Air Pollution Study of Vehicles Emission In High Volume Traffic: Selangor, Malaysia As A Case Study

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Abstract: - In an internal combustion engine, a chemical reaction occurs between the oxygen in air and hydrocarbon fuel. Engines operate at what is termed the stoichiometric air/fuel ratio when there is the correct quantity of air to allow complete combustion of the fuel with no excess oxygen. In reality, the combustion process cannot be perfect and automotive engines emit several types of pollutants.Therefore, it is important to develop and deploy methods for obtaining real-world, on-road micro-scaled measurements of vehicle emissions to estimate the pollutants. In this work, several high traffic roads in Selangor will be selected for the road air-quality measurement and analysis. Comparisons with simulations results, using the Operational Street Pollution Model (OSPM) are shown. The study shows that there were no serious of air pollution recorded in the period of January 2012. Air quality trends for the criteria pollutants in this month generally are continuing to show downward trends or stable trends well below the level of the Malaysian Ambient Air Quality Guideline (RMG). However, PM_{10} and ground-level O_3 are the crucial pollutants in Selangor. The comprehensive review has revealed that moving vehicles creates a significant impact in air quality on the specific locations. Comparison with simulated data also showed good agreement thus indicating suitability of the model to be used in Malaysia condition.

Key-Words: - Air Pollution, Vehicles Emission, Air Polution Modeling, OSPM.

1 Introduction

Emissions from motor vehicles are the single most significant source of air pollution in many Malaysian urban areas. Improved knowledge about the quantity of pollutants that the vehicle fleet is emitting into the air has becoming a high priority research question for authorities who are responsible for managing vehicle emission impacts on air quality - especially in urban areas. In internal combustion engines processes, the actual process is usually far from perfect combustion due to many factors.

The oxidation of the carbon monoxide (CO) contained in the fuel does not proceed to the final product (CO_2) due to a lack of combustion air. Meanwhile, fuel-rich conditions will cause a steep rise in CO formation and emission due to insufficient oxygen being available in the air/fuel mixture. Consequently, a relatively low amount of CO in the exhaust gases indicates that a relatively high amount of complete combustion has taken place in the engine. This is also indicated by a relatively higher amount of CO_2 in the exhaust gases. Carbon monoxide (CO) is a product of incomplete combustion and occurs when carbon in the fuel is partially oxidized rather than fully oxidized to carbon dioxide. In health perspective, carbon monoxide reduces the flow of oxygen in the bloodstream and is particularly dangerous to persons with heart disease.

Meanwhile hydrocarbons (HC) are unburned or partially oxidised fuel is the source of HC emissions. A lack of oxygen during combustion is a cause, but the main physical mechanisms are poor fuel/air mixing, particularly with fuel condensing on combustion chamber surfaces, and flame quenching before complete oxidation. Hydrocarbons react in the presence of nitrogen oxides and sunlight to form ground-level ozone, a major component of smog. It is our most widespread and intractable urban air pollution problem. A number of exhaust hydrocarbons are also toxic, with the potential to cause cancer. Ozone irritates the eyes, damages the lungs, and aggravates respiratory problems.

Last but not least, the formation of NO_x increases exponentially with peak flame temperatures if endured long enough with the simultaneous availability of oxygen. The oxides of nitrogen (NO_x) emissions from motor vehicles principally consist of nitric oxide (NO) and nitrogen dioxide (NO_2). NO is the dominant species contained in motor vehicle emissions and it is generally accepted to be a high proportion of the total NO_x that leaves the vehicle's tailpipe. Under the high pressure and temperature conditions in an engine, nitrogen and oxygen atoms in the air react to form various nitrogen oxides, collectively known as NO_x. Nitrogen oxides, like hydrocarbons, are precursors to the formation of ozone. They also contribute to the formation of acid rain [1].

Historically in testing process, individual vehicle emissions have been measured using dynamometer testing and drive cycles. Dynamometer testing is a labour-intensive process and, as such, the number of vehicle tests undertaken tends to be limited. Due to the intrusive nature of the testing programme it is very difficult to obtain a random set of vehicles for testing. Dynamometer testing tends toward using a better maintained and/or biased vehicle sample. The implications of relatively low vehicle numbers and a biased test sample is that the results may not be representative of real world vehicle emissions. On the other hand, overseas experience, especially in the United States and New Zealand, has shown that field-visit on site measurement is a very effective method for assessing the quantity of pollutants discharged from large numbers of the on-road vehicle fleet [2].

This study involves on the field measurement of roadside vehicle emissions, followed by an analysis of the data. Fives high traffic locations were identified and field sites were conducted. It is therefore expected that the results of this work could further be used for estimation of environmental impact associated with vehicle emissions. Subsequently, a simulation of traffic and emission were conducted to compare with the measured on the rod data. Since there is no similar work conducted before in Selangor, this project will provide for the first time the actual picture and situation of on-road emissions in this state.

2 Problem Formulation

Increases in urban populations, numbers of cars, vehicle miles traveled, and traffic congestion are just a few of the trends that suggest that exposure to traffic-related air pollution is on the rise, particularly in countries with rapidly growing economies. In addition, land-use practices in these countries have resulted in population increases near traffic, suggesting that motor-vehicle emissions must be considered in the context of their proximity to populated areas.

The standard driving cycles (SDC), which are in the theoretical way to assess the performance of vehicles in various ways, as for example fuel consumption and polluting emissions, may not adequately represent real-world driving for particular locations. This is because of its failure to represent the influence of real-world traffic flow. It is important to develop and deploy methods for obtaining real-world, on-road micro-scaled measurements of vehicle emissions during actual and typical vehicle use.

2.1 Emission of Moving Vehicle

The quantification of motor-vehicle emissions is critical in estimating their impact on local air quality and traffic-related exposures and requires the collection of travel-activity data over space and time and the development of emissions inventories. Emissions inventories are developed based on complex emissions models that provide exhaust and evaporative emissions rates for total HC, CO, NO_x, PM_{10}, sulfur dioxide (SO_2), ammonia (NH_3), selected air toxics, and green house gases (GHGs) for specific vehicle types and fuels. The quality of the travel activity data (such as vehicle-miles traveled, number of trips, and types of vehicles) and the complex algorithms used to derive the emissions factors suggest the presence of substantial uncertainties and limitations in the resulting emissions estimation.

The actual measurement of motor-vehicle emissions is critically important for validating the emissions models. Studies that have sampled the exhaust of moving vehicles in real-world situations (specifically, in tunnels or on roadways) have contributed very useful information about the emissions rates of the current motor-vehicle fleet and also have allowed the evaluation of the impact of new emission control technologies and fuels on emissions. Ultimately, an important goal of emissions characterization studies is to improve our ability to quantify human exposure to emissions from motor vehicles, especially in locations with high concentrations of vehicles and people. Such characterization requires improving emissions inventories and a more complete understanding of the chemical and physical transformations on and near roadways that can produce toxic gaseous, semi volatile, and particle- phase chemical constituents.

Exposure models include geo-statistical interpolation, land-use regression, dispersion, and hybrid models. They incorporate numerous parameters (such as meteorological variables, data on land use, traffic data, and monitoring data or emissions rates depending on the model) and can improve the spatial representation of the local impact of traffic against a background of regional and urban concentrations. However, the accuracy of the inputs is critical to the usefulness of any given model.

Factors influencing ambient concentrations of a traffic pollutant surrogate are related to time activity patterns, meteorological conditions, vehicle volume and type, driving patterns, land-use patterns, the rate at which chemical transformations take place, and the degree to which the temporal and spatial distribution of the surrogate reflects the traffic source. The exposure zone within a range of up to 300 to 500 m from a highway or a major road is most highly affected by traffic emissions [3]. Significant increases in the worldwide motor-vehicle fleet commensurate with population growth, increasing urbanization, improving economies, and rapid expansion of metropolitan areas. The characterization of pollutants and their chemical and physical transformations on and near roadways is very complex and has been limited by the availability of instrumentation suitable to support the needed characterization. The study of the effects of exposure to pollutants near roadways remains somewhat nascent and has been limited to criteria pollutants thus far. The transformation processes that occur both in the earliest stages of exhaust dilution and later during plume entrainment can produce toxic gases, semi volatile compounds, and particle-associated chemical constituents.

Assessment of the impact of emissions from motor vehicles in general, and from traffic, on air quality and human exposure is critically dependent on the quality of the estimates of motor-vehicle emissions in time and space. Improving the quality of motor-vehicle emissions inventories is fundamental to advancing air-quality modeling and exposure-assessment techniques.

2.2 Traffic Simulation Software

Traffic simulation or the simulation of transportation systems is the mathematical modeling of transportation systems through the application of computer software to better help plan, design and operate transportation systems. Simulation of transportation systems started over forty years ago, and is an important area of discipline in Traffic Engineering and Transportation Planning today. Many national and local transportation agencies, academic institutions and consulting firms use simulation to aid in their management of transportation networks.

Mathematical models which include relationships between emissions and concentration levels are necessary for estimation of future trends in air quality or evaluation of abatement strategies. There exist many such models, with varying levels of complexity, and they have been used for air quality studies on scales ranging from global to single industrial point sources.

