UNIVERSITI PUTRA MALAYSIA

DISPERSION OF PM_{10} FROM INDUSTRIAL AND ROAD TRANSPORTATION NETWORK EMISSIONS IN THE KLANG VALLEY, MALAYSIA

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By

MOHD. ASRUL BIN JAMALANI

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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Chairman : Professor Ahmad Makmom Hj. Abdullah, PhD
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Particulate matter (PM_{10}) has been the major concern due to their negative impact to the environment, human health and spatial planning for greener environment. In order to have better understanding on the issues, three main objectives were stated in this study. Firstly, was to determine the airborne PM_{10} emission inventory from the local sources. Secondly, was to correlate the meteorological conditions resulted from meteorological modelling towards the study area. Lastly, to validate the obtained concentration thematic map from the integration modelling approach. The Department of Environment (DOE) reported that almost half of the total PM_{10} emission load in Malaysia were contributed by the vehicular and industrial activities. Therefore, the initiative was taken decades ago to monitor the ambient air quality with proper recording. However, Malaysia still lack of pollutant emission inventory due to limitation on expertise. Therefore, this study initiatively collects the information to execute the PM_{10} emission inventory from the best available resources. In general, the air pollutants dispersed freely without knowing the direction and magnitude of the pollutants. Therefore, the Regional Air Quality Model (RAQM) was used to correlate the calculated emission with the meteorological conditions forming the PM_{10} concentration thematic map. Thus, this modelling approach could address the unmonitored area between the DOE monitoring stations with providing the PM_{10} concentration information. The preliminary study on the localised air quality status was conducted by the descriptive statistical and ANOVA analysis. Then, the modelling part were initiated with the calculation of the PM_{10} emission from two main sources consist of the industrial and road transportation network emission. In the end producing the emission inventory file to fulfil the first objective. This emission inventory was processed and converted into gridded emission profile by the application of the Sparse Matrix Operator Kernal Emission (SMOKE) model. To achieve the second objective, the gridded meteorological profile was produced from the Fifth Generation Mesoscale (MM5) model. Community Multiscale Air Quality (CMAQ) model as the chemical transport modelling system was able to simulate the

PM_{10} concentration thematic map. Thus, the integration process between the models create an integrated SMOKE-MM5-CMAQ model under similar gridding system namely known as the RAQM for achieving the third objective. The emission inventory showed higher contribution of PM_{10} emissions in industrial source rather than road transportation network. Whilst, the MM5 model showed positive result in correlating the meteorological conditions. Thus, the integrated modelling system was able to interpolate the PM_{10} concentration thematic map for every location in the domain. However, the obtained concentration was extremely low due to the limitation on the primary input of the emission. This study only considered the generalised industrial area basis and the average on-road vehicles' travel distance emissions from land use map and vehicles statistic, respectively as the input. Besides, the presence of the fugitive elements was being underestimated which contributed to the huge uncertainties in the study. A comprehensive study on determining the fugitive elements in the future is necessary for the emission input improvement in gaining a convincing PM_{10} concentration information.

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

PENYERAKAN PM_{10} DARIPADA PELEPASAN INDUSTRI DAN JARINGAN JALAN PENGANGKUTAN DI LEMBAH KLANG, MALAYSIA

Oleh

MOHD. ASRUL BIN JAMALANI

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Zarahan terampai (PM_{10}) telah mendapat perhatian disebabkan oleh kesan negatif terhadap alam sekitar, kesihatan dan perancangan ruang bagi persekitaran hijau. Bagi memastikan permasalahan ini dapat difahami dengan tebih mendalam, tiga objektif utama telah ditetapkan dalam kajian ini. Pertamanya adalah penentuan penyenaraian pelepasan PM_{10} di udara daripada sumber-sumber tempatan. Kedua pula adalah untuk menhubungkait keadaan meteorologi hasil daripada permodelan meteorologi terhadap kawasan kajian. Akhirnya adalah untuk mengesahkan hasilan peta kepekatan tematik daripada kaedah penyatuan permodelan. Jabatan Alam Sekitar (DOE) melaporkan bahawa hampir separuh daripada jumlah beban pelepasan PM_{10} di Malaysia disumbang oleh aktiviti kendeaan dan juga industri. Oleh itu, insiatif thelah diambil beberapa dekad yang lalu untuk memantau kualiti udara ambien dengan rekod yang betul. Tetapi, di Malaysia masih kekurangan penyenaraian pelepasan bahan pencemar disebabkan oleh kekurangan kepakaran. Oleh yang demikian, kajian ini mengambil inisiatif untuk mengumpul maklumat bagi melaksanakan penyenaraian pelepasan PM_{10} daripada sumber yang terbaik yang boleh didapati. Secara umum, pencemar udara diserakkan secara bebas tanpa diketahui arah dan magnitudnya. Oleh itu, model kualiti udara serantau (RAQM) telah digunakan untuk menghubungkait pengiraan pelepasan dengan keadaan meteorologi yang akhirnya menghasilkan peta kepekatan PM_{10} tematik. Justeru, kaedah permodelan boleh digunakan untuk penentuan kawasan yang tidak dipantau iaitu kawasan di antara stesen-stesen pemantauan dengan menyediakan maklumat kepekatan PM_{10}. Kajian awal mengenai status kualiti udara setempat telah dijalankan melalui analisis diskriptif statsitik dan ANOVA. Kemudian, pada bahagian permodelan dimulakan dengan pengiraan pelepasan PM_{10} daripada dua sumber utama yang terdiri daripada pelepasan daripada industri dan jaringan jalan pengangkutan. Akhirnya, menghasilkan fail penyenaraian pelepasan bagi memenuhi objektif pertama. Penyenaraian pelepasan ini telah diproses dan ditukarkan kepada profil pelepasan berkisi dengan penggunaan model *Sparse Matrix Operator Kernal Emission* (SMOKE). Bagi mencapai objektif kedua, profil meteorologi berkisi telah

