# Air Pollution and Traffic Measurements in Bangkok Streets

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**Abstract:** Ambient air quality and traffic density measurements were conducted during January to December 2001 at four air monitoring sites in Bangkok Metropolitan Region (BMR). The ambient air pollutants included carbon monoxide (CO), particulate matter ($PM_{10}$), nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$), ozone ($O_3$) and benzene. The diurnal variations of air pollutant levels were generally identical to the corresponding traffic volume patterns during rush/non rush hours and day/night times. Average air pollutant concentration during weekday was found to be higher than during weekend. The air pollutant concentration was related to the traffic flow pattern and human activities. The test result showed vide variations between air pollutant concentrations and with traffic characteristic, street geometries and meteorological parameters. Most of the air pollutant concentrations showed indicative correlation with traffic density. However, there was a relatively smaller correlation between average hourly concentrations of sulfur dioxide and ozone and traffic densities.

The finding shows that the average air pollutant concentrations for the three urban sites are noticeably higher than the suburban site. Similarly, the traffic speeds were very well correlated with traffic densities. Lower traffic speeds were observed among station with slow moving traffic (high traffic density) while higher traffic speeds were found among station with fast traffic movement. Our analysis revealed that an obvious way to reduce the build-up of pollutant concentration on Bangkok streets would be to speed up the flow of traffic and prevent long periods of idling in congested streets.

**Keywords:** Bangkok, Benzene, Carbon monoxide, Nitrogen Dioxide, ozone, Particulate matter, Sulphur dioxide.

## Introduction

The Bangkok metropolitan area (1,569 $km^2$) with a total population of about 6.2 million and registered vehicles of more than 4.2 million (1999), is experiencing progressively intensified air pollution problems associated with high levels of vehicular exhaust emission. Vehicle ownership in Bangkok is estimated at approximately 400 vehicles per 1,000 residents.

Rapid growth of the motor vehicle population, coupled with poor engine maintenance, no requirement to fit catalytic converters and continued utilization of unleaded gasoline emits a significant quantity of air pollutants such as hydrocarbons, particulate matter ($PM_{10}$), carbon monoxide, sulphur dioxide, nitrogen oxides, benzene and black smoke from diesel vehicles (Muttamara, et. al, 2000).

The Pollution Control Department, Thailand (Wangwongwatana, 1999) reported that dirty air severely aggravates the symptoms of many kinds of asthma in Bangkok Metropolis. Inhalation of particulate matter ($PM_{10}$) poses a range of health risks, including increased respiratory problems and disease, breathing disorders and premature death. Elevated levels of carbon monoxide can impair human health causing harm to the cardiovascular and nervous systems. Benzene represents a special case due to its toxicity and its carcinogenic effect. Long-term benzene inhalation exposure as low as 0.0003 ppm (1 $\mu g/m^3$) can result in the development of acute leukemia (WHO, 1996).

In view of the importance and complexity of the problem, current understanding of vehicular air pollution and its impact on the environment is extensively studied by many European and North American countries (Elsom et. al, 1996). However, many recent models of roadside air pollution are designed for American and European cities and are clearly inappropriate for application to Asian  cities (Okamato et. al., 1990). In addition, lack of suitable monitoring data has further hindered the use of these models. Consequently, there is considerable interest in estimating roadside air pollutant emissions and their fate in the environment (Jones et al., 2000). Although many studies on the air pollution have been investigated in Bangkok, only few so far have focused on the relationship between traffic density and air pollutants in ambient air quality. Hence, this present study delineates the apparent trends of traffic density, with the aim to improve our present knowledge of the levels of various air pollutants from vehicular emissions, which might prove useful in the management of air quality in Bangkok Metropolis.

## Materials and Methods

### 1. Ambient Air Quality Measurement

Four street sampling stations in the Bangkok Metropolitan Region (BMR) were chosen based on traffic density, flow conditions and wind speed. Individual locations of sampling stations are described in Figure 1. At all of these sites, the measured air pollutants were particulate matter ($PM_{10}$), carbon monoxide (CO), nitrogen dioxide ($NO_2$), sulphur dioxide ($SO_2$), ozone ($O_3$) and benzene. Field measurements of air pollutant levels in Bangkok streets were spread over the period from January to December, 2001. In each monitoring station, on-line analyzers were used to monitor continuously various air pollutants and the data recorded for sessions of hourly, daily (weekday), weekend and monthly. The system provides four types of selectable data: momentary values, integrated values, moving averages and simple averages. Automatic compensation for ambient pressure assures reliable data regardless of the weather or the monitoring location. The influence from interference components is minimal and results are very stable over long periods of measurement. In addition, both ambient air monitoring and traffic flow counting were determined simultaneously over 24-hour periods and was used to identify the rush and non-rush periods.

### *1.1 Particulate Matter ($PM_{10}$)*

Particulate matter was analysed by an Ambient $PM_{10}$ Monitor (Graseby-FH621-N1). The system uses beta ray-absorption to measure particulate matter under 10 $\mu$m in size. A glass-fibre filter tape collects the particulate matter. Oversize particles are filtered out by cyclone filtration. The intensity of beta rays are detected by a plastic scintillator. The instrument has an accuracy of $\pm$ 10 $\mu g/m^3$ or $\pm$ 10% of reading.

