DETERMINATION OF COEFFICIENT FOR PM_{10} MONITORING USING AN OPTICAL DIRECT READING INSTRUMENT AND BETA ATTENUATION MONITOR

By

ZUL AZMI BIN MOHTAR

Thesis submitted in fulfillment of the requirements for the degree of Master of Science

MAY 2013

ACKNOWLEDGEMENTS

ALHAMDULILLAH, and Thank to ALLAH S.W.T, for giving me the wisdom, strength, support and knowledge in exploring things, for the guidance and helping surpass all the trials. This dissertation would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this study.

First and foremost, I would like to express my sincere gratitude to my supervisor Dr. Noor Faizah Fitri Md. Yusof and my co-supervisor Prof. Dr. Nor Azam Ramli for their continuous support during my M.Sc study and research and for their patience, motivation, enthusiasm, and immense knowledge. Besides my supervisor, I would like to thank Assoc. Prof. Ahmad Shukri Yahaya for guiding my analysis work for the past several months. My sincere thanks also goes to my entire colleague in Clean Air Research Group (CARE) especially to Ahmad Zia Ul-saufie, Nurul Izma, Hazrul, Nazatul and Maisarah for their assistance during all these years. I thank my dear parents En. Mohtar and Puan Mariam from the depths of my heart for their never ending love, and for supporting me in all my efforts. Also, I have been lucky to grow up with my dear sisters Noor Irdayu and Hazatul Hani. Finally, I would like to thanks Department of Environment Malaysia for providing data for this research and Alam Sekitar Malaysia Bhd. (ASMA) for their help in conducting the monitoring work. Finally thanks to Universiti Sains Malaysia for their financial support under short term grant (304/PAWAM/60311009) in order for me to carry out this research.

Zul Azmi Mohtar
April 2013

TABLE OF CONTENTS

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULT AND DISCUSSION

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

(0, 20]	0, 1, 2, 3,.....20 percentile
API	Air Pollutant Index
ASMA	Alam Sekitar Malaysia
BAM	Beta Attenuation Monitor
CAQMS	Air Quality Monitoring Station
CO	Carbon monoxide
CO_2	Carbon dioxide
DoE	Department of Environment (Malaysia)
EQR	Environmental Quality Report
IA	Index of Agreement
k	Correction factor
MAAQG	Malaysian Ambient Air Quality Guidelines
NAE	Normalized Absolute Error
NO_2	Nitrogen Dioxide
O_3	Ozone
ODRM	Optical Direct Reading Monitor
R^2	Coefficient of Determination
RH	Relative Humidity
RMSE	Root Mean Square Error
SO_2	Sulphur Dioxide
SPSS	Statistical Product and Services Solution
Temp	Temperature
USEPA	United States Environmental Protection Agency
WD	Wind Direction
WS	Wind Speed
WHO	World Health Organization

PENENTUAN PEKALI BAGI PENGUKURAN PM_{10} MENGGUNAKAN PERALATAN OPTIK BACAAN LANGSUNG (ODRM) DAN ALAT CERAPAN PENGECILAN BETA (BAM)

ABSTRAK

Kajian ini adalah mengenai perbandingan kepekatan jisim cerapan PM_{10} menggunakan dua jenis alat cerapan zarahan iaitu, alat cerapan pengecilan beta (BAM) dan peralatan optik bacaan langsung (ODRM) yang dijalankan di Perai dan Seberang Jaya, Pulau Pinang. Rekod ODRM telah diselaraskan untuk menjangka nilai BAM dengan faktor pembetulan *k* yang diperolehi daripada BAM dan ODRM yang diletakkan bersama di tapak penyelidikan untuk mendapatkan data yang setanding dalam keadaan yang sebenar. Nilai jangkaan BAM telah diperolehi dengan menggunakan dua kaedah regresi (Kaedah Lima Kumpulan Persentil dan Kaedah Tujuh Kumpulan Persentil) dengan menggunakan regresi kuartil. Petunjuk prestasi seperti Pekali Penentuan (R^2), Indeks Keserasian (IA), Ralat Normal Mutlak (NAE) dan Ralat Punca Kuasa Dua (RMSE) telah digunakan untuk mengukur ketepatan BAM ramalan dan BAM sebenar. Faktor *k* telah berjaya dikenalpasti untuk kedua-dua kaedah regresi. Bagi kedua-dua kaedah tersebut, rekod cerapan telah dibersihkan dan dibahagikan kepada dua kumpulan yang dinamakan sebagai Rekod Bersih dan Rekod Asal. Rekod Bersih ialah rekod cerapan di mana rekod untuk dua hari pertama (48 jam) dan kepekatan kurang daripada 10 µg/m³ telah disingkirkan. Untuk Rekod Asal, hanya rekod dua hari yang pertama (48 jam) telah disingkirkan. Korelasi positif diperolehi antara PM_{10} dan suhu di kesemua stesyen menggunakan kedua-dua alat. Bagi korelasi antara PM_{10} dan kelembapan, semua stesyen memperolehi korelasi negatif kecuali di stesyen Perai menggunakan ODRM (0.901). Model persamaan yang digunakan untuk ramalan BAM adalah $BAM_{pred} = \beta. + kx$

dimana β. ialah nilai pada pintasan *y* dan *x* nilai cerapan ODRM. Secara keseluruhan, Kaedah Lima Kumpulan Persentil menggunakan Rekod Bersih adalah yang terbaik bagi kedua-dua stesyen. Nilai R^2 bagi Kaedah Lima Kumpulan Persentil tersebut adalah 0.9170 bagi Perai dan 0.9422 bagi Seberang Jaya berbanding R^2 menggunakan Kaedah Tujuh Kumpulan Persentil iaitu 0.8795 bagi Perai dan 0.8402 bagi Seberang Jaya. Alat cerapan ringkas kini terbukti boleh digunakan untuk menghasilkan rekod bacaan langsung yang tepat pada masa sebenar selepas melalui proses penentu ukuran statistik dengan menggunakan regresi quantil.

