MODELING LOCATIONAL DIFFERENCES AND PREDICTION OF TEMPORAL CONCENTRATION OF PM_{10} USING TIME SERIES ANALYSIS

NURULILYANA SANSUDDIN

UNIVERSITI SAINS MALAYSIA

2010

MODELING LOCATIONAL DIFFERENCES AND PREDICTION OF TEMPORAL CONCENTRATION OF PM_{10} USING TIME SERIES ANALYSIS

NURULILYANA SANSUDDIN

Thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy

UNIVERSITI SAINS MALAYSIA

OCTOBER 2010

PEMODELAN STATISTIK BAGI PERBEZAAN LOKASI DAN PERAMALAN KEPEKATAN BAGI PM_{10}

ABSTRAK

Kajian ini bertujuan untuk memodelkan dan meramalkan kepekatan PM_{10} dengan menggunakan taburan kebarangkalian dan model siri masa untuk membantu mengekang kesan negatif PM_{10} terhadap kesihatan manusia. Sepuluh stesen pemonitoran dengan lima tahun rekod pemonitoran PM_{10} dari 2000 hingga 2004 telah digunakan untuk kajian ini. Empat taburan iaitu taburan gamma, log-normal, Weibull dan Gaussian songsang telah digunakan untuk menyesuaikan data purata dalam jam untuk $PM_{10.}$ Berdasarkan kepada lima petunjuk prestasi yang digunakan, taburan gamma dipilih untuk mewakili Johor Bharu, Jerantut, Kangar dan Nilai manakala, taburan log-normal boleh digunakan untuk mewakili Kota Kinabalu, Kuantan, Kuching, Manjung, Melaka dan Seberang Perai. Ramalan kepekatan PM_{10} yang melebihi tahap piawaian dalam unit hari dianggarkan menggunakan taburan terbaik dan dibandingkan dengan data sebenar. Dalam rangka untuk mengkalibrasi rekod pemonitoran daripada E-sampler dan 'Beta Attenuation Mass' (BAM), faktor-k paling tepat yang diberikan oleh stesen Kuching telah digunakan. Selain itu, data purata kepekatan harian bagi PM_{10} digunakan bagi mendapatkan model siri masa terbaik. Tiga jenis model siri masa digunakan iaitu 'auto mundur (AR)', 'purata bergerak (MA)' dan 'auto mundur purata bergerak (ARMA)'. AR(1) dikenalpasti sebagai model terbaik untuk mewakili semua stesen kecuali untuk Jerantut yang diwakili oleh ARMA(1, 1).

STATISTICAL MODELING FOR LOCATIONAL DIFFERENCES AND PREDICTION OF TEMPORAL PM_{10} CONCENTRATION

ABSTRACT

The aim for this research is to model and predict the PM_{10} concentrations using the probability distributions and time series models to help curb the adverse impact of PM_{10} on human health. Ten monitoring stations with five years PM_{10} monitoring records from 2000 to 2004 were used in this research. Four distributions namely gamma, log-normal, Weibull and inverse Gaussian distributions were used to fit hourly average of PM_{10} observation records. Based on the five types of performance indicator values, the gamma distribution is chosen as the best distribution to fitting Johor Bharu, Jerantut, Kangar and Nilai while, log-normal distribution was fitted to Kota Kinabalu, Kuantan, Kuching, Manjung, Melaka and Seberang Perai. Predicted PM_{10} concentrations which exceeds the threshold limit in unit of days were estimated using the best distributions and were compared to the actual monitoring records. In order to calibrate the monitoring records from E-sampler and Beta Attenuation Mass (BAM), the most appropriate k-factor given by Kuching station was used. In addition, the daily average of PM_{10} concentrations was used to find the best time series model. Three types of time series models were used named autoregressive (AR), moving-average (MA) and autoregressive moving-average (ARMA). The AR(1) is identified as the best model to represent all stations except for Jerantut which is represented by the ARMA(1, 1).

ACKNOWLEDGEMENT

Alhamdulillah, first of all I would like to thanks to Allah, with His permission, I manage to finish my research successfully.

I would like to express my deep gratitude and appreciation to my research supervisor, Associate Professor Ahmad Shukri Yahaya and my co-supervisor, Associate Professor Dr. Nor Azam Ramli for giving me the opportunity to conduct this research under their supervisions. Their scholastic guidance, advice, support, important suggestion, and continuous encouragement made this work possible.

I would also like to thank the members of Clean Air Research Group: Tengku Nuraiti Tengku Izhar, Noor Faizah Fitri Md. Yusof, Nurul Adyani Ghazali, Wesam AlMadhoun and Muhammad Sobri. Their academic knowledge, friendship, cooperation and help during my study were invaluable.

I would like to gratefully like to acknowledge Department of Environment Malaysia for providing data for this research and Alam Sekitar Malaysia Bhd. (ASMA) for their help in conducting and processing measurements collected during the monitoring campaign all over the country.

Finally and most importantly, I would like to thank the following people for their good wishes, continuous support and endless encouragement throughout this research: my parents, Sansuddin Taib and Nor Aini Mas'ud, my sisters, Nor Hafizan Sansuddin and Nur Auni Sansuddin and my best friend, Liana Syafinaz Ab Manaff.