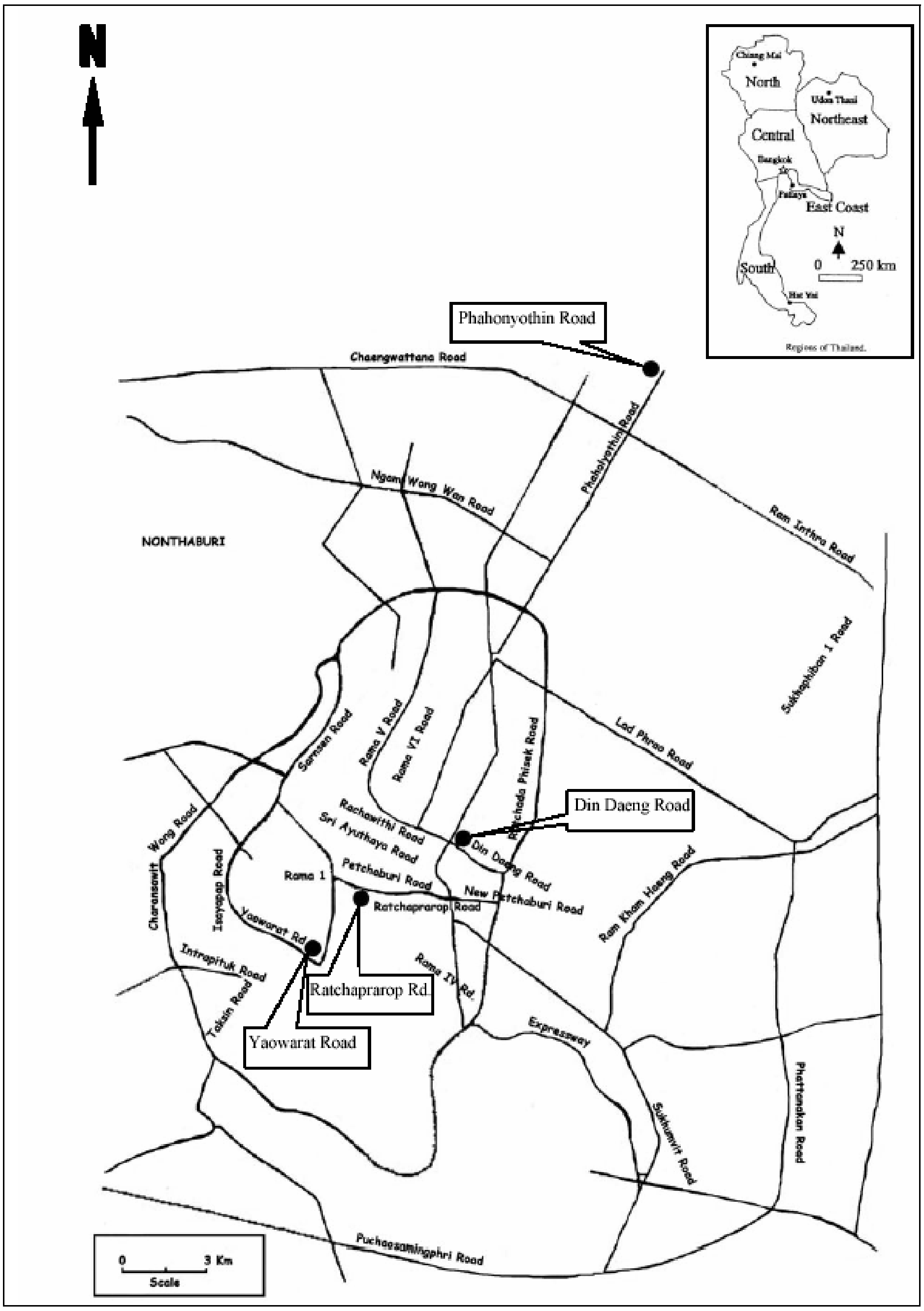


**Figure 1.** Locations of sampling stations at the study area.

### *1.2 Carbon Monoxide (CO)*

Carbon monoxide was analysed by an Ambient CO Monitor (Horiba Model APMA-350E). Cross-flow modulation, non-dispersive infrared absorption technology (NDIR) is the recommended method of continuous analysis for carbon monoxide content in the atmosphere. This instrument has a lower detectable limit of 0.05 ppm. Repeatability is $\pm$ 1.0 %. The zero drift is $\pm$ 0.1 ppm/day or $\pm$ 0.2 ppm/week.

### *1.3 Nitrogen Dioxide ($NO_2$)*

$NO_2$ monitor (Horiba-API-200A) measures hourly average $NO_2$ concentrations. This instrument is based on the principle of chemi-luminescence, whereby NO in the sample air reacts with ozone. The energy with a wavelength in the range 600 nm to 3000 nm passes through the reaction chamber and an optical filter. The intensity is detected by a photo-multiplier tube and recorded as nitric oxide, NO. The concentration of oxides of nitrogen is measured in a separate stream undergoing similar processes whereby $NO_2$ is converted to NO and together with the original NO, it is detected as $NO_X$. The difference between the $NO_X$ and NO is reported as nitrogen dioxide. The instrument operates continuously with a data logger. Calibration of NO is carried out using certified gas mixtures. Nitrogen dioxide calibration is accomplished by use of $NO_2$ permeation tubes. All calibration gases are of chromatographic-grade quality and were purchased from the Thai Industrial Gas Company. The working range of the instrument is 0.1-10 ppm with a minimum detectable limit of 0.15 ppb. The working temperature range is from 10-35 $^{o}$C.

### *1.4 Sulphur Dioxide ($SO_2$)*

Sulphur dioxide was analysed by an Ambient $SO_2$ Monitor (Horiba-API-100). UV-Fluorescence is the recommended method for continuous analysis of atmospheric sulphur dioxide. The UV fluorescence method operates on the principle that when the $SO_2$ molecules in the gaseous sample are excited by UV in the range 220-240 nm, they emit a characteristic fluorescence. The $SO_2$ concentration is obtained from changes in the intensity of the fluorescence. The instrument is designed for a lower detectable limit of 0.5 ppb and repeatability of $\pm$ 1.0 %.

### *1.5 Ozone ($O_3$)*

The analyses for ozone was performed using an Ambient $O_3$ Monitor (Horiba-API-400) based on ultra-violet-absorption method (NDUV). The instrument works on the principle that ozone absorbs UV rays (254 nm) in conjunction with the comparative calculation method. This permits continuous measurement with a lower detectable limit of 0.5 ppb and high sensitivity (0.1 ppm).

