	2	22.34		
	Lumphini2	TSP	Weekday	98.3	5	15.09	0.171	0.871
			Weekend	95.6	2	28.92		
		PM_{10}	Weekday	58.8	5	11.56	0.479	0.652
			Weekend	54.0	2	14.49		
	Suan Luang Rama 9	TSP	Weekday	67.3	8	26.47	0.845	0.423
			Weekend	50.8	2	0.56		
		PM_{10}	Weekday	42.2	8	17.33	0.880	0.404
			Weekend	30.9	2	1.55		
	Benchasiri	TSP	Weekday	78.5	8	27.83	0.738	0.485
			Weekend	56.7	1	-		
		PM_{10}	Weekday	51.2	8	20.90	0.335	0.747
			Weekend	43.8	1	-		
	Saranrom	TSP	Weekday	80.7	7	29.77	0.937	0.380
			Weekend	59.9	2	1.48		
		PM_{10}	Weekday	58.6	7	27.59	0.958	0.370
			Weekend	38.9	2	1.06		

4.3 Influence of seasonal variation on TSP and PM_{10}

4.3.1 Relationship of particulate matter between rainy and winter season

Figures 4.16 and 4.17 indicate that almost all means of 24-hour average TSP and PM_{10} concentrations at all monitoring sites in rainy season are lower than those in winter season, except means of 24-hour average PM_{10} concentration at Suan Luang Rama 9 in winter season was slightly lower than in rainy season (Figure 4.17). The results from this study are in agreement with the 24-hour average TSP and PM_{10}

concentrations in Kolkata, India which were highest during winter and lowest during monsoon (Karar et al., 2006).

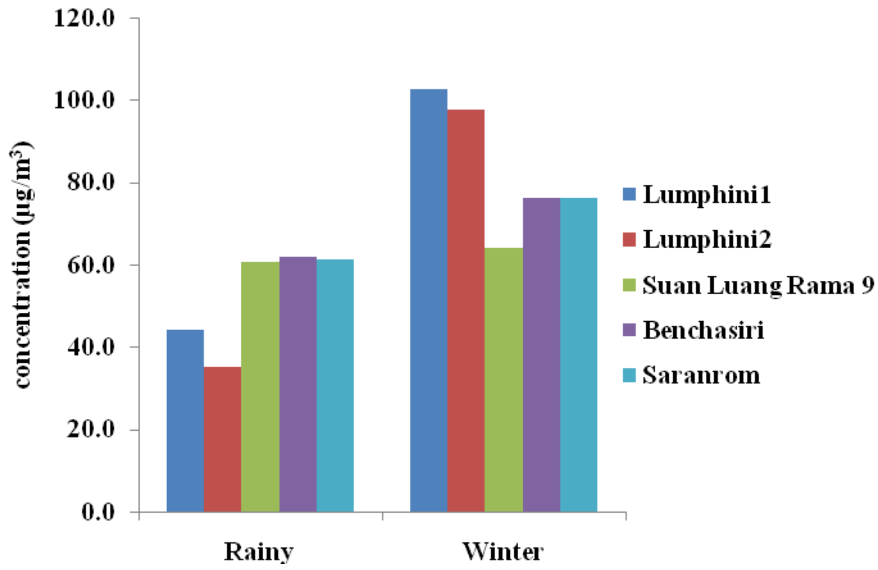


Figure 4.16 Means of 24-hour average TSP concentrations between rainy and winter seasons in each Public Park

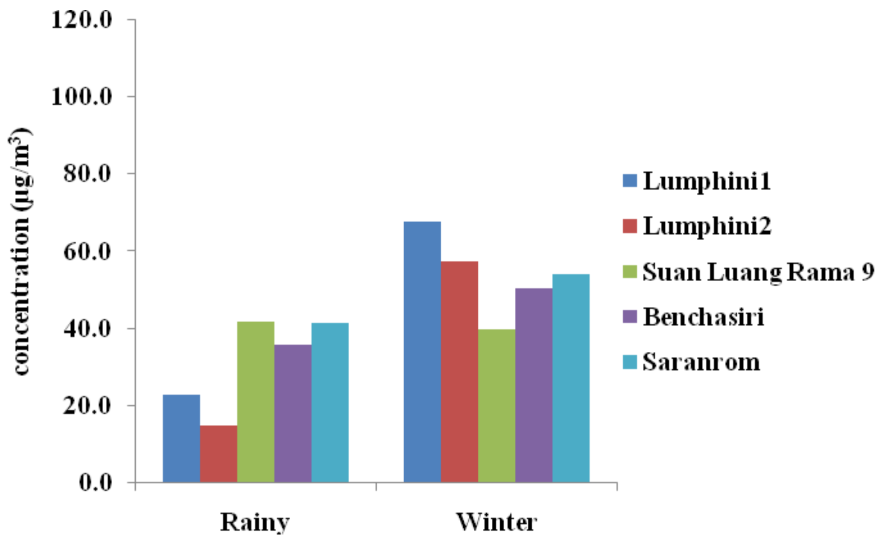


Figure 4.17 Means of 24-hour average PM_{10} concentrations between rainy and winter seasons in each Public Park

The results of independent samples test of TSP and PM_{10} concentrations between rainy and winter seasons are shown in Table 4.14

Table 4.14 Results of independent samples test of TSP and PM_{10} concentrations between rainy and winter seasons

PM	Site	Season	Mean	n	SD	t	Sig.(2-tailed)
TSP	Lumphini1	Rainy	44.1	7	7.82	-8.419	0.000
		Winter	102.6	7	16.60		
	Lumphini2	Rainy	35.2	7	6.38	-9.040	0.000
		Winter	97.6	7	17.11		
	Suan Luang Rama 9	Rainy	60.5	9	16.05	-0.366	0.719
		Winter	64.0	10	24.37		
	Benchasiri	Rainy	62.0	8	14.22	-1.318	0.207
		Winter	76.1	9	27.03		
	Saranrom	Rainy	61.3	8	10.67	-1.430	0.173
		Winter	76.1	9	27.36		
PM_{10}	Lumphini1	Rainy	23.0	7	4.51	-8.636	0.000
		Winter	67.8	7	12.97		
	Lumphini2	Rainy	14.8	7	4.19	-9.282	0.000
		Winter	57.4	7	11.40		
	Suan Luang Rama 9	Rainy	41.9	9	11.56	0.304	0.765
		Winter	39.9	10	16.02		
	Benchasiri	Rainy	35.9	8	10.06	-1.876	0.080
		Winter	50.4	9	19.71		
	Saranrom	Rainy	41.4	8	9.46	-1.337	0.201
		Winter	54.2	9	25.42		

