UNIVERSITI PUTRA MALAYSIA

ASSESSMENT OF HEAVY METALS CONCENTRATION IN AIRBORNE PARTICULATE MATTER (PM10) IN SELECTED TRAFFIC AREAS OF THE KLANG VALLEY, MALAYSIA

RASHEIDA ELAWAD ELHADI ELAWAD

FPAS 2017 14

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By

RASHEIDA ELAWAD ELHADI ELAWAD

Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

Special dedicated to:

My loving late father

My affectionate mother

My beloved husband

My affectionate brothers and sisters

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Doctor of Philosophy

ASSESSMENT OF HEAVY METALS CONCENTRATION IN AIRBORNE PARTICULATE MATTER (PM_{10}) IN SELECTED TRAFFIC AREAS OF THE KLANG VALLEY, MALAYSIA

By

RASHEIDA ELAWAD ELHADI ELAWAD

August 2017

Chairman : Associate Professor Ahmad Makmom Abdullah, PhD
Faculty : Environmental Studies

In recent years the level of heavy metals in the atmospheric particulate matter in traffic areas has been of considerable concern. This study was conducted to assess the heavy metals concentration in airborne particulate matter (PM_{10}) in selected traffic areas of Klang Valley. The PM_{10} samples was collected at four different areas with three sampling sites with different traffic densities (high, medium and low) during the Southwest and Northeast monsoon from June 2014 to Jaunary 2015. The PM_{10} samples were collected by High Volume Sampler (HVS) using glass fibre filter. The Heavy metals in PM_{10} were assessed with inductively coupled plasma mass spectrometry (ICP-MS). Multivariate statistics using Cluster Analysis (CA) and Principal Component Analysis (PCA) were used in source identification. Also AERMOD dispersion model was used to simulate PM_{10} and heavy metals. The finding from this study revealed differences in the mean concentration of PM_{10} between seasons and different traffic density sites. During the Southwest monsoon, Shah Alam recoded the highest mean concentrations for the high, medium and low traffic density sites with 210.14, 171.74 and 111.56 µg/ m^3 respectively. The results recorded for the high and medium traffic sites by far exceeded the standard of 150.0 µg/ m^3 of Recommended Malaysian Air Quality Guidelines (RMAQG). For the Northeast monsoon season Shah Alam recorded the highest mean concentation (139.28 µg/ m) for high traffic density sites, while Cheras recorded the highest mean concentration of (121.11 and 45.68 µg/ m^3) for medium and low traffic density sites respectively. As for the heavy metals the findings showed differences in concentration of heavy metals between seasons and traffic density sites as well. The heavy metals concentration was below the limit of concentration set by both United States Environmental Protection Agency (USEPA) and World Health Organization (WHO except for Arsenic (As). The finding from CA and PCA identified vehicle exhaust emission, non-exhaust emission (brake wear, tire wear and re-suspension dust) and heavy lubricating oil combustion as major sources of PM_{10} and heavy metals. The

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AERMOD model simulation revealed that the maximum concentrations of PM_{10} and heavy metals were observed in central, southeast, southwest and west of the model domain. The validation of the AERMOD model performed well in simulating PM_{10} and most of the heavy metals. Owing to the effects of PM_{10}, which is associated with health risks, the level of PM_{10} and its heavy metals content, especially Arsenic (As), should be monitored frequently to achieve a healthy environment in the study area.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

PENILAIAN KEPEKATAN LOGAM BERAT DALAM PARTIKEL BAWAAN UDARA (PM_{10}) DI KAWASAN TRAFIK TERTENTU DI LEMBAH KLANG, MALAYSIA

Oleh

RASHEIDA ELAWAD ELHADI ELAWAD

Ogos 2017

Chairman : Profesor Madya Ahmad Makmom Abdullah, PhD
Faculti : Pengajian Alam Sekitar

