MONITORING OF GROUND-LEVEL OZONE AT ROADSIDE IN PULAU PINANG

by

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ABSTRACT

Air pollution which is largely caused by urban transport and its interaction within the city has become a growing problem today. The increase in the number of vehicles generates a higher concentration of pollutants. Meteorology factor and poor dispersion phenomena had led to high pollutant concentrations. Air quality is constantly deteriorating in cities world-wide and more people are concerned for their health. Ground-level ozone is the main contributor to photochemical smog in cities. It is responsible for various negative health effects on human being such as damage to lung tissues. High concentration of ozone also damages plant species and several natural materials. Therefore, more and more studies have been done to understand formation of ozone and the factors that influence ozone concentration. This study involves the monitoring of ozone concentration at 10 different roadsides in Penang Island and determining the factors that influence the concentration of ozone. A total of four variables were selected for this study. The variables were nitrogen dioxide concentration, temperature, relative humidity and passenger car unit (PCU). These variables were also used to develop models to predict the ozone concentration in Penang Island's lower atmosphere. From this study, it is found that temperature was directly proportional to ozone concentration while nitrogen dioxide concentration and relative humidity were inversely proportional to ozone concentration. PCU was directly proportional to nitrogen dioxide concentration. Ozone concentration generally peaked during midday and decreased during the evening. Ozone concentration was the highest at Jalan Sungai Nibong with a value of 128 ppb.

ABSTRAK

Sebahagian besar pencemaran udara yang disebabkan oleh pengangkutan bandar dan interaksinya dalam bandar telah menjadi masalah yang semakin meruncing hari ini. Peningkatan jumlah kenderaan telah menghasilkan kepekatan pencemar yang tinggi. Faktor meteorologi dan fenomena penyebaran yang lemah telah menyebabkan kepekatan pencemar yang tinggi. Kualiti udara terus menurun di bandar-bandar seluruh dunia dan ramai yang bimbang terhadap kesihatan mereka. Ozon merupakan penyumbang utama untuk asap fotokimia di bandar. Hal ini mendatangkan kesan negatif terhadap kesihatan manusia seperti kerosakan tisu paru-paru. Kepekatan tinggi ozon juga merosakkan spesies tanaman dan beberapa bahan semulajadi. Oleh sebab itu, semakin banyak kajian telah dijalankan untuk memahami pembentukan ozon dan faktor-faktor yang mempengaruhi peningkatan ozon. Penyelidikan ini melibatkan pemantauan kepekatan ozon di 10 pinggir jalan berbeza di Pulau Pinang dan menentukan faktor-faktor yang mempengaruhi kepekatan ozon. Sebanyak empat pembolehubah telah dipilih untuk kajian ini. Pembolehubah tersebut adalah kepekatan nitrogen dioksida, suhu, kelembapan relatif dan unit kereta penumpang (PCU). Pembolehubah ini juga digunakan untuk membentuk model untuk menganggar kepekatan ozon di atmosfera rendah Pulau Pinang. Dari kajian ini, suhu adalah berkadar terus dengan kepekatan ozon sementara kepekatan nitrogen dioksida dan kelembapan relatif adalah berkadar songsang dengan kepekatan ozon. PCU berkadar terus terhadap kepekatan nitrogen dioksida. Kepekatan ozon umumnya mencapai puncaknya pada tengahari dan menurun pada lewat petang. Kepekatan maksimum ozon adalah 128 ppb di Jalan Sungai Nibong.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

DOE	Department of Environment
EPA	Environmental Protection Agency
NO_x	nitrogen oxide and nitrogen dioxide
NO_2	nitrogen dioxide
O_3	ozone
PCU	passenger car units
PM_{10}	particulate matter less than 10 μm
$PM_{2.5}$	particulate matter less than 2.5 μm
ppb	part per billion
ppm	part per million
U.S.	United States
USEPA	United States Environmental Protection Agency
VOCs	volatile organic compounds
WHO	World Health Organization
NMHC	Non-methane hydrocarbon
Pb	Lead
PAH	polycyclic aromatic hydrocarbons
NE	Northeast
SW	Southwest

CHAPTER 1

INTRODUCTION

1.1 Introduction

Air pollution is a result of rapid urbanization which has caused deterioration in environmental quality. Air quality is substantial in sustaining and maintaining good health particularly human health. Without good air quality, respiratory organs will slowly deteriorate and many respiratory diseases will arise.

Air pollution is defined as the presence in the outdoor and or indoor atmosphere of one or more contaminants or combinations thereof in such quantities and of such duration as may be or may tend to be injurious to human, plant or animal life (Wark, 1998).