LIST OF FIGURES

LIST OF PUBLICATIONS

1. **Nurulilyana Sansuddin**, Nor Azam Ramli and Ahmad Shukri Yahaya (2007) *The incidences of exceedences of PM_{10} concentration in Kuala Lumpur.* In Nor Azam Ramli, Ahmad Farhan Mohd Sadullah, Hamidi Abdul Aziz, Badorul Hisham Abu Bakar, Ismail Abustan, Leong Lee Vien, Mohamad Razip Selamat, Megat Azmi Megat Johari, Wan Hashim Wan Ibrahim, Wan Muhd Aminuddin Wan Hussin, Choong Kok Keong and Shafida Azwina Mohd Shafie (eds) Abstrak AWAM 2007 Persidangan Kebangsaan Keempat Kejuruteraan, Langkawi, Kedah, 2007, May 28th – 31st , ISBN 978-983-42190-1-7

2. **Nurulilyana Sansuddin**, Nor Azam Ramli and Ahmad Shukri Yahaya (2009) *Modeling and prediction for short and long-term duration of PM_{10} concentration at Nilai.* In Nor Azam Ramli, Megat Azmi Megat Johari, Mohd. Razip Selamat, M. Mohamad Ali, A. A. Mokammel Haque, Rozi Abdullah, Meor Othman Hamzah (eds) Persidangan Kebangsaan Kejuruteraan Awam Kelima (AWAM 2009), Corus Hotel, Kuala Lumpur, 2009, October 27th – 29th , ISBN 978-983-42190-2-4

3. Ahmad Shukri Yahaya, Nor Azam Ramli, Fauziah Ahmad, **Nurulilyana Sansuddin** and Noor Faizah Fitri Md Yusoff (2010) *Modelling and Predictions of Air Pollutants Concentrations in Selected Cities.* Malaysia: Pusat Pengajian Kejuruteraan Awam, Universiti Sains Malaysia. ISBN 978-983-42190-6-2

4. Md Yusof, N.F.F., Ramli, N.A., Yahaya, A.S., **Sansuddin, N**., Ghazali, N.A. and AlMadhoun, W. (2010) *Monsoonal differences and probability distribution of PM_{10} concentration*. Environmental Monitoring and Assessment, 163, p. 655 - 667

5. Ghazali, N. A., Ramli, N. A., Yahaya, A. S., Md. Yusof, N. F. F. and **Sansuddin, N.** (2009) *Transformation of nitrogen dioxide into ozone and prediction of ozone concentrations using multiple linear regression techniques.* Environmental Monitoring and Assessment, 165, p. 475 – 489

6. **Sansuddin, N**., Ramli, N. A., Yahaya, A. S., Md Yusof, N. F. F. and Ghazali, N. A. (2010) *Statistical analysis of PM_{10} concentrations at different locations in Malaysia.* Atmospheric Environment, Reference number: ATMENV-D-10-00764 (Communicated)

LIST OF TABLES

TABLE OF CONTENTS

CHAPTER 6 – CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 1

INTRODUCTION

1.1 AIR POLLUTION IN MALAYSIA

Malaysia is composed of the Peninsular Malaysia and the states of Sabah and Sarawak in the island of Borneo. It has a total land area of 330, 252 square km characterized by mostly mountainous terrain (WHO, 2005). Malaysia is composed of 13 states and three federal territories. Kuala Lumpur, the capital city is within the federal territory of Wilayah Persekutuan. Almost 80 percent of the country is covered by tropical rainforest which is home to thousands of flora and fauna.

Based from a 2008 estimate recorded by WHO (2008), the population in Malaysia for the year was 27.6 million. Of this, 17.6 million are in the age bracket of 15 until 64 years old, 8.8 million below 14 years old and 1.2 million above 64 years old. The annual population growth rate is 2.6 percent, which is twice the global rate of 1.3 percent. About 62 percent of the populations live in urban areas.

Malaysia has a total road length of 91, 619.60 km, comprising 73, 854.62 km of state road and 17, 764.98 km of federal road. As recorded by WHO (2008), in 2008, 6527 deaths due to traffic accidents were recorded and 60 percent were motorcyclists.

Air pollution is one of the most important environmental problems, which is restricted mostly to the cities. Bagad (2009) defined air pollution as the undesirable contamination of gas, smoke, dust, fume, mist, odour or chemical particulates in the atmosphere which are injurious to human beings, plants and animals. Elsom (1992) gave a more thorough definition of air pollution as the presence in the atmosphere of substances or energy in such quantities and of such duration that is liable to cause harm to life, damage to man-made materials and structures, or changes in the weather and climate.

Additionally, atmospheric pollutants also can have adverse effects on the environment where the effects normally closely related to the type and concentration of pollutants to which the systems such as humans, ecosystems and buildings are exposed where the exposure is a consequence of the location and characteristics of the emitting sources and the prevailing weather conditions (Watt *et al.*, 2009).

Monitoring data and studies on ambient air quality show that some of the air pollutants in several large cities in Malaysia are increasing with time and are not always at acceptable levels according to the national ambient air quality standards (Department of Environment, Malaysia, 2002). The industrialization policy has started to impose costs in terms of pollution and the degradation of urban environment. Depletion of air and water quality, and contamination by industrial wastes has become more serious in recent years. Among them, air pollution is reported to cause the greatest damage to health and environmental in Asian countries (Hughes, 1997). However, Godish (2004) indicate that such pollution has relatively low significance in causing health and welfare since levels of contaminants associated with natural air pollution are typically very low, large distances often separate sources of natural pollution and large human populations and sources of natural pollution, such as forest fires, dust storms and volcanoes, are episodic and transient.

In addition towards air pollution in Malaysia, Fitri *et al.* (2009) and Juneng *et al.* (2009) observed the air pollutant concentrations during monsoon periods which indicates that the high concentrations of pollutant is drastically reduced during the subsequent months when wind changes signify the beginning of the rainy season over part of Peninsular Malaysia and Borneo based on Southwest monsoon (June – September) and Northeast monsoon (November – March). In line with the need for regional harmonization and for easy comparison with countries in the region, the Department of Environment (Malaysia) revised its index system in 1996, and the Air Pollutant Index (API) was adopted. The API system of Malaysia (as shown in Table 1.1) closely follows the Pollutant Standard Index (PSI) system of the United States (Department of Environment, Malaysia, 1996).

