STUDY OF $PM_{2.5}$ CONCENTRATION AT SCHOOL NEAR ROAD SIDE IN PENANG

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UNIVERSITI SAINS MALAYSIA
2018

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By

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This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)
(CIVIL ENGINEERING)

School of Civil Engineering,
Universiti Sains Malaysia

June 2018

UNIVERSITI SAINS MALAYSIA

SCHOOL OF CIVIL ENGINEERING
ACADEMIC SESSION 2017/2018

FINAL YEAR PROJECT EAA492/6
DISSERTATION ENDORSEMENT FORM

Title: Study of $PM_{2.5}$ Concentration at School Near Road Side in Penang

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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ACKNOWLEDGEMENT

In the of Allah, the Most Gracious and the Most Merciful

Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this study. This thesis has been kept on track and been seen through to completion with the support and encouragement of numerous people including my well wishers, my friends, colleagues and various institutions. At the end of my thesis I would like to thank all those people who made this thesis possible and an unforgettable experience for me. To express my thanks to all those who contributed in many ways to the success of this study and made it an unforgettable experience for me.

Special appreciation goes to my supervisor, Prof. Madya. Dr Noor Faizah Fitri Bt Md Yusof, for her supervision and constant support. Their invaluable help of constructive comments and suggestions throughout the project works have contributed to the success of this research.

I am really grateful to my research member Wan Nur Fazlinda and also Mrs. Azlin Suroto for their advice and their willingness to share their bright thoughts with me, for shaping up my research.

Finally, I thank all those who have helped me directly or indirectly in the successful completion of my thesis. I should not forget to acknowledge my parents for their continuous love, support, understanding and good wishes whenever I needed. For someone that I did not mention here, it does not mean that I do not acknowledge you support and help. Again, I would like to thank everyone for helping me during my bachelor study.

ABSTRAK

Program pemantauan memantau hubungan kepekatan dalaman dan luaran zarah halus ($PM_{2.5}$). Empat sekolah dipilih dalam kajian ini. Kepekatan bahan zarahan halus telah dipantau di kelas yang berlainan dengan tahap lantai yang berbeza. Kepekatan $PM_{2.5}$ dipantau berhampiran dengan sampingan untuk menentukan sama ada lalu lintas menjejaskan kepekatan dalaman $PM_{2.5}$ di lokasi ini. Sumber-sumber lain yang ada di sekitar lokasi pemantauan juga dipertimbangkan. Kepekatan $PM_{2.5}$ dikumpulkan di Sekolah Kebangsaan Bayan Lepas, Sekolah Kebangsaan Tasek Gelugor, Sekolah Menengah Kebangsaan Mutiara Impian dan Sekolah Kebangsaan Machang Bubok. Program pemantauan telah dilancarkan pada 16 Januari 2018 dan diteruskan sehingga 13 Mac 2018. Data pemantauan di tingkat lantai yang berbeza telah diambil secara berselang dengan selang 15 minit. E-sampler diletakkan di belakang kelas dan E-bam diletakkan di luar sekolah berdekatan dengan jalan raya. Maklumat meteorologi dikumpulkan menggunakan dua instrumen dan maklumat trafik terus dikumpulkan melalui kamera video di atau berhampiran tapak pemantauan yang menghadap ke jalan. Data yang direkodkan menggunakan monitor spesifikasi dianalisis menggunakan perisian SPSS untuk menentukan hubungan di dalam rumah dan di luar rumah $PM_{2.5}$ dan perbezaan kepekatannya di tingkat lantai yang berbeza. Analisis nisbah dalaman / luaran (I / O) adalah 0.74 dan 0.76 pada tingkat dua tingkat dan tingkat ketiga Sekolah Kebangsaan Bayan Lepas yang menunjukkan sumbangan dari sumber luar ke arah kepekatan dalaman $PM_{2.5}$. Sebaliknya, tiga sekolah lain menunjukkan sebaliknya. Berdasarkan analisis pembahagian, sumbangan sumber jalan raya tidak begitu kuat berdasarkan keputusan dianalisis dengan menggunakan Korelasi Pearson.

ABSTRACT

The monitoring program monitored the relationship of indoor and outdoor concentrations of the fine particles ($PM_{2.5}$). Four schools were selected in this study. The concentration of fine particulate matter was monitored at different classes with different floor level. $PM_{2.5}$ concentrations were monitored in close proximity to a road side in order to determine whether traffic affect indoor concentration of $PM_{2.5}$ at this location. Other existing possible sources around the monitoring location were also considered. $PM_{2.5}$ concentrations were collected at Sekolah Kebangsaan Bayan Lepas, Sekolah Kebangsaan Tasek Gelugor, Sekolah Menengah Kebangsaan Mutiara Impian and Sekolah Kebangsaan Machang Bubok. The monitoring program was launched on January 16, 2018 and continued until March 13, 2018. The monitoring data at different floor level was taken intermittently with 15 minutes interval . E-sampler was positioned at the back of the classroom and E-bam was positioned at outside of the school near to the roadway. Meteorological information was collected using two instruments and traffic information was continuously collected via video camera at or near the monitoring site facing to the road. The data recorded using the specification monitor were analyzed using SPSS software to determine the relationship of the $PM_{2.5}$ indoors and outdoors and its differences of the concentration at different floor level. The indoor/outdoor (I/O) ratio analysis were 0.74 and 0.76 at second floor level and third floor level of Sekolah Kebangsaan Bayan Lepas which shows the contribution from the outdoor sources toward the indoor concentration of $PM_{2.5}$. In contrast, the other three schools show vice versa. Based on the apportionment analysis, the contribution of roadway sources are not really strong based on the result analysed using Pearson Correlation.