dihasilkan melalui model *Fifth Generation Mesoscale* (MM5). Model *Community Multiscale Air Quality* (CMAQ) adalah system permodelan pengangkutan secara kimia yang berkebolehan untuk menunjukkan peta kepekatan PM_{10} tematik. Justeru, proses penyatuan antara model-model menghasilkan model penyatuan SMOKE-MM5-CMAQ di bawah sistem kekisi yang sama dan juga dikenali dengan RAQM. Penyenaraian pelepasan menunjukkan penyumbang tertinngi kepada pelepasan PM_{10} adalah daripada sumber industri jika dibandingkan dengan jaringan jalan penyangkutan. Sebaliknya, model MM5 menunjukkan keputusan yang positif dalam penghubungkaitan dengan keadaan meteorologi. Oleh itu, system permodelan penyatuan berkebolehan untuk menunjukkan peta kepekatan pelepasan PM_{10} tematik pada setiap lokasi di dalam kawasan. Walau bagaimanapun, kepekatan yang diperolehi adalah terlalu rendah disebabkan had input utama iaitu pelepasan. Kajian ini hanya mengambil kira pelepasan daripada kawasan perindutrian secara umum serta penganggaran jarak perjalanan kenderaan daripada peta guna tanah dan juga statistic kenderaan yang digunakan sebagai input. Selain itu, kehadiran elemen-elemen sampingan telah diabaikan di mana ianya memberikan sumbangan kepada banyaknya ketidakpastian dalam kajian ini. Kajian yang mendalam mengenai penentuan elemen-elemen sampingan pada masa hadapan adalah perlu bagi penambahbaikan input pelepasan dalam pemerolehan maklumat kepekatan PM_{10} yang lebih meyakinkan.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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AERMOD	American Meteorological Society/Environmental Policy Agency Regulatory Model
ANOVA	Analysis of Variance
API	Air Pollution Index
AQMEII	Air Quality Model Evaluation International Initiative
ARINV	Emission inventory file
ARPS	Advanced Regional Prediction System
ASCII	American Standard Code for Information Interchange.
ATCMs	Atmospheric Chemistry Transport Models
BCON	Boundary conditions processor
CO	Carbon monoxide
CALMET	Diagnostic 3-dimensional meteorological model
CALPUFF	Non-Steady-State Puff model
CAMx	Comprehensive Air quality Model with extensions
CARMA	Community Aerosol and Radiation Model for Atmospheres
CCTM	Component chemistry transport model processor
CMAQ	Community Multiscale Air Quality model
CMAS	Community Modelling and Analysis System
CTMs	Chemical Transport Models
DMSP	Defense Meteorological Satellite Program
DOE	Department of Environment
DOSM	Department of Statistic Malaysia
EC	Environment Canada
EIA	Environmental impact assessment
EJRC	European Joint Research Center
EMIMO	Emission Model
EQR	Environmental Quality Report
Eta	National Center of Environmental Prediction Eta Model
Fa2	Fraction of two
FDDA	Four-dimensional data assimilation
FNL	National Centers for Environmental Prediction (NCEP) FNL (final) Operation Model Global Tropospheric Analyses data
GATOR/MMTD	Gaseous, Aerosol, Transportation and Radiation of Atmospheric Model Coupled Mesoscale Meteorological and Tracer dispersion model
GFS	Global Forecast System
GIS	Geographical Information System
HACA	Hierarchical Agglomerative Cluster Analysis
HPC	High-performance-computing sparse-matrix algorithms
HRM	High-resolution Regional Model
H_o	Null hypothesis
H_a	Alternative hypothesis
IA	Index of agreement
IBLTYP	Microphysics (Explicit Moisture) Schemes in MM5 model