Urban air pollution has increased rapidly with urban populations, numbers of motor vehicles, use of fuels with poor environmental performance, badly maintained roads and ineffective environmental regulations (Agrawal et al., 2003). Vehicle related emissions are a significant source of air pollutants emitted in industrialized countries and urban environments in particular (Health Effects Institute, 2010).

Special efforts have been made in Europe aiming to reduce air pollution and, more importantly, to reduce the adverse impacts of atmospheric pollutants. Although these efforts led to a reduction of risks and effects, air pollution in Europe is still a matter of concern. In that regard pollution from industrial sources or vehicular traffic is especially important, because its volume is increasing every year (EEA, 2004). The implementation of some policy measures led to significant decrease of some pollutants, such as lead or sulphur dioxide (SO_2), whereas other, potentially even more hazardous pollutants, such as nitrogen oxides (NO_x), carbon monoxide (CO), and particulate matter (PM) containing polycyclic aromatic hydrocarbons (PAHs) and heavy metals (Muranszky et al., 2011), are emitted into the atmosphere in great amounts, causing significant decline of air quality across Europe (EEA, 2008). These pollutants represent a serious risk for human health; it was estimated that in Europe thousands of premature deaths are annually attributed to poor air quality alone (Kunzli et al., 2000).

In Ontario, Canada, the Ministry of the Environment (MOE) estimates the transportation sector to be the most significant source of nitrogen oxides (NO_x) and carbon monoxide (CO) and a significant source of volatile organic compounds (VOCs) and primary fine particulate matter ($PM_{2.5}$) (MOE, 2008). All these pollutants contribute to formation of secondary pollutants such as ground-level ozone. Ground-level ozone or surface level ozone is a secondary air pollutant formed in the atmosphere under bright sunlight from the oxidation of the primary pollutants NO_x and volatile organic compounds (VOC). Ozone is the most prominent of secondary pollutants formed (Jenkin and Clemitshaw, 2000). High ozone levels not only play a role in damaging plant species, various natural materials, and manufactured goods but also lead to the damage of lung tissues in humans (Wang and Georgopoulos, 2005).

Mobile sources have also been a major source of air pollution in Malaysia, contributing to at least 70-75% of the total air pollution. A study from the Department of Environment (DOE) in 1996 showed that motor vehicles contributed 82% to air pollution (Yahaya et al., 2006). The increase of motor vehicles in Malaysia each year is dramatic. This is due to the decrease of car prices and lack of efficient public transportation especially in urban areas with a high density of population. However, statistical data on transport-related pollution especially for ground-level ozone is lacking. Therefore, it is necessary for a study to be done on ground-level ozone at various sites on Penang Island.

1.2 Problem Statement

Ozone and NO_2 have been associated with poor urban air quality. Ozone is responsible for photochemical smog which causes harm to human lung. Approximately 90% of the emissions from combustion sources are NO rather than NO_2. However, since the NO can potentially oxidize to become NO_2, they are collectively referred to as NO_x. Since exhaust pipe concentration of NO_x can be several hundred parts per million, we should expect peak kerbside concentrations to be higher compared to the background levels.

Epidemiological field studies indicated large increases in mortality rates during summer smog situations, that is, during episodes of high ozone concentrations (Schlink et al., 2002). Ground-level ozone is known to cause damage to lung tissues and thus causing respiratory diseases. In addition, ozone levels play an important role in damage to plant species and it can cause harmful effects in vegetation during the growing season. Ozone is unique among pollutants because it is not emitted directly into the air. This is the main reason why ozone is such a serious environmental problem that is difficult to predict and control (Saleh et al., 2008).

Fuel combustion in vehicles emits by-products like VOCs and NO_x, and for this reason, the increase in the volume of traffic increases the emission of VOCs and NO_x which in turn increases the formation of ground-level ozone. The increase in concentration of ground-level ozone can be harmful to human health.

According to the Road Transport Department of Malaysia, the number of registered road vehicles had increased from more than 6.8 million in 1995 to more than 12.8 million in 2003. In 2008, there are 17.97 million registered cars in Malaysia. In Penang, there are 98,281 new registered cars in 2008 which makes the total registered cars in Penang 1,897,752 from the year 1986 to 2008 (Road and Transport Department of Malaysia, 2008).

1.3 Objectives

The immediate objectives are:

i) To determine the concentration of ground-level ozone at selected roads in Penang.

ii) To determine the influence of the changes in nitrogen dioxide (NO_2), passenger car unit (PCU), temperature and relative humidity to ground-level ozone (O_3).

iii) To predict ground-level ozone from the data collected using linear regression model.