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LIST OF ABBREVIATIONS

Al	Alumimium
API	Air Pollution Index
Ca	Calcium
Cl	Chlorine
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DOE	Department of Environment
Fe	Ferum
K	Potassium
MAAQG	Malaysia Ambient Air Quality Guidelines
Mg	Magnesium
Mn	Mangan
Na	Natrium
NAAQS	National Ambient Air Quality Satus
NO_2	Nitrogen Dioxide
NO_X	Nitrogen oxide
O	Oxygen
O_3	Ozone
Pb	Lead
PCU	Per Car Unit
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter (particles with aerodynamic diameter less than

	2.5μm)
PM_{10}	Particulate Matter (particles with aerodynamic diameter less than 10μm)
S	Sulphur
Si	Silica
SO_2	Sulphur Dioxide
SPSS	Statistical Packages for Social Science
US	United States
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
Zn	Zinc

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Air pollution is a major environmental contributor to the global burden of disease and is associated with a wide range of adverse health outcomes (Lim et al., 2012). More recently, an emerging body of evidence has associated exposure to air pollution in schools with adverse health impacts in school children, and potential effects of elevated air pollution levels include impaired neurodevelopment (Sunyer et al., 2015), behavioural and emotional problems, and respiratory problems (Forns et al., 2016). In the case of children at least a third of their day is spent in the classroom, Particulate Matter levels may vary substantially from outdoors due to building insulation, indoor sources and resuspension.

Buildings are typically ventilated using three mechanisms: mechanical ventilation, natural ventilation and infiltration. All of these mechanisms can result in the transport of outdoor particles into the indoor environment. Mechanical ventilation typically includes a supply of fresh (outdoor) air which contains outdoor-originated particles. Since filters in a mechanical ventilation system cannot completely remove all particles of outdoor origin, these particles enter into the indoor environment. Natural ventilation occurs by moving wind and buoyancy-induced flow through open windows or doors, thereby transporting outdoor particles into the indoors. Pollutants being released from indoor sources are being found at higher concentrations (Isa, 2010). There have been many studies dealing with the application of ventilation in both the indoor and outdoor environment. Ventilation concepts have been used for both indoor building ventilation and the urban environment (Chen and Zhao, 2011).

Children spend a large part of their time at school during hours when traffic pollution is at its daytime peak, and children are likely to be physically active at school (e.g., during sports classes, and break times), which can increase their inhaled doses of air pollution (McConnell et al., 2010). According to Chitra & Nagendra, (2012); school children spend about 6 to 8 hours per weekdays in a school. Therefore, children have greater susceptibility to air pollutants than adults (Hu et al., 2017). Moreover, recent studies have demonstrated that reductions in the level of ambient air pollution have a positive impact on health, significantly reducing bronchitis symptoms in children (Gauderman et al., 2015).

Outdoor air pollutants may intrude indoors by two main mechanisms (Chen and Zhao, 2011); through opened windows or doors (natural ventilation) and by infiltration through cracks and leaks in the building envelope (the latter being uncontrolled and having a relatively low exchange rate).

1.2 PARTICULATE MATTER

Particulate matter (PM) is the general term used to describe solid particles and liquid droplets found in the air. Particles can either be directly emitted into the air (primary PM) or be formed in the atmosphere from gaseous precursors such as sulfur dioxide, oxides of nitrogen, ammonia and non-methane volatile organic compounds (secondary particles). Secondary particles are formed in the air through chemical reactions of gaseous pollutants. They are products of atmospheric transformation of nitrogen oxides (mainly emitted by traffic and some industrial processes) and sulfur dioxide resulting from the combustion of sulfur-containing fuels. Secondary particles are mostly found in fine PM.

The composition and size of these airborne particles and droplets vary. Some particles are large enough to be seen as dust or dirt, while others are so small they can only be seen using a powerful microscope. Two size ranges, known as PM_{10} and $PM_{2.5}$, are widely monitored, both at major emissions sources and in ambient air. (US-EPA, 2016). These particles vary in size, composition and origin. Their properties are summarized according to their particle size according to Isa (2010).

i. PM increase the risk of respiratory death in infants under 1 year, affects the rate of lung function development , aggravates asthma and causes other respiratory systems such as cough and bronchitis in children.
ii. The coarse fraction is called PM_{10} (particles with aerodynamic diameter smaller than 10um), which may reach the upper part of the airways and lung.
iii. Smaller or fine particles are called $PM_{2.5}$ (with an aerodynamic diameter smaller than 2.5 um); these are more dangerous because they penetrate more deeply into the lung and may reach the alveolar region.