ICON	Initial condition processor
ICUPA	Cumulus parameterization schemes in MM5 model
IDA	Inventory Data Analyzer
IDW	Inverse distance weighting
IFRAD	Atmospheric Radiation Schemes in MM5 model
IM	Inter-Monsoon
IMPHYS	Microphysics (Explicit Moisture) Schemes in MM5 model
ISOIL	Surface Scheme in MM5 model
ITZC	Inter Tropical Convergence Zone
JPBD	Federal Department of Town and Country Planning/ *Jabatan Perancangan Bandar dan Desa*
KKR	Ministry of Work/ *Kementerian Kerja Raya*
LAM	Limited-Area Model
LSM	Land Surface Model
MAAQG	Malaysia Ambient Air Quality Guidelines
MB	Mean bias
MCCM	Multiscale Climate Chemistry Model
MCIP	Meteorology– chemistry interface processor
MMD	Malaysian Meteorological Department
MM5	Fifth Generation Penn State/NCAR Mesoscale Model
MM5/CMAQ	Community Multiscale Air Quality Model coupled Fifth Generation Penn State/NCAR Mesoscale Model
MM5-CAMx	Comprehensive Air Quality Model with Extensions coupled MM5
MNAAQS	Malaysian National Ambient Air Quality Standard
Model-3/CMAQ	Community Multiscale Air Quality coupled Model-3
MRF	Medium Range Forcast
NAAPS	Navy Aerosol Analysis and Prediction System
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NE	Northeast Monsoon
NGO	Non-governmental organization
NH_3	Amonia
NMB	Normalised mean bias
NME	Normalised mean error
NOAA	National Ocenic and Atmospheric Administration
NOx	Nitorogen oxides
PBL	Planetary boundary layer
PCA	Principal Component Analysis
PGMs	Photochemical Grid Models
PM_{10}	Particulate matter with size of 10 micron
$PM_{2.5}$	Fine particulate matter with size of 2.5 micron
PSI	Pollutant Standard Index
PSU/NCAR	Penn State University and National Center for Atmospheric Research
R	Correlation coefficient
RAMS	Regional Atmospheric Modelling System
RAQEM	Regional Air Quality Eulerian Model
RAQM	Regional Air Quality Model

RMSE	Root mean square error
ROM	Regional Oxidant Model
RSM	Regional Spectral Model
SCC	Source Clasification Code
SMOKE	Sparse Matrix Operational Kernal Emission model
SMOKE-MM5-CMAQ	An integration regional air quality model used in this study. Similar to Model-3/CMAQ
SOP	Standard operating procedures
SO_2	Sulfur dioxide
SW	Southwest Monsoon
TKE	Turbulent kinetic energy
TSP	Total suspended particles
UAM	Urban Airshed Model
UCAR	University Corporation for Atmospheric Research
USAFWA	United States Air Force Weather Agency
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UTC	Universal Time Coordinate
VERDI	Visualization Environment for Reach Data Interpretation
VOC	Volatile organic compounds
VKT	Vehicle Kilometer Travel
WHO	World Health Organization
WRF	Weather Research and Forecasting model
WRF/CHEM	Weather Research and Forecast model with Chemistry application

CHAPTER 1

INTRODUCTION

This thesis describes the study on air pollution particularly on particulate matter (PM_{10}) from industrial and transportation sector sources by adopting modelling approach. Chapter 1 will cover the study background, problem statement, study objectives, research questions and the significance of study together with the organization of the thesis structure.

1.1 Background

Globally, the air pollution has been a major concern and getting greater attention among public and local authorities because of its massive impact on the large population. While the air pollution as often referred to the deterioration of air quality, the worse of the situation is depending on either the pollutant is stagnant at certain location or disperse to wider area. The transportation of air pollutants rely on several factors such as the obstacles on the surface, the presence of the dispersion agents (e.g. wind) and additional pollutant concentration emitted from multiple sources (Azid et al., 2014).

According to AFP, (2016) the head of Public Health and Environment Division in the World Health Organization (WHO) stated that 90 % of the world population were impacted by the air pollution and the fatality cases had risen every year (see Appendix B1). WHO also mentioned that under develop and developing countries including Malaysia encounter difficulties in implementing the air pollution abatement strategies due to economical and resources constrain.

Besides, according to Husaini (2015), the air pollution was one of the environmental factors that contribute to the increasing health problems among the sensitive receptors. The most affected population include the children, old folks, and the person with respiratory illnesses especially the asthmatic patient. In addition, those who frequently works outdoors are prone to health problems due to the exposure to the particulate matter originated from either vehicular emissions or open burning sources (see Appendix B2).

According to Khan et al. (2019) the mortality count due to the air pollution implication was approximately 3.7 million persons worldwide based on the WHO statistic. The highest score that contribute to the majority of the mortality count were located in Western Pacific and Southeast Asia regions with the death statistic of approximately 2.6 million persons. The implication of air pollution is not restricted only to the health effect but also on the human behaviors and productivity. A study done in National University of Singapore’s Business School showed that the air pollution could reduce the human self-control physically and psychologically, increase the chances of depression, anxiety and insomnia which indirectly affecting human behavior and productivity (NST, 2016) (see Appendix B3).

The other source of air pollution is from the transboundary movement of pollutants commonly known as haze. Webb (2015) claimed that the haze originated from peat and forest fires in Kalimantan and Sumatra, Indonesia due to the land clearing activities for agricultural purposes (see Appendix B4). The particulate emitted from peat and forest fires travels across the boundaries by wind which trigger alert among the local and international community in Southeast Asia. The findings from the haze study done by non-governmental organization (NGO) from United Kingdom indicated that the developing countries showed the highest negligence on the environmental protection. This is due to several factors such as i) lack of legislation and enforcement in protecting public, ii) corruption and economic overpowered by NGOs on public and environment for self-benefits, iii) loose decision making in abatement actions and policies, iv) inadequate of standard operating procedures (SOP) and tools for enforcing sustainable environment and v) lack of qualities in accessing environmental protection procedures and tools by both government and NGOs.