Dalam tahun-tahun kebelakangan ini, tahap logam berat dalam bahan zarah atmosfera di kawasan trafik telah menjadi kebimbangan yang besar. Kajian ini dijalankan untuk menilai kepekatan logam berat dalam Partikel Bawaan udara (PM_{10}) di kawasan trafik tertentu di Lembah Klang. Sampel PM_{10} telah dikumpulkan di empat kawasan yang berbeza dengan tiga tapak persampelan dengan kepadatan lalu lintas yang berbeza (tinggi, sederhana dan rendah) semasa Monsun Barat Daya dan Timur Laut dari Jun 2014 hingga Januari 2015. Sampel PM_{10} dikumpul menggunakan High Volume Sampler (HVS) yang dilengkapi dengan penapis gentian kaca. Logam berat di PM_{10} dinilai dengan spektrometri massa plasma (ICP-MS) secara induktif. Perangkaan multivariat menggunakan Analisis Klausa (CA) dan Analisis Komponen Utama (PCA) telah digunakan dalam pengenalan sumber. Juga model penyebaran AERMOD digunakan untuk mensimulasikan PM_{10} dan logam berat. Hasil daripada kajian ini mendedahkan perbezaan dalam kepekatan purata PM_{10} antara musim dan kawasan ketumpatan lalu lintas yang berlainan. Semasa musim monsun barat daya, Shah Alam mencatatkan kepekatan purata tertinggi untuk kawasan kepadatan lalu lintas tinggi, sederhana dan rendah dengan 210.14, 171.74 dan 111.56 $\mu g/m^3$ masing-masing. Angka yang dicatatkan untuk tapak trafik yang tinggi dan sederhana telah melebihi standard 150.0 μg / m^3 Garis Panduan Kualiti Udara Malaysia yang digariskan (RMAQG). Bagi musim monsun timur laut, Shah Alam mencatatkan jumlah pertumpahan tertinggi (139.28 $\mu g/m^3$) bagi kawasan kepadatan trafik yang tinggi, manakala Cheras mencatatkan kepekatan purata tertinggi (121.11 dan 45.68 $\mu g/m^3$) masing-masing bagi kawasan kepadatan trafik sederhana dan rendah. Bagi logam berat, penemuan menunjukkan perbezaan kepekatan logam berat antara musim dan kawasan kepadatan lalu lintas juga. Penumpuan logam berat adalah di bawah aras kepekatan yang ditetapkan oleh kedua-dua Badan Perlindungan Alam Sekitar Amerika Syarikat (USEPA) dan Pertubuhan Kesihatan Sedunia (WHO) kecuali Arsenik (As). Penemuan dari CA dan PCA telah mengenalpasti pelepasan ekzos

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kenderaan, pemakaian brek, tayar pakai dan habuk penggantungan semula dan pembakaran minyak pelincir berat sebagai sumber utama PM_{10} dan logam berat. Simulasi model AERMOD menunjukkan bahawa kepekatan maksimum PM_{10} dan logam berat diperhatikan di tengah, tenggara, barat daya dan barat model model. Pengesahan model AERMOD dilakukan dengan baik dalam mensimulasikan PM_{10} dan kebanyakan logam berat. Disebabkan kesan PM_{10} tahap PM_{10} dan kandungan logam beratnya, terutamanya Arsenik berkait rapat dengan risiko kesihatan, perkara ini perlu dipantau secara kerap untuk mencapai persekitaran yang sihat di kawasan kajian.

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I would like to express my application and gratitude to all who made it possible for me to accomplish this work. First and foremost my grateful to the Almighty ALLAH the most merciful who gave me the strength and patience to complete this study.

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I certify that a Thesis Examination Committee has met on 23 August 2017 to conduct the final examination of Rasheida Elawad Elhadi Elawad on her thesis entitled "Assessment of Heavy Metals Concentration in Airborne Particulate Matter (PM_{10}) in Selected Traffic Areas of the Klang Valley, Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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- The research conducted and the writing of this thesis was under our supervision;
- Supervision responsibilities as stated in Rules 41 in Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

$\mu g/m^3$	Micrograms per cubic meter
AERMAP	AERMOD Terrain Preprocessor
AERMOD	American Meteorological Society (AMS) and U.S.
ANOVA	Analysis of Variance
API	Air Pollution Index
As	Arsenic
Ba	Barium
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
DOE	Department of Environment
DEM	Digital Elevation Maps
DOSM	Department of Statistics Malaysia
EC	European Commission
EEA	European Environmental Agencies
EMEP	European Monitoring Environmental Pollution
EPA	Environmental Protection Agency
EU	European Union
FA2	Factor of Two
FB	Fraction of Bias
Fe	Iron
Gg	Giga gram
GIS	Geographical Information Systems
HACA	Hierarchical Agglomerated Cluster Analysis
HVS	High Volume Sampler
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IOA	Index of Agreement
JKR	Public Works Department
KMO	Kaiser-Mayer-Olkin
MDL	Method Detection Limit
Mn	Manganese
NEI	National Emission Inventory
ng/m^3	Nano gram per cubic meter
Ni	Nickel
NE	Northeast
NMSE	Normal Mean Square Error
Pb	Lead
PBL	Planetary Boundary Layer