Particles within the two size ranges behave differently in the atmosphere. $PM_{2.5}$, or fine particles, can remain airborne for long periods and travel hundreds of miles (USEPA, 2016). Fine particulate matter, or $PM_{2.5}$, refers to a mixture of solid and liquid atmospheric particles with an aerodynamic diameter (dae) less than 2.5 micrometers is arises mainly from anthropogenic sources such as fossil fuel combustion by electric utilities and motor vehicles, wood burning, and the smelting or other processing of metal (WHO, 2014).Outdoor $PM_{2.5}$ majority produced by anthropogenic sources i.e. industrialization, vehicle and open burning (Raysoni et al., 2011). The increasing number of population in certain area encourages the industrial activities, construction activities and vehicle usage keep increased as to fulfil the needs. This will affect on the production of ambient air pollution including fine particulate matter.

1.3 PROBLEM STATEMENT

According to the World Health Organization (WHO), one in nine deaths worldwide in 2012 was associated with air pollution (WHO, 2016). Increasingly more countries are sparing no effort in the fight against local air pollution issues (Mullins and Bharadwaj, 2015).

PM_{10} is an important component of air-pollution monitoring networks since it affects human health by causing respiratory problems (Awang et al., 2001) while inhaling PM_{10}, and most particularly Particulate Matter < 2.5 μm ($PM_{2.5}$), can cause cardiovascular diseases (Dominici et al., 2006), birth defects and premature death (Ballester et al., 2010). $PM_{2.5}$ may cause respiratory disease, cardiovascular disease, and even lung cancer (Anderson et al., 2012). $PM_{2.5}$ can also interact with the climatic environment. For example, the concentration of $PM_{2.5}$ decreases with increasing wind speed, while it increases with the increase of relative humidity (Batterman et al., 2016).

There is increasing evidence that indoor air quality exposure is also responsible for a rise in mortality and morbidity (Rivas et al., 2014). However, little is known about air quality in indoor environments, where children spend most of the day (approximately 90%; Buonanno et al., 2012). Moreover, children constitute a particularly vulnerable population because of their physiological and behavioural characteristics. At schools, indoor concentrations of particulate matter have been shown to be highly correlated with outdoor levels, suggesting that indoor particles are largely of outdoor origin (Raysoni et al., 2011).

The quality if indoor air is concern more as it will give an effect on health. Moreover, there is still little understanding from the public on Indoor Air Pollution (IAP). Pulau Pinang is one of the fast growing city and thus the population in Pulau Pinang is increasing day by day. The number of vehicle is increasing due to the population boost in that city. School located at near to the roadside are more affected on the exposure of $PM_{2.5}$ as it is expected that the emissions from the vehicle can be a major contributor towards $PM_{2.5}$ level. The information or knowledge on indoor air quality problems including concentration of particulate matter specifically $PM_{2.5}$ is still lacking among Malaysia people. Public does not aware that the level of exposure of $PM_{2.5}$ is varies for each different floor level and they does not know that the indoor air exposure is worse rather than outdoor air exposure.

Pollutant which directly emitted from cars, trucks, and other motor vehicles are found in higher concentrations near major roads (US-EPA, 2016). The pollutants emitted include particulate matter (PM), carbon monoxide, oxides of nitrogen, and benzene, though hundreds of chemicals emitted from vehicles. Beyond vehicles' tailpipe and evaporative emissions, roadway traffic also emit brake and tire debris and can throw road dust into the air. According to the EPA, Motor vehicle pollutant concentrations tend to be higher closer to the road, with the highest levels generally within the first 500 feet (about 150 meters) of a roadway and reaching background levels within approximately 2,000 feet (about 600 meters) of a roadway, depending on the pollutant, time of day, and surrounding terrain. The traffic-related pollutants can be elevated inside classroom, where children spend most of the school day (US-EPA, 2015)

In this study, analyzing the current situation of $PM_{2.5}$ was carried out. The concentration of $PM_{2.5}$ was collected in different floor level of schools building.

1.4 OBJECTIVES

The objectives in this study are:

- To identify concentrations of indoor and outdoor $PM_{2.5}$ in school located nearby roadside.
- To determine the effects of outdoor $PM_{2.5}$ from ambient sources towards indoor $PM_{2.5}$ in classroom at different floor level.
- To determine the relationship of traffic volume (PCU) to $PM_{2.5}$

1.5 SCOPE OF WORK

Monitoring $PM_{2.5}$ was carried out at 4 schools in Penang area which are located near to a roadside. The monitoring for each school is taken 1 days for each school from 16 January 2018 until 13 March 2018. $PM_{2.5}$ concentration was recorded by using E-BAM for data collection for outdoor exposure. Before the monitoring day, the class should be cleaned first, therefore one day was provided for the cleaning process for every schools. As for data collection in the classroom, $PM_{2.5}$ concentration was recorded by using E-Sampler. E-BAM and E-Sampler not only measure the concentration $PM_{2.5}$ only but also measure the wind speed, relative humidity and temperature at the schools. One minute interval of reading collection was recorded at sampling location. Data for traffic volume was collected using a camera. Video was recorded during the sampling period. The video camera was placed at a suitable place which facing directly to the road.