Other than transboundary sources, Tan (2017) found that the haze might originated from the local sources (see Appendix B5). In specific case of haze, the transportation and dispersion of particulates originated from the domestic sources are worst during dry sunny afternoon, the presence of wind effect and also induced by the hot air turbulence movement.

In Malaysia, PM_{10} is the main variable for particulate assessment. The Air Pollutant Index (API) are used in the determination of the air quality level and the indication of the potential health effect to the urban community (Shaadan et al., 2015). PM_{10} is one of the five elements being considered in measuring the API and contributes as the highest portion to the index.

In determining the compliance to the air quality standard, Malaysia mainly follows the Air Pollutant Index (API) system adapting the Pollutant Standard Index (PSI) by United States Environmental Protection Agency (USEPA) based on five major air pollutant namely PM_{10}, SO_2, NO_X, O_3 and CO. The sub-indexes in Malaysian API are based on the collection of five major air pollutants data from the continuous Air Quality Monitoring Stations showed in Table 1.1. Only the highest index value among the air pollutant was chosen as the key component to the API hourly value in certain hour for the indication of the air quality status in Malaysia (Abdullah et al., 2012; Awang et al., 2000). The PM_{10} subindex basically being identified as the dominant air pollutant parameter especially during the occurance of the haze phenomena (Awang et al., 2000). Thus, it is also essential to study the background of PM_{10} in the absent of the haze phenomena as well where the PM_{10} emitted from local sources would add the severity of the air quality degradation during haze.

Table 1.1: Malaysian Ambient Air Quality Guidelines

Air Pollutant	Guidelines	Average Time	API Status
SO_2	0.04 ppm	24 h	Selection of the highest sub-index value as the API indicator
	0.13 ppm	1 h	
	0.19 ppm	10 min	
O_3	0.10 ppm	1 h	
	0.06 ppm	8 h	
NO_2	0.17 ppm	1 h	
CO	30 ppm	1 h	
	9 ppm	8 h	
PM_{10}	150 μgm^{-3}	1 h	
		8 h	

Source: (Abdullah et al., 2012; Awang et al., 2000)

Furthermore, Department of Environment (DOE) as the authority in protecting the environment in Malaysia is currently paying greater attention to the finer particulate ($PM_{2.5}$). DOE has taken several progressive initiatives by introducing the $PM_{2.5}$ detectors at the selected continuous air quality monitoring stations and it is expected to be installed at all monitoring stations in Malaysia in the future.

Generally, the PM_{10} becomes the main issue in Klang Valley based on two main scenarios; emission from local and transboundary sources. The pollutant emission from the local source would originated from the transportation, industrial and other activities such as power plant activity including the natural sources such as wildfires and windblown dust (Rani et al., 2018). Both local and transboundary particulate sources have the negative impact to the environment such as increasing the ambient temperature, decreasing the surface solar radiation and visibility besides affecting human health, rainfall, hydrological cycles and indirectly decreasing the agricultural production (Zhang et al., 2011). The PM_{10} emission from the transboundary source is not being elaborated further as it is not focus of this study. For the preliminary study of the PM_{10} background, it was identified that the PM_{10} pollutant released to the atmosphere is continuously be increased till now due to certain criteria. For example, Figure 1.1 shows the increment of the PM_{10} concentration by the period of 10 years (2000 – 2009) recorded in DOE monitoring stations; Klang, Shah Alam, Petaling Jaya and Kajang. These time series chart which refers to PM_{10} concentration in Klang Valley region were plotted based on the raw PM_{10} data received from the Department of Environment, Malaysia.