ABSTRACT

This research compares PM_{10} mass concentration record generated by two types of aerosol monitoring devices, the Optical Direct Reading Monitor (ODRM) and the BAM1020, were collocated outdoors at Perai and Seberang Jaya. ODRM records were adjusted to predict Beta Attenuation Monitor (BAM) with a correction factor *k* derived from co-located BAM and ODRM at a research site to make data comparable in real terms. Predicted BAM records were obtained using quantile regression. Performance indicator such as Coefficient of Determination (R^2), Index of Agreement (IA), Normalised Absolute Error (NAE) and Root Mean Square Error (RMSE) were used to measure the accuracy of the predicted BAM and actual BAM. The *k* was successfully identified for Five Groups of Percentile and Seven Groups of Percentile. For both methods, monitoring records were treated using two techniques and named as Clean Record and Original Record. Clean Records removed the first two days records and concentrations lower than 10 µg/m³. For Original Record, only the first two days (48 hours) records were removed. Positive significant correlation was found between PM_{10} and temperature at all station using ODRM and BAM. However, for correlation between PM_{10} and RH, all stations showed negative correlation except Perai station using ODRM (0.901). The equation model used for predicted BAM is $BAM_{pred} = \beta. + kx$ which is $\beta.$ is constant value and *x* is observed ODRM. Five Groups of Percentile using Clean Record is the best for both stations. R^2 value for Five Groups of Percentile for Perai is 0.9170 and 0.9422 for Seberang Jaya compared with Seven Groups of Percentiles that is 0.8795 for Perai and 0.8402 for Seberang Jaya. Hence, simple optical direct reading instrument can be used as a surrogate to measure PM_{10} following statistical calibration by using quantile regression.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Dimitriou and Christidou (2007) define air pollution as one of the main global environmental problems that endanger the wellbeing of living organisms, leading to a loss of biodiversity or disrupting the function of the environment as a system. Air pollution occurs as a consequence of natural processes as well as human activity (anthropogenic). Examples of natural causes of air pollution include volcanic eruptions, forest fires and windblown dust. Anthropogenic air pollution from sources like motor vehicles and industries continues to be a serious harm to human health and welfare at highly populated urban areas. The health effects of air pollution include respiratory diseases such as asthma, cardiovascular diseases, changes in lung function, and death.

Colls (1997) reported that particles present in the atmosphere as primary or secondary, and either as solid or liquid. They come into the atmosphere, and leave it again by a wide variety of routes. Particulate matter is characterized by its physical and chemical properties (Nader, 1975). In addition, particle size and particle composition are characteristic that play a significant role in the assessment of health effect. In response to this information, regulatory agencies with a mandate to protect public health must consider the most effective way on implementing monitoring networks that will allow measurement of particulate matter concentration to be carried out.

In recent years, increasing number of monitoring system for particulate matter (PM) are available and are wide ranging in type, cost, flexibility and accuracy. According to Kingham et al. (2006), accurate and reliable monitoring of PM aerosol in the respirable size fraction (<10 μm aerodynamic diameter PM_{10}) is now legislative requirement of local authorities in many developed world countries. One of the essential prerequisites for monitoring requirements is the availability of a cost effective monitoring system that has been demonstrated to be reliable and accurate in its application to stationary source emissions.

Chung et al. (2001), pointed out that regular monitoring instruments for airbone particulate matter are Continuous Aerosol Mass Monitor, Integrating Nephelometer, and Tapered Element Oscillating Microbalance. Some previous studies have evaluated the substantial difference (operational advantages) between tapered element oscillating microbalance (TEOM) and a series of manual gravimetric methods (Allen et al., 1997; Ayers, 2004; Cyrys et al., 2001; Hauck et al., 2004; Williams et al., 2000) but fewer have compared other commercial monitors (Baldauf et al., 2001; Chung et al., 2001; Heal et al., 2000; Monn, 2001; Salter and Parsons, 1999).

1.2 CURRENT AIR QUALITY TREND IN MALAYSIA

There are 52 National Air Quality Monitoring Stations (CAQMS) in Malaysia, function to monitor continuously 5 major pollutants, namely particulate matter (PM_{10}), ozone (O_3), sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and carbon monoxide (CO) (DoE, 2012). For the northern region of Malaysia (Perlis, Kedah, Pulau Pinang and Perak), the overall air quality level was recorded as good to moderate. However, DoE (2012) reported that there are certain places (Tanjung Malim, Alor Star and Sungai Petani) recorded unhealthy level (exceed 101 API index) of the day especially during mid day till late afternoon due to high concentration of ground level ozone (O_3). In Tanjung Malim, one unhealthy day was recorded due to high level of particulate matter (PM_{10}) as shown in Figure 1.1.

