RELATIONSHIP OF TRAFFIC FLOW CHARACTERISTICS AND ROADSIDE SUSPENDED PARTICULATE MATTER (SPM) EMISSIONS IN METRO MANILA

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Abstract: In Metro Manila, recent studies reveal road traffic emission as a major contributor of air pollution. Among the major atmospheric pollutants, suspended particulate matter (SPM) levels have reached an alarming rate oftentimes exceeding thrice the local standards and WHO guidelines. With this perspective, there is a need to predict SPM emission levels by analyzing the relationship of roadside SPM emissions and traffic flow characteristics such as traffic volume and speed of specific vehicle types. In order to study the contributions of SPM, the study is focused on the roadside, street-level concentration and particulate emissions in an open area is monitored. Regression analysis is used to obtain general characteristics of the roadside particulate pollution and to investigate the effects of traffic volume and wind velocity on SPM emission levels.

Keywords: road traffic environment, suspended particulate matter (SPM), traffic flow characteristics

1. INTRODUCTION

In 1999, the Philippine Congress passed and enacted Republic Act No. 8749 known as the Philippine Clean Air Act of 1999 that set into motion a nationwide effort to improve the country's air quality. Although its Implementing Rules and Regulations (IRR), already signed in November 2000, is yet to be enforced, decision makers in government and industry alike require accurate information and advice on environmental issues when recommending policies. With increasing concern about the environmental impact of transportation, environmental standards and constraints seem set to become yet more severe.

The link between vehicular traffic and air pollution is well established. Results of the environmental monitoring survey conducted by the Metro Manila Urban Transportation Integration Study (MMUTIS) in 1996, concluded that Metro Manila is fast becoming polluted due to the rapid increase in motorization and population growth. Several air pollution monitoring studies conducted recently support the increasing trend in particulate matter exceeding the local air quality standards, mainly attributed to diesel-engine vehicles. Among the major atmospheric pollutants, suspended particulate matter (SPM) levels have reached an alarming rate oftentimes exceeding thrice the local standards and WHO guidelines. Diesel-fed vehicle exhaust emission accounts for this rate due to its combustion characteristics and the use of secondhand engines. Diesel exhaust poses a major health hazard aside from environmental degradation and economic loss.

The main objective of the study is to analyze the effects of the traffic flow characteristics of specific vehicle types and wind velocity on roadside SPM emission levels in a road condition with open area. In the Asian Development Bank (ADB)-assisted study on "Vehicular Emission Control Planning in Metro Manila" in 1992, diesel-engined jeepneys, taxis and buses were found to contribute to 2/3 of the particulates. The study also confirmed from its ambient monitoring results that particulate matter is the pollutant of primary concern in Metro Manila.

In order to study the contributions of this pollutant from diesel motor vehicles and their characteristics, the study is focused on the roadside, street-level concentrations. Regression and correlation analyses are used to obtain general characteristics of the roadside particulate pollution and to investigate the effects of traffic flow and wind velocity on the concentration levels. Furthermore, by determining the emission levels of SPM concentration in a roadside environment of known traffic and evaluating its compliance to existing air quality standards, the impact of present and future transportation policies in improving road traffic environment and alleviating economic loss can be assessed. The framework of the study is presented in Figure 1.