1.6 DISSERTATION OUTLINE

The thesis has been categorized into specific chapters for better viewing and understanding of the study. This dissertation consists of five chapters.

Chapter 1: Introduction – this chapter gives an overview of the thesis, followed by the problem statement to identify, and understand why this research was carried out and its relevance to current times followed by the objectives of this research in order to set the desired target of work.

Chapter 2: Literature Review – in this chapter, the content is more to the information that related to this study and can be used as a reference in this study.

Chapter 3: Methodology – this chapter describes the details explanation of methodology that is being used to complete this study such as maps and type of equipment used to monitor the parameters.

Chapter 4: Result and Discussion – Illustrated and discussed the results obtained from the study. All the results were presented in the form of table, figure and graph for easier interpretation.

Chapter 5: Conclusion and Recommendation – explain the major findings of this research objective.Recommendation were made based on the result obtained for the future study.

CHAPTER 2

LITERATURE REVIEW

Pollution, an unwanted destruction of the natural environment by human and naturally induced insults, is a problem facing the present world Wiwanitkit (2011). Due to the expansion of the world population, the number of people is rapidly growing. It is accepted that pollution is a problem, not for a specific group but for everyone.

2.1 AIR POLLUTANTS IN MALAYSIA

Air pollution occurs when air is contaminated with natural and anthropogenic pollutants. Anthropogenic pollutants are contaminants associated with human activities which include polluting residuals from consumption and production activity (Razak et al., 2013). Air pollution has become a serious environmental problem in the developing south-east Asian countries, especially in Malaysia that is aiming to become an industrial nation by 2020. Malaysia is ranked as the 117th worst country among 180 nations worldwide in terms of air quality (Hsu, 2016) with the major sources of air pollutants to be open biomass burning, motor vehicles and industries (Afroz et al., 2003; Hyer et al., 2013; Alias et al., 2014; Khan et al., 2016a).

The air pollution levels in Malaysia are expressed via the Air Pollution Index (API) that is calculated using surface concentrations of carbon monoxide (CO), tropospheric ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and Particulate Matter < 10 µm (PM_{10}) (Awang et al., 2000; Dominick et al., 2012).

2.1.1 Indoor Air Pollution

The quality of air inside homes, offices, schools, day care centers, public buildings, health care facilities or other private and public buildings where people spend a large part of their life is an essential determinant of healthy life and people's well-being, says the WHO Guidelines for Indoor Air Quality (Vijayan et al., 2015). Hazardous substances emitted from buildings, construction materials and indoor equipment or due to human activities indoors, such as combustion of fuels for cooking or heating, lead to a broad range of health problems (WHO, 2014).

At schools, indoor concentrations of particulate matter have been shown to be highly correlated with outdoor levels, suggesting that indoor particles are largely of outdoor origin (Raysoni et al., 2011). However, this indoor penetration of outdoor particles depends not only on the physical barriers of the building and ventilation (natural or mechanical), but also on particle physico-chemical properties (Viana et al., 2011) and size (Tippayawong et al., 2009; Zhu et al., 2002).

2.1.2 Criteria Air Pollutants

The Environmental Protection Agency (EPA) has set National Ambient Air Quality Standards (NAAQS) for six common air pollutants. The six criteria pollutants are sulphur dioxide, nitrogen dioxide, carbon monoxide, particulate matter, lead an ozone.

SO_2), which is a highly reactive gas, flammable, with a pungent odor, which irritates the eyes and the respiratory system. It appears mainly from burning sulfur fossil fuels (coal, oil) and the exhaust of vehicles' engines. The value of anthropogenic emissions of sulfur in the atmosphere, generated by burning coal and sulfur-rich smelting, is estimated at 80 Tg/year, the plants with large combustion capacity being the main source of pollution (about 67%). In Romania, the total sulfur oxides emissions (SO_x) in SO_2 equivalent are 241,864 t/year (EAA, 2015), the largest contribution being that of the energetic sector, as follows: approximately 97% of power stations and other combustion plants and approximately 2.04% of oil and gas refineries. SO_2 is able to form the highly irritating sulphuric acid in reaction with moisture in mucous membranes and lungs (Roberson, 2017).

2.1.3 Air Pollutants Quality Status

According to Ministry for the Environment, New Zealand., 2017 stated that the guideline values are minimum requirements that all outdoor air quality should meet to protect people and ecosystems from significant adverse effects. As with the national air quality standards, they are not 'safe' limits to pollute up to.