Simulation in transportation is important because it can study models too complicated for analytical or numerical treatment, can be used for experimental studies, can study detailed relations that might be lost in analytical or numerical treatment and can produce attractive visual demonstrations of present and future scenarios [4].

Many approaches have been developed to model vehicle fuel consumption and emission rates in order to estimate vehicle fuel consumption and emission rates. They can be classified into five categories of classification:

1. Scale of the input variables-based modeling
2. Formulation approach-based modeling
3. Type of explanatory variable-based modeling
4. State variable value-based modeling
5. Number of dimensions-based modeling.

Based on the scale of the input variables the current state of the art and current state of practice models can be divided into three categories: microscopic, mesoscopic, and macroscopic models. The subcategories of the formulation approach-based modeling classification, for example, the way of building model-based modeling classification, are analytical, empirical, statistical, and graphical models. In the explanatory variable-based modeling classification, there are three subcategories: average speed, instantaneous speed, and specific power models. The state variable value-based modeling classification can be divided into crank-angle resolution-based models and mean value-based models. The subcategories of the number of dimensions-based modeling classification are zero/one dimensional/single zone, quasi dimensional and multi-dimensional modeling [5].

To understand simulation, it is important to understand the concept of system state, which is a set of variables that contains enough information to describe the evolution of the system over time. System state can be either discrete or continuous. Traffic simulation models are classified according to discrete and continuous time, state, and space.

Traffic simulation models are useful from a microscopic, macroscopic and sometimes mesoscopic perspectives. Traffic simulation packages use fundamental traffic flow, speed, and density relationships to estimate network capacity and system performance. There are two primary types of simulation models, micro-simulation and macro-simulation. Micro-simulation models incorporate specific car-following, vehicle performance, and lane changing algorithms to model individual vehicle behavior. Traffic simulation models can be also used to predict the behaviour of some pollutants. For instance, the authors apply the “car following” model to the prediction of acoustical noise produced by road traffic flow [6].

Macro-simulation models, on the other hand, focus not on individual vehicles in the traffic stream but instead consider traffic as an aggregate flow using continuum equations. These macroscopic models usually require less data input and simpler coding efforts but provide lower levels of output detail.

2.3 Pollution Street Model

Concentrations of exhaust gases are calculated using a combination of a plume model for the direct contribution and a box model for the recirculating part of the pollutants in the street. The model can be used for streets with irregular buildings or even buildings on one side only but it is best suited for regular street-canyon configurations. The model should not be used for crossings or for locations far away from the traffic lanes. The model is designed to work with input and output in the form of one-hour averages. The required input data are hourly values of wind speed, wind direction, temperature and global radiation. The model requires also hourly values of urban background concentrations of the modeled pollutants. Beside the hourly input parameters, the model requires also the data on the street geometry and the traffic in the street.

The basic equations used for description of the mean flow are the continuity equation:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

and the steady state momentum conservation equation

$$u_j \frac{\partial u_i}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\nu \frac{\partial u_i}{\partial x_j} - \overline{u'_i u'_j} \right) - \frac{1}{\rho}\frac{\partial p}{\partial x_i}; i = 1,2,3 \tag{2}$$

where

u_i are the three mean velocity components (i=1, 2, 3 or x, y, z),

u'_i are the turbulent fluctuation components (deviations from the mean velocity); the over bar means time averaging,

p is the pressure,

ρ is the air density

Modeling dispersion of pollutants in streets is inevitably connected with wind flow modeling. The mathematical principles are basically the same, for example, the governing equation is the steady state mass conservation equation for a scalar,

$$u_j \frac{\partial c}{\partial x_j} = -\frac{\partial}{\partial x_j}\overline{c' u'_j} + S \tag{3}$$

where c denotes the mean concentration and c’ is the deviation from the mean value. S represents here all possible sources and sink terms, for example emission or chemical reactions.

An existing emission dispersion model, called STREET model; assumes that emissions from the local street traffic (street contribution, c_s) are added to the pollution present in the air that enters from roof level (background contribution c_b). The relationship is.

$$c = c_b + c_s \tag{4}$$

The street contribution is proportional to the local street emissions Q ($gm^{-1}s^{-1}$) and inversely proportional to the roof-level wind speed u. For winds blowing at an angle of more than 30^o to the street direction, two formulas are derived:

for the leeward side,

$$c_s = \frac{\mathrm{K}}{(u+u_s)}\left(\frac{\mathrm{H}-z}{\mathrm{H}}\right)\sum_i \frac{Q_i}{\left[\left(x_i^2+z^2\right)^{\frac{1}{2}}+h_o\right]} \tag{5}$$

for the windward side

$$c_s = \frac{\mathrm{K}}{(u+u_s)}\left(\frac{\mathrm{H}-z}{\mathrm{H}}\right)\sum_i \frac{Q_i}{[W]} \tag{6}$$

where

K is an empirically determined constant (K=7),

u_s accounts for the mechanically induced air movement caused by traffic (u_s = 0.5 ms^{-1}),

h_o accounts for initial mixing of pollutants (h_o =2 m)

x_i and z is the horizontal and the vertical distances from the i^{th} traffic lane to the receptor point,
Q_i is the emission strength of the i^{th} traffic lane,
H and W are the height and the width of the canyon, respectively.

Another model is introduced by Yamartino and Wievand which is called Canyon Plume-Box Model (CPBM) [7]. In this model, the concentrations are calculated by combining a plume model for the direct impact of vehicle emitted pollutants with a box model that enables computation of the additional impact due to pollutants recirculated within the street by the vortex flow.

2.4 Description of Parameterization in Operational Street Pollution Model (OSPM)

A widely used model in this context is Operational Street Pollution Model (OSPM). OSPM is developed by the Department of Environmental Science at Aarhus University Denmark. For almost 20 years, OSPM has been routinely used in many countries for studying traffic pollution, performing analyses of field measurements, studying efficiency of pollution abatement strategies, carrying out exposure assessments and as reference in comparisons to other models. OSPM is generally considered as state-of-the-art in applied street pollution modeling.

OSPM is based on two sub models: an emission model and a dispersion model. The emission model is developed using the current experience with emission factors, traffic flow modeling, and traffic composition. The dispersion model is based on the STREET-model. OSPM is based on similar principles as the CPBM as shown in the Fig. 1. Concentrations of exhaust gases are calculated using a combination of a plume model for the direct contribution and a box model for the recirculating part of the pollutants in the street. Flow of air movement is show in Fig. 1 above. OSPM makes use of a very simplified parameterization of flow and dispersion conditions in a street canyon [8]. This parameterization is deduced from extensive analysis of experimental data and model tests. Results of these tests are used to improve the model performance, especially with regard to different street configurations and a variety of meteorological conditions [7].

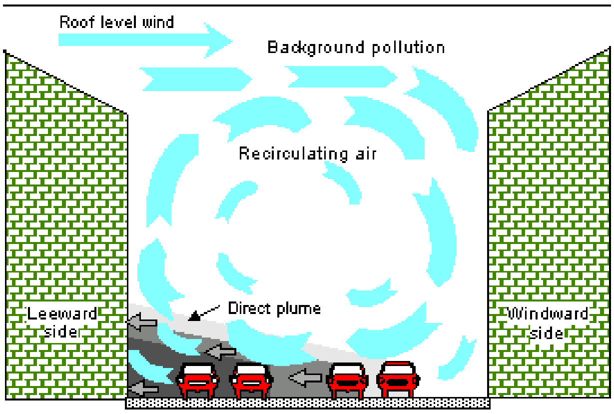


Fig. 1: Wind Circulation. (Retrieved from http://www.dmu.dk/fileadmin/dmu.dk)

The direct contribution is calculated using a simple plume model. It is assumed in OSPM that both the traffic and traffic emissions are uniformly distributed across the canyon. The emission field is treated as a number of infinitesimal line sources aligned perpendicular to the wind direction at the street level and with thickness *dx*. It is disregard the cross wind diffusion. The line sources are treated as infinite line sources. The emission density for such a line source is:

$$dQ = \frac{Q}{W} dx \tag{7}$$

where Q is the emission in the street (g/(m·s)) and W is the width of the street canyon. The contribution to the concentration at a point located at a distance x from the line source is given by,

$$dC_d = \sqrt{\frac{2}{\pi}} \frac{dQ}{u_b \sigma_z(x)} \tag{8}$$

where u_b is the wind speed at the street level and $\sigma_z(x)$ is the vertical dispersion parameter at a downwind distance x.