### *1.6 Benzene ($C_6H_6$)*

Charcoal tubes (SKC Cat. N0. 226-09) installed in a portable air-sampling pump (SKC Model 224-PCXR8) were used to collect ambient benzene samples. This procedure is strictly followed the NIOSH method (P&CAM127). The flow rate of air sampler was adjusted to be 2.0 l/min approximately. Benzene was captured in the coconut-based charcoal tubes (6 mm OD x 70 mm length) packed with activated carbon (about 150g). After sampling, the trapped benzene in the charcoal tube was desorbed in 3 ml of carbon disulphide, shaken for 30 min in ultrasonic bath and analyzed by gas chromatography. In this study, the gas chromatograph was Shimadzu 14A fitted with a 1/8in. x 6ft. stainless steel column with packing material, 10% 1,2,3 tris (2 cyanoethoxy) propane, (Chromosorb PAW-DMCS, 80/100 mesh) and a flame ionisation detector (FID). The column temperature was 80$^{o}$C, injector and detector temperature at 110$^{o}$C, with a nitrogen flow rate of 35 ml/min. Benzene peak was eluted after 1.8 minutes. The linearity of the system was calibrated by injecting a series of benzene standard solutions in the range of 10 to 1000 ppbv. The detection limit of benzene by considering $S/N > 3$ is 0.05 mg/l. All analytical measurements were performed in triplicate to obtain mean values. Results of replicated analyses were used for testing significance of benzene concentration in ambient air.

## 2. Traffic Data Collection

Throughout the monitoring period, traffic volumes at all the study sites were continuously measured over 24-hour periods using a photographic technique through video cameras. For this study, the vehicles were classified into 4 types: (1) Passenger car, (2) Pick-up & Van, (3) Truck & Bus and (4) Motorcycle. In this traffic analysis, volumes and travel speeds were observed for all vehicles, both from inbound and outbound directions. Average traffic speed was determined on an hourly basis by randomly selecting 30 to 50 vehicles in the hour and measuring the time it took each to travel through a fixed distance (1 km) marked on the kerb. Average traffic density for each hour of the air sampling period could then be obtained from the traffic volume and average speed.

### 3. Wind and Rainfall Measurements

Wind velocity and direction at a height of 3 m above street level were measured continuously using an automatic wind gauge attached to a recorder, model TV 112P manufactured by Texas Electronic Inc. Hourly average wind speed values were determined from the records. Raw wind and rainfall data were also obtained from the Meteorological Department of Thailand.

## Results and Discussion

### 1. Ambient Air Quality Analysis

#### *1.1 Particulate Matter ($PM_{10}$)*

In this study, noticeably higher measured particulate matter concentrations were frequently found in busy urban areas. These locations accumulated pollutants due to heavy traffic, tall buildings on both sides and narrow streets. Throughout the monitoring period, a higher average particulate matter ($PM_{10}$) concentration of 157.18 *u*g/m$^3$ was observed for the urban site at Yaowarat Road while a lower average $PM_{10}$ concentration of 78.53 *u*g/m$^3$ was exhibited for the suburban site at Phahonyothin Road. The ambient air quality standard for particulate matter ($PM_{10}$) in Thailand is 120 *u*g/m$^3$ (24hr average). The elevated concentration of $PM_{10}$ in Bangkok air quality poses a range of health risks, including reduced lung capacity, respiratory disease, breathing disorders and premature death. Similarly, higher concentration of particulate matter in Bangkok can serve as health indicators, which indicates that frequencies of respiratory symptoms and hospital admission for respiratory and cardiovascular illness are higher when $PM_{10}$ concentrations are higher.

### *1.2 Carbon Monoxide (CO)*

The hourly average CO concentrations at the monitoring sites varied between 9.6 – 20.6 mg/m$^3$ which was within the ambient air quality standard of 34.20 mg/m$^3$. However, elevated concentrations of carbon monoxide were often experienced from time to time at busy roads, especially during rush hours. During this period, frequent traffic jams and low speed were exhibited and air pollution emissions were beyond maximum allowable levels. Elevated levels of carbon monoxide warrant serious concern due to their likely role in human health causing harm to the cardiovascular and nervous systems. Carbon monoxide affects the transport of oxygen around the body by the blood. At very high levels, this can lead to a significant reduction in the supply of oxygen to the heart. Those who die or become ill are usually old or suffering from cardiovascular disease and therefore were unable to cope with the added stress caused by the heavily polluted air.

### *1.3 Nitrogen Dioxide ($NO_2$)*

Like particulate matter ($PM_{10}$), average nitrogen dioxide concentrations were highest close to busy roads, particularly in large urban areas. The hourly mean concentrations of nitrogen dioxide ($NO_2$) measured at the four monitoring stations in Bangkok did not fluctuate over a wide range and were found to be between 19.6 – 96.9 *u*g/m$^3$, well below the ambient air standard of 320 *u*g/m$^3$. Exposure to nitrogen dioxide can decrease lung function and increase airway responsiveness in wheezing, coughing, colds, influenza and bronchitis. At very high concentrations, nitrogen dioxide gas irritates and inflames the airways of the lungs. This irritation causes a worsening of symptoms of those with lung or respiratory disease. In addition, nitrogen dioxide is a major component of photochemical smog in the summer months.

### *1.4 Sulphur Dioxide ($SO_2$)*

The measured hourly average sulphur dioxide at the four monitoring stations in Bangkok were found to be between 4.6 – 17.4 *u*g/m$^3$, well below the ambient air standard (780 *u*g/m$^3$).

Short-term exposure to high levels of sulphur dioxide may cause coughing, tightening of the chest and irritation of the lungs.

### *1.5 Ozone ($O_3$)*

The hourly average concentration of ozone determined by the study ranged from 2.8 to 30.2 *u*g/m$^3$. The intensity and strength of ozone begins with low values in the early morning. As the solar intensity increases, ozone begins to accumulate, reaching the recorded maximum at its midday peak. As solar energy decreases, ozone begins to decline and reaches its minimum at late evening. Like nitrogen dioxide, high concentrations of ozone can irritate and inflame the lungs. It can also cause eye irritation and coughing. It is also a strong oxidizing agent and can catalyze the reaction of red blood cells (RBC) causing the destruction of chromosomes.