Key differences between the national ambient air quality guidelines and the national environmental standards for air quality are that the guidelines:

- include a wide variety of pollutants, including toxics, whereas the national environmental standards include only five priority pollutants
- promote the protection of both ecosystems and human health whereas the national environmental standards are based on human health only
- recognise and promote the maintenance and enhancement of air quality through the use of environmental indicators (for example, the establishment of action and alert levels below the guideline values).

The air quality standards have been set by the United States Environmental Protection Agency (USEPA) and the Department of Environment Malaysia which is to determine the concentration of polluted air that is considered harmful to public health and environment. In this study, the Recommended Malaysian Air Quality Guidelines (RMAQG) which set up by DOE was used to configure the concentration of contaminants in polluted air. Table 1 shows the guidelines for the concentration of air pollutants in Malaysia.

Table 2-1: Malaysia Ambient Air Quality Guidelines (DOE,2014)

Air pollutant	**Average time**	**Malaysia guidelines**	
		(ppm)	(µg/m^3)
Carbon Monoxide (CO)	1 Hour	30	35 mg/m^3
	8 Hour	9	10 mg/m^3
Nitrogen Monoxide (NO)	1 Hour	0.17	320
Sulphur Dioxide (SO_2)	10 Minute	0.19	500
	1 Hour	0.13	350
	24 Hour	0.04	105

New Ambient Air Quality Standard was established in order to replace the older Malaysia Ambient Air Quality Guideline that has been used since 1989.

The New Ambient Air Quality Standard adopts 6 air pollutants criteria that include 5 existing air pollutants which are particulate matter with the size of less than 10 micron (PM_{10}), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), and ground level ozone (O_3) as well as 1additional parameter which is particulate matter with the size of less than 2.5 micron ($PM_{2.5}$)

Table 2-2 : New Malaysia Ambient Air Quality Standard (NMAQS,2018)

Pollutants	Averaging Time	Ambient Air Quality Standard		
		IT-1 (2015)	IT-2 (2018)	Standard (2020)
		µg/m³	µg/m³	µg/m³
Particulate Matter with the size of less than 10 micron (PM_{10})	1 Year	50	45	40
	24 Hour	150	120	100
Particulate Matter with the size of less than 2.5 micron ($PM_{2.5}$)	1 Year	35	25	15
	24 Hour	75	50	35
Sulfur Dioxide (SO_2)	1 Hour	350	300	250
	24 Hour	105	90	80
Nitrogen Dioxide (NO_2)	1 Hour	320	300	280
	24 Hour	75	75	70
Ground Level Ozone (O_3)	1 Hour	200	200	180
	8 Hour	120	120	100
*Carbon Monoxide (CO)	1 Hour	35	35	30
	8 Hour	10	10	10

*mg/m³

The data obtained from the monitoring process will help in evaluating the air pollution distribution profile. Air quality status in the country will be determine according to the Air Pollution Index (API). The API is an indicator of the air quality including the haze and was developed based on sciencetific assessment to indicate in an easily understood manner, the presence of pollutant in air and its impact on human health. Table 2.3 shows API in Malaysia based on Environment Protect Agency (EPA).

Table 2-3 : Value of Air Pollution Index (API) and its relation with health effect

API	Status	Health effect	Health advice
0-50	Good	Low pollution without any bad effect on health	No restriction for outdoor activities to the public.Maintain healthy lifestyle
51-100	Moderate	Moderate pollution that does not pose any bad effect on health.	No restriction for outdoor activities to the public. Maintain healthy lifestyle
101-200	Unhealthy	Worsen the health condition of high-risk people with heart and lung complications.	Limited outdoor activities for the high risk people. Public need to reduce the extreme outdoor activities.
201-300	Very unhealthy	Worsen the health condition and low tolerance of physical exercises to people with heart and lung complications. Affect public health	Old and high-risk people are advised to stay indoor and reduce physical activities. People with health complications are advised to see a doctor
301-500	Hazardous	Hazardous to high risk people and public health	Old and high-risk people are prohibited for outdoor activities. Public are advised to prevent from outdoor activities

Sources: DOE,2014

2.2 PARTICULATE MATTER

Particulate matter (PM) is a various solid or liquid particles that suspended in air, which are often collectively. These particles are usually individually invisible to the naked eyes (Zereini & Wiseman., 2011)

Particulate matter refers to the solid and liquid particles that are dispersed into ambient air. These particles can be classified in several ways. Firstly, they can be classified into primary and secondary particles based on the mechanism of their formation. Primary particles are emitted directly as particles, whereas secondary particles are formed from precursor gases in the atmosphere via gas-to-particle conversion. Both types of particles are subject to growth and transformations since there can be formation of secondary material on the surface of existing particles.