The TSP and PM_{10} concentrations at Lumphini1 and Lumphini2 show the p-value lower than the determined statistical significance at $\alpha = 0.05$, it means that the TSP and PM_{10} concentrations at Lumphini1 and Lumphini2 are statistically significant difference between rainy and winter seasons. Whereas TSP and PM_{10} concentrations at Suan Luang Rama 9, Benchasiri and Saranrom show the p-value higher than the determined statistical significance at $\alpha = 0.05$, it means that TSP and PM_{10} concentrations at Suan Luang Rama 9, Benchasiri and Saranrom are not statistically significant difference between rainy and winter seasons.

4.3.2 Relationship between concentration levels of particulate matter and meteorological factors

Table 4.15 shows the relationship of particulate matter (TSP and PM_{10}) and meteorological factors at each site, which is determined at the statistic significant level of 0.05. It can be summarized as follows:

- At Lumphini1 in rainy season, levels of TSP and PM_{10} are influenced by wind speed with $r^2 = 0.579$ and 0.651, respectively.

- At Lumphini2 in rainy season, levels of TSP are influenced by wind speed with $r^2 = 0.625$.

- At Suan Luang Rama 9 in winter season, levels of TSP and PM_{10} are influenced by wind direction with $r^2 = 0.815$ and 0.742, respectively.

- At Benchasiri in winter season, levels of TSP are influenced by wind direction, rain and wind speed with $r^2 = 0.985$. While level of PM_{10} are influenced by wind direction and rain with $r^2 = 0.919$.

- At Saranrom in winter season, levels of TSP and PM_{10} are influenced by wind direction with $r^2 = 0.763$ and 0.813, respectively.

Table 4.15 Results of stepwise multiple regression analysis of particulate matter and meteorological factors

Site	PM	Season	Stepwise multiple regression analysis	r^2	n
Lumphini1	TSP	Rainy	TSP = 59.358 – 6.784WS	0.579	7
		Winter	-	-	-
	PM_{10}	Rainy	PM_{10} = 32.273 – 4.153WS	0.651	7
		Winter	-	-	-
Lumphini2	TSP	Rainy	TSP = 48.046 – 5.753WS	0.625	7
		Winter	-	-	-
	PM_{10}	Rainy	-	-	-
		Winter	-	-	-
Suan Luang Rama 9	TSP	Rainy	-	-	-
		Winter	TSP = 132.083 – 0.445WD	0.815	10
	PM_{10}	Rainy	-	-	-
		Winter	PM_{10} = 82.618 – 0.279WD	0.742	10

Table 4.15 Results of stepwise multiple regression analysis of particulate matter and meteorological factors (cont.)

Site	PM	Season	Stepwise multiple regression analysis	r^2	n
Benchasiri	TSP	Rainy	-	-	-
		Winter	TSP = 150.110 – 0.659WD + 2.979Rain + 13.741WS	0.985	9
	PM_{10}	Rainy	-	-	-
		Winter	PM_{10} = 108.850 – 0.391WD + 1.518Rain	0.919	9
Saranrom	TSP	Rainy	-	-	-
		Winter	TSP = 144.979 – 0.405WD	0.763	9
	PM_{10}	Rainy	-	-	-
		Winter	PM_{10} = 120.297 – 0.389WD	0.813	9

In accordance with the relationship analysis of particulate matter and meteorological factors, it shows a partial relationship. This might be due to sampling sites and meteorological stations are not located in the same area. Other studies showed that levels of particulate matter can be affected by meteorological factors e.g. Karar et al. (2006) indicated that TSP and PM_{10} were negatively correlated with wind speed, temperature and relative humidity in Kolkata, India whereas Shah and Shaheen (2008) indicated that suspended particulates were positively correlated with temperature and wind speed but negatively correlated with relative humidity in Islamabad, Pakistan.

4.4 Interlaboratory comparison between the PM_{10} high volume air sampler used by this study and that used by the PCD

Two PM_{10} high-volume air samplers (one from this study and another one from PCD) were compared at the temporary air quality monitoring station of PCD (Land Development Department site) during 2 to 10 December 2009. A total of seven samples each were collected and determined for 24-hour average PM_{10} concentrations as shown in Table 4.16.

Table 4.16 Comparison of 24-hour average PM_{10} concentrations between the instrument used by this study and that used by the PCD

Date	PM_{10} ($\mu g/m^3$), 24-hour average	
	This study	**PCD**
2/12/09	93.3	95.8
4/12/09	104.1	104.9
5/12/09	85.3	89.8
7/12/09	131.4	129.1
8/12/09	143.2	135.3
9/12/09	140.4	133.2
10/12/09	124.0	122.2

To test the hypothesis of no difference between results obtained from the high volume air sampler used by this study and that used by the PCD. A paired t-test was used for the statistical analysis as follows:

Hypothesis: $H_o : \mu_1 = \mu_2$

$H_1 : \mu_1 \neq \mu_2$

Whereas μ_1 = mean of 24-hour average concentration of PM_{10} from the instrument used by this study

μ_2 = mean of 24-hour average concentration of PM_{10} from the instrument used by the PCD

The result of a paired t-test (Table 4.17), which is determined at $\alpha = 0.05$ show the probability Sig. (2-tailed) of 0.393 that is larger than the determined statistical significant, therefore it accepted the H_o. It means that 24-hour average concentrations of PM_{10} obtained from this study are not significantly difference from those obtained from the PCD. This result showed the compatibility of data between this study and PCD and indicated that the data of TSP and PM_{10} from the 5 sampling sites are compatible with those from the PCD.