### *1.6 Benzene ($C_6H_6$)*

Results of the ambient air quality study revealed that current benzene concentrations in all the study areas ranged from 15.1 to 42.4 ug/m$^3$ which were comparable relative to other countries such as 3-12 *u*g/m$^3$ on the Hertfordshire motorway, U.K (Brown et al., 1998) and 11.7-20.2 *u*g/m$^3$ in urban areas of Central Seoul, South Korea (Jo and Choi, 1996). Due to the influence of higher traffic density, the diurnal pattern of benzene showed some marked divergences from urban (Yaowarat Road) to suburban (Phahonyothin Road) sites. WHO (1996) indicates that long-term benzene inhalation exposure as low as 0.0003 ppm

(1 *u*g/m$^3$) can result in the development of acute leukemia. In some cases, pollutant mixtures containing a low concentration of benzene, $NO_2$, $SO_2$ and $O_3$ have been reported to be more detrimental to plants, animals, materials, etc. than benzene alone.

### *1.7 Diurnal Variations*

Figure 2 shows the diurnal pattern of air pollutant levels in four Bangkok air monitoring stations, during rush and non-rush hours. Generally, most of the pollutants such as $PM_{10}$, CO, $NO_2$ and benzene for each of the four roads gave almost the same diurnal patterns. The concentration of air pollutants at all monitoring stations showed a minimum level over the period 0.00-05.00. There was higher value for the pollutant concentrations at morning rush hour (07.00 - 09.00). A slight decrease in pollutant concentration occurred at non-rush hour (11.00-15.00) and a rising level of pollutants was experienced in the evening rush hour (16.00-18.00). The levels then tended to reduce reaching a minimum at night time (19.00-24.00). These observations could be explained by the morning and evening traffic rush hours, as determined from the traffic survey data. It was revealed that during rush hours a comparably higher traffic volume occurred for all the monitoring stations. During this time, traffic moved more slowly, particularly the number of passenger cars and buses resulting in high smoke, particulate and carbon monoxide emissions. During non-rush hours, higher vehicle speeds could be expected to give a higher degree of street turbulence and cause greater movement of air pollution than would occur when traffic speeds were reduced later in the day due to higher volumes.

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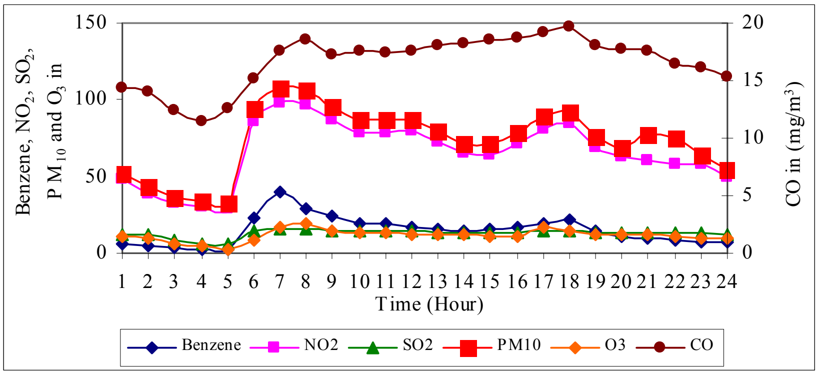


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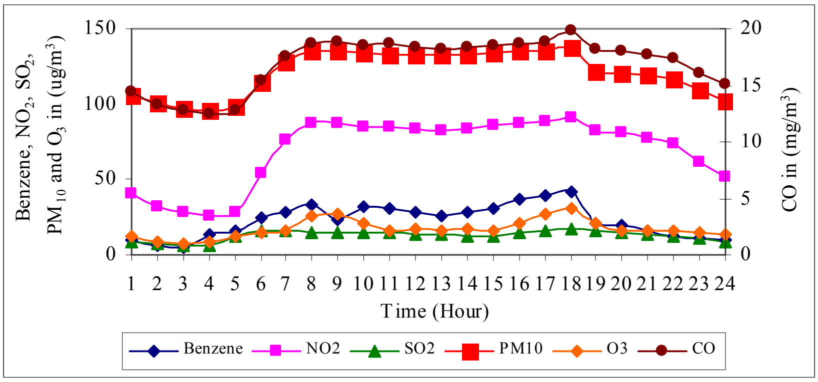


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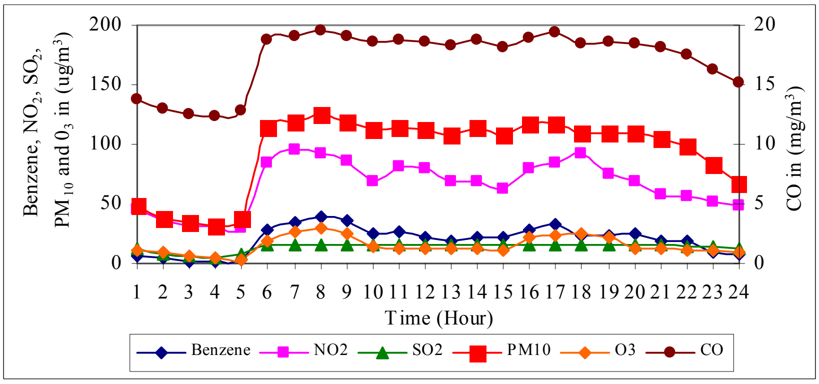

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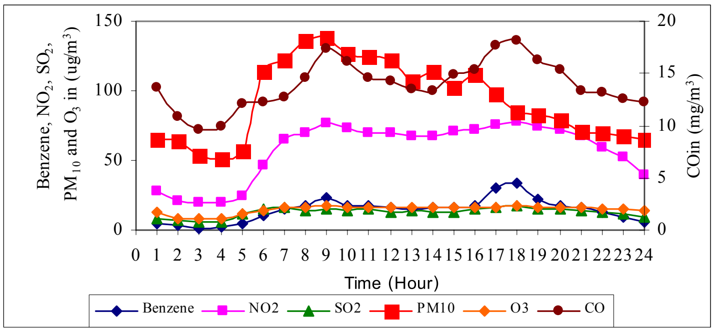



**Figure 2.** Average air pollutant hourly concentration at (a) Yaowarat Road, (b) Din Daeng Road, (c) Ratchaprarop Road and d) Phahonyothin Road, for 26 March 2001.