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PCA	Principal Component Analysis
PCs	Principal Components
PM	Particulate matter
PM_{10}	Particulate Matter with aerodynamic diameter of 10 micron
$PM_{2.5}$	Particulate Matter with aerodynamic diameter of 2.5 micron
PSI	Pollutant Standard Index
QA/QC	Quality Assurance/ Quality Control
R	Correlation Coefficient
RMAQG	Recommended Malaysian Air Quality Guidelines
SEM	Scan Electron Microscopy
SPM	Suspended Particulate Matter
SRM	Standard Reference Material
SW	Southwest
TSP	Total Suspended Particulate Matter
USEPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator system
V	Vanadium
VKT	Vehicle Kilometer Traveled
WHO	World Health Organization
Zn	Zinc

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Air pollution is a serious issue that needs to be given immediate and serious attention by all relevant authorities around the globe, as it is one of the most important factors that contribute to the quality of life and living (Azid et al., 2014). Air pollution refers to any condition in the atmosphere in which particular matters exist in certain levels and durations that they may adversely affect human health, ecosystems, materials, buildings, vegetation and visibility (Miller et al., 2007). It has been estimated that indoor and outdoor air pollution directly or indirectly was responsible for approximately seven million deaths in 2012 worldwide, and is currently the world's single largest environmental health threat (WHO, 2014). Some air pollutants are described by referring of their mass and volume of concentration normally, in terms of micrograms of pollutant per cubic meter of air ($\mu g/m^3$), but such units of measurement significantly according to the origin of pollution and how they are dispersed, weather conditions and the topography of the environment (Ilyas et al., 2010; Riga-Karandinos and Saitanis, 2005).

Although the level of air pollution in Malaysia is not as high as compared with several other Asian urban centres such as Jakarta or Metropolitan Manila. However, pollution level increases outside extreme haze periods and this is worsened by the rapid increase in the number of vehicles, distances travelled and the continuing increase of industrial activities. Hence, preventive action, thought the most costly response to this situation, is something Malaysia must take. As the air continues to be polluted, air pollution is now a matter of great concern. Primarily because of the negative effect it has on human health. It has become important to monitor the quality of the air we breathe and investigate the air pollutants such as particulate matter and the presence of heavy metals being dispersed in the urban areas (Amir, 2007; Azmi et al., 2010).

Particulate matter is a substantial constituent of polluted air and causes serious health problems that claim an average of three million lives a year at the turn of the century and has continued to increase (Borrego et al., 2006; WHO, 2001). Particulate matter contains a mixture of several substances, either solid or liquid in the atmosphere (Viana et al., 2006) and usually consists of total suspended particles (TSP) that are classified as PM_{10} and $PM_{2.5}$. Among these, PM_{10} is a particle with an aerodynamic diameter of less than 10 µm (Pérez et al., 2008; Viana et al., 2008). PM_{10} is commonly selected as a monitoring parameter for evaluation of air quality, usually emitted from natural and anthropogenic sources (Viana et al., 2008). These particles have profound effects on human health, climate, cloud formation, visibility reduction and can damage the environment (Pope et al., 2009; Seinfeld and Pandis, 2012).

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Numerous epidemiological studies have identified that high levels of inhalable particles (PM10) are closely related to higher incidence of mortality (Das et al., 2015; Lin and Lee, 2004; Namdeo and Bell, 2005). This particulate, if deposited on the skin and in the nasal passage could cause an allergy, skin and respiratory diseases when it reaches the lungs. The accumulation of particulate matter in lungs may cause fibrogenesis of lung tissues (Das et al., 2015; Pope and Dockery, 2006). The relationship between atmospheric particulates and heart disease has been documented since the 19th century when it was observed that there was a higher number of hospital admissions on days that the ambient air levels of PM were at abnormally high levels (Peters, 2005).