Table 4.17 Result of a paired t-test of 24-hour average PM_{10} concentrations between this study and the PCD

	Mean	**n**	**SD**	**Correlation**	**t**	**Sig.(2-tailed)**
This study	117.38	7	23.17437	0.998	0.921	0.393
PCD	115.76	7	18.68893			

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1) The ambient 24-hour average TSP and PM_{10} concentrations in both rainy and winter seasons at all 5 sampling sites in 4 public parks did not exceed the ambient air quality standards. Therefore, it appears that the ambient air quality in those 4 public parks are good and safe for people to come to visit or exercise.

2) The ambient 24-hour average TSP and PM_{10} concentrations obtained from this study are as follows:

2.1) Concentration levels of TSP at Lumphini1, Lumphini2, Suan Luang Rama 9, Benchasiri and Saranrom in rainy season varied from 34.1-55.6, 26.6-42.9, 33.7-78.2, 42.0-83.6 and 43.9-73.7 $\mu g/m^3$, respectively and in winter season varied from 81.8-124.2, 75.2-118.9, 36.9-113.0, 47.6-125.0 and 56.4-139.9 $\mu g/m^3$, respectively.

2.2) Concentration levels of PM_{10} at Lumphini1, Lumphini2, Suan Luang Rama 9, Benchasiri and Saranrom in rainy season varied from 17.5-28.1, 10.4-20.5, 23.4-55.2, 22.2-49.0 and 31.0-60.0 $\mu g/m^3$, respectively and in winter season varied from 51.1-82.7, 42.0-71.2, 20.8-74.9, 27.3-90.6 and 37.0-110.2 $\mu g/m^3$, respectively.

3) It was observed that most of the 2-hour average PM_{10} concentrations (morning and evening) were lower than the 24-hour average PM_{10} concentrations measured on the same day.

4) It was found that most of the relationships between TSP and PM_{10} measured at the same sampling site were quite high with r^2 ranging from 0.897 to 0.985. Furthermore, the ambient 24-hour average TSP and PM_{10} concentrations at 4 sampling sites were statistically significant correlation for both rainy and winter seasons at $p<0.05$, except at Saranrom sampling site which showed no statistically

significant correlation in rainy season. Moreover, the means of 24-hour average for both TSP and PM_{10} concentrations on weekday appeared to be higher than those on weekend. However, the statistical analysis showed that both TSP and PM_{10} concentrations on the weekday were not statistically significant difference from those on the weekend.

5) The statistical analysis showed that TSP and PM_{10} concentrations between rainy and winter seasons at both Lumphini1 and Lumphini2 were statistically significant difference, while TSP and PM_{10} concentrations between rainy and winter seasons at Suan Luang Rama 9, Benchasiri and Saranrom were not statistically significant difference.

6) Meteorological factors, i.e. wind speed, wind direction and rain were found to influence on TSP and PM_{10} concentrations at certain sampling sites in this study.

7) From interlaboratory comparison of results obtained from the PM_{10} high volume air sampler used in this study and that used in PCD's monitoring station which sampling on the same day at the same sampling location, it was found that the 24-hour average PM_{10} concentrations obtained from the instrument used in this study did not statistically significant difference from those obtained from the PCD's instrument.

5.2 Recommendations

1) It is recommended that further measurement of particulate matter (TSP, PM_{10} and $PM_{2.5}$) at aerobic exercise sites in smaller Public Parks especially those locate near crossroad or roadside such as Prachanukul Intersection Park should be studied.

2) Measurement of particulate matter (TSP, PM_{10} and $PM_{2.5}$) at aerobic exercise sites locate near car park such as those in the supermarket's car park areas should be investigated.

3) Monitoring of TSP, PM_{10} and $PM_{2.5}$ in the study areas should be continued in order to obtain baseline data and the long-term trend of these pollutants in Public Parks.

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APPENDICES

APPENDIX A

SAMPLING SITES

Figure A-1 Suan Luang Rama 9 site

Figure A-2 Lumphini1 site

Figure A-3 Lumphini2 site

Figure A-4 Benchasiri site

Figure A-5 Saranrom site

Figure A-6 Land Development Department site

APPENDIX B

MEASUREMENT DATA

Table B-1 Data of TSP and PM_{10} measurement (24-hour) at Lumphini1 in rainy season

Date	Time	PM	Filter No.	Filter weight (g)		Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight with Blank (g)	Concentration ($\mu g/m^3$)
				Initial weight (g)	Final weight (g)				
14/9/2009 (Monday)	12.30 – 12.30	TSP	013	2.7370	2.8248	1.139	1574.85	0.0875	55.6
		PM_{10}	014	2.7354	2.7775	1.075	1486.14	0.0418	28.1
16/9/2009 (Wednesday)	11.00 – 11.00	TSP	018	2.7198	2.7985	1.139	1603.79	0.0784	48.9
		PM_{10}	019	2.7372	2.7817	1.143	1609.97	0.0442	27.5
18/9/2009 (Friday)	06.00 – 06.00	TSP	022	2.7228	2.7869	1.098	1565.20	0.0638	40.8
		PM_{10}	023	2.7102	2.7412	1.034	1473.43	0.0307	20.8
20/9/2009 (Sunday)	06.00 – 06.00	TSP	029	2.7480	2.8028	1.112	1596.79	0.0545	34.1
		PM_{10}	030	2.7646	2.7943	1.102	1583.19	0.0294	18.6
22/9/2009 (Tuesday)	12.00 – 12.00	TSP	035	2.7519	2.8303	1.112	1546.73	0.0781	50.5
		PM_{10}	036	2.7551	2.7976	1.116	1552.63	0.0422	27.2
24/9/2009 (Thursday)	10.00 – 10.00	TSP	039	2.7539	2.8112	1.112	1562.33	0.0570	36.5
		PM_{10}	040	2.7494	2.7772	1.116	1568.28	0.0275	17.5
26/9/2009 (Saturday)	07.00 – 07.00	TSP	043	2.7306	2.7975	1.098	1565.26	0.0666	42.6
		PM_{10}	044	2.7197	2.7551	1.171	1668.89	0.0351	21.0

Table B-2 Data of TSP and PM_{10} measurement (24-hour) at Lumphini2 in rainy season