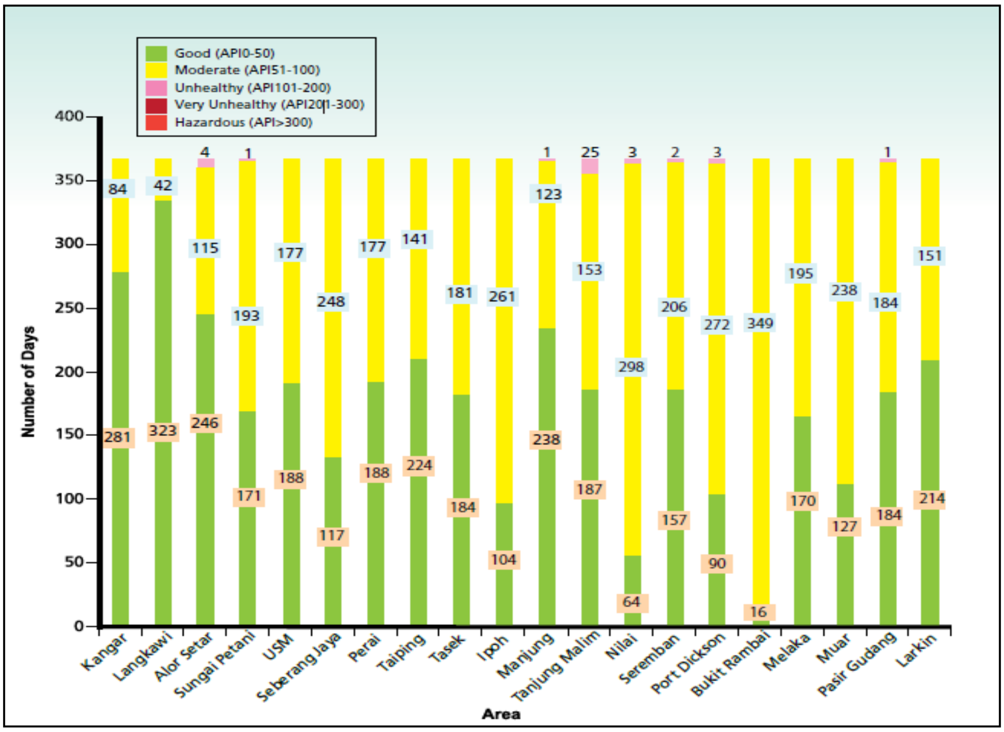


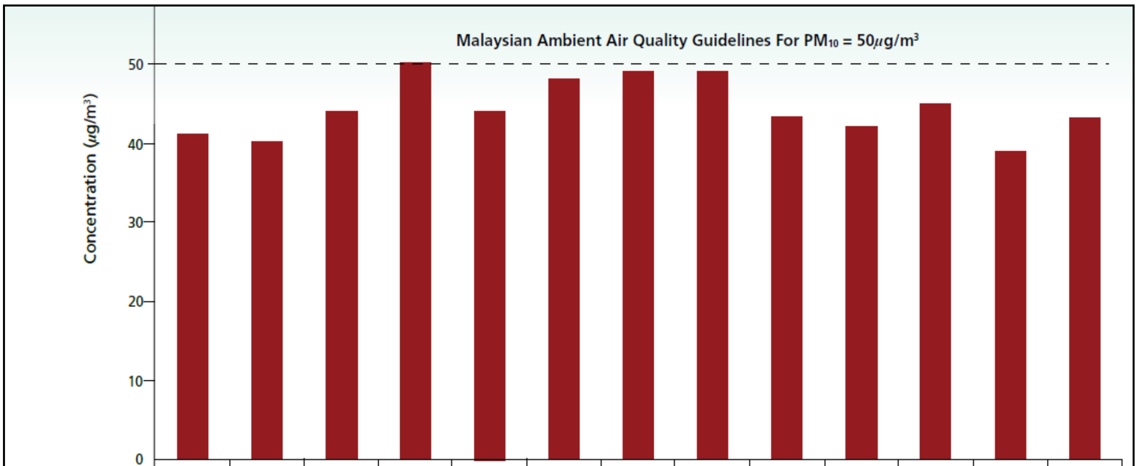
Figure 1.1 Air Quality Status, Peninsular Malaysia (West Coast) (DoE, 2012).

Air Pollutant Index (API) system was used in reporting the air quality status in Malaysia. The API was compute from the concentration of ground level ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and particulate matter of less than 10 microns in size (PM_{10}). Air quality status can be categorized in five main levels (good, moderate, unhealthy, very unhealthy and hazardous) as in Table 1.1.

Table 1.1 Malaysia : Air Pollutant Index (API) (DoE, 2012).

API	**Air Quality Status**
0-50	Good
51-100	Moderate
101-200	Unhealthy
201-300	Very unhealthy
301-500	Hazardous
Above 500	Emergency

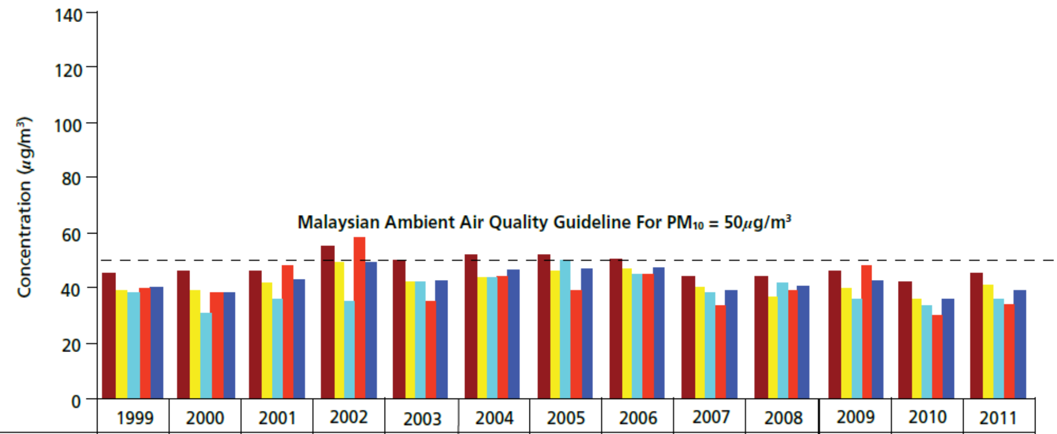
DoE in Malaysia Environmental Quality Report 2011 highlights the annual average of PM_{10} in Malaysia was 43 $\mu g/m^3$, but was slightly increased compared to 2010 (39 $\mu g/m^3$). However, for both year (2010 and 2011) the value was still below the Malaysian Ambient Air Quality Guidelines i.e 50 $\mu g/m^3$. The annual average levels of PM_{10} concentration in the ambient air between 1999 and 2011 is shown in Figure 1.2. Figure 1.3 shows the trend based on land use categories (Urban, Sub Urban, Background and Rural). These figures illustrated that annual average concentration of PM_{10} exceed MAAQG in 2002. In 2004, 2005 and 2006, the average concentration of PM_{10} is also high and almost exceeds the MAAQG level that are 48, 49 and 49 $\mu g/m^3$, respectively. This might be due to the influence of haze event reported in 2002, 2004, 2005 and 2006 (DoE, 2003; DoE, 2005; DoE, 2006; DoE, 2007).



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Concentration	41	40	44	50	44	48	49	49	43	42	45	39	43
Number of Sites	45	50	50	50	51	51	51	51	51	51	51	52	52

Figure 1.2 Malaysia : Annual Average Concentration of Particulate Matter (PM_{10}) 1999-2011(DoE, 2012).