### *1.8 Weekday and Weekend Variations*

Surveys carried out in January to December 2001 found that the average air pollutant concentration during weekdays was higher than during weekends (Figure 3). The weekday and weekend patterns for air pollutant concentrations were very distinct. Fluctuation of ambient air pollutants by day was investigated, and indicated that there is little difference in ambient air pollutant concentrations between weekdays. However, a marked decrease in air pollutant concentration is recorded during weekends. The air pollutant concentration was related to the traffic flow pattern and human activities. Observations indicated that there was decreased traffic activity on Sundays (Leong et al., 2002).

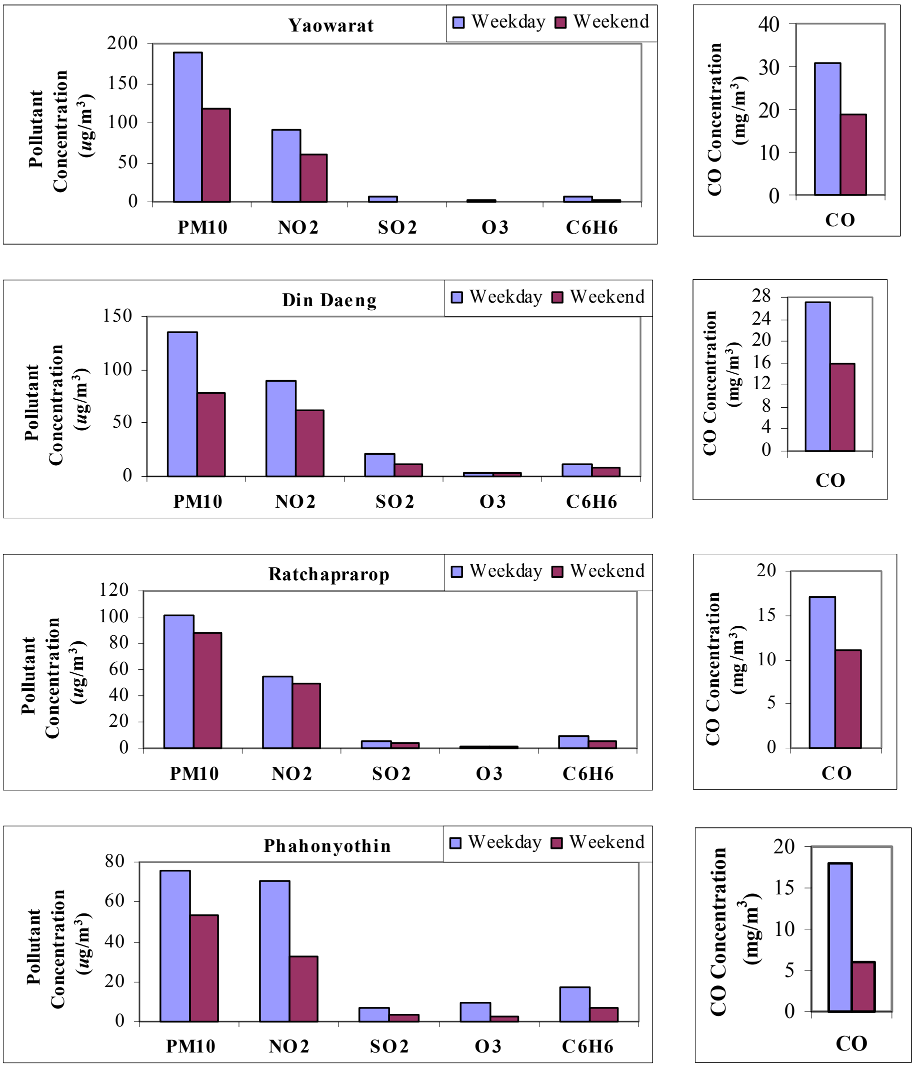



**Figure 3.** Variation of average air pollutant concentration during weekday and weekend, from January to December 2001 at (a) Yaowarat Road, (b) Din Daeng Road, (c) Ratchaprarop Road and (d) Phahonyothin Road.

### *1.9 Influence of Human Activities*

The concentration of air pollutants at all monitoring stations were also affected by human activities During the months of March-May and August-October, most of the schools in Bangkok were closed, being the holiday season for students. This affects the traffic flow and hence, upsets the usual concentration of ambient air pollutants

### *1.10 Relationship with Meteorological Parameters*

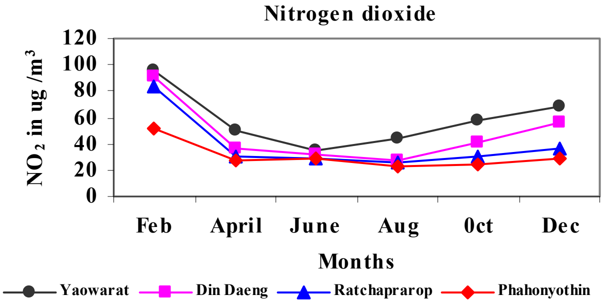
Weather variables play a major role in dispersing air pollutants and thus the determination of the level of their concentration. Bangkok has three seasons: the “cold season” (December to January), “ dry season” (February to May) and “rainy season” (June to October). Normally, high pollution can be observed during the cold season at the beginning and at the end, due to a high pressure system creating a more stable atmosphere brought about by inversion layer phenomenon, thus, more accumulation of pollutants in the air. Generally, during the dry season, pollution is low due to high atmospheric dispersion attributed to the existence of a less stable atmospheric system. However, the graphs (Figure 4) indicate that almost the same ambient air pollutant concentrations were recorded during rainy and dry seasons. The findings revealed that seasonal variation coupled with school term breaks and national holidays contributed toward a lower air pollutant concentration during both seasons. However, seasonal variation of sulphur dioxide and ozone concentrations was not observed at each of the four locations. This is probably due to the low sulphur content in the gasoline. Present sulphur content in Thai gasoline is 0.01 %wt. Sulphur dioxide emission was usually varied with sulphur content in gasoline. Likewise, ozone emission is dependable entirely on sunlight.