Date	Time	PM	Filter No.	Filter weight (g)		Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight with Blank (g)	Concentration (μg/m^3)
				Initial weight (g)	Final weight (g)				
14/9/2009 (Monday)	12.30 – 12.30	TSP	015	2.7377	2.8046	1.119	1554.02	0.0666	42.9
		PM_{10}	016	2.7379	2.7730	1.223	1699.51	0.0348	20.5
16/9/2009 (Wednesday)	11.00 – 11.00	TSP	020	2.7192	2.7852	1.119	1571.30	0.0657	41.8
		PM_{10}	021	2.7163	2.7437	1.019	1431.64	0.0271	18.9
18/9/2009 (Friday)	06.00 – 06.00	TSP	024	2.7286	2.7802	1.119	1594.25	0.0513	32.2
		PM_{10}	025	2.7183	2.7390	1.223	1743.50	0.0204	11.7
20/9/2009 (Sunday)	06.00 – 06.00	TSP	031	2.7506	2.7937	1.119	1606.49	0.0428	26.6
		PM_{10}	032	2.7504	2.7687	1.211	1738.56	0.0180	10.4
22/9/2009 (Tuesday)	12.00 – 12.00	TSP	037	2.7293	2.7920	1.119	1556.13	0.0624	40.1
		PM_{10}	038	2.7750	2.8008	1.019	1417.82	0.0255	18.0
24/9/2009 (Thursday)	10.00 – 10.00	TSP	041	2.7450	2.7925	1.119	1571.81	0.0472	30.0
		PM_{10}	042	2.7388	2.7565	1.134	1593.46	0.0174	10.9
26/9/2009 (Saturday)	07.00 – 07.00	TSP	045	2.7352	2.7872	1.119	1594.32	0.0517	32.4
		PM_{10}	046	2.7495	2.7713	1.121	1598.09	0.0215	13.5

Table B-3 Data of TSP and PM_{10} measurement (24-hour) at Suan Luang Rama 9 in rainy season

Date	Time	PM	Filter No.	Filter weight (g) Initial weight (g)	Filter weight (g) Final weight (g)	Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight with Blank (g)	Concentration (μg/m^3)
5/10/2009 (Monday)	12.00 – 12.00	TSP	051	2.7621	2.8809	1.123	1565.66	0.1185	75.7
		PM_{10}	052	2.7651	2.8434	1.159	1616.30	0.0780	48.3
7/10/2009 (Wednesday)	08.00 – 08.00	TSP	057	2.7689	2.8819	1.123	1600.98	0.1127	70.4
		PM_{10}	058	2.7465	2.8325	1.159	1652.78	0.0857	51.9
9/10/2009 (Friday)	08.00 – 08.00	TSP	063	2.7425	2.8710	1.155	1639.51	0.1282	78.2
		PM_{10}	064	2.7447	2.8299	1.159	1645.17	0.0849	51.6
11/10/2009 (Sunday)	08.30 – 08.30	TSP	070	2.7372	2.8060	1.155	1656.39	0.0685	41.4
		PM_{10}	071	2.7378	2.7816	1.159	1662.11	0.0435	26.2
13/10/2009 (Tuesday)	13.15 – 13.15	TSP	076	2.7890	2.8443	1.139	1634.29	0.0550	33.7
		PM_{10}	077	2.7732	2.8124	1.159	1663.21	0.0389	23.4
15/10/2009 (Thursday)	07.15 – 07.15	TSP	082	2.7628	2.8823	1.155	1666.89	0.1192	71.5
		PM_{10}	083	2.7520	2.8424	1.131	1631.88	0.0901	55.2
17/10/2009 (Saturday)	09.00 – 09.00	TSP	088	2.7749	2.8839	1.139	1618.15	0.1087	67.2
		PM_{10}	089	2.7525	2.8283	1.145	1626.71	0.0755	46.4
19/10/2009 (Monday)	08.00 – 08.00	TSP	094	2.7251	2.8205	1.123	1611.68	0.0951	59.0
		PM_{10}	095	2.7578	2.8183	1.102	1582.73	0.0602	38.0
21/10/2009 (Wednesday)	08.00 – 08.00	TSP	101	2.8920	2.9722	1.171	1679.58	0.0799	47.6
		PM_{10}	102	2.8791	2.9380	1.131	1621.60	0.0586	36.1

Table B-4 Data of TSP and PM_{10} measurement (24-hour) at Benchasiri in rainy season

Date	Time	PM	Filter No.	Filter weight (g)		Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight with Blank (g)	Concentration ($\mu g/m^3$)
				Initial weight (g)	Final weight (g)				
5/10/2009 (Monday)	14.30 – 14.30	TSP	053	2.7606	2.8661	1.133	1579.87	0.1052	66.6
		PM_{10}	054	2.7465	2.8035	1.105	1540.34	0.0567	36.8
9/10/2009 (Friday)	10.00 – 10.00	TSP	065	2.7424	2.8626	1.133	1602.26	0.1199	74.8
		PM_{10}	066	2.7507	2.8234	1.158	1637.62	0.0724	44.2
11/10/2009 (Sunday)	10.15 – 10.15	TSP	072	2.7328	2.8005	1.133	1606.47	0.0674	42.0
		PM_{10}	073	2.7350	2.7714	1.145	1623.01	0.0361	22.2
13/10/2009 (Tuesday)	15.30 – 15.30	TSP	078	2.7579	2.8492	1.133	1609.14	0.0910	56.6
		PM_{10}	079	2.7660	2.8197	1.145	1625.71	0.0534	32.9
15/10/2009 (Thursday)	09.15 – 09.15	TSP	084	2.7654	2.9024	1.133	1635.40	0.1367	83.6
		PM_{10}	085	2.7605	2.8408	1.131	1632.99	0.0800	49.0
17/10/2009 (Saturday)	10.45 – 10.45	TSP	090	2.7611	2.8728	1.133	1600.15	0.1114	69.6
		PM_{10}	091	2.7542	2.8305	1.158	1635.47	0.0760	46.5
19/10/2009 (Monday)	09.45 – 09.45	TSP	096	2.7416	2.8188	1.158	1656.04	0.0769	46.4
		PM_{10}	097	2.7267	2.7668	1.145	1636.48	0.0398	24.3
21/10/2009 (Wednesday)	09.45 – 09.45	TSP	103	2.8743	2.9649	1.133	1605.93	0.0903	56.2
		PM_{10}	104	2.8806	2.9320	1.158	1641.38	0.0511	31.1