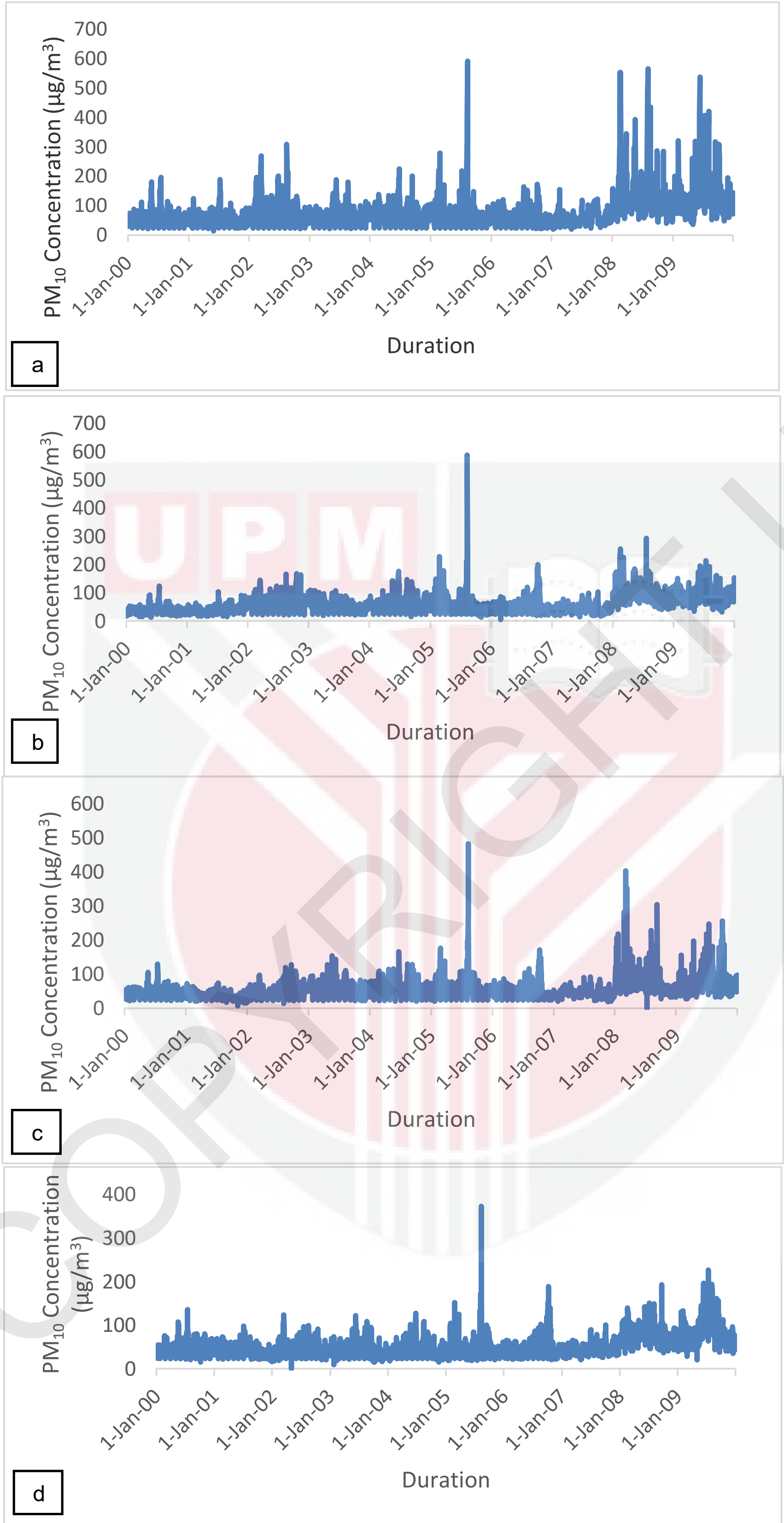

Figure 1.1: PM_{10} concentrations recorded at the DOE monitoring stations in (a) Klang, (b) Shah Alam, (c) Petaling Jaya and (d) Kajang for year 2000 to 2009

From road transportation perspective, the total vehicle registration in Malaysia had risen from 10.6 million in 2000 to 19 million in 2009 while the total of road mileage which includes the paved and unpaved roads in Malaysia had risen from 67.6 thousand kilometres in 2000 to 124.7 thousand kilometres in 2009 as shown in Table 1.2.

Table 1.2: Development in road transportation perspective for 10 years' duration.

Perspective	Details	Year		Increment (%)
		2000	2009	
Road transportation	Total vehicles registration	10.6 million	19 million	79
	Total of road mileage (km)	67.6 thousand	124.7 thousand	84

*Note: These values were calculated based on one decimal rounding.
(Source: KKR, 2013)

Meanwhile for the industrialization perspective, the Malaysian's industrial production indexes of 10 years (2000 – 2009) for mining, manufacturing and electricity had risen from 86.9, 77.3 and 68.9 to 99.9, 100.9 and 111.4 respectively as shown in Table 1.3. In the money matters perspective of construction, mining and stone quarrying industry, it shows that the gross output values had risen from RM39.9 million to RM70.6 million for construction (2000 – 2009), RM38.9 million to RM91.2 million for mining industries (2000 – 2009) and for stone quarrying industries (2000 – 2010) the gross output value risen from RM1.3 million to RM3.0 million as shown in Table 1.2.

Table 1.3: Development in industrialization and money matters in industrialization perspective for 10 years' duration

Perspective	Details	Year			Increment (%)
		2000	2009	2010	
Industrialization	Production indexes for mining	86.9	99.9	**N/A	15.0
	Production indexes for manufacturing	77.3	100.9	**N/A	30.5
	Production indexes for electricity	68.9	111.4	**N/A	61.7
Money matters in industrialization	Gross output for construction industry (RM)	39.9 million	70.6 million	**N/A	76.9
	Gross output for mining industry (RM)	38.9 million	91.2 million	**N/A	134
	Gross output for stone quarry industry (RM)	1.3 million	**N/A	3.0 million	130

*Note: These values were calculated based on one decimal rounding.
** N/A = Not applicable
(Source: DOSM, 2016)

1.2 Problem Statement

According to the Environmental Quality Report (EQR), the industries and motor vehicles contribute almost half (49 %) of the total PM_{10} emission load in Malaysia (DOE, 2015) as shown in Table 1.4. The PM_{10} emission load from industries and motor vehicles can be controlled as the sources are restricted to the permissible limit of emission which be the main characteristic to the study of PM_{10} emission in this research.