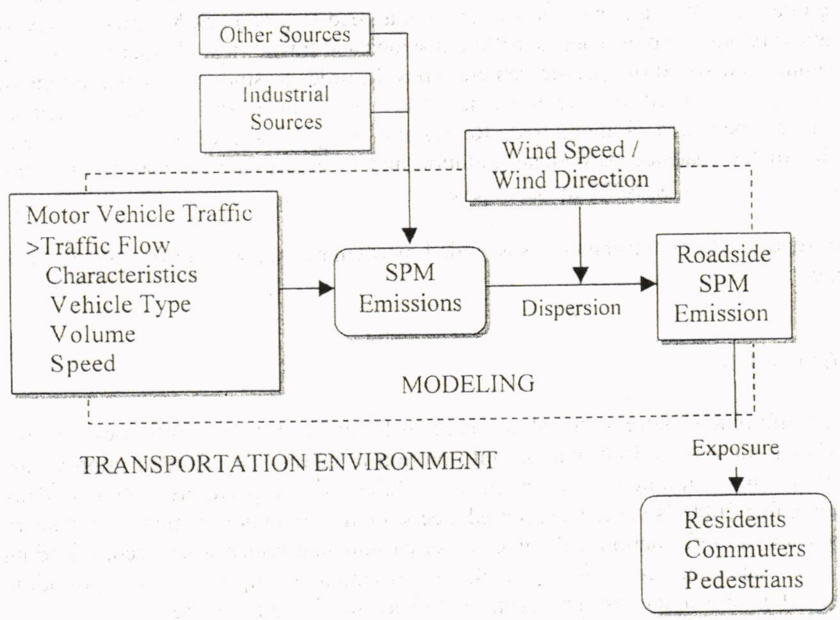

Figure 1. Framework of the Study

2. LITERATURE REVIEW

2.1 The Impact of SPM Emissions on Human Health and the Environment

Air pollution is a major environmental health problem, affecting developed and developing countries around the world. The WHO Guidelines for Air Quality 2000 reported that aside from mortality due to exposure of high concentrations of SPM in the indoor air environment, the excess mortality due to SPM and SO_2 in the ambient air amounts to about 500,000 people annually. Moreover, recent estimates of the increase in daily mortality show that on a global scale, 4-8% of premature deaths are due to exposure to particulate matter in the ambient and indoor environment.

Concern about air pollution stems mainly from high concentrations of suspended particulates, critically exceeding local and WHO health guidelines. The World Bank-assisted Urban Air Quality Management Strategy in Asia (URBAIR) in 1997 reported that morbidity due to PM_{10} in Metro Manila, such as the many cases of chronic bronchitis, restricted activity days (RAD), respiratory hospital diseases (RHD), emergency room visits (ERV), bronchitis, asthma attacks, and respiratory symptoms days (RSD) can be attributed to particulate pollution. Dose-response relationships for particulate concentrations are described in the URBAIR Guidebook. Mortality and morbidity cases in an URBAIR study, "Valuation of Air Pollution Damages in Metro Manila", conducted by H.A. Francisco in 1994, showed that the monetary value of damage to health due to air pollution was estimated using the Contingent Valuation Method (CVM). CVM is a survey method in which respondents are asked about their willingness-to-pay to reduce damage. The total estimate of damage to health amounted to P300-450 million. Although there is no figure for the damage that air pollution causes to buildings and materials, Francisco (1994) indicates that there are indications of substantial damage. Interviewed households reported perceived damage due to air pollution to be in the range of P3,233 to P5,500 per year per house. The United States Environmental Protection Agency (USEPA) fact sheet on the Health and Environmental Effects of Particulate Matter in 1997 reported that the fine particles linked to serious health effects are also a major cause of visibility impairment in many parts of the US. Airborne particles can also cause soiling and damage to materials.

2.2 Traffic Flow and Roadside Pollutant Concentration Studies

Road-based transport is the primary contributor of the environmental degradation from the transport sector.

Vergel, *et. al* (1999) implemented an environmental survey in Metro Manila measuring and understanding the actual conditions of roadside total particulate matter (TPM) and NO_2 concentration levels. The study analyzed special traffic flow characteristics such as the presence of paratransit vehicles such as jeepneys and its relationship with the air pollution and modeled roadside pollutant concentration. The study found passenger car, jeepney and traffic flow parameters as significant factors influencing roadside TPM concentration and further concluded that there are differences in generated unit emission across vehicle types. The pollutant emission mass rate generated by the vehicle traffic was then calculated from the measured roadside pollutant mass concentration. The study recommended additional collection of roadside pollutant concentration data to improve model accuracy.

Teodoro and Villoria (1997) proposed an empirical model estimating ambient air pollution, particularly CO, in a roadside environment. The study utilized multiple linear regression and non-linear parameter estimation expressed in terms of traffic flow parameters (e.g. traffic volume and traffic speed) and simple meteorological parameters, wind speed at a particular direction. The study made an assessment of the ambient air quality of the study area in EDSA and Commonwealth Avenue, identified general air pollution problems and their causes, and cited workable abatement strategies based on the observed conditions. Results of the air pollution monitoring activity conducted identified SPM as the most critical pollutant in the area exceeding the hourly National Ambient Air Quality Standard value of 250 μg/Ncm by a factor of 1.3.