Table B-5 Data of TSP and PM_{10} measurement (24-hour) at Saranrom in rainy season

Date	Time	PM	Filter No.	Filter weight (g)		Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight with Blank (g)	Concentration (μg/m^3)
				Initial weight (g)	Final weight (g)				
5/10/2009 (Monday)	17.30 – 17.30	TSP	055	2.7491	2.8528	1.128	1599.30	0.1034	64.7
		PM_{10}	056	2.7550	2.8116	1.095	1552.15	0.0563	36.3
7/10/2009 (Wednesday)	12.00 – 12.00	TSP	061	2.7627	2.8738	1.128	1591.94	0.1108	69.6
		PM_{10}	062	2.7329	2.7922	1.217	1716.95	0.0590	34.4
9/10/2009 (Friday)	12.30 – 12.30	TSP	067	2.7296	2.8418	1.128	1556.15	0.1119	71.9
		PM_{10}	068	2.7212	2.7814	1.109	1528.95	0.0599	39.2
11/10/2009 (Sunday)	11.30 – 11.30	TSP	074	2.7385	2.8084	1.128	1586.74	0.0696	43.9
		PM_{10}	075	2.7390	2.7906	1.176	1654.22	0.0513	31.0
13/10/2009 (Tuesday)	17.00 – 17.00	TSP	080	2.7553	2.8492	1.128	1604.58	0.0936	58.3
		PM_{10}	081	2.7589	2.8352	1.122	1595.78	0.0760	47.6
15/10/2009 (Thursday)	11.00 – 11.00	TSP	086	2.7656	2.8848	1.128	1613.01	0.1189	73.7
		PM_{10}	087	2.7404	2.8370	1.122	1604.17	0.0963	60.0
19/10/2009 (Monday)	11.30 – 11.30	TSP	098	2.7268	2.8049	1.128	1555.67	0.0778	50.0
		PM_{10}	099	2.7329	2.7893	1.122	1546.48	0.0561	36.3
21/10/2009 (Wednesday)	12.30 – 12.30	TSP	105	2.8906	2.9848	1.128	1617.04	0.0939	58.1
		PM_{10}	106	2.8564	2.9282	1.068	1530.55	0.0715	46.7

Table B-6 Data of TSP and PM_{10} measurement (24-hour) at Lumphini1 in winter season

Date	Time	PM	Filter No.	Filter weight (g)		Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight with Blank (g)	Concentration (μg/m^3)
				Initial weight (g)	Final weight (g)				
10/1/2010 (Sunday)	06.00 – 06.00	TSP	131	2.8406	3.0333	1.130	1627.26	0.1924	118.2
		PM_{10}	132	2.8395	2.9745	1.131	1629.06	0.1347	82.7
12/1/2010 (Tuesday)	08.00 – 08.00	TSP	137	2.8201	2.9972	1.130	1613.67	0.1768	109.6
		PM_{10}	138	2.8519	2.9715	1.131	1615.46	0.1193	73.9
14/1/2010 (Thursday)	05.45 – 05.45	TSP	141	2.8298	3.0047	1.130	1634.25	0.1746	106.8
		PM_{10}	142	2.8200	2.9327	1.144	1654.78	0.1124	67.9
16/1/2010 (Saturday)	07.15 – 07.15	TSP	148	2.8586	2.9945	1.145	1656.91	0.1356	81.8
		PM_{10}	149	2.8517	2.9356	1.131	1637.12	0.0836	51.1
18/1/2010 (Monday)	08.00 – 08.00	TSP	153	2.8547	3.0612	1.145	1660.17	0.2062	124.2
		PM_{10}	154	2.8756	3.0116	1.131	1640.34	0.1357	82.7
20/1/2010 (Wednesday)	14.30 – 14.30	TSP	157	2.8724	3.0048	1.130	1579.45	0.1321	83.6
		PM_{10}	158	2.8790	2.9614	1.118	1563.10	0.0821	52.5
22/1/2010 (Friday)	08.00 – 08.00	TSP	163	2.8797	3.0316	1.130	1620.64	0.1516	93.5
		PM_{10}	164	2.8613	2.9639	1.118	1603.86	0.1023	63.8

Table B-7 Data of TSP and PM_{10} measurement (24-hour) at Lumphini2 in winter season

Date	Time	PM	Filter No.	Filter weight (g)		Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight with Blank (g)	Concentration (μg/m^3)
				Initial weight (g)	Final weight (g)				
10/1/2010 (Sunday)	06.00 – 06.00	TSP	133	2.8462	3.0351	1.128	1624.75	0.1886	116.1
		PM_{10}	134	2.8557	2.9614	1.140	1641.79	0.1054	64.2
12/1/2010 (Tuesday)	08.00 – 08.00	TSP	139	2.8399	3.0085	1.128	1615.47	0.1683	104.2
		PM_{10}	140	2.8361	2.9466	1.153	1651.37	0.1102	66.7
14/1/2010 (Thursday)	05.45 – 05.45	TSP	143	2.8346	2.9997	1.128	1631.73	0.1648	101.0
		PM_{10}	144	2.8272	2.9283	1.140	1648.84	0.1008	61.1
16/10/2010 (Saturday)	07.15 – 07.15	TSP	150	2.8561	2.9792	1.128	1632.78	0.1228	75.2
		PM_{10}	151	2.8480	2.9196	1.127	1630.75	0.0713	43.7
18/1/2010 (Monday)	08.00 – 08.00	TSP	155	2.8850	3.0798	1.128	1636.00	0.1945	118.9
		PM_{10}	156	2.8919	3.0112	1.153	1672.36	0.1190	71.2
20/1/2010 (Wednesday)	14.30 – 14.30	TSP	159	2.8836	3.0109	1.128	1577.01	0.1270	80.5
		PM_{10}	160	2.8827	2.9484	1.114	1556.53	0.0654	42.0
22/1/2010 (Friday)	08.00 – 08.00	TSP	165	2.8743	3.0154	1.128	1618.14	0.1408	87.0
		PM_{10}	166	2.8440	2.9302	1.127	1616.12	0.0859	53.2