Table 1.4: Sources and its percentage contribution towards the PM_{10} emission load in Malaysia

Sources of PM_{10} emission load in Malaysia	Percentage of contribution (%)
Industries and motor vehicle	49
Others	51

Source: (DOE, 2015)

The other sources which contribute slightly higher (51%) PM_{10} than industries and motor vehicles are due several factors such as the loose control on enforcement, poor monitoring and regulation and also the land use emissions during the land development. These criteria would be the fugitive's aspects that also contribute to the PM_{10} emission generally and not being considered in this study.

Furthermore, the reason why only PM_{10} is considered in this study was due to the predominant air pollutant characteristic during haze phenomena where the PM_{10} sub-index showed the major contributor compared to the other 4 pollutants' sub-index in monitoring the ambient air quality worldwide (Awang et. al., 2000). However, this study only considers the PM_{10} pollution under normal condition without haze as the sources of haze were not from the local sources and occur occasionally.

Other than that, there are also problems in the managing the air pollution due to several factors:

i. Variety of unstructured pollution information where temporal patterns of the emission sources; mobile or stationery sources rather than hourly emitted emission database.
ii. Unmatched relationship which indicate direct regulation and enforcement but indirect economic control in pollution reduction with multiple of aims by the regulatory actors.

All the factors above indicate the complexity of the problems towards the decision making process in pollution abatement strategies (Abdullah et al., 2012). Besides, the capacity of the officer which are not to be train in managing the inventory would be the other factor to the air pollution management in Malaysia especially to the Klang Valley region as the selected study area.

The implication to the above matters would result the lacking of organized emission inventory not only become localised issue but also becoming the national issue. In terms of transportation emissions, there are no specific government agencies that conduct the exact PM_{10} or other air pollutant emission from the vehicles which in the lay man words there are unavailability on how much PM_{10} emission concentration from each types of vehicle. One of the relevant agency is the Public Works Department (JKR) under Ministry of Work Malaysia (KKR) conducting traffic survey of 6 classes of vehicle in three types of road, road mileage paved or unpaved roads and the number of registered vehicles for whole Malaysia including Sabah and Sarawak and those data were provided for the study purpose.

In terms of industrial emissions, there is one specific government agency which is the Department of Environment under the Ministry of Natural Resources that conduct and monitored the industrial emission. Unfortunately, those data are considered as private and confidential and could not be released to public. The most available industrial information used in this study was by utilizing the industrial area from land use map from Federal Department of Town and Country Planning (JPBD) along the application of an appropriate emission factor to PM_{10}. Besides, the most famous on air pollutants studies in Malaysia are overlaying the Geographical Information System (GIS) and topographical layers in showing the pollutant dispersion in certain area that based on the DOE ambient air pollutants secondary data (Tarmizi et. al., 2014 and Noor et. al., 2018) without knowing on how the of air pollutants being produced, what are the air pollutant sources and how they being distributed in the air.

The air pollutants including the focal air pollutant in this study which is PM_{10} are being dispersed freely by the effect of meteorological conditions like wind speed, wind direction and other dispersion agents (Khan et al., 2019) without knowing the dispersal's direction after released from the sources. In general, the air pollutant that released from sources was transported and diluted in the air when arrived to the monitored area. Therefore, the role of DOE is to monitor the ambient air quality through the application of the continuous air quality monitoring stations located at the selected monitored areas besides monitoring the Malaysian API status online and other enforcement related works. However, the concentration of unmonitored areas between the DOE monitoring stations focusing in Klang Valley are unknown. Therefore, the aim of this study is to address the unmonitored area between the DOE monitoring stations by the application of the regional air quality model showing the PM_{10} being dispersed from the calculated local sources to any area especially at the unmonitored area with known PM_{10} concentration

The study on the PM_{10} concentration is determined based on the calculation of emission from selected sources. The calculation from the Vehicle Kilometer Travel (VKT) emissions according to vehicle classes utilizing the road traffic volume data for road vehicle emissions while industrial area emission utilizing land use map for the industrial emissions and both will apply an appropriate emission factor. The generalised industrial area and types of industry are selected as the raw material in determining the PM_{10} emission from industries due to the limitation of information in the land use map as the best available resources in this study.

The Regional Air Quality Model (RAQM) like the integrated SMOKE-MM5-CMAQ model in this study is referred to a modelling system that able to show the spatial-temporal of PM_{10} concentration to every location within the gridded study domain. The spatial-temporal pollutant concentration covers the whole area gridded study domain including the monitored areas similar to the location of the DOE's monitoring stations and also any of the unmonitored areas. The integrated model has the ability to simulate the air pollution dispersion with the gridded domain beyond 100 km^2.