In Asian cities, PM_{10} has been recognized as a significant atmospheric pollutant and in the majority of cases, elevated PM_{10} levels particularly in the dry season were reported and frequently for more than USEPA 24-hrs and exceeding annual standards (Fang and Chang, 2010; Hopke et al., 2008; Kim Oanh et al., 2006). This will adversely affect the human respiratory system thus chronic obstructive pulmonary ailments as well as asthma (Mott et al., 2005).

In Malaysia, research on particulate matter has been going on since the 90s (Juneng et al., 2009; Yusup and Alkarkhi, 2011). PM_{10} is one of the main factors of air pollutants in calculating the Malaysian Air Pollution Index (MAPI) (Afroz et al., 2003; Azmi et al., 2010; bin Abas et al., 2004). Over the Klang Valley, the PM_{10} levels during the dry season (Southwest monsoon) is significantly higher than in the Northeast monsoon due to smoke from the combustion of biomass burning in regional sources (Awang et al., 2000; Juneng et al., 2009). Additionally, PM_{10} concentrations over the Klang Valley have been recorded as increased because of the urban traffic in comparison with those of rural stations (Awang et al., 2000; Azmi et al., 2010).

Furthermore, in the past few years, air pollution has become a serious environmental problem primarily because of the toxic heavy metals existing in PM due to rapid industrialization and increased transportation (Shah et al., 2006). The term "heavy metals" have been defined in different ways over the years and established by density, specific gravity, atomic weight, atomic number, and toxicity (Draghici et al., 2011; Duffus, 2002). It is frequently applied as a group name referring to metals and metalloids that are linked with contamination and possible toxicity or ecotoxicity (Duffus, 2002). Trace elements, microelements, and trace metals are some other commonly used terms for heavy metals (Adriano, 2001).

Heavy metals are the main class of globally-dispersed natural elements that have been extract from the earth and used for industrial purposes (Bilos et al., 2001). Heavy metals are various substances with different properties because of their toxicity to humans and ecosystems (Pizzol et al., 2011). Recent epidemiological studies revealed that heavy metals in the airborne particles are a serious environmental problem because they pose a threat to human health and the

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ecosystem (Das et al., 2015; Garcia et al., 2011; Mavroidis and Chaloulakou, 2010). They influence the target organ in biological function, affecting the healthy development, growth of body tissues, enzyme activities and their proper functioning (Andersen et al., 2007; Liu et al., 2009; Mavroidis and Chaloulakou, 2010; Shaheen et al., 2005).

Heavy metals exist practically in all atmospheric aerosol fractions and generally, finer PM particles possess a higher load of toxic heavy metals than the coarse PM particles (Fang et al., 2000). PM_{10} has high levels of heavy metals that are toxicologically significant with approximately 75 – 90 % of metals such as copper (Cu), cadmium (Cd), nickel (Ni), zinc (Zn), iron (Fe) and lead (Pb) found in the PM10 fractions (Mohanraj et al., 2004; Rizzio et al., 1999). Heavy metals in the atmosphere are highly mobile and may be moved by prevailing winds over long distances from sources to the receptor which means that they may are in fact transboundary pollutants. Many heavy metal emissions have been controlled because of their initial toxicity as well as the impacts of bioaccumulation (Adriano, 2001).

Particulate matter can be emitted to the atmosphere from a sizeable range of sources, including natural and anthropogenic or it may form in the atmosphere through reactions of gaseous substances. Studies on the formation of particles have revealed the relevance of size and chemical composition indicators. The primary sources of particulate matter include natural emissions (crustal minerals, biomass burning, and sea salt spray) and anthropogenic sources such as road dust, construction, fossil fuels, motor vehicles and industrial activity). Traffic emission has a significant contribution to both the quality and quantity of the ambient air particulate matter (Samara and Voutsa, 2005; Shah et al., 2012). Traffic emissions influence total levels of PM in urban areas. In recent decades the exposure to PM from vehicular emissions has been established to have adverse effects on human health, biogeochemical cycling in the ecosystem and impact on the radiation balance which consequently affects the climate (Fan et al., 2009; Kendall et al., 2011; Masiol et al., 2012; Vega et al., 2010). The United Nations has indicated that more than 600 million urbanites globally are subjected to hazardous levels of air pollutants derived from vehicle traffic (Cacciola et al., 2002).