Particulate air pollution is a mixture of solid, liquid or solid and liquid particles suspended in the air (Pope and Dockery, 2005). These suspended particles vary in size, composition and origin. It is convenient to classify particles by their aerodynamic properties because: (WHO, 2016) they govern the transport and removal of particles from the air; (Friedlander & Lippman.,1994) they also govern their deposition within the respiratory system; and (Jenko Pražnikar & Pražnikar, 2012) they are associated with the chemical composition and sources of particles. These properties are conveniently summarized by the aerodynamic diameter, that is the size of a unit-density sphere with the same aerodynamic characteristics. Particles are sampled and described on the basis of their aerodynamic diameter, usually called simply the particle size.

PM is a widespread air pollutant. Commonly used indicators describing PM that are relevant to health refer to the mass concentration of particles with a diameter of less than 10μm (PM_{10}) and of particles with a diameter of less than 2.5 μm ($PM_{2.5}$). $PM_{2.5}$, often called fine PM, also comprises ultrafine particles having a diameter of less than 0.1μm. In most locations in Europe, $PM_{2.5}$ constitutes 50–70% of PM_{10}. PM between 0.1μm and 1μm in diameter can remain in the atmosphere for days or weeks and thus be subject to long-range transboundary transport in the air. PM is a mixture with physical and chemical characteristics varying by location. Common chemical constituents of PM include sulfates, nitrates, ammonium, other inorganic ions such as ions of sodium, potassium, calcium, magnesium and chloride, organic and elemental carbon, crustal material, particle bound water, metals (including cadmium, copper, nickel, vanadium and zinc) and polycyclic aromatic hydrocarbons (PAH). In addition, biological components such as allergens and microbial compounds are found in PM. (WHO, 2013).

2.2.1 Physical Characteristic

Atmospheric particulate matter (PM) is generally defined as a mixture of solid and/or liquid particles that remains individually dispersed in the air. Atmospheric PM can be emitted by a wide variety of sources that influence its physical properties (size, surface area, density), chemical composition and size distribution. In particular, PM may be classified as primary or secondary in accordance with its formation mechanism: primary particles are directly emitted into the atmosphere while secondary particles are formed after chemical transformation of their gaseous precursors (Perrino et al., 2008).

It is important to have knowledge about the physical properties of particles for the characterization of their behaviour, source identification, and possible health risks. The role of the number concentration and number size distribution measurements is important in characterizing the particulate emissions of different engine and after treatment technologies. However, there are no clear epidemiological nor toxicological evidence on the correlation of the inverse health effects and the number concentration of fine particles (HEI Review Panel on Ultrafine Particles, 2013). Diameter and shape of particulate matter are the most discussed from this point of view as these properties determine PM hazardousness (Weijer et al, 2001). The shape determines the PM incidence toward the cell walls of the respiratory system, thus the diameter determines whether the particle can be inhaled and in which part of the respiratory system it can deposited (Weijer et al., 2001).

2.2.1.1. Particle Size

Particles can be classified by their physical size; the size is from a few nanometers (nm) to tens of micrometers (m) in diameter. Size is the single most important determinant of the properties of particles and it has implications on formation, physical and chemical properties, transformation, transport, and removal of particles from the atmosphere. Particle size is normally given as the aerodynamic diameter, which refers to the diameter of a unit density sphere of the same settling velocity as the particle in question. The notation PMX refers to particulate matter comprising particles less than Xm in diameter (most often, X is 10, 2.5 or 1 m). Particles greater than 2.5 m in diameter are generally referred to as coarse particles, and particles less than 2.5 m and 100 nm in diameter as fine particles and ultrafine particles, respectively. The term total suspended particles (TSP) refers to the mass concentration of particles less than 40 to 50 m in diameter (Seinfeld and Pandis., 1998)

The behaviour of particles in the atmosphere and within the human respiratory system is determined largely, but not wholly, by their physical properties which have a strong dependence on size, varying from a few nanometres to tens of micrometres. A crude distinction is that particles of less than about 2.5μm penetrate to the alveoli and terminal bronchioles, larger particles of up to 10μm will deposit primarily in the primary bronchi and much larger particles (up to 100μm), will deposit in the nasopharynx.

Fine PM consists of particles having a diameter of between 0.1 and 2.5 μm and this, together with the ultra-fine mode, is designated $PM_{2.5.}$ The fine mode contains primary combustion particles and secondary particles, which have grown by coagulation and condensation. Owing to their ability to penetrate into the alveolar gas exchange region of the lungs, $PM_{2.5}$ is also referred to as respirable particles.

The coarse particle mode, consists of particles having diameters greater than 2.5 μm (of note, studies examining the toxicity of the coarse PM invariably define the fraction as $PM_{10-2.5}$ or occasionally $PM_{15-2.5}$). They may vary in size up to 100μm, with the larger particles becoming too heavy to remain airborne for any length of time. This class includes the most visible or obvious forms of PM such as black smoke, soil, dust from roads and building sites, large salt particles from sea spray, mechanically generated particles, as well as some secondary particles. Coarse particles also include pollen, mould, spores and other plant parts. Whereas the larger particles contribute rather little to particle number, they contribute the major proportion of particle mass. PM_{10} denotes all ambient PM (i.e. ultra-fine, fine and coarse particles) having a diameter of 10 μm or less and are sometimes termed “thoracic” particles in that they can escape the initial defences of the nose and throat and penetrate beyond the larynx to deposit along the airways in the thorax. Approximate size ranges of the various types of particulate pollutants are shown in Figure 2-1.