1.4 Scope of study

The sampling sites that were selected for the research included USM main campus, Jalan Air Itam, Jalan Jelutong, Jalan Masjid Negeri, Jalan Perak, Jalan Scotland, Jalan Sungai Dua, Jalan Sungai Nibong, Jalan Sungai Pinang, Pekan Air Itam and Weld Quay. There were 11 sites in total including the site for pilot study which was at USM main campus. The parameters considered in the research were Ozone (O_3), Nitrogen Dioxide (NO_2), Relative Humidity (rh), Temperature (temp), and Passenger Car Unit (PCU). For the pilot study, the distance from the vehicle's exhaust to the sampling point was varied to obtain the concentration of ozone and nitrogen dioxide. For this research, the AEROQUAL 550 air monitoring device was used to measure the concentration of ozone and nitrogen dioxide. Both ozone and nitrogen dioxide concentration measurements utilised two separate AEROQUAL 550 devices which consist of two separate sensor heads. A tripod was used to obtain a fix height of elevation from the ground which was set at 1.3 meters.

1.5 Thesis Layout

This thesis is divided into 5 chapters. In the first chapter, a brief description is made in general concerning air pollution. Air pollution and its environmental problems are described in the introduction along with some statistics on increasing traffic volume in Malaysia and the state of Penang. The objectives of this study were also stated to give an idea about the research carried out. The problem statement was covered to provide a general view of the current situation pertaining to air pollution in Penang and also its main concern.

In Chapter 2, a literature review was done to give a clearer understanding concerning air pollution worldwide. Previous studies on this air pollution namely ground-level ozone were stated in this chapter to allow comparison and reference to the current research. Basic information and definitions of ground-level ozone were discussed along with health effects on human and the environment. International and national regulations and legislations related to ozone were also discussed in this chapter.

In Chapter 3, the methodology of this study was covered to provide a detailed and systematic description of the procedures and steps used to carry out the entire research. The specific details of equipments used and location of the sampling sites were described in this chapter. An explanation on the methods of analysis of data was also given.

In Chapter 4, the results of the findings of this research were displayed. The three main studies of this research were discussed, namely determination of the concentration of ground-level ozone at selected roads in Penang, determination of the influence of the changes in nitrogen dioxide (NO_2), passenger car unit (PCU), temperature and relative humidity to ground-level ozone (O_3), and the prediction of previous hour ground-level ozone from the data collected using statistical model.

In Chapter 5, conclusion and recommendations were made in closing of the study. Methods to improve this study mainly relating to data collection and analysis were stated for future references or future studies on this subject.

CHAPTER 2

LITERATURE REVIEW

2.1 Air pollution

Air pollution can be defined as the presence in the contaminant of outdoor atmosphere of any form including discharge from stacks, chimneys, open fires, vehicles, processes, or any other source of any smoke, in such place, manner, or concentration inimical or which may be inimical to the public health, safety, or welfare. Furthermore, it may be injurious to human, plant or animal life, or to property, or which unreasonably interfaces with the property, or which unreasonably interferes with the comfortable enjoyment of life and property (Heinsohn and Kabel, 1999).

Among the activities which lead to air pollution is fuel combustion from the residential, commercial/institutional, and small industrial space heating, steam, or process heat generation. Waste treatment and disposal method such as illegal was created open burning, apartment/institutional incinerators, landfills, agricultural and forest managed burning will also lead to air pollution problem. Besides that, in architectural coating, dry cleaning, equipment cleaning, graphic arts, pesticide application, auto refinishing, other surface coating and consumer products which used the organic solvent will also contributed to air pollution. The material handling and storage and miscellaneous which refer to transportation of petroleum, forest wildfires, dust, construction and other activities had created air pollution problem (Placet et al., 2000).

Monitoring data and studies on ambient air quality show that some of the air pollutants in several large cities are increasing with time and are not always at acceptable levels according to the national ambient air quality standards. Data on air pollution and case studies are very limited in Malaysia (Afroz et al., 2003).

2.2 Transportation and air pollution

The three major sources of air pollution in Malaysia are mobile sources, stationary sources, and open burning sources. For the past 5 years, emissions from mobile sources (i.e., motor vehicles) have been the major source of air pollution, contributing to at least 70–75% of the total air pollution. Emissions from stationary sources generally have contributed to 20–25% of the air pollution, while open burning and forest fires have contributed approximately 3–5%. According to the Department of the Environment (DOE, 1996), the percentages, of the air emission load by type were motor vehicles, 82%; power stations, 9%; industrial fuel burning, 5%; industrial production processes, 3%; domestic and commercial furnaces, 0.2%; and open burning at solid waste disposal sites, 0.8%.