Table 1.1 Malaysia Air Pollutant Index (API)

API	DESCRIPTOR
0 – 50	Good
51 – 100	Moderate
101 – 200	Unhealthy
201 – 300	Very unhealthy
> 300	Hazardous

(Source: Department of Environment, Malaysia, 1996)

Subsequently, the Air Pollution Index (API) was introduced as an index system for classifying and reporting ambient air quality in Malaysia. The concentrations of five pollutants (sulphur dioxide, nitrogen dioxide, ozone, carbon monoxide and particulate matter below ten micron in size or PM_{10}) are measured continuously on an hourly basis, with the highest value of all individual pollutants for that hour converted into sub-index values. This is expressed as the API for the hour. Consequently, API values can, by and large, be interpreted directly as PM_{10} values (Ramli *et al*., 2001). Awang *et al*. (2000) and Ramli *et al*. (2001) found that in general, during haze events, it is PM_{10} which is at the highest level when expressed on an API basis and the government can announce an emergency status for locations with prolonged APIs above 300. Therefore, Table 1.2 summarizes the API in relation to PM_{10} levels.

Table 1.2 API intervals, description of air quality and relation with PM_{10} values

API INTERVALS	DESCRIPTION	PM_{10} VALUES ($\mu g/m^3$)
0 – 50	Good	0.00 – 75.00
51 – 100	Moderate	76.50 – 150.00
101 – 200	Unhealthy	152.00 – 350.00
201 – 300	Very unhealthy	350.70 – 420.00
301 – 500	Hazardous	420.80 – 600.00
Above 500	Very hazardous	Above 600

(Adopted from Department of Environment, Malaysia (1996), Awang *et al*. (2000) and Ramli *et al*. (2001))

The index value of 100 for PM_{10} corresponds to the maximum concentration level of the pollutant before it is considered as unhealthy. Thus, the API sub-index for PM_{10} is set at Malaysian Ambient Air Quality Guidelines (MAAQG) value of 150 $\mu g/m^3$ for 24 hour running average. The MAAQG levels were set at the concentration for each pollutant below which no adverse health effects had been observed (Department of Environment, Malaysia, 1994).

Table 1.3 Malaysian Ambient Air Quality Guidelines (MAAQG)

Pollutant	**Averaging Time**	**Malaysia Guideline**	
		ppm	**μg/m³**
Particulate matter (PM_{10})	24 Hour 1 Year		150 50
Carbon monoxide (CO)	1 Hour 8 Hour	30 9	35 10
Nitrogen dioxide (NO_2)	1 Hour 24 Hour	0.17 0.04	320
Sulphur dioxide (SO_2)	1 Hour 24 Hour	0.13 0.04	350 105
Ozone (O_3)	1 Hour 8 Hour	0.10 0.06	200 120

(Source: Department of Environment, Malaysia, 2002)

The Malaysian Ambient Air Quality Guidelines (MAAQG), which forms the basis for interpretation the API, is presented in Table 1.3. In the MAAQG, the listed concentration values are regarded as being the 'safe levels' (Awang *et al*., 2000). As a main pollutant that is involved in this research, the guidelines secure concentration or 'safe level' for particulate matter (PM_{10}) is at 150 $\mu g/m^3$ for 24 hour averaging time.

Air quality status in Peninsular Malaysia according to the land use and level of compliance based on studies conducted by the Department of Environment (Malaysia) from 1981 to 1983 demonstrated that serious problems existed only in highly urbanized areas, particularly with respect to dust fall-out, suspended particulate matter and lead in the air along congested roadside. Those problems were largely attributed to the emissions from motor vehicles (Awang *et al*., 2000).

Separate study on fine and coarse atmospheric particle concentrations in Kuala Lumpur between 1988 and 1990 by Rashid *et al*. (1997) showed that the highest monthly mean concentration was observed between January and March with a second peak occurring in July – August, while the levels tend to decrease in June and December partially due to particulate washout effects and also to the absence of strong ground-based inversions during the rainy period.

Earlier, Chow and Lim (1984) observed that maximum and minimum levels of particulate concentrations corresponded, respectively, with the relatively dry and wet seasons experienced in the region. They also suggested that scavenging effects of rainfall on particulates appeared to be one of the important contributing factors besides frequency of calm conditions and wind directions in determining the air quality in the area.

Besides, Abas *et al.* (2004) interpreted in terms of major sources of air pollution are due to local build-up of organic contaminants from vehicular emissions, smoke from burning and natural background. It is a result from the atmospheric stability during the haze episodes of 1997.

The ambient conditions during 1989 until 1995 provided a range of variability which was suitable for revealing the impacts of meteorological fluctuation. It was obvious that particulate emission levels peaked around August to October which coincided with dry seasons and air stagnation (wind velocity, 3 m/s). Evidently, the increase in particulate emission was a result of an increase in a number of acres of land burnt from wildfires and also due to exhaust emissions and from construction sources which increased over the last few years, particularly in the Klang valley (Awang *et al*., 2000).

In a separate study of daily samples by Rashid *et al*. (1997), from July 1988 to December 1990, atmospheric aerosols were segregated into fine (aerodynamic diameter less than 2.5µm) and coarse particles (2.5 – 10µm) and were analyzed for total elemental concentration. The analyses showed that the total elemental concentration of atmospheric aerosols consists of 19%, 33% and 53% fine particle, coarse particle and total particle fractions, respectively.