Formation of a canyon vortex is confirmed when the flow is normal to the street axis. The wind direction at the bottom of the canyon is approximately a mirror reflection of the above roof wind direction. When roof level wind speeds exceed about 2 ms^{-1}, the street level wind speed is approximately 2/3 of the wind flow above roof top [9]. The plume expression for a line source is integrated along the path defined by the street level wind. The length of the integration path depends on the extension of the recirculation zone. Most trajectories are nearly circular or elliptical and extended throughout the depth of the canyon. The process is shown in Fig. 2:

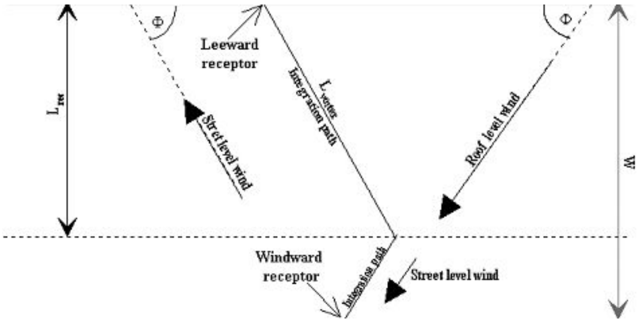


Fig. 2: The Wind Direction at the Bottom of the Canyon. (Retrieved from http://www.dmu.dk/fileadmin/dmu.dk)

For roof-level wind speeds below 2 m/s, the length of the vortex decreases linearly with the wind speed. The buildings along the street may have different heights, affecting the length of the vortex and subsequently the modeled concentrations. The upwind receptor (leeward side) receives contribution from the traffic emissions within the area occupied by the vortex (the recirculation zone), the recirculated pollution and a portion of the emissions from outside of the vortex area. Meanwhile, the downwind receptor (windward side) receives contributions from the recirculated pollution and the traffic emissions from outside of the recirculation zone only. As the wind speed approaches zero or is parallel with the street, concentrations on both sides of the street became equal. The ventilation of the recirculation zone takes place through the edges of the building but the ventilation can be limited by the presence of a downwind building if the building intercepts one of the edges. The concentration in the recirculation zone is calculated assuming that the inflow rate of the pollutants into the recirculation zone is equal to the outflow rate and that the pollutants are well mixed inside the zone. When the wind vortex extends through the whole canyon, the direct contribution at the windward side is zero and the only contribution is from the recirculation component. The concentration at the leeward side is always computed as a sum of the direct contribution and the recirculation component. The direct contribution is usually much larger than the recirculation component.

The Traffic Produced Turbulence (TPT) within the canyon is calculated taking into account the traffic produced turbulence. The TPT plays a crucial role in determination of pollution levels in street canyons. During windless conditions the ambient turbulence vanishes and the only dispersion mechanism is due to the TPT [10]. Thereby, the TPT becomes the only factor determining the pollution levels in a street canyon.

Meanwhile, concentration distribution of pollutants in the street is calculated taking into account that wind direction fluctuates. For each calculation hour, the resulting concentrations are averaged over a wind direction sector centered on the hourly mean wind direction. The width of the averaging wind sector depends on the roof level wind speed and increases with the decreasing wind speed. For calm conditions the averaging sector approaches 360°, this results in uniform concentration distribution across the street [10].

The NO_2 concentrations are calculated taking into account $NO\text{-}NO_2\text{-}O_3$ chemistry and the residence time of pollutants in the street. The presence of NO_2 in ambient air is mainly due to the chemical oxidation of the emitted NO by background ozone. Under sunlight conditions, photo dissociation of NO_2 leads to partial reproduction of NO and O_3. The relationship between NO_2 and NO_x concentrations in the ambient air is non-linear and depends on the concentrations of ozone. The time scales characterizing these reactions are of the order of tens of seconds. Generally, the chemical transformations and exchange of street canyon air with the ambient air are important for NO_2 formation.

OSPM is based on many simplified assumptions about flow structure and dispersion conditions in street canyons and in order to verify the model performance, comparison with field measurements is necessary.

2.5 Malaysian Situation

Statistics in Malaysia show that from 8.9 million motor vehicles registered in 1998, approximately 2 million tons of carbon monoxide, 237 000 tones of oxides of nitrogen, 111 000 tones of hydrocarbons, 38 000 tones sulfur dioxide and 17 000 tones particulate matters are emitted into the atmosphere. Concurrent with the increasing awareness of the impact of vehicular emissions on the global environmental quality, the industry concerned has invented many new technologies on reducing the emission level. These include catalytic converters, reformulated fuels and natural gas vehicle [11]. Malaysia is promoting the use of cleaner fuel (natural gas) in power vehicle. As for the past years motor vehicles remain the major contributor of air pollution especially in urban areas.

In 2010, there is an overall increase in the number of motor vehicles registered. The number of registered passenger cars increased by 7.16%, motorcycles by 5.61%, buses by 3.86%, goods vehicles by 3.20% and taxis by 6.96% in 2010 compared to 2009. The number of in-use or active vehicles on the road had shown an increasing trend except for buses and taxis. In 2010 annual report, the number of in-use passenger cars increased by 5.73%, motorcycles by 4.63% and goods vehicles by 1.61% while the number of in-use buses and taxis decreased by 6.85% and 1.15% respectively compared to 2009. Up at December 31, 2011, there were 21,401,269 vehicles registered [12]. These include motorcycles, motorcars, buses, taxis, rental vehicles, goods vehicles, excavators, and other vehicles for which registration is required. All data based on statistics supplied by the Road Transport Department of Malaysia are shown in Figs. 3 and 4.

With over 1 million cars registered in Selangor, the state with only 8103 square km in size, it is not surprising that there is severe congestion daily on its road. The vehicle populations are shown in Fig. 5. The national average of 2.95 persons/car is based on a projected Malaysian population figure of around 28.725 million**.**

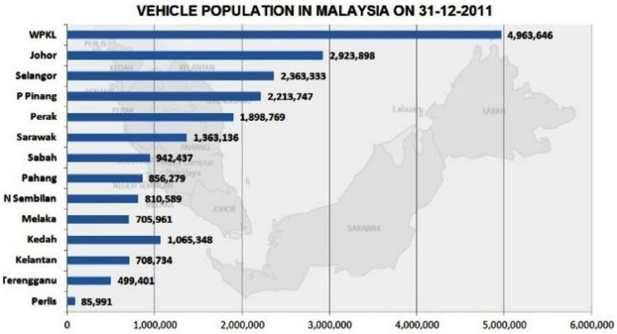
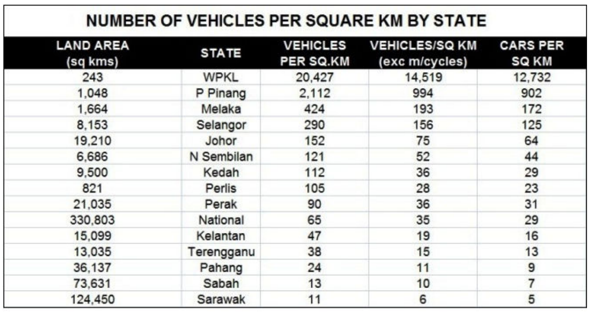


Fig. 3: Vehicle Population in Malaysia in 2011. (Retrieved from www.jpj.gov.my/)



NUMBER OF VEHICLES PER SQUARE KM BY STATE

LAND AREA (sq kms)	STATE	VEHICLES PER SQ.KM	VEHICLES/SQ KM (exc m/cycles)	CARS PER SQ KM
243	WPKL	20,427	14,519	12,732
1,048	P Pinang	2,112	994	902
1,664	Melaka	424	193	172
8,153	Selangor	290	156	125
19,210	Johor	152	75	64
6,686	N Sembilan	121	52	44
9,500	Kedah	112	36	29
821	Perlis	105	28	23
21,035	Perak	90	36	31
330,803	National	65	35	29
15,099	Kelantan	47	19	16
13,035	Terengganu	38	15	13
36,137	Pahang	24	11	9
73,631	Sabah	13	10	7
124,450	Sarawak	11	6	5

Fig.4: Number of Vehicles per Square Km by State of Malaysia in 2011. (Retrieved from www.jpj.gov.my/)

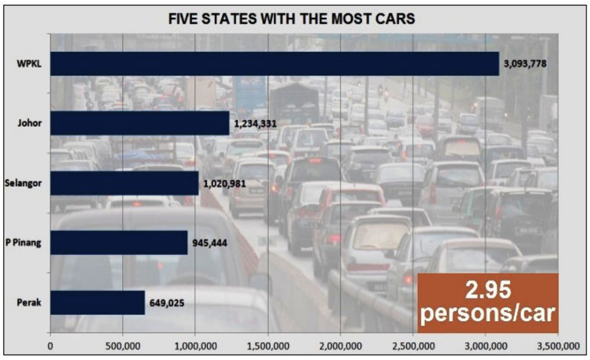


Fig.5: Five States in Malaysia with the Most Cars in 2011. (Retrieved from www.jpj.gov.my/)

Among all types of vehicles, motorcycle became the second large contributor of the pollutants. In Malaysia, statistics have shown that nearly five million units or over half of the motor vehicles in Malaysia are motorcycles. These are mostly small capacity, two or four-stroke engine motorcycles owned by the lower income group.

Among measures taken includes steps such as phasing out of existing two-stroke motorcycle and new models have to comply with emissions regulations in the future. Besides that, several actions have been taken to support the use of clean fuels and natural gas vehicles, namely incentive policies, mandates, financial support for research and development of vehicle emission standards [13].