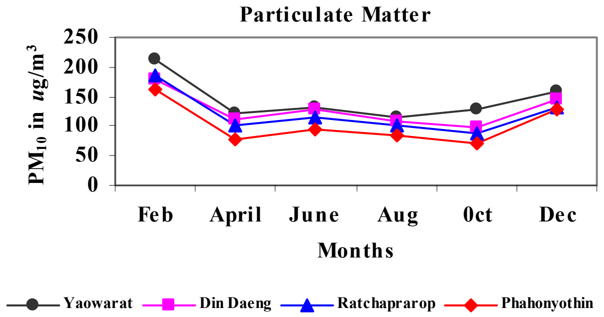
Attempts had been carried out to determine if any correlation exists between the air pollutant concentrations and the meteorological parameters at the various sites. However, negative correlation was established between air pollutant concentration and the meteorological factors. No significant temperature effects on ambient pollutant concentrations were found, as ambient temperature during the sampling period is rather stable. Average temperatures during the monitoring period were reported to be between 25$^{o}$C to 33$^{o}$C.

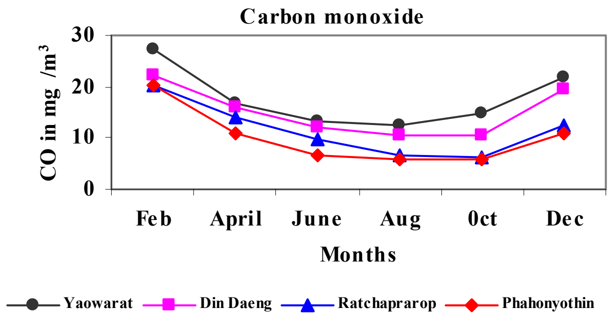
## 2. Traffic Analysis

### *2.1 Traffic Composition*

As it can be clearly seen from Figure 5 that the most dominant type of traffic was passenger cars, which represented the highest percentages (54-63%) of the total traffic volume at all monitoring stations. Motorcycles represent the second largest group, ranging between 17-28% of total traffic at most observation stations. On the contrary, trucks and buses represented the smallest group of vehicles representing only about 10% of the total traffic. It is observed that passenger cars and motorcycles exhibit higher percentages in total traffic composition than other vehicle types, thus they will have significant influence on the roadside pollutant concentrations.



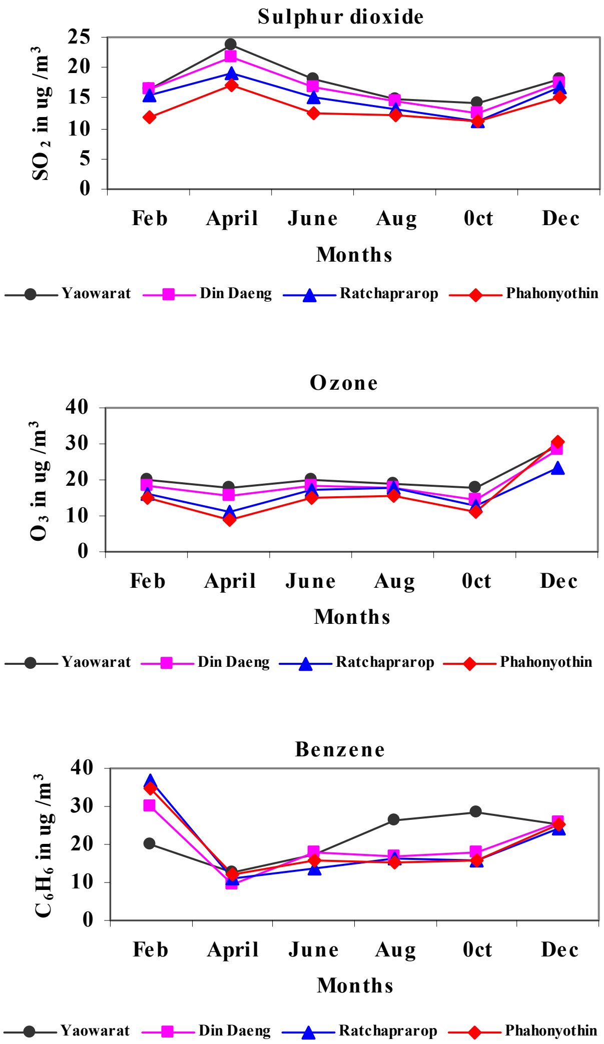



**Figure 4.** Average air pollutant monthly concentrations at (a) Yaowarat Road, (b) Din Daeng Road, (c) Ratchaprarop Road and (d) Phahonyothin Road, for Year 2001.

Different vehicles generate different pollutants. For example, two-stroke motorcycles will emit more white smoke, hydrocarbons and benzene than others (Japan Automobile

Manufacturers Association, 1990), thus they will contribute significantly to roadside pollutant concentrations. During observation periods, it was revealed that more than 80% of the total motorcycle population at all monitoring stations used two-stroke engines. The predominance of two-stroke engines is one of the significant factors for higher benzene concentrations in ambient air.