In 1996, only two out of 13 places monitored were affected by dust, in terms of particulate matter less than ten micron in size (PM_{10}), but only for 0.2% or less of the time. For 99.8% of the time, the air was considered 'clean' (Awang *et al*., 2000). According to Awang *et al*. (1997) and Department of Environment, Malaysia (1997), the generally good quality air prevailing throughout the country had been adversely affected largely by the forest and peat fires in the region in 1997. All 29 Continuous Air Quality Monitoring (CAQM), except the latest one in Miri, Sarawak which came into operation only in October 1997 onwards, had recorded hourly measurements of PM_{10} exceeding the MAAQG level of 150µg/m^3, up to 15% of the time for the year or about 1300 total number of hours recorded in Kuala Lumpur, and two the other most affected places were Klang (12%) and Gombak (10%).

The overall conditions did improve in 1998, except at some places during the early parts of the year, due to the local peat-forest fires in Miri, Sarawak (30% of the time, the measurements of PM_{10} exceeded the acceptable concentrations of 150µg/m^3), Kota Kinabalu (0.4%), Gombak (0.3%), Pengkalan Chepa (0.1%) and Kota Bharu (0.002%) (Awang *et al*., 2000).

Focusing on haze events, it is now a common phenomenon in urban and industrial areas in Malaysia due to increasing quantities of pollutants from local anthropogenic sources emitted into the atmosphere (Malaysian Meteorological Service, 1998). Malaysia had experienced several hazy episodes in the 1980s, 1990s and 2000s. A number of similar episodes have occurred subsequently and the 1997 haze episode is regarded as the most severe in Malaysian history. Nevertheless, this type of haze does not occur continuously and the levels are generally below those necessary to evoke an emergency status being called. Furthermore, they occur and pose an impact only at a local level. This can be categorized as ‘localized haze’ (Ramli *et al*., 2001).

Ayers *et al*. (1997) have focused on the haze event that occurred in Southeast Asia in September 1994. Their study showed that the general chemical nature of the haze aerosol at Petaling Jaya was that the PM_{10} component consisted of approximately one-quarter inorganic components, one-quarter elemental carbon and one-half organic material. Moreover, even the 'background' levels of PM_{10} at Petaling Jaya, at around 50 – 60µg/m^3, were primarily due to anthropogenic emissions. Furthermore, the time series of aerosol components indicated correlation with the PM_{10} series during the haze event, suggesting a definite smoke component.

Smoke haze is an influential factor from the burning of biomass and organic soil which produces large quantities of soot particles comprising burnt or partially burnt carbon. Because of its small size (approximately 90% of soot from biomass burning is less than 2.5µm in size and the reminder less than 10µm (Ward, 1990) the soot can be transported in the air for large distances and remain suspended for up to one week (Bridgman, 1990).

Referring to Nichol (1997), haze episodes in 1997 are the results of the trans-boundary movement of air pollutants emitted from forest fires and open burning activities in Indonesia coupled with emissions from local sources. Transmigration policy of the Indonesian government to relocate people from the densely populated island of Java has led to the opening-up of new land on a large scale in Sumatra and Kalimantan. The fastest and cheapest means of land clearance is to burn the forest. The Department of

Environment, Malaysia (1997) reported that a detection of hot spot via satellite imagery has shown that most of the fires started in plantation areas in Indonesia.