3 Method Description

Several high traffic roads in Selangor are selected for the road air-quality measurement and analysis. Field measurements data along with the traffic information are collected in each week in January 2012. Meanwhile, the latest data concerning carbon monoxide, nitrogen monoxide, hydrocarbon and particulate emissions and other necessary information are obtained from the Department of Environments (DOE) Malaysia. An analysis of the vehicle fleet emission data and other relevant data that must be completed for simulations are obtained from Pelabuhan Klang, Banting, Shah Alam, Kuala Selangor and Petaling Jaya. Subsequently, simulation analysis is conducted using traffic software based on Operational Street Pollution Model (OSPM).

3.1 The Experimental Location

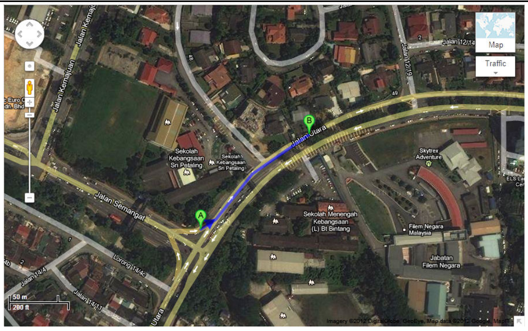
Several measuring site are identified in connection with a permanent pollution monitoring station, operating by DOE, which are in Kuala Selangor, Pelabuhan Klang, Petaling Jaya, Banting and Shah

Alam. Continuous traffic counts are collected on the traffic flow. The meteorological data used for the model calculations with OSPM are also obtained from DOE and Malaysian Metrological Department (MMD). Measurements of wind speed and direction, temperature, humidity and global radiation are obtained from several agencies such as ASEAN Specialised Meteorological Centre (ASMC) and Public Works Department of Malaysia.

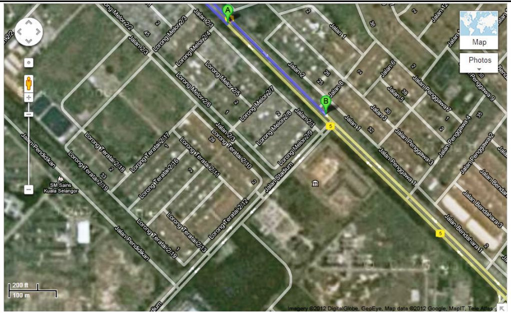
The map with all locations is shown in Fig. 6 and general descriptions of the locations are summarized in Table 1.

The following general criteria are adopted for the selection of the locations:

1. The locations should be located within the city borders and very close to the population centroid.
2. The locations cannot be placed too close to local source emissions, particularly industrial, and they should be generally located in residential areas.
3. The daily correlation among the selected locations should be reasonably high (more than 0.7), to exclude outliers or monitors measuring hotspots instead of regional background concentrations.
4. The locations should provide a sufficient number of data (more than 50% of possible data must be valid for a given period of time).



(a) Kuala Selangor



(b) Pelabuhan Klang

(c) Petaling Jaya

(d) Banting

(e) Shah Alam

Fig.6: Locations of Experimental Study (http://maps.google.com.my/)

Table 1: Description of Five Experimental Locations

Site	**Traffic Data**	**Features**
Kuala Selangor	• Average vehicle per hour: 600.2 vehicles. • Average speed: 80 km/h • Average wind: SSE at 13.5 km/h Percentage vehicle: • Motorcycle: 46% • Car: 48% • Heavy and light duty 5.5%	• A broad street oriented 30^o with respect to North • The monitoring station is on the west-east side where the street is on the residential area, but on average 6-10m tall building. • On the opposite side the street is practically open as it is next to the low-cost residential area.

	• Other: 0.5%	• The traffic created turbulence possibly appears to dominate on that place
Pelabuhan Klang	• Average vehicle per hour: 702.9 vehicles. • Average speed: 53 km/h • Average wind: SSE at 14 km/h Percentage vehicle: • Motorcycle: 50% • Car: 42% • Heavy and light duty 7% • Other: 1%	• Highest proportion of diesel vehicles • Well- known street canyon effect
Petaling Jaya	• Average vehicle per hour: 590 vehicles. • Average speed: 56 km/h • Average wind: SSE at 12 km/h Percentage vehicle: • Motorcycle: 45% • Car: 51% • Heavy and light duty 3% • Other: 1%	• A 2-narrow street canyon with closed building facades on both sides. • The street is oriented 21^o with respect to North • The monitoring station is on the middle side of the Jalan Utama Street. • The dependence on wind speed is obvious, and as expected, shows decreasing concentrations with increasing wind speed.
Banting	• Average vehicle per hour: 523 vehicles. • Average speed: 58 km/h • Average wind: SSE at 10 km/h Percentage vehicle: • Motorcycle: 48% • Car: 49.2% • Heavy and light duty 2% • Other: 0.8%	• Location is in the suburban village. • Have the lowest CO and HC emissions.
Shah Alam	• Average vehicle per hour: 670.2 vehicles. • Average speed: 75 km/h • Average wind: SSE at 12 km/h • Percentage vehicle: • Motorcycle: • 44% • Car: 49% • Heavy and light duty 6% • Other: 1%	• 25m wide and is flanked on both sides with about 8-12m high buildings • The street is 90^o with respect to North • East side of the street where the building facades are closed. On the opposite side, some wide side-streets make openings between the building facades. • Well known street canyon effect.

4 Result and Discussions

The air quality status for Malaysia is determined and disseminated according to the Air Pollution Index (API). Before 1 March 2012, there is no real-time air quality data made available to the public. To determine API for a given time period, the sub-index values (sub-API) for five air pollutants are calculated for the air quality data collected from the CAQM stations. The API value reported for a given time period represents the highest API value among all the sub-APIs calculated during that particular time period.

The following analyses are based on maximum daily measurement and annual average. Four criteria pollutants, namely Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Ozone (O_3), and Particulate Matter (PM_{10}) are monitored continuously at five locations. The air quality trend for the period 31-days in January 2012 is received from DOE and has been computed by averaging direct measurements from the monitoring sites on a monthly basis and cross-reference with the Recommended Malaysian Ambient Air Quality Guidelines (RMG) [14].

4.1 Pollutants

4.1.1 Particulate Matter (PM_{10})

The maximum daily levels of ambient PM_{10} in five places are generally within the Malaysian Ambient Air Quality Guideline (RMG) for PM_{10} which is 150 $\mu g/m^3$ per hour. Fig. 7 shows the daily average reading in all five locations, indicating that Pelabuhan Kelang measured the highest reading. Daily data indicate the readings for Pelabuhan Klang are consistently higher than other places.

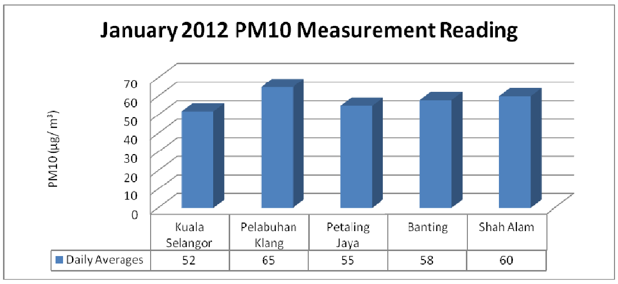
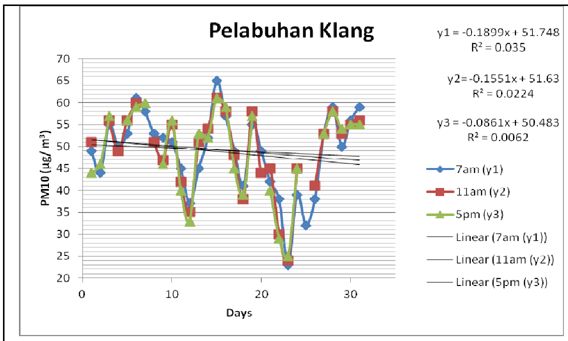


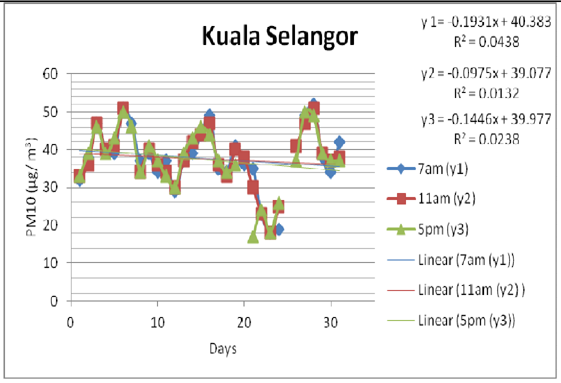
Fig.7: PM_{10} Measured Reading for January 2012

However, as shown in Fig. 8(a)-(e), Pelabuhan Klang experienced slow and consistent declining trend throughout the January 2012. Providing the PM_{10} behavior is air-regional pollutant, several consistent measurements that show the linear regression with low correlation coefficient can be noticed. Since the buildings at measurement site aren't all of the same size, recirculation of wind is noticed. The highest buildings are on the other side of the street are making a barrier, affecting mainly the residents. Despite of the clear and mild current air drawn by the wind, smoke from traffic sources is trapped by the recirculation, thus increasing PM_{10} concentration. On the other hand, wind from south side, causes also recirculation, and since the smaller buildings are on the other side of the street, PM_{10} are carried over these buildings by the whirlwind. This temporary seasonal-variation and weather-dependent process happened in a slow but constant rate.