Mobile sources include motor vehicles such as personal cars, commercial vehicles, and motorcycles. By the end of 2000, there were 10.6 million vehicles registered in Malaysia, compared to 7.7 million in 1996, an increase of almost 2.9 million vehicles or 26% (DOE, 2001). The federal territory of Kuala Lumpur has the highest vehicle population followed by Johor, Selangor, Perak, and Pulau Pinang. These conditions have caused severe congestion in almost all parts of the highway network and corridors, especially in the central business areas, and inevitably the environment in these areas has deteriorated due to exhaust emissions from motor vehicles (Afroz et al., 2003).

Traffic-related sources of air pollution are drawing increasing concerns from interested exposure assessors, epidemiologists, as well as toxicologists (Han and Naeher, 2006). Pollution from motor vehicles has become an issue simply because of the steady increase both in the number of vehicles in used and the distance travelled by each vehicle each year. Since 1960s, the number of motor vehicles in the world has been growing faster than its population. In 1950, there were 50 million cars for 3.5 billion people. Currently, there are 600 million cars for 6 billion people, with a global production of 45 million cars per year. Therefore it can be estimated that there will be close to a billion cars globally by the year 2020. The net growth rate for all motor vehicles is now around 5 %, compared to a population growth rate of 1-2 % (Colls, 2002).

Consequently, the use of motor vehicles generates more air pollution than any other single human activity. Since the major part of the energy has been produced by fossil fuels, and to a minor extent by biofuels, initially without flue gas cleaning, the global emissions of air pollutants have increased correspondingly (Fenger, 1999).

Urban congestion and air pollution are seen as a high priority problem in China (UNEP, 1997). In Beijing air quality is in transition from coal burning caused problems to traffic exhaust related pollution (Zhang et al., 1997) since the number of private passenger cars is increasing dramatically recently and in the near future. Vehicle emissions are, therefore, projected to double within the next two decades unless drastic strategies to lower actual emissions are employed.

Over 100 million people in Latin America and the Caribbean live in areas with air pollution concentrations above the health-based World Health Organization (WHO) guidelines (WHO, 2000). Latin America is increasingly urbanized and faces related air quality problems, such as those associated with growth in transportation networks. About three quarters of persons in Latin American and the Caribbean live in urban areas, and many large cities, such as Mexico City and Sao Paulo, have increasing levels of air pollution (UNEP, 2002).

The main ambient pollutants of concern include carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2), tropospheric ozone (O_3), and particulate matter (PM). The transportation sector is estimated to account for over 40% of PM_{10} (PM with an aerodynamic diameter less than 10 mm) emissions in Mexico City, 86% of PM_{10} emissions in Santiago, and over 75% of NO_x emissions for both cities (O'Ryan and Larraguibel, 2000). Pollution from the expanding transportation network is exacerbated by the older transportation fleet, low turnover of vehicles at about 10–20 years, inadequate vehicle maintenance, and traffic congestion. Other key emission sources include industry and dust from roads. Many cities in this region also have topographic and meteorological conditions that can prevent emitted pollution from dispersing, allowing the build-up of pollutants (Bell et al., 2006).

At present, the pollutant of greatest concern are, PM (particulate matter), ground-level ozone and nitrogen dioxide. This is because of their huge negative impact on human health and the transportation sector is an important contributor of all three pollutants (Hoek et al., 2002). As the air pollution proceeds as stepwise processes (including emission, diffusion, and transport), its impact is widespread both horizontally and vertically (Shon et al., 2004).

2.3 The combustion of motor vehicles

The common vehicles worldwide use internal combustion engines, which utilizes burning of petrol or diesel or gas hydrocarbon fuels for their energy supply.

If a pure hydrocarbon fuel was burn under ideal conditions, then the simple reaction taking place would be similar to:

$$C_xH_y + (x + y/4)\ O_2 \rightarrow xCO_2 + y/2H_2O \qquad (2.1)$$

Therefore, carbon dioxide and water would be the only combustion products (Colls, 2002). However in practice, this perfect combustion never occurs. First, oxygen is not present alone, but mixed with nitrogen and a variety of other components of the atmosphere. Secondly, the fuel is not a single pure hydrocarbon, nor even a blend of pure hydrocarbons, but a rather an impure mixture of hydrocarbons and other compounds that contain sulphur, nitrogen, lead and other minor constituents. Third, perfect combustion implies perfect mixing, however, the internal combustion cannot achieve this. Due to these factors, some atmospheric and fuel nitrogen is oxidized to NO_x, and some of the fuel are imperfectly combusted to new HC or CO or carbon particles instead of CO_2. Some fuel is not combusted at all and is emitted as VOCs, and the minor contaminants are emitted in various form. Many of which are harmful to human health (Colls, 2002).