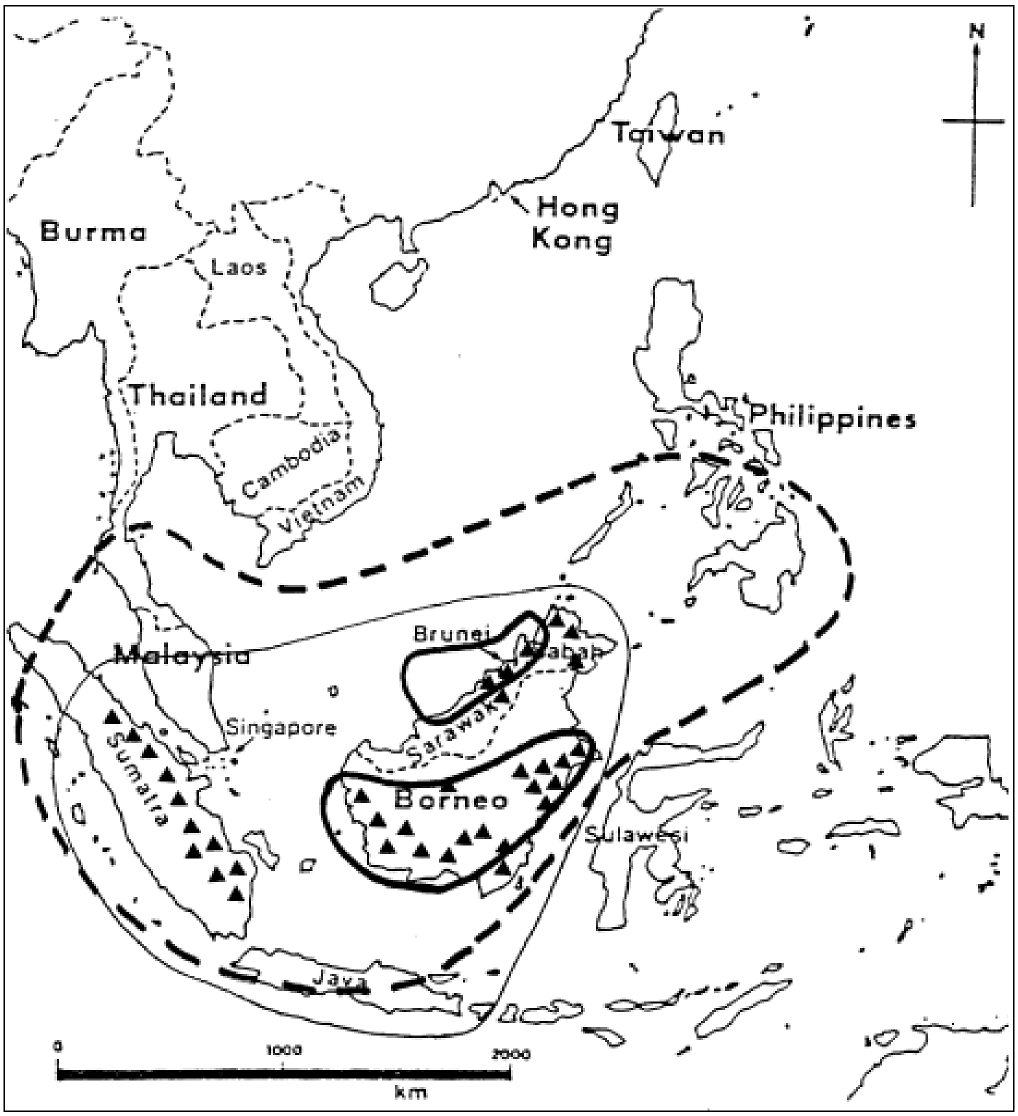

Figure 1.1 Approximate location of forest fire hot-spots and area affected by regional haze in Southeast Asia. (——) Aug–Oct 1994, (– –) July–Oct 1997, (▬) Feb–Apr 1998 and (▲) site of forest fires (Source: Radojevic and Tan, 2000)

Radojevic (1997 and 1998) had concluded that extensive forest fires in Borneo and Sumatra have been responsible for major regional haze episodes in Southeast Asia, notably in 1994, 1997 and 1998. The main forest fire hot-spots and the area affected by regional haze during the last three major episodes in Southeast Asia are indicated in Figure 1.1. In Indonesia, the 1994 fires consumed an area greater than 50 000 km^2 (Nichol, 1997) and during 1997 episode is estimated at around 21 000 km^2 (Simons, 1998).

The intrusion of transboundary particles arising from the Indonesian forest fires into Malaysia was the result of transport by the Southerly and North Easterly winds (Department of Environment, Malaysia, 1994). The transport of the haze to cities to the West of the source region such as Singapore, Kuala Lumpur and Penang, was due to its coincidence with the inter-monsoon 'doldrums' period of slow-moving, stable air masses at the equator (Nichol, 1997).

The situation has been worsened by the recurrence of the 'El Nino' Southern Oscillation (ENSO) warming trend which led to a very dry climate in the region in 1997, a phenomenon often seen in the early 1990s, which has also caused many unexpected forest fires (Ramli *et al*., 2001). Kelly (1995) stated that the period 1991 – 1994 corresponded to an ENSO event in the tropical Pacific, with drought throughout Australasia and Malaysia due to unusual high pressure over the region. The Department of Environment, Malaysia (1997) stated that the unusual prolonged severe drought caused by 'El Nino' which started in March 1997 aggravated the situation.

In 1998, the March API for Miri and Kota Kinabalu reached the hazardous level, mainly due to the high concentration of particulate matters (PM_{10}) from the forest and peat fires around the areas and aggravated by the dry weather conditions (Department of Environment, Malaysia, 1998).

Besides that, it is known that the trans-boundary pollution caused by forest fires may also cause the hazy condition. Likewise, the unhealthy air quality recorded in Sarawak from the middle of July to September 2002 was mainly due to transboundary pollution caused by forest fires in a neighbouring country. Except for the Limbang station, all other stations in Sarawak recorded unhealthy levels between 3 to 22 days, due to high levels of particulate matter in the air (Department of Environment, Malaysia, 2002).

A report from Department of Environment, Malaysia (2004) stated that in 2004, Malaysia experienced short periods of slight to moderate haze in the months of June, August and September brought about mainly by transboundary pollution. The land and the forest fires in several provinces in Sumatra as reported by the Association of Southeast Asian Nations (ASEAN) Specialized Meteorological Center (ASMC) coupled with the direct influence of South Westerly winds contributed to the deterioration of air quality in the west coast of Peninsular Malaysia. The fires in Kalimantan also contributed to the slight haze in the Southern part of Sarawak. Apart from these haze episodes, there were no other serious incidences of air pollution in 2004. Particulate matter (PM_{10}) and ground level ozone remained as the prevailing pollutants in the country.

On the other hand, following the prolonged dry season in the region, coupled with the direct influence of South Westerly wind, several parts of Malaysia experienced short-term mild to severe haze episodes from mid-May until mid-October 2005. The land and forest fires in the Riau Province of Central Sumatra, Indonesia as reported by the ASMC were the primary cause of transboundary pollution which was aggravated by the stable atmospheric conditions during the period (Department of Environment, Malaysia, 2005). Between 1 August 2005 and 15 August 2005, the central, Eastern and Northern parts of Peninsular Malaysia experienced severe haze. The hazy conditions in the Klang Valley and surrounding areas were more severe in intensity than that of September 1997 in Peninsular Malaysia (Department of Environment, Malaysia, 2005).

From early July to October in 2006, biomass burning in Indonesia caused severe smoke haze over Southeast Asia, affecting many neighbouring countries including Malaysia (Department of Environment, Malaysia, 2006; Hyer and Chew, 2010). The situation was worsened with the direct influence of South Westerly winds contributed to the deterioration of air quality during these periods. During the haze event, the air quality monitoring stations operated by Department of Environment (DoE) Malaysia and National Environment Agency (NEA) of Singapore constantly monitored the situation and provided air quality advisories to the public. Needless, the smoke haze had a strong negative impact on air quality in the region (Hyer and Chew, 2010).