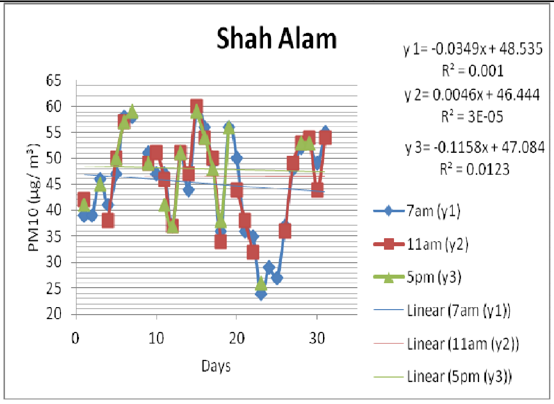
Similar trend is shown for all other location except, Petaling Jaya, probably because of its largely populated areas. In Petaling Jaya, areas include the Subang area; Petaling Jaya Selatan and Kelana Jaya are the most populated residential area compared to other locations.



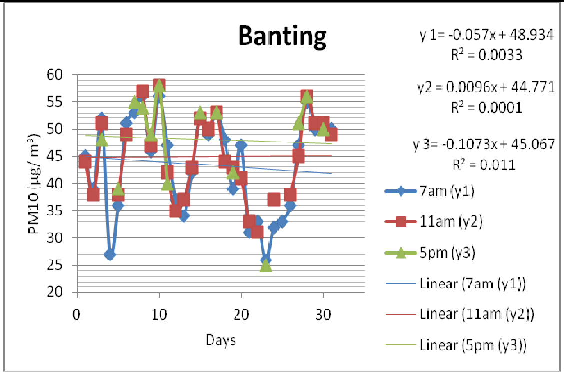
(a) Pelabuhan Klang



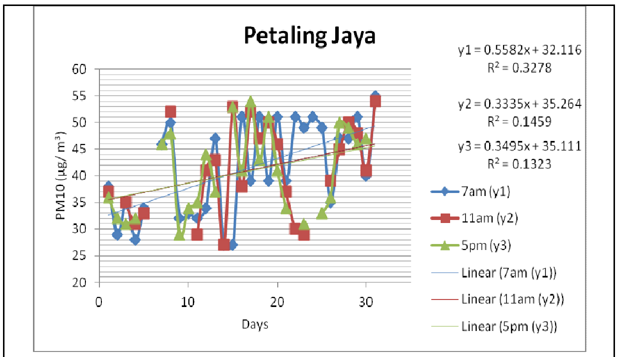
(b) Kuala Selangor



(c) Shah Alam



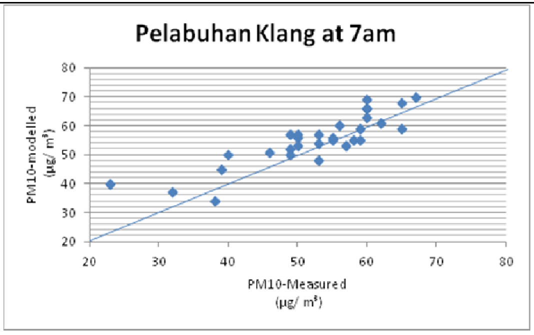
(d) Banting.



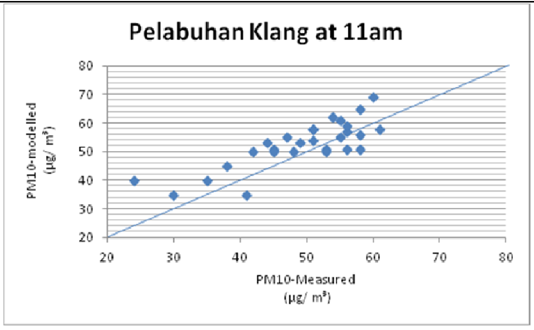
(e) Petaling Jaya

Fig.8: Daily PM_{10} concentration in January 2012

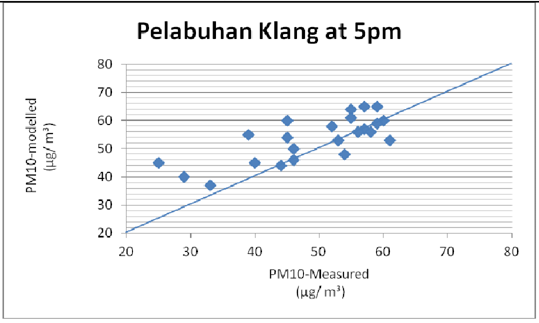
Fig. 9 shows the relationship between measured and modeled PM_{10} concentration of three random locations, to assess how closely the two data sets agree to each other by P-P Plot. A good agreement is observed. Subsequently, comparison between measured and modeled PM_{10} concentration at 7am, 11am and 5pm for Pelabuhan Klang, Kuala Selangor and Petaling Jaya are shown in Figs. 10-11 to show further agreement.



(a) 7am

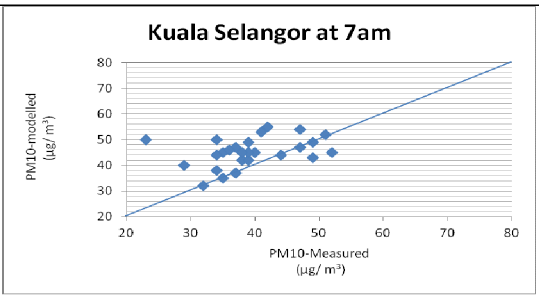


(b) 11am

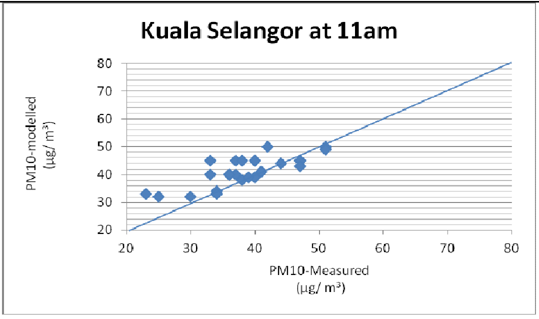


(c) 5pm

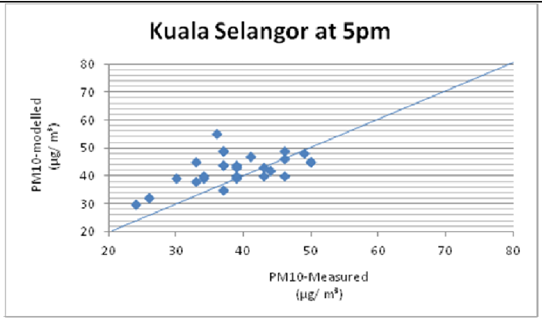
Fig.9: Relationship between measured and modeled PM_{10} concentration for Pelabuhan Klang at various time



(a) 7am

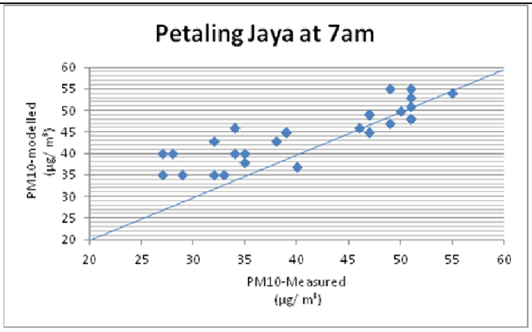


(b) 11am

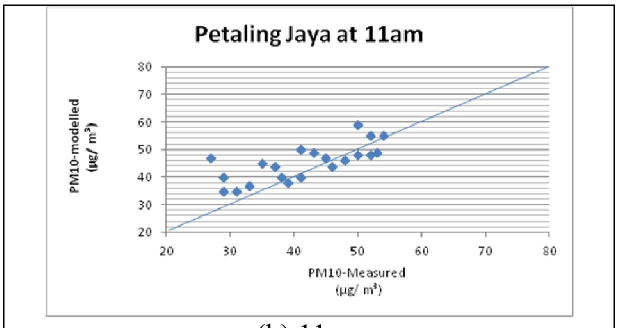


(c) 5pm

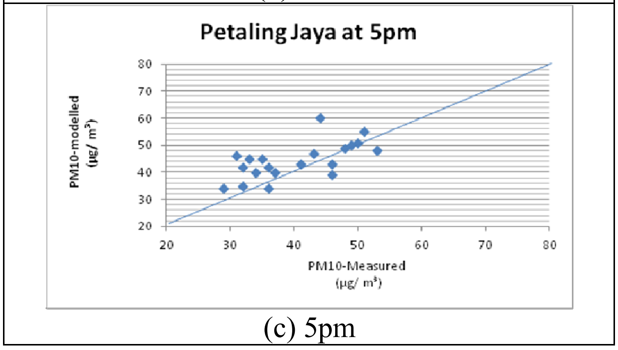
Fig.10: Relationship between measured and modeled PM_{10} concentration for Kuala Selangor at various time



(a) 7am



(b) 11am



(c) 5pm

Fig.11: Relationship between measured and modeled PM_{10} concentration for Petaling Jaya at various time

Fig. 12 presents a comparison between measured and modeled daily average for the five locations. Generally the data satisfactorily agrees even though the measured data shows slightly lower value than simulation data. However, different trend is observed in the annual average prediction as shown in Fig. 13. It shows inverted behaviour that the values measured in 2011 are always higher than the simulation.