High particulate event in 2002 and 2004 to 2006 occurs due to local and transboundary sources. In 2002, major fires occur in Kalimantan, destroying 1.2 to 1.5 Mha during August to November 2002 (Heil, 2007 and DoE, 2003). This could be the reason that increases the annual average of PM_{10} concentration. Similarly in 2005, haze event occurred due to fires from local sources. In 2005, peat land fires occur in several areas in the state of Selangor between February to March. Between mid May until mid October, peat land fires not only occur in Selangor, but the air quality was also deteriorated due to forest fires in Sumatera aggravated by prolonged dry season in the region and south westerly wind. 2004 and 2005 also recorded high annual average PM_{10} concentration as the effect of land and forest fires from several provinces in Sumatera, coupled with the direct influence of south westerly wind (DoE, 2005 and DoE, 2006).



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Urban	45	46	46	55	50	52	52	50	44	44	46	42	45
Sub Urban	39	39	42	49	42	44	46	47	40	37	40	36	41
Background	38	31	36	35	42	44	50	45	38	42	36	34	36
Rural	40	38	48	58	35	44	39	45	33	39	48	30	34
Mean	40.5	38.5	43.0	49.3	42.3	46.0	46.8	46.8	38.8	40.5	42.5	35.5	39.0

Figure 1.3 Malaysia : Annual Average Concentration of Particulate Matter (PM_{10}) by Land Use, 1999-2011 (DoE, 2012)

Figure 1.3 shows that concentration for urban are mostly higher compared to other land use and exceed MAAQG in 2002, 2004, 2005, and 2006. High concentration in urban areas are mostly affected by industrial and traffic pollutant as well as forest fires from local and transboundary sources in 2004, 2005 and 2006. The lowest concentration is at rural area because there is no significant industrial activities and far from the traffic sources, except for 2002 where the annual average concentration was very high due to forest fires.

1.3 MONITORING METHODS AND INSTRUMENTS

Monitoring of airborne particulate matter in the ambient atmosphere is mainly for determination of the mass of the particle. The methods used for monitoring of concentration of PM can differ and are very dependent upon the aim of monitoring, sites location, monitoring problem and resource that available during monitoring period. Table 1.2 summarizes the examples of the instrument for PM_{10} monitoring and the detection methods.

Table 1.2 Summary of instruments to monitor PM

Instrument	Principle of detections
Beta Attenuation Monitor (BAM)	The beta ray sources used in BAM are ^{14}C. Directly measured the particle based on relationship between beta ray attenuation to particle mass. Depends on the near exponential decrease in the total number of beta particle transmitted through a thin sample as the density increase (William et al., 2000) For gravimetric method only the mass of particle can affected the detector not by the size of distribution, physical size, shape or either by chemical composition (Chow et al., 1996)
Tapered Element Oscillating Microbalance (TEOM)	Tapered hollowed channel will act as a gateway where the particles are collected on a filter. For minimum thermal expansion that occurred at the tapered channel, the sample area is maintained at 50°C. Thermal expansion may affect the oscillation frequency and might be reduce the total amount of particle bound water (Ferm et al., 2006).
Dusttrak	Hands carry instrument and highly portable direct reading monitor. Using light scattering laser to detect the particles. Particles scattered the light which is from laser diode drawn through a constant stream. Liu et al. (2002) mentions the amount of light scatter influenced by the particles mass concentration.

Currently, monitoring of total suspended particulate (TSP) and suspended particulate matter (SPM) have become outdated with the awareness that PM effects vary depending on sizes of the particle. QUARG (1996) pointed that the latest method of monitoring (gravimetric and direct reading method) are designed to determine the concentration of particle in the different sizes (PM_{10} and $PM_{2.5}$).

1.4 PROBLEM STATEMENT

In Malaysia, PM_{10} monitoring was conducted by Alam Sekitar Malaysia Sdn. Bhd. (ASMA). Md Yusof et al., (2010) lists two instruments used for monitoring of PM_{10} that are high volume sampler (HVS) and beta attenuation monitor (BAM). BAM is the standard instrument used by Department of Environment (DoE) to measure particulate matter in 52 Continuous Air Quality Monitoring Station (CAQMS) in Malaysia.

However, air quality at areas without CAQMS cannot be monitored and observed because there are no monitoring instruments installed yet. In order to develop new monitoring stations, definitely it will be costly because the ODRM cost is cheap (RM 45, 000) compared to BAM (RM 150, 000) (Md Yusof et al., 2009) and need good maintenances. Therefore, a new alternative instrument such as Optical Direct Reading Monitors (ODRM) will enable air pollutants to be monitored more comprehensively even at areas without CAQMS. Even though DoE has set up their monitoring station, the number of monitoring stations is limited. With the use of simple instruments and cost effective, the air quality in areas without monitoring stations can be monitored and assessed. Monitoring can be carried out by DoE as well as the local authority concerned.

There are many researchers comparing the mass concentration results of the BAM and gravimetric methods (Gehrig et al., 2005; Hauck et al., 2004; McNamara et al., 2011). However, in this research, PM_{10} concentration recorded by the ODRM was compared with data monitored using BAM provided by DoE. Optical direct reading monitor (ODRM) was used to monitor PM_{10} concentration at selected stations. However, PM_{10} concentration recorded using ODRM and BAM was different (Md Yusof et al., 2010). This is due to different detection method between both instruments (ODRM used laser and BAM used beta ray) and response time for ODRM was set to one minutes, while BAM records hourly $PM_{10.}$ In addition, ODRM is portable instrument and the accuracy of the reading might be affected during transportation of this instrument. Therefore, an appropriate coefficient is needed to make sure the reading obtained from the ODRM is comparable with the reading obtained from the BAM. Furthermore, reading recorded by ODRM and BAM are influenced by meteorological factors (Chung et al., 2001). Therefore, it is crucial to consider influence of this meteorological factors on different reading recorded by ODRM and BAM.