The Southwest monsoon that is also known as the Northern hemisphere summer monsoon which considered by Fitri *et al.* (2009) in line to show the monsoonal differences in PM_{10} concentration in Malaysia, gives the facts that the differences in weather condition experienced in different monsoon do affect the concentration of PM_{10} readings.

Based on the Department of Environment, Malaysia (2007) report, the overall air quality for Malaysia in 2007 is improved significantly compared to 2006. This is due to the favourable weather conditions experienced which resulted in a decreased number of hotspots detected that consequence of no transboundary haze events are observed.

Most of the time in 2008, the overall air quality was between good to moderate levels where there was a slight improvement in the air quality as indicated by the increasing number of good air quality days recorded in 2008 (59 percent of the time) compared to that in 2007 (56 percent) while remaining 40 percent at moderate level and only one percent at unhealthy level (Department of Environment, Malaysia, 2008). This is due to an intensified undertaken by the DoE in action to improve the air quality status in the country. Other factors that influenced to the good air quality days were the wet weather conditions experienced in the region. Consequently, there was no transboundary haze pollution are observed in 2008.

1.2 PROBLEM STATEMENT

Currently, air pollution is one of the most important issues that have been discussed every day by related bodies and the public. The Department of Environment (DoE) is one of the bodies that are responsible in monitoring the statuses of air quality throughout the country to perceive any significant change which may cause harm to human health and the environment. Additional air pollutants or atmospheric effects which have become of concern according to Canter (1996) include photochemical smog, acid rain and global warming.

Malaysia experienced good to moderate air quality status most of the time. However, several unhealthy air quality statuses were also recorded at several parts of the countries that include growth of population but also industrialization which is accompanied by a growing number of vehicles that contribute to air pollution problem. The Department of Environment, Malaysia (2008) listed 51 monitoring locations throughout the country that belong to the DoE. The parameters monitored include particulate matter (PM_{10}), sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2) and ozone (O_3).

Haze is form by tiny particulates suspended in the atmosphere. It related to biomass burning that is a recurring environmental problem which affects air quality not only in the source regions, but also in the surrounding areas. Biomass burning may be related to forest clearing, wildfires during drought (El Nino) years or agricultural practice. Fuller and Murphy (2006) stated that the forest clearing fires in the region are tightly linked to the monsoonal systems in the region. At the same time, according to Hyew and Chew (2010), accidental fires can be easily started in the forest, especially in Kalimantan during the dry season. In the case of haze event in 1997, the particles come from biomass burning in Indonesia for clearing vegetated (forest and grassland) areas. The wild fires significantly increase the input of organic aerosol components to the atmosphere (Abas *et al*., 2004).

According to DoE report on air quality in 1997, the 1997 haze episode was primarily due to forest and land fires in Kalimantan and Sumatra, Indonesia. Detection of hot spots via satellite imagery had shown that most of the fires started in plantation areas in Indonesia. The unusual prolonged severe drought caused by El Nino which started in March 1997 aggravated the situation. Several economic sectors were affected. Among those severely affected were transport services, manufacturing activities and the tourism sector. The haze also increased complaints of respiratory problems particularly among asthmatic patients and caused decline in agriculture and fishing yield.

Department of Environment, Malaysia (1998) reported that 1998 was a satisfying year for environmental management in Malaysia. On average, the air quality in the country was good throughout the year except for a brief spell of hazy condition in and around the vicinity of Miri, Sarawak, when the Air Pollution Index (API) touched the hazardous level for duration of about three weeks in the month of March. Local forest and peat fires were the cause of the problem.

On the other hand, motor vehicles remained the major source of air pollution in the country. From 1998, there were 8.9 million motor vehicles registered are has increased to 20 million in 2009 (Department of Statistics, Malaysia 2009) which caused an increasing of pollutants approximately 1,451,746 metric tonnes of carbon monoxide, 409,972 metric tonnes of oxides of nitrogen, 161,913 metric tonnes of sulphur dioxide and 31,672 metric tonnes of particulate matters were emitted into the atmosphere (Department of Environment, Malaysia, 2008).

According to 2000 data, about 29 percent of the population used solid or biomass fuels for their cooking and heating needs. Only 11 percent of the vehicles still use diesel while 89 percent have been using unleaded gasoline. As stated before, the air pollution sources in Malaysia are from mobile and stationary sources (WHO, 2005). In Malaysia, WHO (2005) recorded that emissions from mobile sources contributed to 80.4 percent of the total load, followed by emissions from stationary sources such as industrial fuel consumption (9 percent), industrial processes (1.2 percent), power stations (8.8 percent), domestic fuel (0.2 percent) and open burning at solid waste dumping sites (0.4 percent).

Department of Environment, Malaysia (2006) stated that the total number of industrial sources (including power stations) identified in 2006 was 13,239, which is Selangor reported the highest number of stationary pollution sources (2,943), followed by Johor (2,693) and Sarawak (1,806). Earlier, vehicle emissions that are also claimed as main sources for air pollution in Malaysia, which include from cars, taxis, buses, motorcycles, vans and lorries. However, a decreasing trend in the emission load of PM_{10} was observed by DoE, Malaysia in 2006 compared to 2005 which stated at 4,602 metric tonnes as compared to 5,897 metric tonnes in 2005 (21.96 percent decrease).