Table B-8 Data of TSP and PM_{10} measurement (24-hour) at Suan Luang Rama 9 in winter season

Date	Time	PM	Filter No.	Filter weight (g) Initial weight (g)	Filter weight (g) Final weight (g)	Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight with Blank (g)	Concentration ($\mu g/m^3$)
25/1/2010 (Monday)	12.45 – 12.45	TSP	167	2.8350	2.9948	1.151	1605.49	0.1595	99.4
		PM_{10}	168	2.8457	2.9381	1.145	1596.59	0.0921	57.7
27/1/2010 (Wednesday)	08.15 – 08.15	TSP	173	2.8382	3.0225	1.127	1628.43	0.1840	113.0
		PM_{10}	174	2.8422	2.9621	1.105	1597.83	0.1196	74.9
29/1/2010 (Friday)	06.00 – 06.00	TSP	179	2.8537	2.9679	1.114	1593.91	0.1139	71.5
		PM_{10}	180	2.8603	2.9354	1.132	1619.16	0.0748	46.2
31/1/2010 (Sunday)	06.00 – 06.00	TSP	187	2.8536	2.9342	1.114	1592.33	0.0803	50.4
		PM_{10}	188	2.8640	2.9113	1.105	1579.81	0.0470	29.8
2/2/2010 (Tuesday)	11.15 – 11.15	TSP	195	2.8310	2.9259	1.139	1584.56	0.0946	59.7
		PM_{10}	196	2.8212	2.8798	1.145	1592.94	0.0583	36.6
4/2/2010 (Thursday)	11.30 – 11.30	TSP	202	2.6744	2.7339	1.139	1604.86	0.0592	36.9
		PM_{10}	203	2.6663	2.7001	1.145	1613.34	0.0335	20.8
6/2/2010 (Saturday)	07.00 – 07.00	TSP	208	2.6855	2.7694	1.139	1632.74	0.0836	51.2
		PM_{10}	209	2.6994	2.7522	1.145	1641.37	0.0525	32.0
8/2/2010	07.15 – 07.15	TSP	216	2.6837	2.7540	1.139	1637.14	0.0700	42.8
(Monday)		PM_{10}	217	2.6716	2.7154	1.132	1626.83	0.0435	26.7
10/2/2010	12.00 – 12.00	TSP	224	2.6917	2.7825	1.139	1598.02	0.0905	56.6
(Wednesday)		PM_{10}	225	2.6701	2.7299	1.145	1606.48	0.0595	37.0
12/2/2010	12.15 – 12.15	TSP	232	2.6856	2.7806	1.139	1609.61	0.0947	58.8
(Friday)		PM_{10}	233	2.7041	2.7645	1.132	1599.47	0.0601	37.6

Table B-9 Data of TSP and PM_{10} measurement (24-hour) at Benchasiri in winter season

Date	Time	PM	Filter No.	Filter weight (g)		Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight with Blank (g)	Concentration (μg/m^3)
				Initial weight (g)	Final weight (g)				
25/1/2010 (Monday)	16.15 – 16.15	TSP	169	2.8531	3.0342	1.133	1564.49	0.1808	115.6
		PM_{10}	170	2.8443	2.9518	1.087	1500.95	0.1072	71.4
27/1/2010 (Wednesday)	09.45 – 09.45	TSP	175	2.8450	3.0506	1.148	1642.20	0.2053	125.0
		PM_{10}	176	2.8579	2.9992	1.087	1555.51	0.1410	90.6
29/1/2010 (Friday)	09.45 – 09.45	TSP	181	2.8416	2.9675	1.148	1640.56	0.1256	76.6
		PM_{10}	182	2.8390	2.9270	1.101	1572.89	0.0877	55.8
31/1/2010 (Sunday)	09.15 – 09.15	TSP	189	2.8678	2.9622	1.163	1660.85	0.0941	56.7
		PM_{10}	190	2.8396	2.9088	1.101	1572.38	0.0689	43.8
2/2/2010 (Tuesday)	13.00 – 13.00	TSP	197	2.8055	2.9104	1.163	1628.87	0.1046	64.2
		PM_{10}	198	2.8088	2.8724	1.101	1542.11	0.0633	41.1
4/2/2010 (Thursday)	13.15 – 13.15	TSP	204	2.6674	2.7443	1.148	1608.45	0.0766	47.6
		PM_{10}	205	2.6742	2.7181	1.140	1597.76	0.0436	27.3
8/2/2010	06.00 – 06.00	TSP	218	2.6860	2.7733	1.148	1635.19	0.0870	53.2
(Monday)		PM_{10}	219	2.6798	2.7329	1.127	1605.46	0.0528	32.9
10/2/2010	13.30 – 13.30	TSP	226	2.6709	2.7930	1.148	1607.91	0.1218	75.8
(Wednesday)		PM_{10}	227	2.6760	2.7492	1.127	1578.68	0.0729	46.2
12/2/2010	14.30 – 14.30	TSP	234	2.6929	2.8065	1.163	1619.83	0.1133	69.9
(Friday)		PM_{10}	235	2.7138	2.7842	1.127	1570.45	0.0701	44.6

Table B-10 Data of TSP and PM_{10} measurement (24-hour) at Saranrom in winter season