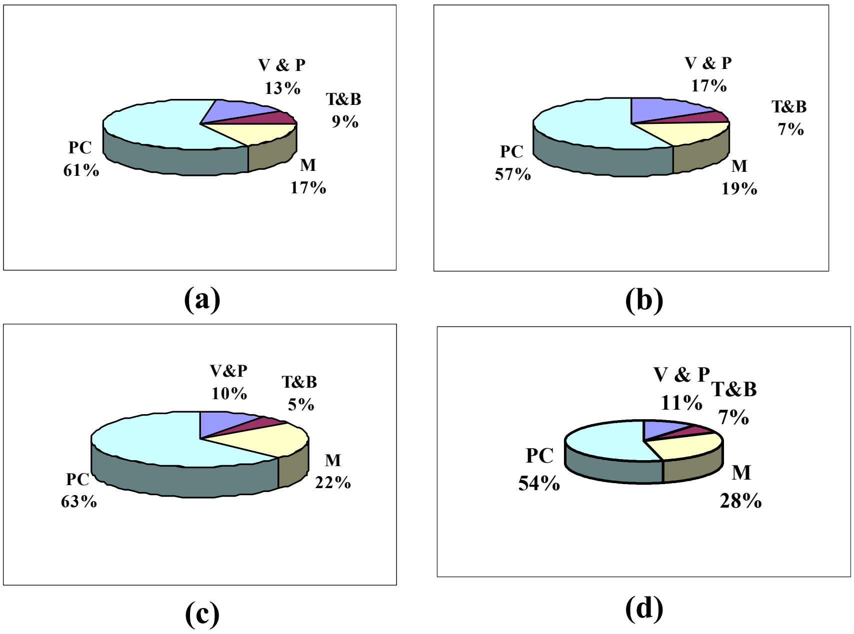



**Figure 5.** Vehicle Composition during January-December 2001 at (a) Yaowarat Road, (b) Din Daeng Road, (c) Ratchaprarop Road and (d) Phahonyothin Road.

**Note:** PC = Passenger Car, V&P = Van & Pickup, T&B = Truck & Bus and M = Motorcycle

### *2.2 Traffic and Street Characteristics*

A comparison of traffic characteristics between the rush hour and the non-rush hour was performed at different monitoring stations (Table 1). The observed travel speeds at Yaowarat and Din Daeng stations were found to be slower than at other locations and corresponded to higher air pollutant concentrations relative to traffic. Where traffic flows are slow, more pollutants will be emitted by vehicles, especially diesel-engined buses, many of which are old and inefficient. In addition, the finding also revealed that air pollution from traffic emissions depends on the physical conditions in narrow streets enclosed by tall buildings which govern the ability of atmosphere to disperse the pollutants. The street geometry of Yaowarat station is flanked by tall buildings and shows characteristics of a canyon street with frequent traffic jams. Similarly, traffic at Din Daeng and Ratchaprarop sites moves more slowly with the approach of major junctions and this appears to increase the air pollutant level. In contrast, a lower air pollutant concentration was observed at Phahonyothin station, having lower traffic volume and more stable traffic flow. Thus, marked differences for street level pollutants in Bangkok have been found between canyon streets with slow-moving traffic and more open radial streets with fast-moving traffic. An obvious way to reduce the build-up of pollutant concentration on Bangkok streets would be to speed up the flow of vehicles and prevent long periods of idling in congested traffic.

**Table 1**. Comparison of traffic characteristics at different sampling stations, during rush and non-rush hours.

| Station | Traffic Vol. | (vehicle/hr/lane) | Ave. Traffic | Speed (km/h) | Road Layout |
|---|---|---|---|---|---|
| (Traffic zones) | Rush Hr | Non-Rush Hr | Rush Hr | Non-Rush Hr | |
| Yaowarat Rd (Inner Core) | 1,212 | 606 | 11 | 36 | 6 lanes |
| Din Daeng Rd (Inner, section I ) | 1,132 | 566 | 18 | 38 | Near T-junction 6 lanes |
| Ratchaprarop Rd (Inner, section II) | 1,104 | 552 | 21 | 39 | Near T-junction 6 lanes |
| Phahonyothin Rd (Middle) | 920 | 460 | 30 | 56 | 8 lanes |

### *2.3 Traffic Density*

Traffic density, which incorporates the number of vehicles passing a given section of roadway during a given time interval, seems to be more suitable to use instead of traffic volume. Density is an appropriate parameter to indicate the quantity of traffic operations. In this study, traffic density is used to correlate with air pollutant concentrations in each of the monitoring stations in different parts of the city. In this finding, scatter-point diagrams were established and showed indicative correlation between most pollutant concentrations and traffic density (Figure 6). The finding revealed that sulphur dioxide and ozone concentrations showed a relatively smaller correlation with traffic densities. This is probably due to the low sulphur content in the gasoline. Emissions will usually vary with mixed types of gasoline combustion engines in Bangkok traffic. In the presence of sunlight, oxygen reacts with nitrogen oxides and volatile organic compounds to produce ozone, its concentration is dependable entirely on sunlight.