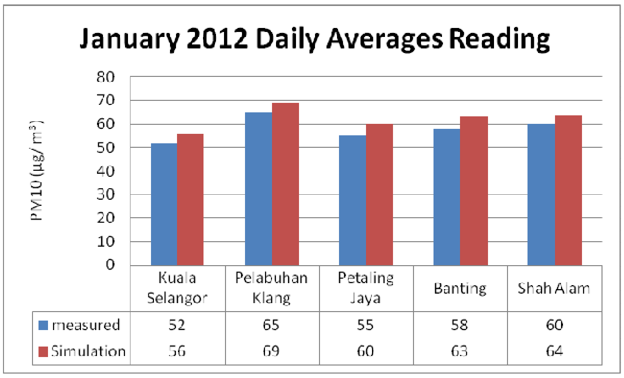


Fig.12: January 2012 Daily Averages Reading

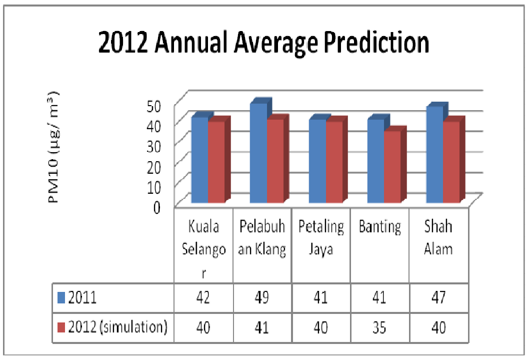


Fig.13: 2012 Annual Average Prediction

4.1.2 Ozone (O_3)

The trend of daily averages concentration of Ozone (O_3) are shown in Fig. 14. Shah Alam shows the highest level of ozone for January 2012, followed by Pelabuhan Klang, Banting, Petaling Jaya and Kuala Selangor, as indicated in the figure.

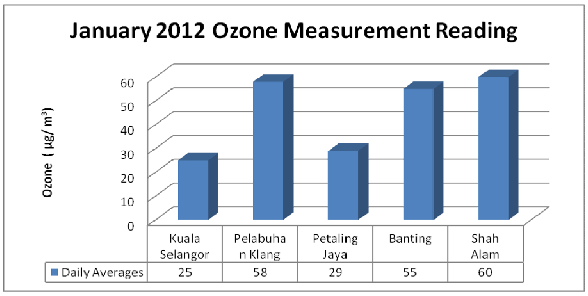
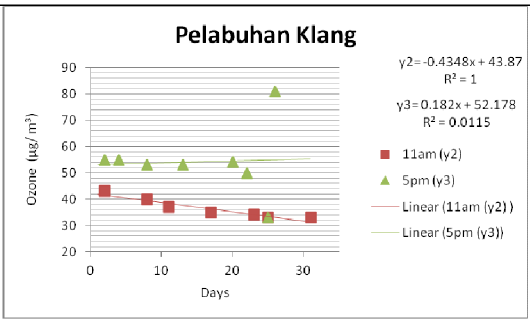


Fig.14: Ozone Measured Reading for January 2012

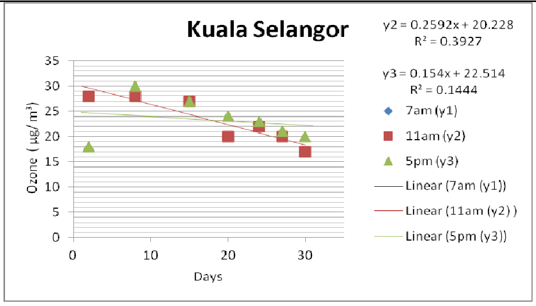
Daily readings throughout the month for all locations are shown in Fig. 15. There are some fluctuation seen in the level of ozone, yet generally all places are under the permissible limit, which is 120µg/m^3. Based on the observation from each location, the trends of ozone formation are increasing only afternoon onwards. No significant level of ozone is present in the morning since ozone is formed in the atmosphere by photo-chemical reactions in the presence of sunlight and precursor pollutants, such as the oxides of nitrogen (NO_x) and volatile organic compounds (VOCs).

Meanwhile in Shah Alam, the ozone trend is decreasing and for Kuala Selangor relatively low level of ozone has been experienced. The wet weather condition with increased amount of rainfall experienced in Kuala Selangor at the late of evening on this January (200mm^2 for January 2012 rainfall distributions) had resulted in decreased number of hotspots detected in that area. A similar weather condition in the neighboring place Shah Alam also led to a decreasing trend in the total number of hotspots reported by the Metrological Malaysia Department (MMD) compared to the trend in the others places. Several storm systems and cold front passages occurred during this month of January and early June producing cool and wet conditions.

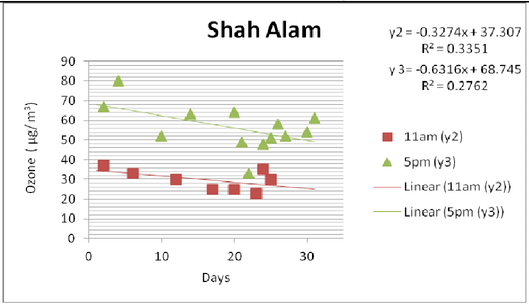
As a place in the seashore nearby, Kuala Selangor also experiences land and onshore breeze effects especially 200km near to the seashore. Mainly, these are due to temperature differences between the road and the sea. During the day, the road gets warmer faster than the sea, and thus creates low pressure area inland. The cooler and relatively higher pressure air will move towards the land. At night, the reverse process takes place since the land cools down quicker than the sea. The onshore breeze, or sea breeze, can reach up to 10 to 15 knots but the land breeze normally blows at a weaker strength. Since wind is also the cause of copious rain in this place, road-users will highly likely to experience rain and high wind at the same time. Consequently, the reading of the regional pollutant like ozone is tending to decrease.



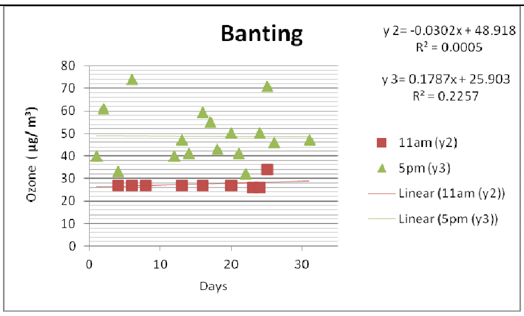
(a) Pelabuhan Klang



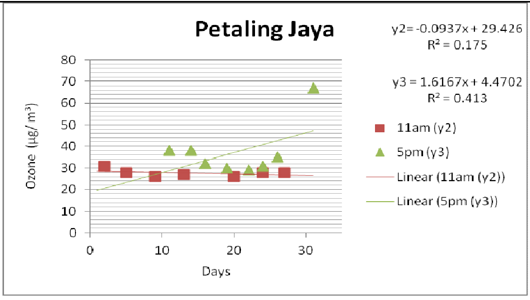
(b) Kuala Selangor



(c) Shah Alam



(d) Banting.

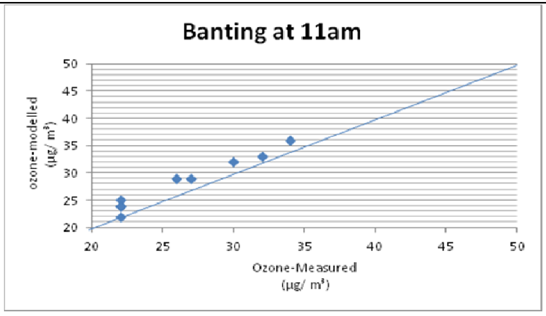


(e) Petaling Jaya

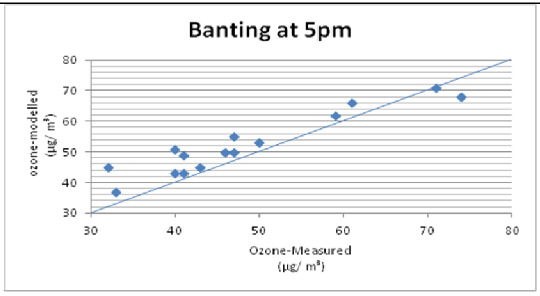
Fig.15: Ozone concentration in January 2012

Figs. 16 and 17 present the relationship between measured and modeled Ozone concentration for two random locations, namely Banting and Shah Alam. Results indicate good agreement between the two. Some of the weak relationship present may indicate that there are other factors that influence the ozone concentration which was not taken into consideration by the simulation.