Villoria, *et. al* (1996) reviewed the air pollution monitoring activities of the Philippines. Factors contributing to vehicular air pollution were identified as increasing motorization trend, engine performance of vehicle fleet, worsening traffic congestion and motor vehicle composition.

Balogh, *et. al* (1993) studied particulate matter smaller that 2.5 micrometers (microns), typically denoted $PM_{2.5}$, from data collected along paved roads on the University of Washington campus. The general objective of the study was to provide additional evidence on the suitability of USEPA's procedure for AP-42 for estimating $PM_{2.5}$ vehicle emission rates. Results of the data collection and subsequent statistical analysis indicated that urban buses were by far the major source of particulate emissions. Notably buses with low exhaust pipes generated higher concentrations of roadside fine particulate matter than those with elevated exhausts. The findings suggested that the USEPA's procedure AP-42 for calculating resuspended particulate matter near urban roadways was grossly inaccurate, producing values that were 9 to 20 times higher than observed fine particulate levels.

This section reviews the recent trend of SPM emissions problem and the impact of SPM on human health and the environment in Metro Manila, the Philippines. Recent studies on the relationship of traffic flow and roadside pollutant concentration suggest additional collection of roadside particulate pollutant concentration data in order to assess and analyze present air quality conditions of the roadside environment. This study is focused on a longer monitoring period of the traffic flow, wind velocity and of the roadside SPM concentration to establish a weekly diurnal fluctuation to improve model accuracy.

3. AMBIENT AIR QUALITY AND TRAFFIC MONITORING

The study was directed on the ambient measurements of SPM concentration from vehicle-attributed sources in an urban arterial roadside. Monitoring activities were conducted at mid-block of at least 200-meter distance form the intersection or a nearby parallel road considering that pollutant level is a cumulative contribution of various sources within the immediate vicinity.

The Horiba Air Pollution Monitoring System, fixed in a Mitsubishi Rosa van, was used during the conduct of the roadside SPM emissions and wind velocity monitoring. The Horiba 350 Series Air Pollution monitoring equipment, particularly the APDA-360 Ambient Particulate Monitor, measures hourly averages of SPM using beta ray absorption.

The site was chosen mainly due to the prevalence of high truck traffic volume being a designated truck route as well as due to its open space. The study is also limited to a roadside environment considerably away from other pollution sources. The hourly average concentration of SPM and wind velocity data were monitored on November 13-19, 2000 for 24 hours, continuous for 7 days along R10 Road, in the northern section of the City of Manila. Simultaneously, traffic flow was monitored using a video camera system mounted on a Pajero van for 12 hours, from 6 am to 6 pm for 7 days. For the traffic flow survey, vehicles were classified into six groups, namely: trailer/articulated trucks, single-unit trucks, cars, buses, jeepneys and motorcycle/tricycle (MC/TC).

Wind velocity monitoring was conducted using an anemometer and anemoscope raised to an elevation of 9.0 meters to be cleared of any windward obstacle. Hourly measurements of wind speed are expressed in m/s. Most prevalent hourly wind directions were established using 16 compass degrees oriented to the location of the receptor to assume a line source. The receptor height is 3.5 meters. Figure 3 shows the map of the location of the survey site along R10 road.