Date	Time	PM	Filter No.	Filter weight (g)		Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight with Blank (g)	Concentration ($\mu g/m^3$)
				Initial weight (g)	Final weight (g)				
25/1/2010 (Monday)	18.45 – 18.45	TSP	171	2.8296	2.9838	1.137	1574.55	0.1539	97.7
		PM_{10}	172	2.8329	2.9574	1.102	1526.70	0.1242	81.4
27/1/2010 (Wednesday)	11.15 – 11.15	TSP	177	2.8232	3.0436	1.123	1572.81	0.2201	139.9
		PM_{10}	178	2.8199	2.9926	1.118	1565.19	0.1724	110.2
29/1/2010 (Friday)	15.15 – 15.15	TSP	183	2.8499	2.9783	1.137	1583.13	0.1281	80.9
		PM_{10}	184	2.8747	2.9655	1.118	1557.31	0.0905	58.1
31/1/2010 (Sunday)	10.30 – 10.30	TSP	191	2.8310	2.9273	1.137	1574.17	0.0960	61.0
		PM_{10}	192	2.8557	2.9182	1.133	1566.05	0.0622	39.7
2/2/2010 (Tuesday)	15.30 – 15.30	TSP	199	2.8309	2.9316	1.123	1512.55	0.1004	66.4
		PM_{10}	200	2.8257	2.8897	1.133	1525.49	0.0637	41.8
6/2/2010 (Saturday)	10.00 – 10.00	TSP	212	2.6632	2.7586	1.150	1615.52	0.0951	58.9
		PM_{10}	213	2.6543	2.7145	1.118	1569.78	0.0599	38.2
8/2/2010	10.00 – 10.00	TSP	220	2.6793	2.7716	1.150	1630.99	0.0920	56.4
(Monday)		PM_{10}	221	2.6718	2.7324	1.149	1628.87	0.0603	37.0
10/2/2010	06.00 – 06.00	TSP	228	2.6696	2.7658	1.123	1595.72	0.0959	60.1
(Wednesday)		PM_{10}	229	2.6639	2.7280	1.102	1565.92	0.0638	40.7
12/2/2010	19.15 – 19.15	TSP	236	2.6766	2.7766	1.123	1578.43	0.0997	63.2
(Friday)		PM_{10}	237	2.6826	2.7461	1.102	1548.95	0.0632	40.8

Table B-11 Data of PM_{10} measurement (2-hour) at Lumphini1 in winter season

Date	Time	PM	Filter No.	Filter weight (g)		Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight with Blank (g)	Concentration (μg/m^3)
				Initial weight (g)	Final weight (g)				
10/1/2010 (Sunday)	06.00 – 08.00	PM_{10}	135	2.8067	2.8150	1.129	135.53	0.0080	59.0
	17.10 – 19.10	PM_{10}	136	2.8097	2.8205	1.129	132.85	0.0105	79.0
14/1/2010 (Thursday)	05.45 – 07.45	PM_{10}	145	2.8465	2.8540	1.129	136.12	0.0072	52.9
	17.30 – 19.30	PM_{10}	146	2.8488	2.8567	1.129	134.53	0.0076	56.5

Table B-12 Data of PM_{10} measurement (2-hour) at Lumphini2 in winter season

Date	Time	PM	Filter No.	Filter weight (g)		Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight with Blank (g)	Concentration (μg/m^3)
				Initial weight (g)	Final weight (g)				
16/1/2010 (Saturday)	17.15 – 19.15	PM_{10}	152	2.8582	2.8620	0.999	119.38	0.0035	29.3
20/1/2010 (Wednesday)	17.00 – 19.00	PM_{10}	162	2.8740	2.8813	1.126	133.76	0.0070	52.3

Table B-13 Data of PM_{10} measurement (2-hour) at Suan Luang Rama 9 in winter season

Date	Time	PM	Filter No.	Filter weight (g)		Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight with Blank (g)	Concentration (μg/m^3)
				Initial weight (g)	Final weight (g)				
29/1/2010 (Friday)	06.00 – 08.00	PM_{10}	185	2.8749	2.8810	1.194	142.30	0.0058	40.8
	17.00 – 19.00	PM_{10}	186	2.8563	2.8639	1.194	141.83	0.0073	51.5
31/1/2010 (Sunday)	06.00 – 08.00	PM_{10}	193	2.8609	2.8637	1.194	142.16	0.0025	17.6
	17.00 – 19.00	PM_{10}	194	2.8636	2.8667	1.194	141.73	0.0028	19.8

Table B-14 Data of PM_{10} measurement (2-hour) at Benchasiri in winter season

Date	Time	PM	Filter No.	Filter weight (g)		Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight with Blank (g)	Concentration ($\mu g/m^3$)
				Initial weight (g)	Final weight (g)				
6/2/2010 (Saturday)	06.00 – 08.00	PM_{10}	214	2.6644	2.6697	1.129	134.04	0.0050	37.3
	17.30 – 19.30	PM_{10}	215	2.6505	2.6552	1.075	126.92	0.0044	34.7
8/2/2010 (Monday)	06.00 – 08.00	PM_{10}	222	2.6747	2.6791	1.200	142.43	0.0041	28.8
	17.30 – 19.30	PM_{10}	223	2.6743	2.6790	1.200	141.21	0.0044	31.2

Table B-15 Data of PM_{10} measurement (2-hour) at Saranrom in winter season

Date	Time	PM	Filter No.	Filter weight (g)		Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight with Blank (g)	Concentration ($\mu g/m^3$)
				Initial weight (g)	Final weight (g)				
10/2/2010 (Wednesday)	06.00 – 08.00	PM_{10}	230	2.6774	2.6819	1.147	135.78	0.0042	30.9
	17.30 – 19.30	PM_{10}	231	2.6722	2.6762	1.129	132.43	0.0037	27.9
13/2/2010 (Saturday)	06.00 – 08.00	PM_{10}	238	2.6732	2.6773	1.165	137.49	0.0038	27.6
	17.00 – 19.00	PM_{10}	239	2.6666	2.6696	1.165	136.91	0.0027	19.7