Comparison between measured and modeled daily maximum reading for the five locations shown in Fig. 18 indicate that simulation data are slightly higher from the measured reading. The simulation data for annual average predicts that the concentration for ozone will be slightly higher from previous reading in 2011 as shown in Fig. 19.

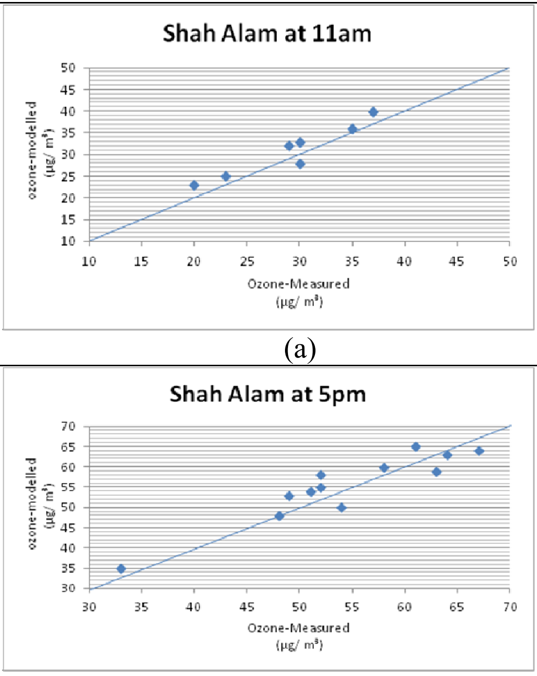


(a)



(b)

Fig.16: Relationship between measured and modeled ozone concentration for Banting at a) 11am b) 5pm.



(a)

(b)

Fig.17: Relationship between measured and modeled ozone concentration for Shah Alam at a) 11am b) 5pm.

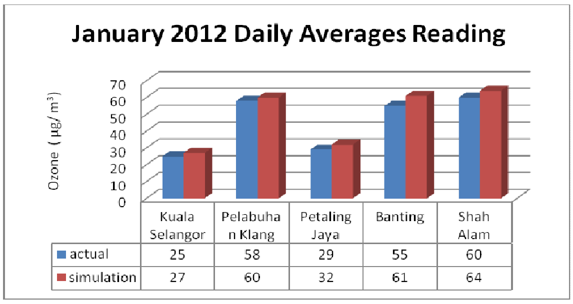


Fig. 18: January 2012 Daily Averages Reading

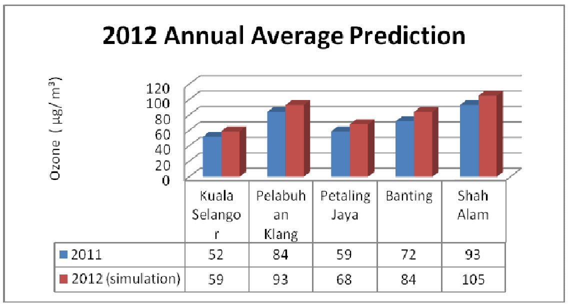


Fig. 19: 2012 Annual Average Prediction

4.1.3 Nitrogen Dioxide (NO_2)

Fig. 20 shows the relationship between measured and modeled NO_2 concentration in Banting. Again, the result indicates good agreement with the measured data. No measurement at 7am and 5pm are presented since no significant level of NO_2 is formed.

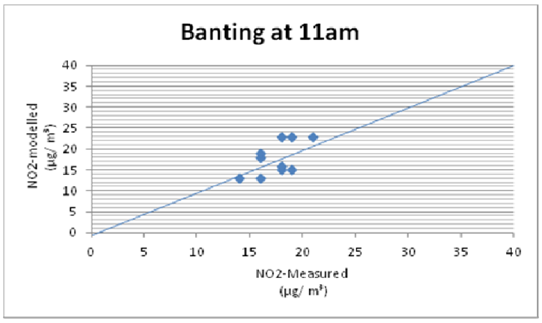
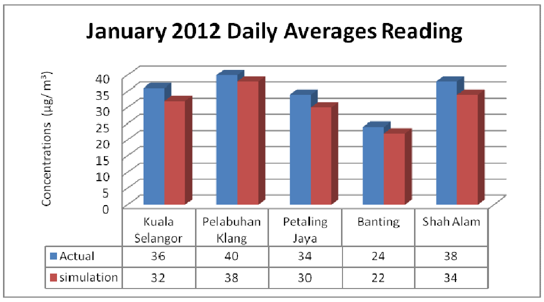


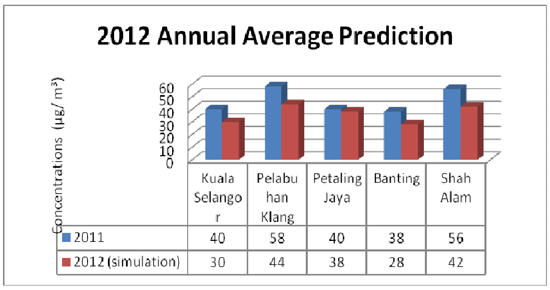
Fig.20: Relationship between measured and modeled NO_2 concentration for Banting at 11am

Comparison between measured and modeled daily average reading for the five locations shown in Fig. 21 indicate that simulation data are slightly lower from the measured reading. The annual averages prediction of ambient concentrations of NO_2, shown in Fig. 22 is relatively lower than the previous year. Pelabuhan Klang has the highest level of NO_2, followed by Shah Alam and Kuala Selangor. The recommended Malaysian limit is 320µg/m^3. In Pelabuhan Klang, in some cases, the weak blowing wind allowed the pollutants from moving vehicles to stay in the atmosphere for several weeks, which to some extend contributed to the high level.



	Kuala Selangor	Pelabuhan Klang	Petaling Jaya	Banting	Shah Alam
🟦 Actual	36	40	34	24	38
🟥 simulation	32	38	30	22	34

Fig.21: January 2012 Daily Averages Reading



	Kuala Selangor	Pelabuhan Klang	Petaling Jaya	Banting	Shah Alam
🟦 2011	40	58	40	38	56
🟥 2012 (simulation)	30	44	38	28	42

Fig.22: 2012 Annual Average Prediction

4.1.4 Carbon monoxide (CO)

Fig. 23 shows the relationship between measured and modeled CO concentration in Pelabuhan Klang, showing a slightly agreement. The difference is considered small, between range 0.1µg/m$^{3.}$ No measurement at 7am and 5pm are presented since any significant level of CO measured.

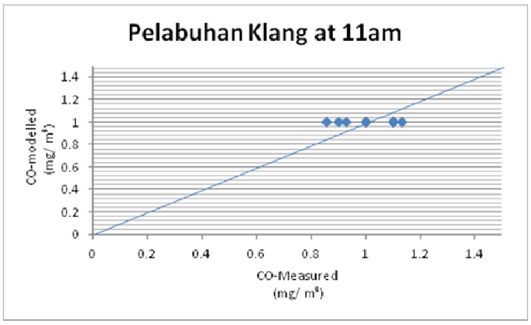
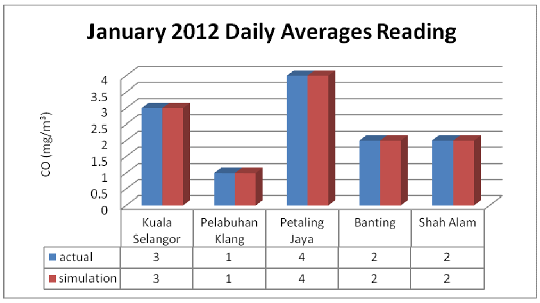
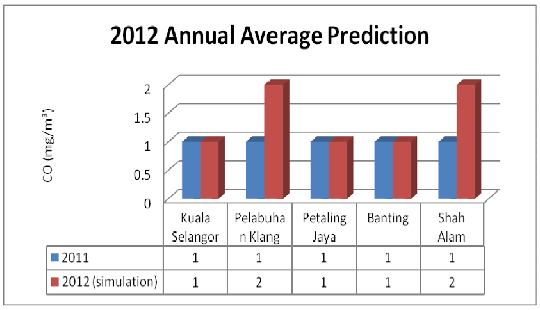


Fig.23: Relationship between measured and modeled CO concentration for Pelabuhan Klang at 11am



	Kuala Selangor	Pelabuhan Klang	Petaling Jaya	Banting	Shah Alam
🟦 actual	3	1	4	2	2
🟥 simulation	3	1	4	2	2

Fig.24: January 2012 Daily Averages Reading



	Kuala Selangor	Pelabuhan Klang	Petaling Jaya	Banting	Shah Alam
🟦 2011	1	1	1	1	1
🟥 2012 (simulation)	1	2	1	1	2

Fig.25: 2012 Annual Average Prediction

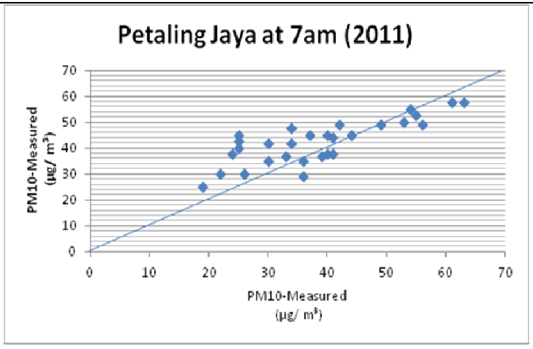
Comparison between measured and modeled daily average reading is shown in Fig. 24, indicating good agreement of both. The predicted annual average for CO is quite low compared to the other pollutants. The simulation predicted an increase in reading for the Pelabuhan Klang and Shah Alam compared to the previous year, yet still well below the limit, which is 10 mg/m^3. This is shown in Fig. 25.