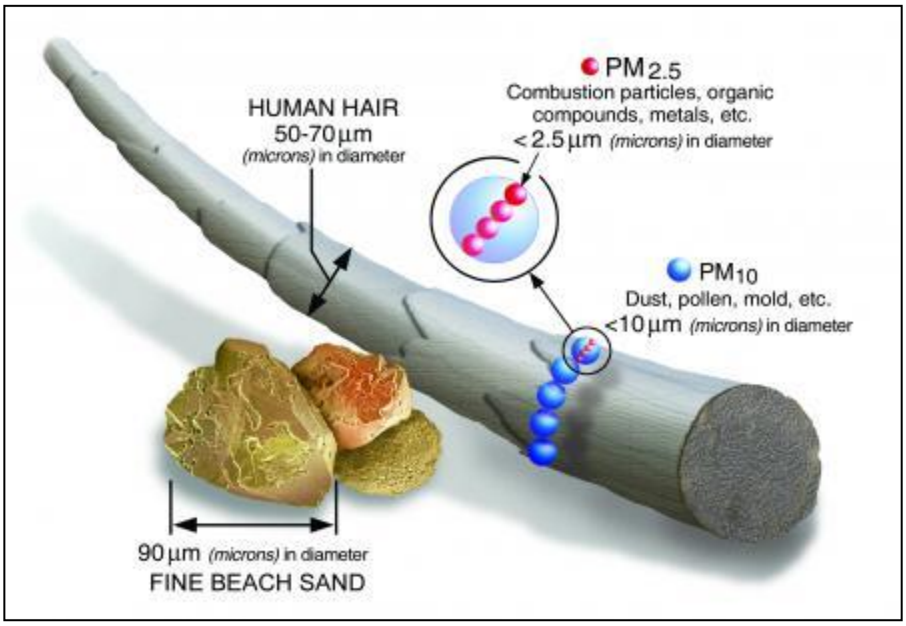


Figure 2-1 : Approximate size of particulate matter (USEPA,2016)

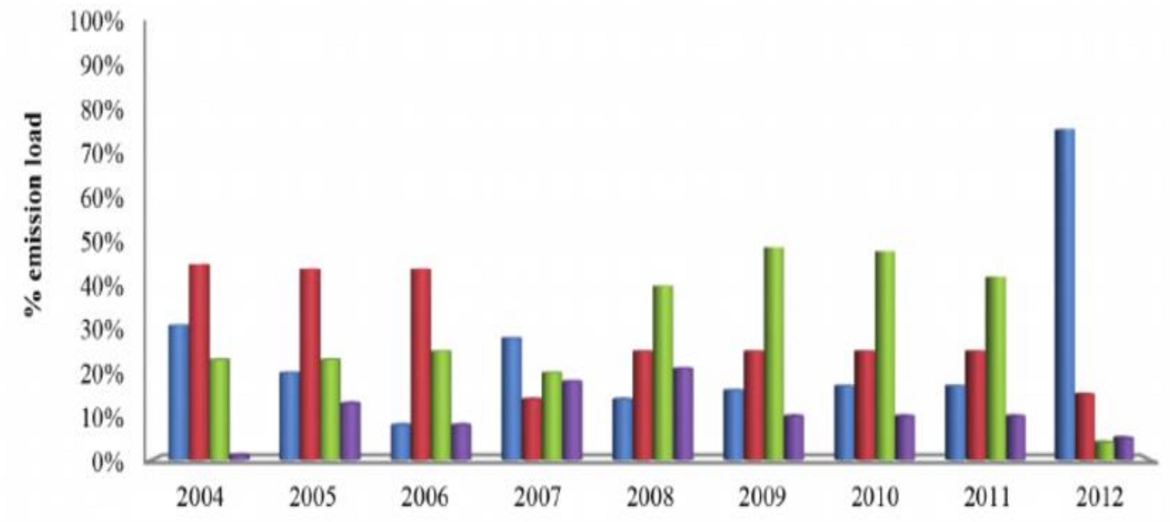
2.2.1.2. Chemical Characteristics

During recent years, substantial improvements have been carried out in the chemical characterisation and identification of the main atmospheric aerosol components (Viana et al., 2008). All the individual inorganic species typically representing more than 1% of the total PM mass can be easily determined and their main sources identified: crustal elements (silicon, aluminium, iron, calcium, carbonate), sea-salt aerosol (sodium chloride), inorganic secondary species (nitrate, sulphate ammonium), primary anthropogenic species (elemental carbon). The heavy metals found were dominated by Ba and Fe, followed by Cu > V> Zn > pb > Mn > Cr> As > Ni >Cd > Co . Heavy metal such as cadmium and lead are highly toxic and can remain in the environment longer periods of time (Joshi & Balasubramanian., 2010).