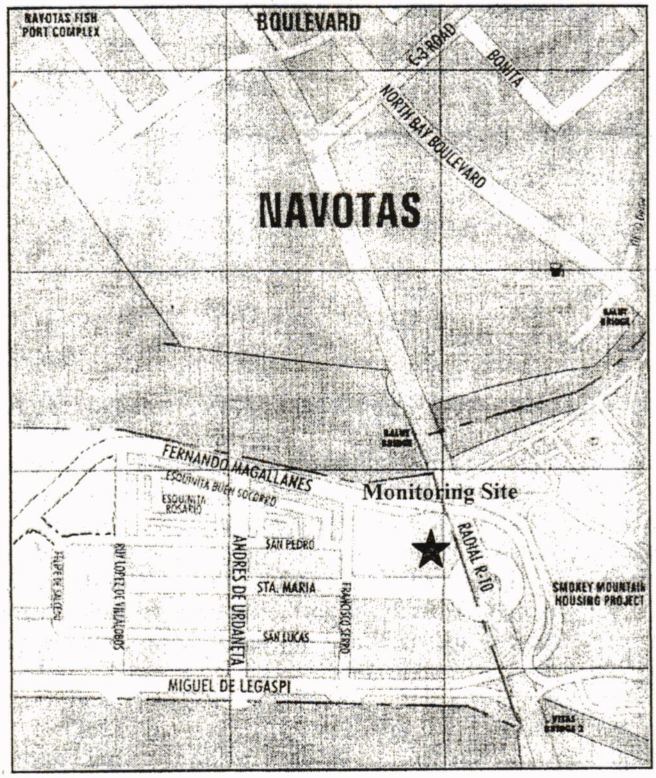

Figure 3. Location map of the study area

3.1 Roadside SPM Concentration and Traffic Flow Profiles

Under the Clean Air Act – Implementing Rules and Regulations, the National Ambient Air Quality Guideline Values (NAAQGV) necessary to protect public health and safety and general welfare for SPM for the short-term 24-hr daily average is proposed at 150 μg/Ncm., noting provisional limits with mass median diameter less than 10 mm and below until sufficient monitoring data are gathered to base a proper guideline.

The R10 Road study area yielded a maximum measured daily average roadside SPM concentration of 155 μg/Ncm. exceeding the NAAQG value of 150 μg/Ncm., while the average recorded concentration for the weeklong monitoring period was 113.90 μg/Ncm. A total of 168 hourly average SPM concentration values were generated during the 7-day ambient air monitoring.

Results of the monitoring showed that SPM measurements were relatively lower than the results of several previously conducted observational studies. The difference can be attributed to some identified factors such as site characteristic and the governing seasonal and local meteorological factors during the conduct of the survey. Figure 4 shows the variation of the daily average roadside SPM concentration for the study area.

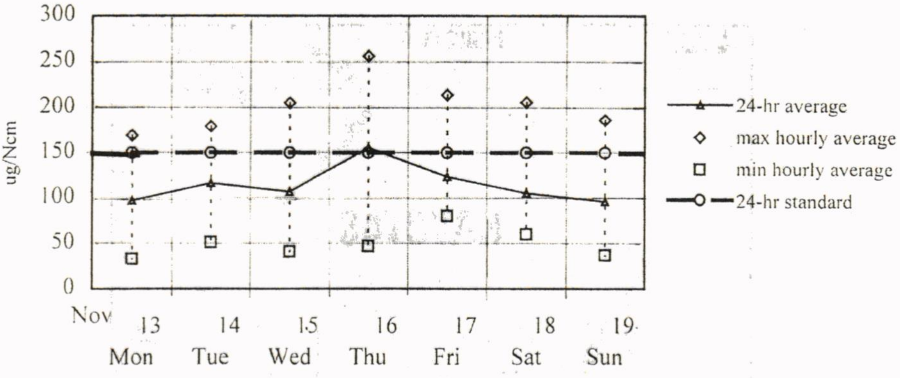

Figure 4. Variation of the Daily Average SPM concentration at R10 Road

In the simultaneous traffic flow monitoring by video, a total of 84 hourly volumes and hourly speeds in the daytime were observed and encoded into the computer. The study area recorded an average of 1,328 vehicles per hour (vph) during the weeklong monitoring period with a maximum hourly traffic volume of 1,935 vph. It can be observed that an increasing trend in total volume usually resulted to a decrease in truck volume during the early morning traffic at 7-8 AM. This may be attributed to the freight distribution activity schedule of trucks during late afternoons and nighttime. Figure 5 shows the truck and total volume profile at R10 Road.