In Malaysia, the principal sources of air pollution especially in metropolitan areas are vehicular traffic. The Department of Environment (DOE, 2006) has reported that motor vehicles were responsible for 82% to the total air emission in Peninsular Malaysia, followed by power stations (9%), industrial combustion (5%), industriy-related activities (3%), commercial and domestic furnaces (0.2%), and open burning of solid waste contribute (0.8%) (Azmi et al., 2010).

Moreover, vehicular emissions are the most common sources of heavy metals such as combustion of fuel, tire and brake wear, materials used in constructing roads, and re-suspension of soil and road dust (El-Fadel and Hashisho, 2001). The concentrations and size distributions of heavy metals are governed by the kind of

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emissions released and also by the levels of wet and dry deposition, the effect of clouds, chemical reactions and the exchange of air that takes place at the boundary layer and free troposphere (Samara and Voutsa, 2005). Several studies have demonstrated that exhaust and non-exhaust traffic-related sources are responsible for the total traffic-related PM_{10} and heavy metals emissions. However, because of ongoing decrease of exhaust emissions, there is a likelihood that the emission of non-exhaust sources will be elevated over time (Amato et al., 2014; Amato et al., 2011; Bukowiecki et al., 2010).

Moreover, it would be appropriate to recognize and estimate emissions from vehicular sources, which would aid the regulating and planning authorities in making decisions for the improvement of the quality of air in the study area. Emission inventories have become a critical tool for estimating ambient air quality of an area, as this comprises the description of air pollutant emitting sources along with the pollutant emission quantities. This provides the required information in understanding the regional and sectoral emission sources, which guide air pollutants control authorities to formulate policies to imptove air quality (Hu et al., 2011; Qiu et al., 2014). Thus, it is obvious that air quality relies not only on the sources of emission, but also more importantly on the climatic aspects with complex features and spatio-temporal scales (Demuzere et al., 2009).

Air quality dispersion models are one of the tools that can be used to investigate dust emissions and dispersion, and also, employed to comply with laws and regulations for the protection of air quality. The models have been extensively evaluated to determine the performance under various meteorological conditions. Atmospheric dispersion models are mathematical simulations of the dispersal of pollutants mostly in the boundary layer of the atmosphere. It is computer-based programmes that provide the solutions for mathematical equations and algorithms which generate simulations of the dispersion of pollutants (Mustapha et al., 2008). The development of dispersion models have been developed for ground level concentration prediction, and mostly for regulatory purposes (Harsham and Bennett, 2008). Dispersion models differ in their assumptions and structure as well as in the algorithms used, thus, resultant predictions often vary from model to model.

1.2 The Problem Statement

Over the past 20 years, urbanization, industrialization, and economic growth caused a profound deterioration of air quality particularly in urban areas in Malaysia (Azmi et al., 2010; Wahid, 2006). Moreover, remarkable movement of rural to urban drift has contributed more significant emissions into the air, which has mainly been related to increased vehicular emissions (Azmi et al., 2010; Baldasano et al., 2003).

Recently, the effect of vehicular emissions on the air quality has received greater attention in most countries worldwide. Malaysia is a developing economy and its

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development has led to significant increase in vehicle emission which has contributed to the rising levels of pollutants in the ambient air such as the particulates matter and their contents of heavy metals. Results on air pollution levels from earlier studies have shown an obvious decline in air quality status in Peninsular Malaysia particularly in heavily urbanized areas due to motor vehicular emissions, industrial, power plants (stationary sources) and the combustion of biomass (Afroz et al., 2003; bin Abas et al., 2004; Wahid et al., 2014).

Klang Valley is considered to be the most industrialized area in Malaysia with high industrial activity and other anthropogenic activities particularly traffic emission, hence, air pollution in the Klang Valley has become a critical problem (Latif et al., 2011). Furthermore, previous studies undertaken have also concentrated on the Klang Valley area, which is the most badly hit by annual trans-boundary haze from Sumatra (Indonesia). The topography of the Klang Valley traps the air pollutants within the area (Awang et al., 2000; Azmi et al., 2010).