4.2 Further Simulation for Year 2011

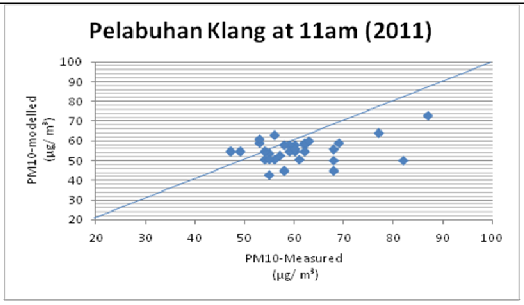
The simulation work is further extended to compare with the previous January 2011. Selected locations are used for each comparison and presented in Figs. 26-30. In general, the results indicate good correlation between the modeled and the measured values. Some deviation is observed especially at higher concentrations. Uncertainties in some part of emission estimations may have contributed to this scatter but the main contribution is attributed to the uncertainties in a few meteorological data.

4.2.1 Particulate Matter (PM_{10})

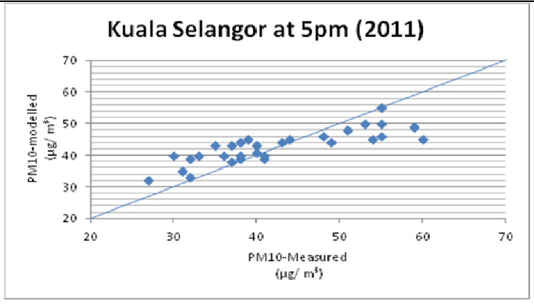
For PM_{10}, three locations are selected, which are Petaling Jaya, Pelabuhan Klang and Kuala Selangor, which are the most PM_{10} polluted area. Three different times are selected, namely 7am, 11am and 5pm. Results are shown in Fig. 26.



(a) Petaling Jaya at 7am



(b) Pelabuhan Klang at 11am

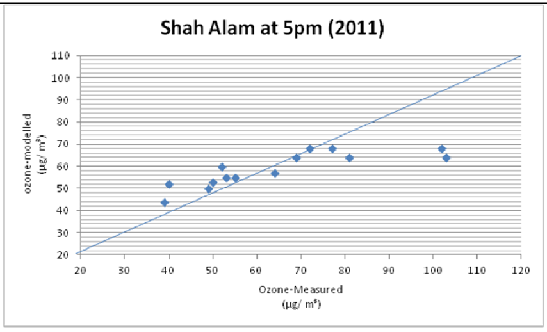


(c) Kuala Selangor at 5pm

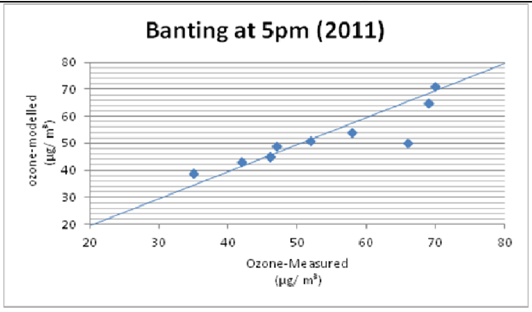
Fig.26: Relationship between measured and modeled PM_{10} concentration for concentration at selected location

4.2.2 Ozone

Two locations are selected, which are Shah Alam and Banting as presented in Fig. 27. A good agreement is observed



(a) Shah Alam at 5pm



(b) Banting at 5pm

Fig.27: Relationship between measured and modeled ozone concentration for ozone concentration at selected location

4.2.3 Nitrogen Dioxide and Carbon Monoxide

For nitrogen dioxide and carbon monoxide, one location is selected for each pollutant, which are Kuala Selangor and Banting respectively. Time is selected based on the time when these pollutants obtain the highest concentration in January 2012, which are 11am and 7am respectively. Results are presented in Figure 28 and Figure 29, respectively.

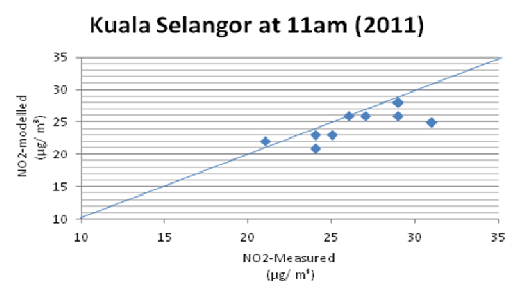


Fig.28: Relationship between measured and modeled concentration for for NO_2 - Kuala Selangor at 11am

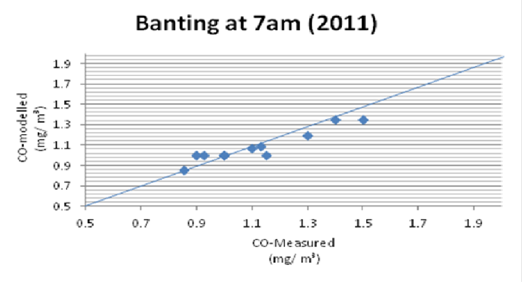


Fig.29: Relationship between measured and modelled concentration for CO - Banting at 7am

4.3 Selangor's Compliance within Recommended Malaysian Ambient Air Quality (RMG) and World Health Organizations Guidelines (WHO)

Figs. 30 and 31 summarize all pollutants in the studied locations for daily averages and annual average predictions respectively. All the measurement units are according to the authority standard that been underlined by DOE Malaysia. Note that unit for CO concentration is in mg/m^3, while others are in $\mu g/m^3$.

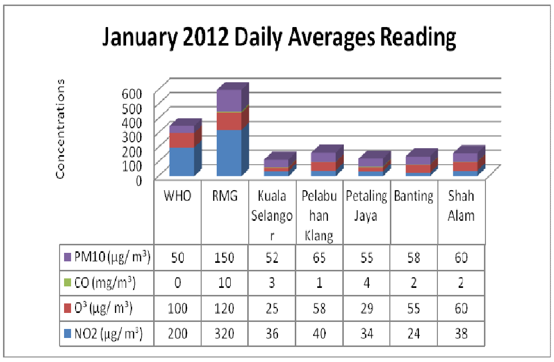


Fig.30: January 2012 Daily Averages Reading

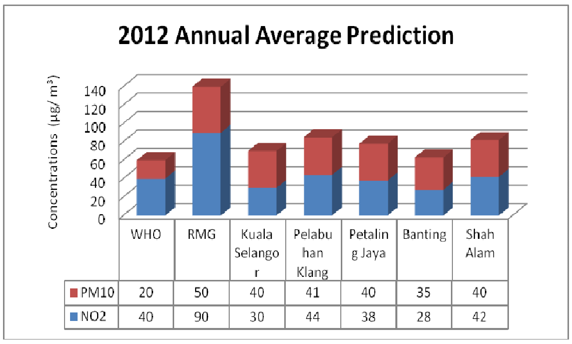


Fig. 31: 2012 Annual Average Prediction

Generally, the air qualities for January 2012 are within RMG limit. However, this study found that the average daily PM_{10} in all the area exceeds the WHO limit. Furthermore, all locations are predicted to exceed the annual average limit for PM_{10}, while two locations are predicted to exceed NO_2 limit.

4 Conclusions

There were no serious incidences of air pollution recorded in the period of January 2012. Air quality trends for the criteria pollutants in this particular month generally continue to show downward trends or stable trends well below the level of the national standards.

The presented analysis has revealed that moving vehicles creates a significant impact in air quality on the specific locations. Good correlations between measured and modeled data also indicate that OSPM simulation can be used to predict the measured readings of air pollution in Malaysia's environment. More knowledge and information should be acquired on local meteorological phenomenon, road condition, traffic volume and driver's mobility and vehicle profile. Also, the impact of non-precipitation weather elements such as wind, sunlight and temperature should be explored further.

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[1] Cadle, S., Gorse, J. R. & Bailey, B., Real-World Vehicle Emissions: A Summary of the 12th Coordinating Research Council On-Road Vehicle Emissions Workshop. *Journal of Air & Waste Management Association*, Vol.53, 2003, pp. 152-167.

[2] Makra, L. A., Selections from the History of Environmental Pollution, With Special Attention to Air Pollution, *International Journal of Environment and Pollution,* Vol.22(6), 2004, pp. 641- 656.

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