1.5 OBJECTIVES

The objectives of this research are:-

1. To determine the influence of meteorology on PM_{10} concentration using ODRM and BAM.

2. To estimate correction factor (*k*) that relates ODRM and BAM by using regression techniques.

3. To identify the best correction factor (*k*) between ODRM and BAM based on performance indicator.

1.6 SCOPE OF STUDY

In Malaysia, Beta Attenuation Monitor (BAM) is the standard instrument used by DoE to measure particulate matter in 52 monitoring stations. This instrument automatically measures and records hourly particulate mass concentration in ambient air. It uses beta ray attenuation to calculate collected particle mass concentration in the units of $\mu g/m^3$. For this research, Optical Direct Reading Monitor (ODRM) was used to monitor PM_{10} concentration at CAQMS conducted by Alam Sekitar Malaysia (ASMA). The station selected for this research is Prai and Seberang Jaya. Both stations are situated in the north part of Peninsular Malaysia.

Quantile regression was used to investigate the relationship between the ODRM and BAM monitoring record. A 24 hour PM_{10} monitoring was conducted for 14 days for Perai station and 29 days for Seberang Jaya station. In all, total 384 for Perai PM_{10} data were collected. For seberang Jaya, 648 data were collected. For both sites, PM_{10} concentration collected using the Optical Direct Reading Monitor (ODRM) co-located with Beta Attenuation Monitor (BAM). Temperature, relative humidity, wind speed and wind direction were also recorded using ODRM and BAM for both site Perai and Seberang Jaya.

1.7 THESIS OUTLINE

This thesis has five chapters and the brief outlines of this thesis are as follows.

Chapter 1 gives an introduction about air quality monitoring in Malaysia and sources of air pollution in Malaysia. This chapter also includes the problem statement, objectives, scope of study and the thesis outline.

Chapter 2 discussed about the literature review of the research area (PM_{10} and measurement for PM_{10}), and also review that determines to what extent the issues related to this research has been investigated. From this chapter, a good view and knowledge about research area can be undertaken.

Chapter 3 describes the methodologies that have been used in this research. The area of study, setting and sitting of instrument, monitoring of PM_{10} using ODRM and BAM, and method to analyse the monitoring records were also discussed in this chapter.

Chapter 4 presents the result from data analysis in the form of graphical techniques and tables, for all two methods and meteorological effect with the detail discussion.

Chapter 5 gives conclusion of this research and list of recommendations for future research

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Sherman and Matson, (2003) defined air pollution as the presence of undesirable levels of physical or chemical impurities, e.g the existence of contaminants that posed a possible health risk to human. Many organization such as the World Health Organization (WHO, 1999) recognized particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), lead (Pb) and sulfur dioxide (SO_2), as classical pollutants presenting a hazard to sensitive populations. Air pollution now becomes an increasing source of environmental degradation in the developing nations of East Asia (Alles, 2009).

The air pollution in Malaysia has not reached a critical level as in other metropolitan areas in Asia, like Jakarta or Manila (Sastry, 2002). However, air pollution levels in Malaysia is increasing despite tight regulations, and increase in the number of vehicle, distance travelled and growth in industrial production would worsen the air pollution (Afroz et al., 2003).

Air quality in Malaysia is a major concern as the nation forged ahead to become an industrialized nation by the year 2020. The Malaysian Air Pollution Index (API) is obtained from the measurement of PM_{10} and several toxic gases such as SO_2, CO, NO_2, and O_3. The air quality status in Malaysia is determined according to API, which indicates the level of pollution in the atmosphere. The API system of Malaysia closely follows the Pollutant Standard Index (PSI) system of the United States of America. According to Department of Environment, the (API) shows that the overall air quality for Malaysia in 2010 was between good to moderate levels most of the time. Figure 2.1 show the Malaysia air quality for 2010 and 2011.

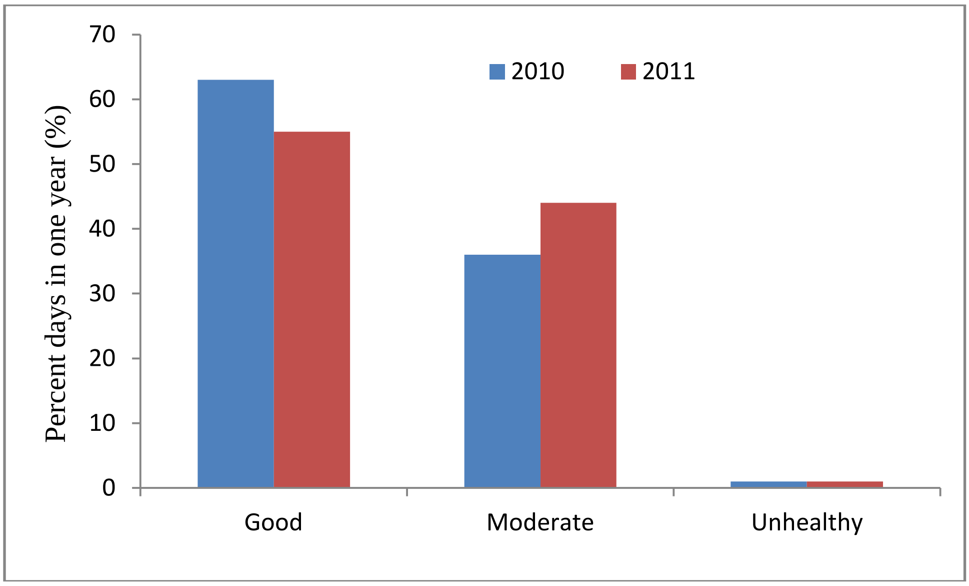


Figure 2.1 Malaysia Air Quality in 2010 and 2011(DoE, 2011; 2012)

Overall number of good air quality in 2011 were decreased (55 percent of the time) compared to that in 2010 (63 percent of the time) while remaining 36 percent at moderate level and one percent at unhealthy level. However, peatland fires resulting in transboundary air pollution that occurred in the Southern Asean region in the month of October resulted in a short spell of haze episode in the southern part of

Peninsular Malaysia (DoE, 2010; DoE, 2011). DoE also reported that the overall air quality of the northern region of the West Coast of Peninsular Malaysia (Perlis, Kedah, Pulau Pinang and Perak), was between good to moderate most of the time. The pollutants of concerned were ground level ozone (O_3) and PM_{10} (DoE 2012).