Pervious studies were conducted to investigate health issues due to PM exposure associated with heavy metals in the ambient air causing health problems, such as chronic respiratory and cardio-vascular diseases, cancer, and ill effects to other organs (Miller et al., 2007; Wild et al., 2009). The atmosphere in Klang valley is polluted with variety of air pollutants especially heavy metals in particulate matter as reported by (Khan et al., 2015; Tahir et al., 2013; Wahid et al., 2014) with adverse health implication. These studies highlighted the need for direct quantification of air pollutants as a priority issue. But, so far all the previous studies that were conducted in Malaysia used statiscal approach such as multivariate analysis for source identification of heavy metals in PM. No study was conducted to estimate the emission of heavy metals in PM_{10} using AERMOD dispersion model which will enable mapping out the distribution and the concentration of PM_{10} and heavy metals with their emission inventory. Hence, this study is intended to fill in this gap by using AERMOD dispersion model in the assessment of heavy metals concentration in airborne particulate matter (PM_{10}) in selected traffic areas of Klang Valley.

1.3 Research Question

1. What are the concentrations of PM_{10} and heavy metals from various locations?
2. Are there any variations of PM_{10} and heavy metals concentrations between three traffic densities (high, medium and low)?
3. Are there any significant differences between PM_{10} and heavy metals during Southwest and Northeast monsoons in the study area?
4. What are the sources of identification that contribute to heavy metals pollution in PM_{10} in the study areas?
5. What is the spatial distribution of PM_{10} and heavy metals in the study area?

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1.4 Scope of Study

This research basically focuses on the heavy metals in particulate matter (PM_{10}) from the traffic areas of Klang Valley. The study concentrates on the determination of the PM_{10} and associated heavy metals from traffic sources including exhaust and non-exhaust emission only. The study did not entail emission of PM_{10} and other associated heavy metals from haze. Also, it is within the scope of this study to identify the sources of PM_{10} and heavy metals that influence the air quality in the study area through the application of different multivariate techniques. The study is moreover, utilizes Air quality dispersion model (AERMOD) in the estimation of PM_{10} and heavy metals distribution in this area.

1.5 Main Objectives

To assess the heavy metals concentration in airborne particulate matter (PM_{10}) in selected traffic areas of Klang Valley.

1.6 Specific Objectives

1. To evaluate twelve heavy metals concentrations (As, Pb, Cu, Ni, Cd, Co, Mn, Zn, Fe, Cr, V, Ba) in airborne particulate matter (PM_{10}) from traffic areas.
2. To identify sources of PM_{10} and heavy metals in the study area using the multivariate technique.
3. To model the spatial distribution of PM_{10} and heavy metals in the study area using AERMOD model and GIS technique.

1.7 Significance of the Study

The novelty of this present study is in methodological approach where the AERMOD model was employed for the first time in the study area, as the model capability of estimating the spatial distribution and concentration of PM_{10} and heavy metals as well mapping out the various areas of different concentration. This information when provided will enable a better appreciation of the challenges of air pollution and how best it can be tackled, more especially as the study equally provides useful direction to the sources identification of these pollutants and establishing emission inventory which may aid in the establishment of emission factor for Malaysia in the future..

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Academically, this present study will contribute to the existing body of literature on the study of heavy metals in Particulate matters (PM_{10}) particularly using this approach. It is hoped that the findings from this work will also open up new vistas of researches along this direction by considering the effect of weather conditions and traffic intensity on air pollution. The findings of this current study can be use in developing a database and improve inventories on air pollution index and heavy metals in particulate matter (PM_{10}) in Peninsular Malaysia which will ultimately help the government to formulate policies and provide interventions in tackling the air pollution problem in Peninsular Malaysia, as currently Malaysia lacks emission inventory on PM_{10} and associated heavy metals.

1.8 Thesis Structure

This thesis comprises five chapters:
Chapter 1 begins with the background of the work, followed by the problem statement, the general and specific objectives, research questions and the significance of the study.

Chapter 2, reviews the literature on air quality status in Malaysia, previous studies on particulate matter and PM_{10}, heavy metals in the atmosphere, health effects of particulate matter (PM_{10}) and heavy metals, heavy metals concentration in PM, air quality ACT and regulation of PM_{10} and heavy Metals. Also, review on sources of heavy metals in particulate matter, application of Cluster Analysis (CA) and Principal Components Analysis (PCA) for identifying the sources of air pollution, air quality dispersion modeling, factors influencing air quality, application of AERMOD modeling were provided.

Chapter 3 describes all the methodologies, research instruments and techniques that are used for data collection and analysis. Furthermore, the modeling process is explained. Chapter 4 focuses on the presentation of results, intepretation and discussion, while Chapter 5 discusses the summary of the research findings and makes recommendations for further study.

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