In 2007, a total of 13,443 industrial source were identified which is increased from 2006 with the highest number of stationary pollution sources indicate at Selangor followed by Johor and Sarawak (Department of Environment, Malaysia, 2007). The other major contributor of air pollution especially in urban areas was motor vehicles which there were an overall increase in the number of motor vehicle registered. The number of registered passenger cars increased by 6.9 percent, motorcycles by 6.4 percent, goods vehicles by 4.4 percent, buses by 5.6 percent and taxis by 2.5 percent in 2007 compared to 2006. Besides, industries is the highest contributor to PM_{10} (40 percent) followed by motor vehicles (28 percent), power stations (14 percent) and others (18 percent) (Department of Environment, Malaysia, 2007).

Recently, Department of Environment, Malaysia (2008) claimed that industries (including power stations), motor vehicles and also open burning activities remain the major sources of air pollution in the country. In 2008, a total of 22,971 industrial sources were recorded with the highest number of stationary sources was in Johor (35.4 percent) followed by Selangor (18 percent) and Perak (12.9 percent).

As recorded up to the end of the year 2008, Malaysia has 11,227,144 registered drivers. In 2008, 1,135,813 units of new motor vehicles were registered on the road, of which 48 percent were motorcycles. Most passenger cars and the motorcycles on Malaysia road are either manufactured or assembled locally. The total number of vehicles registered on the road is approaching 18 million units in 2008 with 47 percent of them motorcycles and it is increasing up to 20 million units in 2009 (Department of Statistics, Malaysia, 2009).

As usual, there was an increased in the number of motor vehicles registered compared to previous year. However, the number of in-use or active vehicles on the road namely taxis, busses and goods vehicles decreased significantly in 2008 compared to the previous year. This could be due to an increased in fuel price in 2008 (Department of Environment, Malaysia, 2008). Based on Department of Environment report on air quality from year 1997 to 2008, particulate matter and ozone were the prevalent pollutants recorded throughout the country. Several unhealthy air quality statuses were also recorded at several parts of the countries especially in major cities.

In the Northern region of the West Coast of Peninsular Malaysia, comprising the states of Perlis, Kedah, Pulau Pinang and Perak, the overall air quality ranged between good and moderate most of the area in most of the time except at Seberang Perai over the past several years. As Seberang Perai is a heavily industrialized area with several petrochemical complexes, the air quality remained at the moderate level more than 90 percent of the time.

The major sources of air pollution come from industrial areas, transboundary haze and traffics for Seberang Perai. It is a heavily industrialized area which is contributing to the pollutant such as sulphur dioxide (SO_2) as the main pollutant of concern in the area due to industrial activities in the vicinity. This situation shows that there are many causes of air pollution which comes from a variety of natural and man-made sources. It has been claim by DoE annual report in 2004 which claims that emission from mobile and stationary sources and open burning activities remained the most significant contributors to air pollution load in the country in 2004.

Nevertheless, according to DoE report on air quality in 2004, air quality stations in Seberang Perai recorded moderate air quality 97 percent of the time and unhealthy air quality for the remaining three percent where the main pollutant detected in the area was PM_{10}. Main sources of PM_{10} identified were industrial activities, motor vehicle emissions and transboundary pollution which occurred during the Southwest monsoon. Notably, the high levels of sulphur dioxide (SO_2) observed in previous years were significantly reduced. This could be attributed to the measures taken to promote the use of cleaner fuel such as natural gas in the industrial combustion process.

The annual average levels of PM_{10} concentration in the ambient air between 1996 to 2008 were below the Malaysian Ambient Air Quality Guidelines (MAAQG) of 50 µg/m^3, except during the unprecedented 1997 haze episodes also in 2002 and 2004 when Malaysia experienced short periods of slight to moderate haze in the months of June, August and September brought about mainly by transboundary pollution with the annual average concentration of PM_{10} was equivalent to the MAAQG.

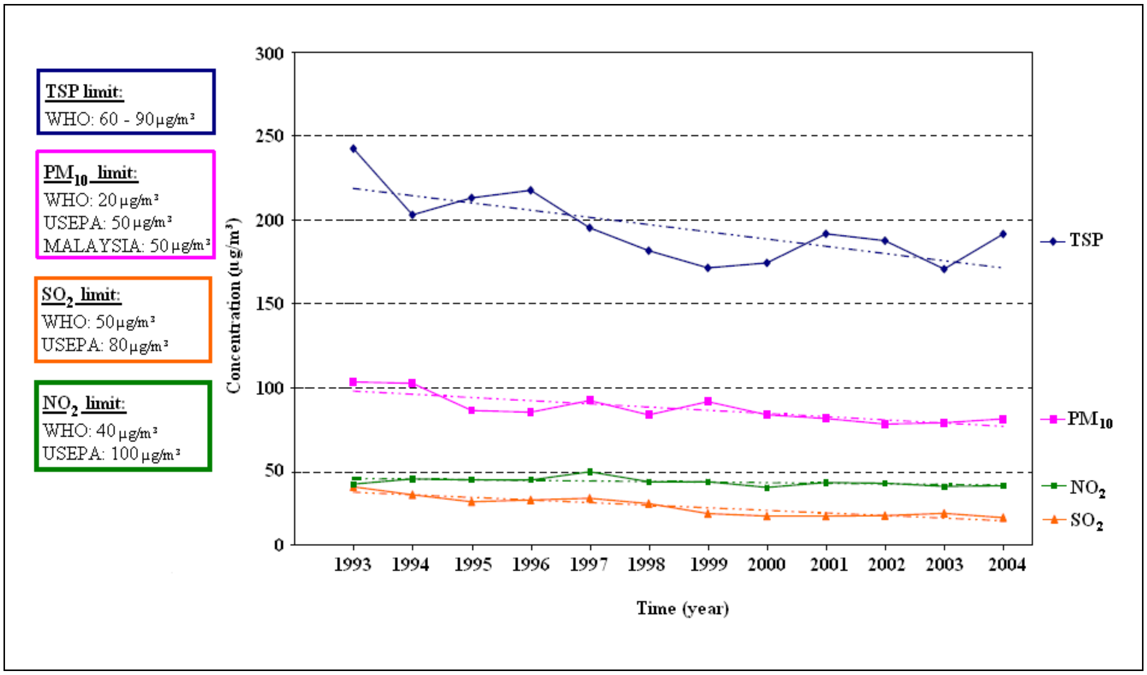

Figure 1.2 Trend of major criteria air pollutants (1993 – 2004)
(Adopted from Zhang, 2008)