2.2 CONTINUOUS AIR QUALITY MONITORING IN MALAYSIA

In order to ascertain the quality of the environment in Malaysia, the Department of Environment (DoE) regularly monitor the air quality. The air quality monitoring, which involves measurements of total suspended particulates, ozone, carbon monoxide, nitrogen dioxide, sulphur dioxide and particulate matter (PM_{10}) through 52 monitoring stations (Figure 2.2 and 2.3) categorised as industrial, background urban and sub urban station (DoE, 2011). A continuous automatic monitor which gives instantaneous measurements of gaseous pollutants such as CO, SO_2, NO_2 and O_3 as well as suspended particulate matter and total hydrocarbon was used as monitoring equipments by the DoE to assess air quality (Abdullah,1995).

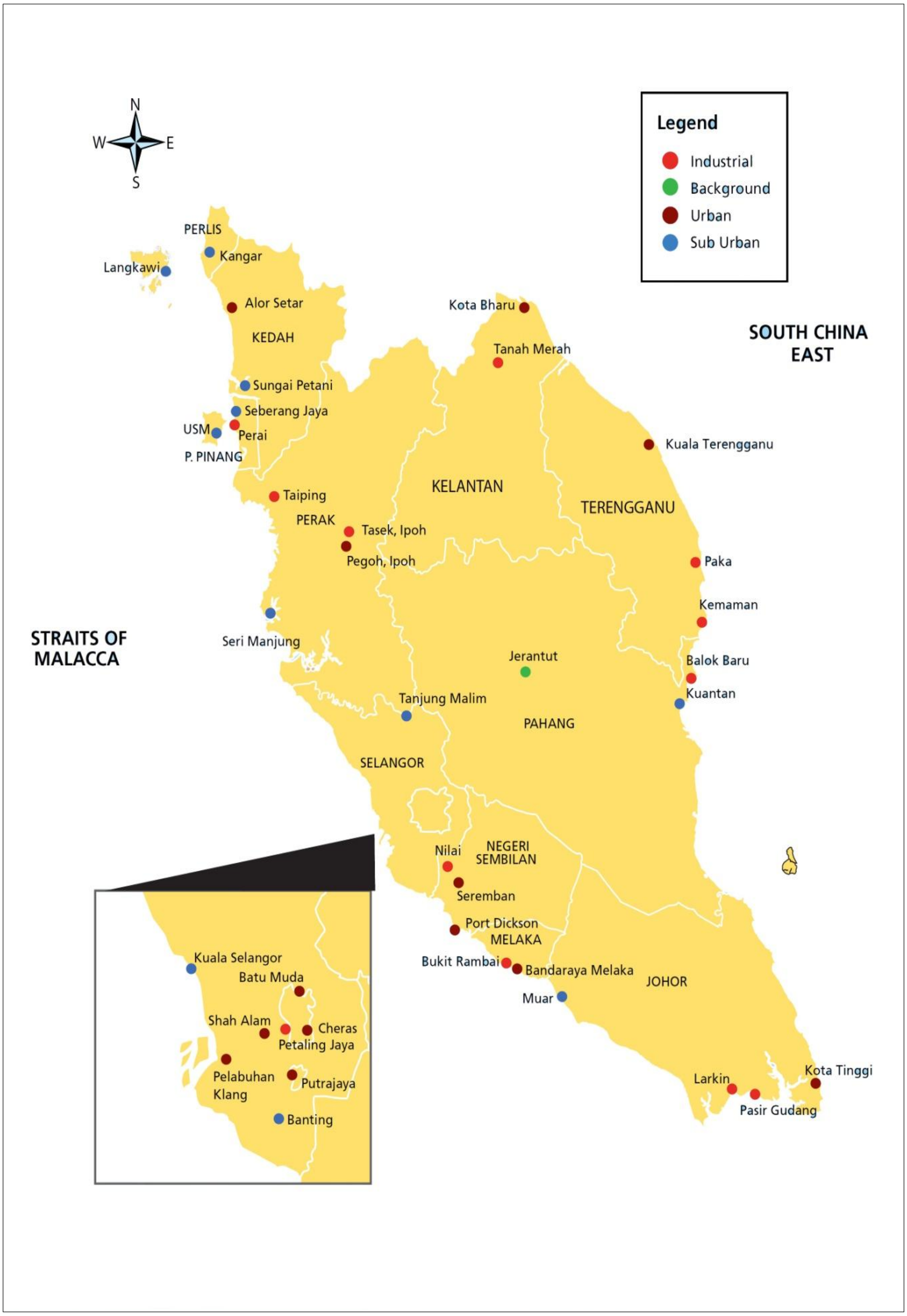


Figure 2.2 Continuous Air Quality Monitoring Station (CAQMS) in Peninsular Malaysia (DoE, 2011).