Many of the fossil-fuel combustion processes that produce CO_2 and other greenhouse gases also produce a host of air pollutants such as particulate matter (PM), sulphate, ozone, and other pollutants, all of which have short-term adverse effects on public health (Davis, 1997).

2.4 Ozone

Ozone is a bluish gas, 1.6 times heavier than air, and a very reactive oxidant. Ozone is naturally present in relatively large concentrations in the stratosphere, an upper atmospheric layer. Stratosphere ozone should not be considered a photochemical air pollutant; a phrase that is used which should be restricted to ozone issues associated with the lower atmosphere or troposphere (Freedman, 1995).

Ozone is unique among pollutants because it is not emitted directly into the air. This is the main reason why ozone is such a serious environmental problem that is difficult to predict and control. Ozone results from complex chemical reactions in the atmosphere (Abdul-Wahab and Al-Alawi, 2002). It is produced when the primary pollutants, nitrogen oxides (NO_x) and non-methane hydrocarbons (NMHC), interact under the action of sunlight. The equation 2.2 and 2.3 shows the transformation from nitrogen dioxide to ozone.

$$NO_2 \longrightarrow NO + O(^3P) \qquad (2.2)$$

$$O(^3P) + O_2 \longrightarrow O_3 \qquad (2.3)$$

High ozone concentrations are strongly related to meteorological conditions and usually occur during sunny days, when primary pollutants (NO_x and NMHC) interact photochemically, supported by strong solar radiation and high temperatures (San Jose et al., 2005). Therefore, meteorological conditions strongly influence the efficiency of photochemical processes leading to ozone formation and destruction (Lengyel et al., 2004).

Ozone concentrations can vary at different time of the year and from year to year. Changing weather patterns, especially the number of hot sunny days, periods of air stagnation, wind patterns, and other factors can contribute to ozone formation. Urban areas with heavy traffic and large industrialized communities are the primary areas with ozone problems. When temperatures are high and there is little wind, ground-level ozone can reach levels that are dangerous to one's health (Ghazali et al., 2010).

To track and predict ozone, one must create an understanding of not only ozone itself, but also the conditions that contribute to its formation (Abdul-Wahab and Al-Alawi, 2002).

Emission rates of NO_x and NMHC can be estimated to some extent, since they are closely related to the nature of industrial and urban activities. It is, therefore, useful if some relationship can be found between these primary pollutants and meteorological factors, which can then be used to determine ozone levels (Elkamel et al., 2001).

2.4.1 Health effects of ozone

Ozone can be regarded as a beneficial UV shield in the stratosphere, but a harmful pollutant to human being at ground level. The detrimental effects of ambient ozone on human health address much concern in recent years world-widely.

Some previous studies about the ozone effect on human health can be found in literature.

Previous studies have shown associations between short-term changes in ozone levels and several health effects including hospitalisation, lung inflammation, increased respiratory symptoms, and increase mortality (Bell et al., 2005). Epidemiologic studies in polluted areas have also suggested that ozone concentrations increase the risk of asthma-related hospital visits and premature mortality (Levy et al., 2005).

Ozone exposure at ground level also produces cellular and structural changes, the overall effect of which is a decrease in the lung capability to perform normal functions. Ozone exposure causes major lesions in the centriacinar area of the lung that includes the end of the terminal bronchioles and the first few generations of either respiratory bronchioles or alveolar ducts. Ozone also induces the increase of nonspecific airway sensitivity to inhalation challenge testing with bronchial constrictive agents (Wang et al., 2003).

2.5 Nitrogen Dioxide

Nitrogen dioxide is a reddish brown trace gas that is part of the urban atmosphere. It is primarily produced by combustion processes (WHO, 2005). Therefore, the environmental concentration depends on traffic, particularly automobile traffic, which causes up to 50% of industrial countries' total emissions of nitrogen oxides (Kraft et al., 2004).

During recent years attention has focused on the role of nitrogen dioxide (NO_2) in the formation of photochemical oxidants and its contribution, together with its oxidation products, to wet and dry deposited acidity and the formation of aerosols. It can act as an acidifying agent in terrestrial ecosystems following dry deposition or more importantly by dry or wet deposition of its oxidation product, nitric acid. Nitrogen dioxide is a minor component (usually < 10%) of the mixture of nitrogen oxides (NO_x = NO + NO) formed during combustion processes and emitted. Nitric oxide (NO) predominates in the emission mixture, and most of the NO_2 in the atmosphere is formed by the oxidation of NO by ozone (O_3). The reaction is rapid, but may be limited by the availability of O_3 in urban areas (Atkins and Lee, 1995).