2.3 SOURCES OF PARTICULATE MATTER

The major sources of anthropogenic, i.e., man-made, particles include transportation, stationary combustion, space heating, biomass burning, and industrial and traffic-related fugitive emissions (street dust). Urban PM from man-made sources is a complex mixture, since the majority of sources emit both primary particles and precursor gases for the formation of secondary particles. The majority of anthropogenic PM is emitted within relatively small urban and industrial areas, resulting in hot spots of high concentrations of particulate matter and other air pollutants. Man-made primary and secondary particles also affect regional background PM concentrations since a fraction of the emitted particles can remain in suspension for several days and travel up to thousands of kilometres in the atmosphere (Harrison and Yin., 2000).

The most important emission that affect air quality are PM, SO_2 and NO_X (Pedrero et al., 2009). Resuspended road dust has been discussed at more length due to its marked impact on urban ambient PM levels, and the inadequate scientific information on its composition and other characteristics.



	2004	2005	2006	2007	2008	2009	2010	2011	2012
Motor vehicles	31%	20%	8%	28%	14%	16%	17%	17%	76%
Power plants	45%	44%	44%	14%	25%	25%	25%	25%	15%
Industrial	23%	23%	25%	20%	40%	49%	48%	42%	4%
Others	1%	13%	8%	18%	21%	10%	10%	10%	5%

Figure 2-2 : Particulate matter (PM) emission load by sources (in percentage), 2004-2012 (Source: Malaysia Environmental Quality Report 2012, 2011, 2010, 2009, 2008, 2007, 2006, 2005 & 2004)

2.3.1 Traffic

Vehicular particle emissions are the result of a great many processes, e.g.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).

Traffic emission and road dust have often been used for detecting heavy metal environmental pollution (Duong & Lee., 2011). Hence, the degrees of heavy metal pollution in road dust reported worldwide have existed for decades (Ondracek et al., 2011). Metals, including Cd, Co, Ni, pb, and Zn, maybe grouped as road-specific heavy metals. They are primarily a result of combustion residues, losses from fuels, engine, transmission oils, brake linings, exhaust catalysts, and abrasion from tires and road pavement (Amato et al., 2013; Harison et al., 2012). A high number of motor vehicles, together with more industries and a huge quantity of road dust, are suspected to contribute to the level of pM10 in the atmosphere (Juneng et al., 2011). Some research has been conducted on the properties of heavy metal levels in road dust produced by vehicular activities (Duong &Lee., 2011; Lawrence et al., 2013). For instance, the concentration and distribution of heavy metals in urban airborne particulate matter in Frankfurt, Germany were the highest values on a main street with high traffic density. Non-exhaust sources contributed almost the same levels as engine exhaust on a high-traffic road in London. The non-exhaust particles are normally derived from abrasive sources such as tire wear, brake wear, and road surface abrasion. Brake and tire wear contribute significantly to the presence of heavy metals in urbanized areas, and especially in places with high traffic (Harrison et al., 2012). Furthermore, particle re-suspension from the road surface is very important, particularly in drier weather (Harrison et al., 2012).

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. Physical and chemical characteristics of the particles emitted from these source categories depends 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).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter covers the details explanation of methodology used to complete this project. In order to achieve the objectives of this study, a systematic process was organized. Figure 3.1 shows the flowchart of the planning process for the monitoring program and Figure 3.2 shows the flowchart of methodology.

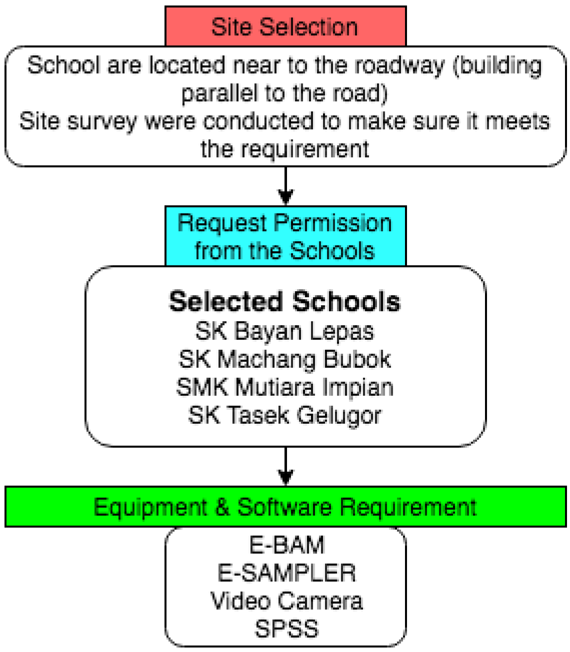


Figure 3-1: Flowchart of Planning Process