In general, the calculated PM_{10} emission is used as an input to the emission model; Sparse Matrix Kernel Emission (SMOKE) model and undergo the transformation into gridded emission profile. The gridded emission profile then will be used as primer input to the chemical transport model; Community Multiscale Air Quality (CMAQ) model. Simultaneously, the gridded meteorological profile resulted from the meteorological model; Fifth-generation Mesoscale (MM5) model is used as another primer input to CMAQ. The CMAQ model will produce the PM_{10} dispersion concentration thematic map as the output. All the three models above could be linked with each other to perform the integration modelling system due to its similarities gridding properties. Latter, the PM_{10} pollutant will be extracted and compared with the ambient PM_{10} concentration monitored by the DOE following the recent National Ambient Air Quality Standard (NAAQS). On the other hand, the external PM_{10} source that coming from the transboundary pollution commonly known as haze could also be assessed using this RAQM by assessing PM_{10} concentration, wind vector and other meteorological properties set in each grid within the domain in the stipulated time frame.

1.3 Objective of Study

General objective of this research is to predict the particulate (PM_{10}) pollution in Klang Valley area specific from industrial and transportation emission basis activities and the use of modelling approach in determining the status of PM_{10} pollution within the study area

1.3.1 Specific Objectives

The research goal is to study the followings:

1. To determine the inventory of airborne particulate matter (PM_{10}) emission sources in Klang Valley through the activity of emission rating.
2. To correlate the meteorological conditions of the study area using MM5 model.
3. To validate the PM_{10} concentration thematic map using integrated SMOKE-MM5-CMAQ Model.

1.4 Research Questions

According to the research goal, research questions are as follow:

1) How to conduct the inventory of the airborne particulate matter (PM_{10}) from the emission sources?
2) How to correlate the meteorological conditions of the study area?
3) How can the PM_{10} concentration thematic map being evaluated?

1.5 Significant of Study

Generally, the study of PM_{10} is essential as this air pollutant give such impact not only to the degradation of the air quality but also to the economic loss. The Malaysian economic loss is difficult to be measured. However, the economic loss can be discussed which is closely related to the air pollution or haze issues (1999 to 2016). The air pollution has cause the increment in cost of illness from RM 9.5 million to RM 410.6 million in recent 15 years for whole Malaysia not including Pahang, Terengganu and Kelantan in the beginning while latter for the whole Peninsular Malaysia. Besides, the hospital admission cost had risen from RM 1.8 million to RM18.9 million for the recent 2 years. Thus, the air pollution had significantly impact the health which simultaneously the economic loss due to the risen cost of medication and hospital admission that promote the loss of income (Manan et al., 2018).

Malaysian citizens are unfortunate to conduct research related to the air pollutant emission due to the insufficiency of the air pollutants emission database where some are due to lack of expertise and instrumentation, while some are being considered as a confidential and not for public release. Therefore, this research is conducted by applying new approach in predicting the air pollution emission in achieving the air pollutant emission (PM_{10}) data base for further investigation on the PM_{10} emission towards the environmental aspect from the best available sources.

Several key elements that comprise of emission, meteorological and chemical transport are involve in the modelling stage. This study provides the emission profile (SMOKE model application), climatic profile (MM5 model application) along with providing the PM_{10} concentration and dispersion patterns (CMAQ model application) starting from the defined sources at the selected time frame of any grid within the Klang Valley region. The relationship between urbanization leading to the air pollution and changes in climate and land use will also be discussed in this research.

The major contribution in this study is by providing the PM_{10} concentration information at every location in Klang Valley especially to the unmonitored area (beyond the area of DOE continuous air quality monitoring station) through the application of regional air quality modelling. Besides, conducting this modelling approach in this study would also provide an initial PM_{10} dispersion information from the pollution source to certain area especially to the unmonitored area which may beneficial to the sensitive receptors.

The application of these integrated models on the regional scale could help in assessing the air quality status in term of initial spatial air pollutant dispersion information (PM_{10}) from sources. This approach would be beneficial for the city planners to conduct spatial planning on the pollution reduction strategies and develop the official Malaysian Environmental Policies. This study could help the decision makers either for the government or the non-government bodies in order to strengthen the environmental regulation not to forget will be useful in pollution prevention strategies implementation and legislating the official environmental policies.

1.6 Scope of Study

Emission inventories approaches with the combination of emissions factors and statistics had been widely used to investigate the variety of anthropogenic emission sources such as form industrial, road transportation, agricultural activities and residential emission that contributed to the major air pollution (Li et al., 2011).

Conducting the emission inventory can get the estimation of PM_{10} emission sources within the study area either point source emission or non-point source emission. Emission inventory in general was the conversion and compilation of annual values for an individual emission within the research boundary that based on the statistical data (Woo et al., 2012).

The emissions basically can be divided into two scope; industrial and on-road transportation emissions. The regional emission inventory can be accomplished via applying “top-down” and “bottom-up” approaches (Colvile et al., 2001; Thunis et al., 2016) where “top-down approach apply the concept of total polluting activity over the whole area of interest while “bottom-up” approach apply the concept of using the detail geographical resolved data which consist of location, rate of emission from both major sector; industries and transportation.