2.5.1 Health effects of nitrogen dioxide

NO_2 is an irritant gas and can increase susceptibility to airway infections and impair lung function in exposed populations (Kattan et al., 2007). Several, multi- and single pollutants time-series studies have also found association between NO_2 and non-accidental mortality (Beelen et al., 2008). The toxicity of NO_2 depends on its oxidative and free radical properties, as well as its ability to form nitric and nitrous acids in aqueous solution on the moist surfaces (Sandstrom, 1995). Its main effect, therefore, on human health is to damage respiratory tract cells such as mucous membranes of the lung (Frampton et al., 2002).

It has been established that nitrogen dioxides in combination with other gases like carbon monoxide (CO) are toxic to small animals such as rats in concentrations of 104 ppm and higher (Smith et al., 1996). NO_2 exposures at concentrations of 200 ppm for 30–60 min and 25–50 ppm for 8 h are lethal for many species of animals (Chitano et al., 1995). These toxic effects of high NO_2 concentrations result from lipid peroxidation and membrane damage to lung epithelial and alveolar cells (Velsor and Postlethwait, 1997). Inflammatory processes compromise cell membrane integrity and lead to edema. The lowest concentration found to effect morphological changes in the respiratory tract was 3 ppm NO_2 (Kakinoki et al., 1998).

2.6 Meteorology and air quality

Meteorology, along with emissions and atmospheric chemistry, is well known as a major contributor to air pollution episodes. As such, accurate definition of the meteorological environment has always been one of the chief requirements for understanding air quality (Seaman, 2003).

Meteorological parameters are inherently linked, resulting in strong interdependencies, for example, the dependency of boundary layer height on surface temperature or the link between surface temperature and radiation. These associations make separating the effects of individual parameters a highly complex task. Meteorological parameters can also affect pollutants through direct physical mechanisms such as the relationship with radiation and ozone or indirectly through influences on other meteorological parameters such as the association between high temperatures and low wind speed (Jacob and Winner, 2009). Thus, multiple approaches are necessary to understand the true nature of meteorological pollutant relationships. To further complicate matters, the magnitude and nature of these effects can vary from one air shed to the next as well as across seasons, making site specific assessments necessary for understanding local responses (Dawson and Adams, 2007).

One approach that has proven effective in measuring the effects of meteorology on air pollution is statistical modelling (Camalier and Cox, 2007). Statistical models are well suited for quantifying and visualizing the nature of pollutant response to individual meteorological parameters as they directly fit to the patterns that arise from the observed data (Schlink and Herbarth, 2006). However, statistical techniques do not aim to fully describe the formation and accumulation of air pollutants in their chemical, physical, and meteorological processes (Schlink and Herbarth, 2006).

In the context of climate change impacts on air quality it has been suggested that statistical studies are most capable of providing insight into the potential impacts through development of observational foundations (Jacob and Winner, 2009). These foundations provide a window into the possible extent of climate change impacts on air quality (Camalier and Cox, 2007).

2.6.1 Wind Direction

Pollutants emitted by motor vehicles impact the spatial and temporal distribution of ambient concentrations, which are also determined by meteorological factors, such as wind direction (Lau et al., 2008). Air movements are key determinants of pollution concentrations because horizontal and vertical airflows influence the mixing and transport of air pollutants. The former represent wind and the latter turbulence (Seaman, 2000).

2.6.2 Wind Speed

In many of the studies on airborne particulate matter and gases, authors have made qualitative observations on the relationship between airborne concentration and wind speed. It has been widely observed that for most airborne particulate and gas metrics, concentration reduces as wind speed increases, although in some cases, an increase in the concentration may be observed at the highest wind speeds (Jones et al., 2010). While NO_2 and NO_x concentrations consistently decreased with increasing wind speed, airborne particulate mass concentrations initially reduced with increasing wind speed but then reached a plateau or increased at higher wind speeds. This was particularly noticeable in the case of coarse particulate matter ($PM_{2.5-10}$), consistent with earlier observations (Harrison et al., 2001).