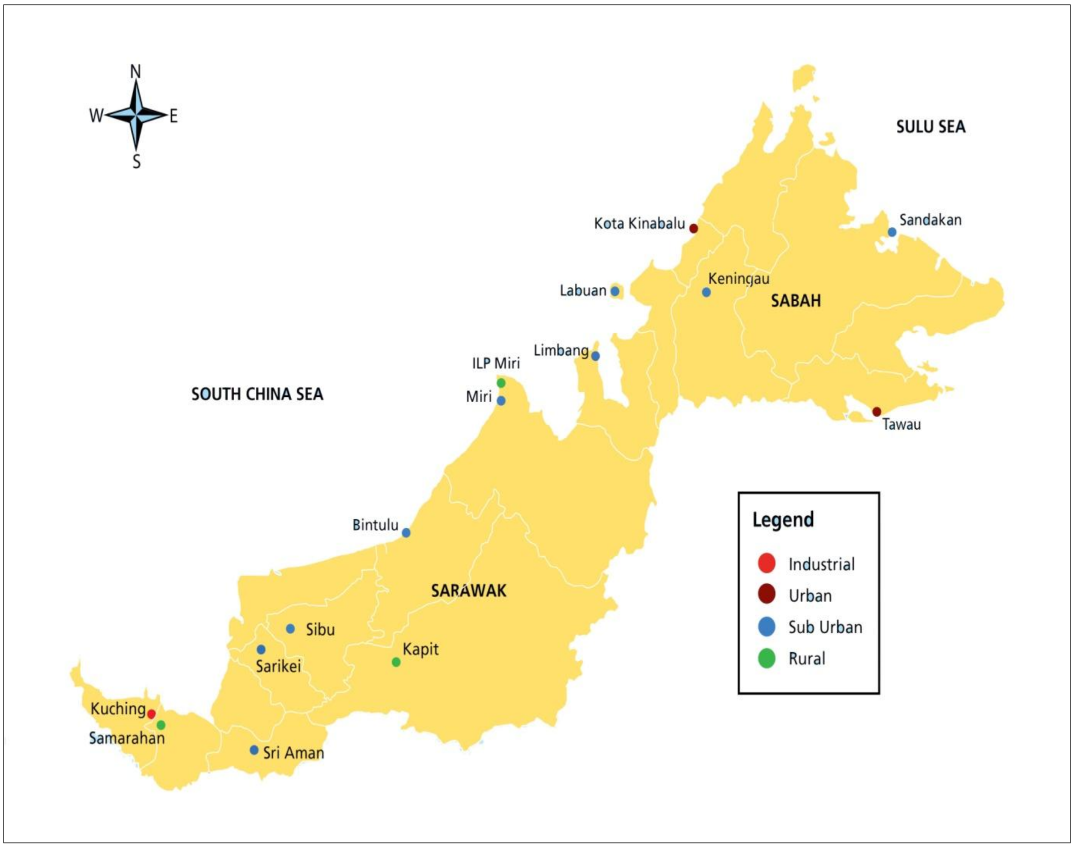


Figure 2.3 Continuous Air Quality Monitoring Station (CAQMS) in East Malaysia (DoE, 2011).

2.3 COMMON SOURCES OF PM_{10}

US EPA, (2004) defines particulate matter (PM) as a mixture of solid particles and liquid droplets found in the air. PM can be in sizes or colors large or dark enough to be observed or it can be so small that an electron microscope is required to distinguish it. Coarse particles are formed by mechanical disruption (e.g. crushing, grinding, abrasion of surfaces), evaporation of sprays, and suspension of dust. PM_{10} particles are small enough to be inhaled and accumulate in the respiratory system (Colls, 1997).

Particulate matter can originate from many sources. Generally, any activity which involves burning of materials or any dust generating activities are sources of PM. Some sources are natural, such as volcanoes and water mist (Bates, 1995). PM is introduced to the air through both natural and human causes (Harrison and Yin, 2000). PM from specific sources typically follow short term and long term (seasonal) trends (Yatin et al., 2000). For example, space heating generates more combustion related PM emissions during the cold seasons while, at the same time, snow cover can inhibit PM emissions from the soil.

QUARG (1996) described that primary particles are those directly emitted to the atmosphere from sources such as road traffic, coal burning, industry, windblown soil and dust and sea spray. On the other hand, secondary particles are particles formed within the atmosphere by chemical reaction or condensation of gases, and the major contributors are sulphate and nitrate salts formed from the oxidation of sulphur dioxide and nitrogen oxides respectively.

The primary sources of PM in Malaysia are motor vehicles, diesel trucks, industrial emissions, agricultural, slash and yard waste burning, and even exhaust from lawn mowers and boats (DoE, 2011). PM concentrations tend to be high especially in area with greater population density, nearby industries or agriculture, or where local topography or weather conditions contribute to air stagnation (Ebelt et al., 2005).

2.3.1 Traffic Emission

Vehicular emissions came in many processes, such as combustion products from fuel and oil, wear products from brake linings, tyres, bearings, car body and road material, and the resuspension of road and soil dust (Laschober et al., 2004). Traffic is an effective source of both fine and coarse mode primary particles, condensable organic gases, and a major source of nitrogen oxides that then form secondary nitrate aerosols. Particles of condensed carbonaceous material are emitted mainly by diesel vehicles and poorly maintained petrol vehicles (Vardoulakis et al., 2003). Diesel exhaust particles have been shown to display a multimodal size distribution (Kerminen et al., 1997) and are mainly carbonaceous agglomerates below 100 nm in diameter, whereas particles emitted by gasoline vehicles are also mainly carbonaceous agglomerates but considerably smaller, ranging from 10 to 80 nm (Morawska and Zhang, 2002).

Particulate matter originating from traffic can present at elevated concentrations especially during high traffic density and poor dispersion conditions, e.g. in street canyons, which can lead to high human exposures to traffic-related pollutants (Vardoulakis et al., 2003). Identification of traffic related particulate matter in source apportionment studies has become difficult due to phasing out of Pb as an additive to gasoline. Elements that have often been associated with vehicular emissions include Cu, Zn, Pb, Br, Fe, Ca and Ba (Huang et al., 1994; Cadle et al., 1997; Kemp 2002; Morawska and Zhang 2002; Sternbeck et al., 2002). Emissions of many metallic elements from vehicular sources are mainly due to non exhaust emissions, examples from the wearing of tyres, brakes and other parts of vehicles (Sternbeck et al., 2002; Adachi and Tainosho, 2004; Laschober et al., 2004; Lough et al., 2005). In addition to road traffic, emissions from the main and auxiliary engines of ships can be a significant source of particulate matter and associated elements such as V and Ni (Lyyranen et al. 1999) at certain locations (Ohlstrom et al., 2000; Colvile et al., 2001; Isakson et al., 2001).

2.3.2 Stationary sources

The most significant stationary combustion sources include energy production facilities such as municipal power plants, waste incineration, and residential combustion. Several industrial processes, such as iron and steel production, also involve combustion of fossil fuels or biomass for generating power and heat needed for the process. Most of these sources are considered point sources, although smaller and more widespread sources such as residential combustion could also be considered as an area source (Morawska and Zhang, 2002) .

Physical and chemical characteristics of the particles emitted from stationary source categories depend on the combustion process itself, and the type of fuel burnt (solid, liquid, or gas). Combustion processes and properties of particulate matter emitted from these sources have been comprehensively reviewed by Morawska and Zhang (2002). The major industrial processes include factories processing metals and chemicals, materials handling, construction and mining. Particulate matter from these sources are partly released as fugitive emissions, which are not collected and released in a controlled manner, but emitted from a variety of points and areas connected to a process (Seinfeld and Pandis, 1998). Chemical and physical properties of fugitive emissions depend on the processes by which they are emitted. Since the bulk of most trace metals are emitted from industrial processes, their concentrations are spatially heterogeneous and subsequently, their measurement is quite sensitive in terms of location; however, the reported concentrations of trace metals in major cities demonstrate rather similar levels of trace metals (Harrison and Yin, 2000).