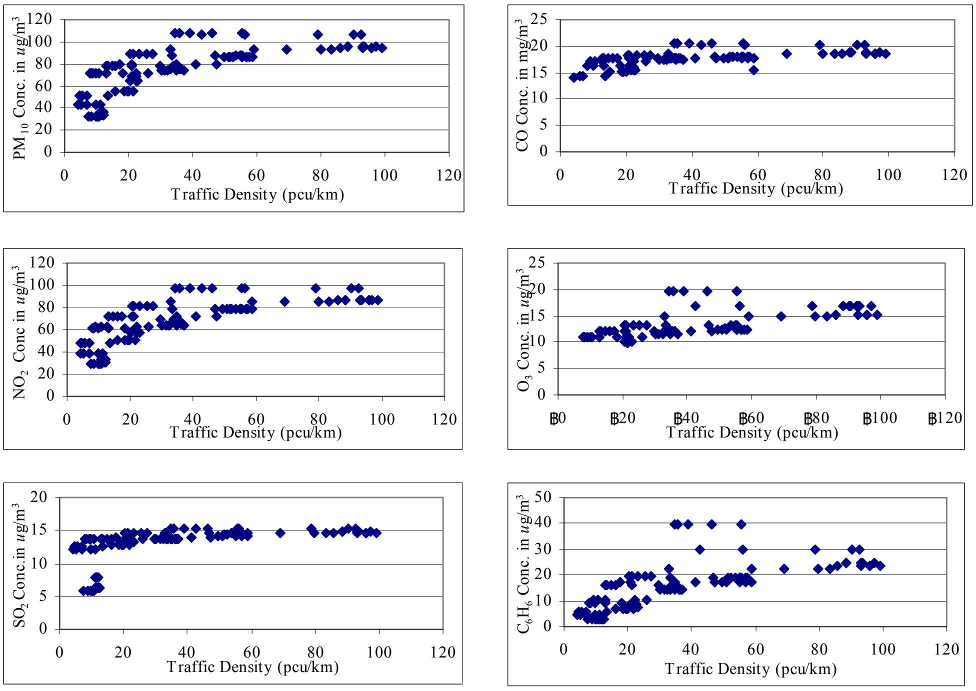



**Figure 6.** Relationship between traffic density and pollutant concentration at Bangkok air monitoring sites, for Year 2001.

### *2.4 Traffic Density and Speed*

Observations indicated that travel speeds were lower during rush hours and weekday speeds were also slower than weekend speeds. During these periods of lower travel speeds, more vehicles can be found on the streets with slow-moving traffic. Theoretically speaking, when traffic is heavy and as density increases, maneuverability becomes restricted and speed is reduced. The observed congestion conditions at Yaowarat and Din Daeng stations were also supported by the recorded travel speeds at these locations. Their average travel speeds were found to be slower than other locations (Figure 7). This thus proves for the case of Bangkok that traffic speeds were very well correlated to the number of vehicles.

## Conclusion

Results of this study revealed that current air pollutant concentrations in Bangkok street air are relatively dependable on: emission conditions, traffic characteristics and atmospheric dispersion conditions. In traffic analysis, the combined effects of street topography and traffic flows established high impact on the overall air pollutant concentration in Bangkok. High levels of air pollution found at roadsides, such as bus station areas, are a cause of concern for passengers waiting at these stops who will be exposed to vehicular air pollution. In this study, the area of greatest concern to health is the elevated level of $PM_{10}$ in Bangkok air. To protect the public from this pollution, preventive measures are necessary to reduce the air pollutant emission rate by improving traffic conditions. As data on atmospheric pollution and conditions in Thailand are rather scarce, this study could serve as a good support to better understanding of the atmospheric environment in Bangkok. In addition, the presented monitoring work can also serve as useful data for applicability to other tropical cities.

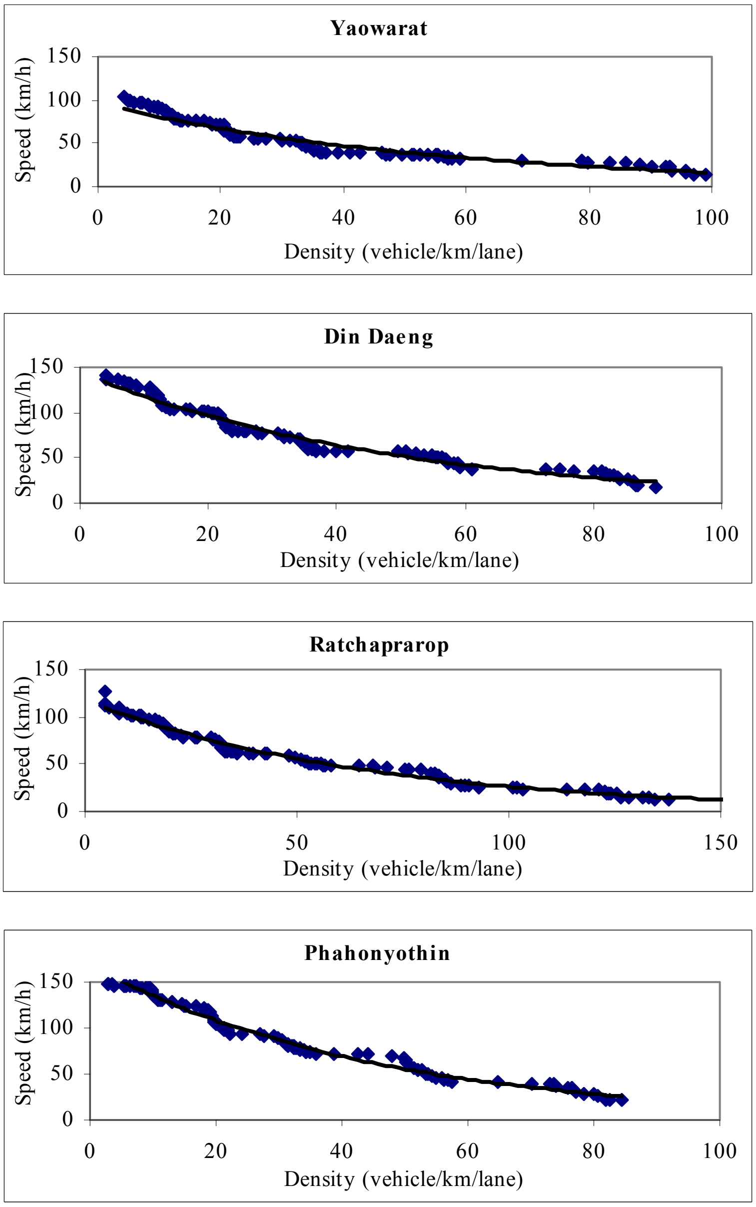



**Figure 7.** Speed-density relationship, from January to December 2001 at (a) Yaowarat Road, (b) Din Daeng Road, (c) Ratchaprarop Road and (d) Phahonyothin Road.

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