2.6.3 Temperature Inversion

Temperature inversion is the inverted temperature profile. This bizarre temperature profile results in the creation of a warm-air lid over cooler air. Pollutants become trapped in the lower layers and sometimes reaching dangerous levels because the cool and dense air on the ground cannot mix vertically. Temperature inversion occurs in two ways. A subsidence inversion occurs when a high-pressure air mass (warm front) slides over a colder air mass that failed to move out when the warm-air front arrived. Subsidence inversion may extend over many thousands of square kilometres. A radiation inversion, the second type, is typically local and usually short lived. It is a phenomenon many of us witness on cold winter days. Radiation inversions begin to form a few hours before the sun sets. As the day ends, the air near the ground cools faster than the air above it. Thus, warm air lay over the cooler ground air, preventing it from rising and causing pollutants to accumulate. It also correspond with the evening commute, when traffic and pollution emission peak. Fortunately, radiation inversion usually breaks up in the morning when the sun strikes the Earth and vertical mixing begins (Daniel, 2009).

2.6.4 Humidity

The effect of the relative humidity on atmospheric corrosion has been reported for a variety of metals including zinc, magnesium, copper and lead. In most cases, metal corrosion drops off steeply when the relative humidity decreases. This effect is used by, e.g., museums that control the relative humidity in order to minimize the atmospheric corrosion of metal objects (Niklasson et al., 2008).

2.7 International air quality standards

The World Health Organization (WHO) assists countries in reducing the health effects of air pollution by providing guidance to countries in setting their National Ambient Air Quality Standards (NAAQS) through the WHO Ambient Air

Quality Guidelines (AQG). The WHO AQG, first published in 1987, identify pollutant levels below which exposure to a pollutant for a given averaging time either does not constitute a health risk or the least health risk. In 2005, the WHO updated the AQGs by setting guidelines for PM_{10} and $PM_{2.5}$. The 2005 Global Update also indicated that reducing levels of PM_{10} could decrease mortality in polluted cities by as much as 15% every year. Interim targets were also provided for some pollutants. The 2005 version also lowered the recommended limits of many pollutants, including O_3 and SO_2, making them much more stringent than the national standards currently applied in many parts of the world (CAI-Asia, 2010).

The United States Environmental Protection Agency (EPA) established the air quality standard under Clean Air Act in order protect public health, including the health of "sensitive" populations such as people with asthma, children, and older adults. EPA also sets limits to protect public welfare. They also include the ecosystems (plants and animals), and protecting against decreased visibility and damage to crops, vegetation, and buildings.

2.8 National air quality standards

Six criteria pollutants, namely Carbon Monoxide , Nitrogen Dioxide, Ozone, Sulphur Dioxide and Particulate Matter (PM_{10}) were monitored continuously at 51 locations while lead concentrations was measured once in every six days at two locations. The air quality trend for the period 1998 to 2006 was computed by averaging direct measurements from the monitoring sites on a yearly basis and cross-reference with the Malaysian Ambient Air Quality Guidelines.

There are no ambient air quality standards in Malaysia. The Malaysian government, however, established Ambient Air Quality Guidelines in 1988.

Pollutants addressed in the guidelines include ozone, carbon monoxide, nitrogen dioxide, sulphur dioxide, total suspended particles, particulate matter less than 10 microns, lead and dust fall. The averaging time, which varies from 1 to 24 hours for the different air pollutants in the Recommended Malaysian Air Quality Guidelines (RMAQG) (Table 2.8), represents the period of time over which measurements is monitored and reported for the assessment of human health impacts of specific air pollutants.

Table 2.8: WHO Ambient Air Quality Guidelines (AQG), US EPA National Ambient Air Quality Standards (NAAQS) and Recommended Malaysian Air Quality Guidelines (RMAQG)

Pollutant	Averaging Time	WHO Guidelines	US EPA NAAQS	Recommended Malaysian Air Quality Guidelines (RMAQG)
$PM_{2.5}$*	Annual mean	10 µg/m^3	15 µg/m^3	-
	24-hour mean	25 µg/m^3	35 µg/m^3	-
PM_{10}*	Annual mean	20 µg/m^3	-	50 µg/m^3
	24-hour mean	50 µg/m^3	150 µg/m^3	150 µg/m^3
Ozone (O_3)	8-hour mean	100 µg/m^3	147 µg/m^3	120 µg/m^3
	1-hour mean	-	235 µg/m^3	200 µg/m^3
Nitrogen (NO_2)	Annual mean	40 µg/m^3	100 µg/m^3	-
	1-hour mean	200 µg/m^3	-	320 µg/m^3
Sulphur dioxide (SO_2)	Annual mean	-	78 µg/m^3	-
	24-hour mean	20 µg/m^3	365 µg/m^3	105µg/m^3
	10-minute mean	500 µg/m^3	-	350 µg/m^3 (1 hour mean)
Lead (Pb)	Annual mean	0.5 µg/m^3	-	-
	3-month mean	-	1.5 µg/m^3	1.5 µg/m^3
Carbon monoxide (CO)	1-hour mean	30,000 µg/m^3	40,000 µg/m^3	35,000 µg/m^3
	8-hour mean	10,000 µg/m^3	10,000 µg/m^3	10,000 µg/m^3