Some of the importance data such as the emission data are almost impossible to be obtained due to the confidentiality issue in which cannot be shared to public. Therefore, this study focuses on determining the PM_{10} emission from rate of activities of local sources; industrial area and vehicle kilometre travel and its suitable emission factor as the alternative to overcome the in-availability of the emission data result from the confidentiality issue. The data selection is based on the best available sources from industries and transportation sector and this study sufficiently cover the Klang Valley region and presenting the PM_{10} emission over the area. Thus, method to develop local PM_{10} emission inventory as an input to the regional air quality models is showed in this study.

This study also utilizes an integrated modelling system on air quality that includes emission, meteorological and chemical transport simulation within 3km resolution radius over Klang Valley, Malaysia that covers the year of 2012 scenario. Various fields of interaction between the emission, meteorology and chemical transport aspect involve in this study through the application of the integration models.

The surrogating process on the emission input data is taken place during the emission simulation. The collected and organised emission inventory file by the annual means is surrogated into an hourly gridded model-ready emission input profile. According to Borge et al. (2008) this gridded form of the emission input profile is the vital element to the integrated model. Thus, SMOKE model which liaise with the United State Environmental Protection Agency (USEPA) had been applied by researchers for preparing the model-ready emission input profile to fulfil the requirement of the final component (CMAQ) in the integrated SMOKE-MM5-CMAQ model (Mao et al., 2006). Meanwhile, the MM5 model works as the meteorological conditions data supplier to the CMAQ component in the integrated model. The meteorological condition profile is another vital input besides emission which is required for the completion of the complex interaction processes operated by CMAQ in order to produce the pollutant concentration thematic map. This situation showed the complex interaction processes between the three models executing the unified regional air quality modeling system.

The MM5 and CMAQ models are validated by conducting the comparison between the simulated temperature, wind speed and PM_{10} data with the actual data collected from the Department of Environment (DOE), Malaysia. The output of the integrated models is the PM_{10} concentration dispersion thematic map from the industrial and road network emissions throughout the Klang valley region that will beneficial in providing the PM_{10} emission information in every location in the studied domain which include the unmonitored locations.

1.7 Thesis Organization

In order to accomplish this research, several objectives have to be achieved including determining the airborne PM_{10} emission sources through emission rating activity, generating the simulated meteorological conditions of the studied area in selected time frame and lastly to produce the spatial PM_{10} distribution through the application of integrated model.

Review in literature regarding the air quality status, particulate matter (PM_{10}) characteristics, factors determining the particulate dispersion, PM_{10} emission inventory and regional air quality modelling were conducted for achieving the research objectives as recorded in the Chapter 2.

Chapter 3 shows the conceptual research frameworks that covers the flow of this research including the elaboration of study area, the Klang Valley population, data collection process, emission inventory construction, the experimental design and principal of each selected regional air quality models towards achieving the integration of emission, meteorological and chemical transport modelling system criteria, the validation of those models and application of the SMOKE-MM5-CMAQ modelling system elaboration throughout the study.

Chapter 4 shows and discuss the outcomes from the emission inventories, the prediction of meteorological conditions from meteorological model, the PM_{10} distribution generation from chemical transport model and the validation process for both meteorological and chemical transport model and the limitation of the study.

The concluding process and giving the author's point of view regarding the study limitation and future research improvement were discussed in the last section of Chapter 5.

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LIST OF PUBLICATIONS

Jamalani, M. A., Abdullah, A. M., Azid, A., Ramli, M. F., Baharudin, M. R., Bose, M. M., Elhadi, R. E., Youssef, K. A. A. B., Gnadimzadeh, A., and Gumel, D. Y. (2016). Monthly analysis of PM_{10} in ambient air of Klang Valley, Malaysia. *Malaysian Journal of Analytical Sciences*, 20(5):1159-1170.

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Proceeding

Jamalani, M.A., Abdullah, A.M., Ramli, M.F. and Baharudin, M.R. 2015. Spatial-temporal of monthly PM_{10} in ambient air of Klang Valley, Malaysia. International Conference on Environmental Forensics (iENFORCE2015). *Procedia Envirnmental Science*.

List of Conference Attended

1. 24th Malaysian Science and Technology Congress 2015 (MSTC 2015) by Ministry of Science, Technology and Innovation (MOSTI). Faculty of Agriculture, Universiti Putra Malaysia, Selangor. 20-21 January 2015.

2. International Conference on Environmental Forensic 2015 (iENFORCE2015); From Source to Solutions by Faculty of Environmental Studies, Universiti Putra Malaysia. Marriot Hotel, Putrajaya. 19-20 August 2015.

3. 2nd University Consortium Graduate Forum (UCGF); The Quest for Environmental and Food Security, Inclusive and Sustainable Agricultural Development. by University of the Philippines Los Banos (UPLB), College, Laguna, Philippines 11-12 November 2016.

4. International Conference on Environment, Sports & Recreation (ICESR); Synergizing Environment, Sports & Recreation for Sustainability by Universiti Sultan Zainal Abidin. 1M4U Outreach Camp, Merang Setiu, Terengganu. 3-5 October 2017

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