Table B-16 Data of PM_{10} measurement at Land Development Department

Date	Time	PM	Filter No.	Filter weight (g)		Flow rate (m^3/min)	Volume (m^3) at 25°C, 760 mmHg	PM weight (g)	Concentration (μg/m^3)
				Initial weight (g)	Final weight (g)				
2/12/2009 (Wednesday)	13.32 – 13.29 (23.57 hours)	PM_{10}	114	2.8650	3.0168	1.150	1627.10	0.1518	93.3
4/12/2009 (Friday)	14.00 – 13.00 (23 hours)	PM_{10}	116	2.8399	3.0047	1.180	1582.91	0.1648	104.1
5/12/2009 (Saturday)	13.09 – 12.33 (23.24 hours)	PM_{10}	117	2.8500	2.9865	1.170	1601.15	0.1365	85.3
7/12/2009 (Monday)	13.25 – 12.37 (23.12 hours)	PM_{10}	119	2.8867	3.0933	1.150	1572.42	0.2066	131.4
8/12/2009 (Tuesday)	12.46 – 12.40 (23.54 hours)	PM_{10}	120	2.8772	3.1082	1.150	1612.89	0.2310	143.2
9/12/2009 (Wednesday)	12.48 – 12.30 (23.42 hours)	PM_{10}	121	2.8634	3.0872	1.150	1594.46	0.2238	140.4
10/12/2009 (Thursday)	12.41 – 12.41 (24 hours)	PM_{10}	122	2.8704	3.0685	1.150	1597.26	0.1981	124.0

APPENDIX C

METEOROLOGICAL DATA

Table C-1 Meteorological data of Lumphini1 and Lumphini2 site (from Bangkok station)

Season	Date	Rain (mm)	RH (%)	Temp (°C)	WD (degree)	WS (knots)
rainy	14/9/2009	10.4	78.25	29.5	280	2.2
	16/9/2009	4.6	82.75	28.8	190	1.5
	18/9/2009	0	74.37	30.1	200	2.1
	20/9/2009	0.3	76.12	30.2	210	3.5
	22/9/2009	23.7	82.62	27.8	320	1.0
	24/9/2009	0.9	78.37	28.1	300	3.2
	26/9/2009	0.6	80.87	28.6	190	2.2
winter	10/1/2010	0	69.75	28.4	0	0
	12/1/2010	0	76.00	28.7	240	0.6
	14/1/2010	0	65.25	26.4	50	2.7
	16/1/2010	0	56.25	27.4	70	1.2
	18/1/2010	0	59.25	25.3	310	0.9
	20/1/2010	0	67.50	27.7	120	0.5
	22/1/2010	0	81.25	27.1	60	0.6

Source: Meteorological Development Bureau (2010)

Table C-2 Meteorological data of Suan Luang Rama 9 site (from Bangna station)

Season	Date	Rain (mm)	RH (%)	Temp (°C)	WD (degree)	WS (knots)
rainy	5/10/2009	12.9	81.87	28.7	170	0.6
	7/10/2009	7.2	85.25	28.0	170	0.9
	9/10/2009	13.4	84.62	27.5	210	0.6
	11/10/2009	0.5	81.12	28.5	330	1.1
	13/10/2009	66.4	87.87	27.1	180	0.5
	15/10/2009	2.1	85.75	28.1	0	0
	17/10/2009	56.7	90.62	26.9	320	0.4
	19/10/2009	0	80.12	28.8	170	0.7
	21/10/2009	15.2	92.25	26.3	0	0
winter	25/1/2010	0	75.12	28.5	60	0.2
	27/1/2010	0	69.25	28.6	60	0.5
	29/1/2010	0	79.50	28.6	180	2.1
	31/1/2010	0	76.62	29.2	180	2.0
	2/2/2010	0	75.50	29.2	180	2.4
	4/2/2010	0	74.87	29.4	180	3.2
	6/2/2010	0	76.37	29.0	160	3.4
	8/2/2010	0	77.25	29.0	180	4.4
	10/2/2010	0	77.25	29.1	170	3.1
	12/2/2010	0	78.62	29.3	180	3.4

Source: Meteorological Development Bureau (2010)

Table C-3 Meteorological data of Benchasiri site (from Bangkok station)

Season	**Date**	**Rain (mm)**	**RH (%)**	**Temp (°C)**	**WD (degree)**	**WS (knots)**
rainy	5/10/2009	0.5	78.87	29.3	320	1.0
	9/10/2009	9.0	83.37	27.9	140	1.1
	11/10/2009	2.6	80.00	28.7	110	0.4
	13/10/2009	4.4	87.00	27.6	190	0.7
	15/10/2009	0	84.25	28.7	160	0.5
	17/10/2009	62.6	89.00	27.3	260	0.5
	19/10/2009	0	79.37	28.9	320	0.2
	21/10/2009	1.7	92.62	26.3	0	0
winter	25/1/2010	0	73.50	29.1	80	1.6
	27/1/2010	0	66.50	28.9	60	0.9
	29/1/2010	21.7	83.50	27.9	220	0.5
	31/1/2010	0	75.50	29.3	170	1.5
	2/2/2010	0	75.62	29.1	170	1.9
	4/2/2010	0	74.75	29.5	180	1.2
	8/2/2010	0	76.62	28.8	200	2.9
	10/2/2010	0	76.50	29.2	170	2.4
	12/2/2010	0	77.87	29.5	180	2.5

Source: Meteorological Development Bureau (2010)

Table C-4 Meteorological data of Saranrom site (from Bangkok station)

Season	Date	Rain (mm)	RH (%)	Temp (°C)	WD (degree)	WS (knots)
rainy	5/10/2009	0	78.00	29.6	310	1.4
	7/10/2009	0	81.25	28.4	130	1.2
	9/10/2009	9.0	83.87	27.9	140	1.1
	11/10/2009	2.6	80.25	28.5	110	0.7
	13/10/2009	4.1	86.87	27.7	0	0
	15/10/2009	0	82.50	28.9	160	0.6
	19/10/2009	0	78.37	29.1	320	0.2
	21/10/2009	1.7	91.00	26.5	0	0
winter	25/1/2010	0	73.12	28.9	80	1.6
	27/1/2010	0	68.00	28.9	60	0.5
	29/1/2010	21.7	86.25	27.1	210	0.2
	31/1/2010	0	75.12	29.3	170	1.5
	2/2/2010	0	75.25	29.2	180	2.2
	6/2/2010	0	75.50	29.0	210	3.4
	8/2/2010	0	76.50	28.8	200	2.9
	10/2/2010	0	76.37	29.2	200	2.6
	12/2/2010	0	77.12	29.5	220	2.4

Source: Meteorological Development Bureau (2010)

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