*$PM_{2.5}$ = particles less than 2.5 micrometers in aerodynamic diameter
*PM_{10} = particles of 10 micrometers or less in aerodynamic diameter

CHAPTER 3

METHODOLOGY

3.1 Sampling location

3.1.1 General information of Pulau Pinang

Pulau Pinang is one of the 13 states in Malaysia and is located at the North West coast of Peninsula Malaysia. Pulau Pinang consists of the island of Penang and a coastal strip on the mainland known as Province Wellesley. The island and the mainland are separated by the Malacca strait and is linked by the 13.5 km long Penang Bridge and ferry. The state of Pulau Pinang has an area of 1,048 km^2, located at Latitudes 5° 8' - 5° 35', Longitudes 100° 8'-100° 32' and a total population of 1,577,300 as of 2009. The average annual rainfall of Pulau Pinang is 267 cm with average daytime temperature of 27-30°C and average night time temperature of 22-24°C. Population density is 1,505 people per sq km with average annual population growth rate of 2.0%. For this study, Pulau Pinang is selected. Pulau Pinang is divided into two districts which are North East (NE) and South West (SW). The North East district takes up 121 km^2 while the South West district takes up an area of 176 km^2. In total, Pulau Pinang covers an area of 297 km^2 (Penang State Government Official Portal, 2009). Map 3.1 shows the map of South West and North East district of Pulau Pinang.

Map 3.1: Source: http://mappery.com/Penang-Island-Map

For this study, a total of 10 sites were selected for sampling. The sites were Jalan Air Itam (SW), Jalan Jelutong (NE), Jalan Masjid Negeri (SW), Jalan Perak (NE), Jalan Scotland (SW), Jalan Sungai Dua (SW), Jalan Sungai Nibong (SW), Jalan Sungai Pinang (NE), Pekan Air Itam (SW) and Weld Quay (NE).

3.1.2 Jalan Air Itam

Figure 3.2 shows the schematic diagram of sampling point at Jalan Air Itam.

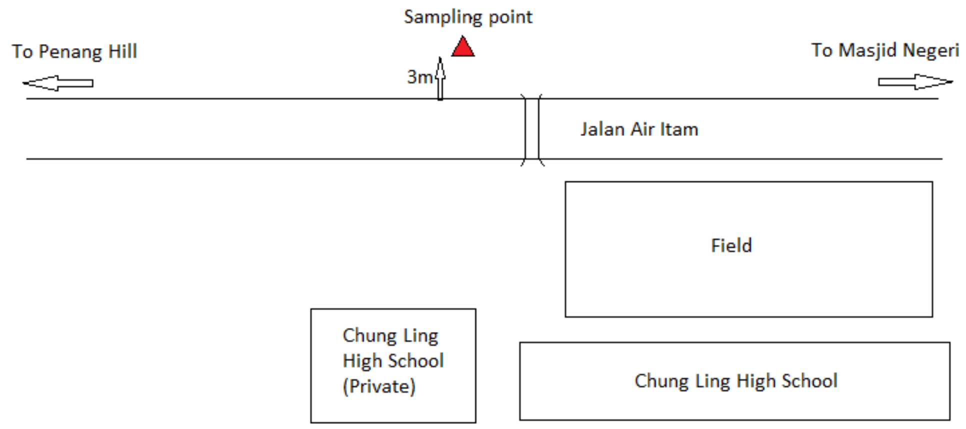

Figure 3.2: Schematic diagram of sampling point at Jalan Air Itam.

3.1.3 Jalan Jelutong

Figure 3.3 shows the schematic diagram of sampling point at Jalan Jelutong.

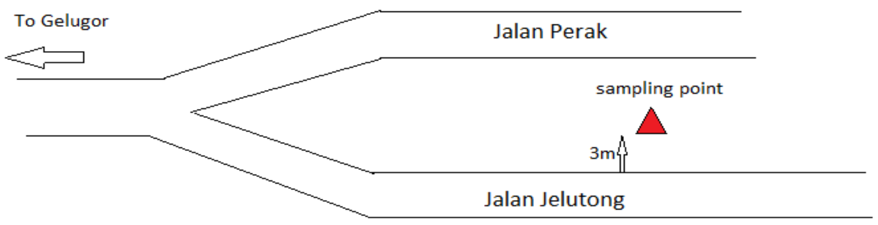

Figure 3.3: Schematic diagram of sampling point at Jalan Jelutong.