An ongoing study (Figure 1.2) show that, despite the levels of air pollution in Asian cities show downward trends over time, it regularly exceeds the World Health Organization (WHO) recommended guidelines as well as MAAGQ and United States Environmental Protection Agency (USEPA). Although particulate matter (PM_{10}) remains at levels harmful to human health, SO_2 levels are now, on average, below the guideline values set by the WHO, proving that air quality management policies and measures can work in Asia. A macro-analysis of air pollution trends in Asian cities shows that, in general, TSP and PM_{10} have decreased from 1993 to 2004, but ambient levels remain above limits set by the WHO, MAAQG and USEPA. Figure 1.2 also shows that the levels of ambient concentrations of pollutants indicate that particulate matter (TSP and PM_{10}) are main pollutants of concern in Asian cities where it fail to meet WHO, MAAQG and USEPA standards.

Zhang (2008) claims that air pollution levels is among the highest in the Asian cities and continuously increased in the most populated cities including Malaysia. Developing Asian countries likes Malaysia are confronted with indoor air pollution as well as outdoor air pollution. Table 1.4 shows that outdoor air pollution is to blame for a total of about 865,000 deaths in Asia, about 60 percent of the world's total. As mention, the increase in PM_{10} emission in Malaysia was due to increase in a number of acres of forest fires and stationary sources. Early prevention to decrease the emissions is by setting and enforcing emissions standards for mobile and stationary sources, where the tougher

European Standards has begun to adopt by Malaysia and other developing Asian countries (Zhang, 2008) that are facing acute air pollution problems.

Table 1.4 Estimated deaths caused by outdoor air pollution in 2002

Country	**Outdoor Air Pollution**	
	Annual PM_{10} ($\mu g/m^3$)	**Deaths per year**
Bangladesh	157	8,200
Cambodia	51	200
China	80	275,600
DPR Korea	88	4,900
India	84	120,600
Indonesia	114	28,800
Japan	33	23,800
Lao PDR	25	<100
Malaysia	**28**	**500**
Myanmar	75	3,900
Nepal	161	700
Pakistan	165	28,700
Philippines	34	3,900
Republic of Korea	43	6,800
Singapore	48	1,000
Sri Lanka	93	1,000
Thailand	77	2,800
Vietnam	66	6,300
Asia (total)	-	517,700
World (including Asia)	61	865,000

(Adopted from Zhang, 2008)

To cope with increasing of PM_{10} concentration in Malaysia as response to the haze events, Association of Southeast Asian Nations (ASEAN) adopted the Agreement of Transboundary Haze Pollution in 2002 whereby this agreement is aimed to prevent and monitor transboudary haze pollution as result of land and forest fires and to control sources of fires. Besides, Department of Environment (DoE) Malaysia which is the body that is responsible for monitoring and acquiring air pollutants monitoring records in Malaysia provide continuous measurement and maintain records of pollutants in the ambient air. However, these monitoring records have not been used extensively to develop forecasting model for PM_{10} in Malaysia using the time series analysis. Therefore, it is very important to conduct research on its characteristics of the air pollutants monitoring records and its statistical forecasting using the time series models to help curb the adverse impact of PM_{10} on human health.

Moreover, in recognition of the importance of cities in improving environmental sustainability, a method is required to predict the concentrations of the pollutant (as PM_{10} is highlighted in this research) in the future year for long and short-term periods and to predict the number of days where air pollutant exceeds the MAAQG. On the other hand, this research provides information to the related responsible agencies to ensure the prevention for human health regarding to the possibilities of the exceedences of PM_{10} concentrations in future year.

In addition, the PM_{10} monitoring using E-sampler is important to verify the statistical prediction especially in findings the correlation calibration factor (k-factor) between Beta Attenuation Mass (BAM) and E-sampler. Instead of using E-sampler during PM_{10} monitoring, it is easy to use, portable, calibrated and low cost compared to BAM.

1.3 OBJECTIVES

The aim of this research is to obtain the best model to predict particulate matter (PM_{10}) concentration level in Malaysia. Three theoretical distributions namely Weibull, gamma and log-normal were used to fit the parent distribution of PM_{10} followed by one competitor distribution that is inverse Gaussian distribution. These distributions were later used to understand the characteristic of PM_{10} concentration for five years cycle. The other important work in this research is to forecast the PM_{10} concentrations using time series analysis where it never been used as implementation for forecasting work in Malaysia. Therefore, the objectives for this research are:

1. To determine the characteristics of time series data of PM_{10} concentrations and the patterns of time series plots for ten monitoring stations all over the country.
2. To predict the number of exceedences for the nest year monitoring records using the best distribution obtained from four fitted distribution selected.
3. To validate the secondary data using coefficient of calibration (k-factor) and verify the best distribution.
4. To forecast the short-term PM_{10} concentrations using time series analysis.