2.3.3 Biomass burning

Biomass burning is the burning of living or dead vegetation, forests (tropical, temperate, and boreal) savannas, and agricultural lands, is a persistent activity in many tropical countries such as Brazil, Indonesia, Nigeria and Mexico (Balasubramanian, 2001). Biomass burning is one of many sources of particulate pollution in Southeast Asia, and the smoke haze related to biomass burning is a recurring environmental problem in Southeast Asia which affects air quality not only in the source regions, but also in the surrounding areas (Tayeh and Ramli, 2012).

Huge amounts of air pollution are produced worldwide by the annual burning of 3 billion metric tons of biomass such as wood, leaves, trees, grass and trash. Biomass burning represents the largest source of air pollution in many rural areas of the developed and developing world. Biomass burning is used to create heat, to clear forests, to dispose of leaves, crop stubble, trash and wood (Abelson, 1994). Globally, biomass burning is estimated to produce 40 percent of the carbon dioxide, 32 percent of the carbon monoxide, 20 percent of the particulates, and 50 percent of the highly carcinogenic poly-aromatic hydrocarbons produced by all sources (Levine, 1990).

Burning vegetation releases large amounts of particulates (solid carbon combustion particles) and gases, including greenhouse gases that help warm the Earth. Greenhouse gases may lead to an increased warming of the Earth or human initiated global climate change (NASA, 2012). Biomass burning particulates impact climate and can also affect human health when they are inhaled, causing respiratory problems (Finlayson-Pitts and Pitts Jr 1999). Since fires produce carbon dioxide, a major greenhouse gas, biomass burning emissions significantly influence the Earth's atmosphere and climate (Buseck and Adachi, 2008). Biomass burning in Asia is an important contributor to air pollution in the region (Streets et al., 2003). On a regional scale, uncontrolled biomass burning from the land clearing processes can result in transboundary haze, poor visibility and degradation of the local air quality between neighbouring countries such as these in Southeast Asia (Mahmud, 2005).

In Sweden, combustion of biomass is increasing and this may lead to locally increased particle concentrations in the ambient air (Johansson et al., 2003). Biomass burning has attracted the attention of people around the world due to its contribution of particles (Andreae, 1991; Ostermann and Brauer, 2001; Dennis et al., 2002) and gases in the atmosphere (Dennis et al., 2002). Particulate matter released from biomass burning can be divided into several categories such as suspended particulate matter (SPM), total suspended particulate (TSP) and total particulate matter (TPM) represent the sum of all the suspended particles in the atmosphere at a given time (Ostermann and Brauer, 2001).

2.4 PM_{10} CHARACTERISTICS

PM is characterized by its physical, chemical and optical properties. The quality of air that human breathe in every second is determined by the amount of particulate matter in it (Grobety et al., 2010). These particulate matters were measured by their particles size. Those with the particles size less than 10 µm (PM_{10}) is used to monitor the air quality which in turn is related to the health problems of the workers or public at large (Alias et al., 2007). The most important characteristic of particulate matter (PM) is the particle size. This property has the greatest impact on the behavior of particulate matter in control equipment, the atmosphere, and the respiratory tract. Particles of importance in air pollution control span a broad size range from extremely small (0.01 µm) to more than 1000 µm (US EPA, 2004).

The suspended particles vary in size, composition and origin. It is convenient to classify particles by their aerodynamic properties because, (a) these properties govern the transport and removal of particles from the air, (b) they also govern their deposition within the respiratory system and (c) they are associated with the chemical composition and sources of particles (WHO, 2003).

2.4.1 Physical Characteristic

Particulate matter (PM) exceeding 2.5 μm in aerodynamic diameter is generally defined as coarse particles, while particles smaller than 2.5 μm ($PM_{2.5}$) are called fine particles (World Bank Group, 1998). Particles of any substances that are less than 10 or 2.5 μm diameter make up a large proportion of dust that can be drawn deep into the lungs. Larger particles tend to be trapped in the nose, mouth or throat (Phalen, 2002).

The concentration and other characteristics of suspended particulate matter are determined by the presence and activity of sources. Once formed, particles change their size and composition by condensation or evaporation, by coagulating with other particles or by chemical reactions (Seinfeld and Pandis, 1998). Pohjola et al. (2000), found that meteorological factors such as wind speed and direction, temperature, amount of precipitation, and the height of the atmospheric boundary layer, are most important in governing the concentration variations of particulate matter. The highest PM concentrations are often reported during stable meteorological conditions such as inversion with low wind speeds (Pohjola et al., 2004). Also the physical and chemical processes affecting the particles are regulated to a great extent by meteorological factors.

2.5 HEALTH EFFECTS OF PARTICULATE MATTER

There are a very limited number of studies that relate air pollution to its health impact in Malaysia. The lack of data gathering for environmental epidemiological analysis makes it difficult to estimate the health impact of air pollution (Afroz et al., 2003). Whilst epidemiological studies have consistently demonstrated adverse effects of particulate matter exposure on human health, the mechanism of effect is currently unclear (Harrison and Yin, 2000).

Some research has identified several plausible biological mechanisms for both the initial pulmonary injury and the consequent systemic effects (Neas et al., 1999). The respiratory system is the major route of entry for airborne particulates. The deposition of particulates in different parts of the human respiratory system depends on particle size, shape, density, and individual breathing patterns (mouth or nose breathing) (World Bank Group, 1998).

In adults, PM exposure was associated with increased incidence of respiratory symptoms, transient decrements in pulmonary function levels, and the onset of chronic pulmonary disease. Neas et al. (1999) and Seaton et al. (1995), has identified several plausible biological mechanisms for both the initial pulmonary injury and the consequent systemic effects following PM exposure and the initial pulmonary injury may be related to one or more properties of PM and its constituents including physical, chemical and biological characteristics. The most obvious