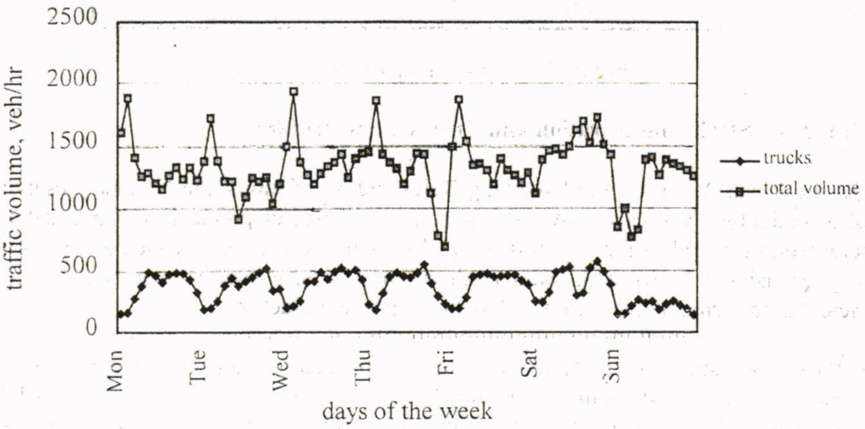

Figure 5. Truck and Total Volume Profile at R10 Road

The combined average speed for both directions was estimated to be 40.82 kph, with a maximum and minimum hourly average of 53.87 kph and 14.61 kph, respectively. Generally, low speeds were observed in the afternoons during the week of observation due to traffic congestion observed during these periods. Figure 6 shows the percentage of truck per total volume of traffic per hour for the traffic flow monitoring. The highest hourly percentage of truck was recorded at a relatively high 41.45% with the lowest hourly percentage of 8.45 %. The mean truck proportion was 27.82% indicating a relatively high level of truck traffic in this urban arterial road.

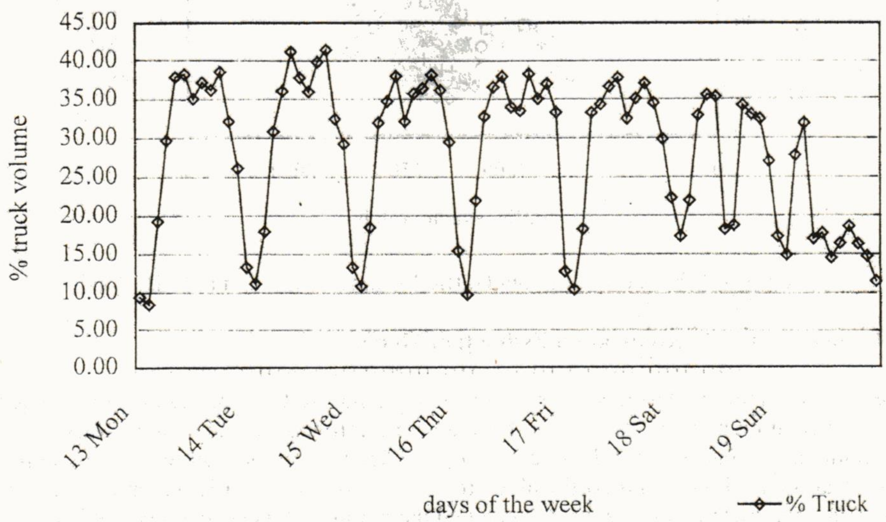

Figure 6. Truck percentage profile of the week

Wind velocity monitoring yielded an average wind speed of 1.74 m/s with a maximum and minimum hourly speed of 5.4 m/s and 0.2 m/s, respectively. The most prevalent wind direction was observed at NNE, establishing a direction away from the receptor.

4. RELATIONSHIP OF TRAFFIC FLOW CHARACTERISTICS AND ROADSIDE SUSPENDED PARTICULATE (SPM) CONCENTRATION

4.1 Traffic Flow Characteristics and Roadside SPM Concentration

Comparison between trendlines based on the regression coefficients giving preference to the function of higher determination. R^2, with a 95% confidence level, suggested transformation of the dependent variable. There are many transformations that may enhance the fit and predictability of the model. Through investigation of the graphs, the logarithmic (*ln*) transformation of the roadside SPM concentration was chosen.

Figure 7 relates the roadside SPM concentration and traffic volume in the R-10 Road study area. From the scatterplot, there seems to be a direct proportional relationship between roadside SPM concentration and traffic volume. The maximum recorded hourly roadside SPM concentration on Thursday, November 16, of 256 μg./Ncm, coincided with a traffic volume of 1,863 vehicles per hour. Consequently, the maximum recorded traffic volume of 1,935 vehicles per hour on Wednesday, November 15, corresponded to an hourly roadside SPM concentration of 136 μg/Ncm.

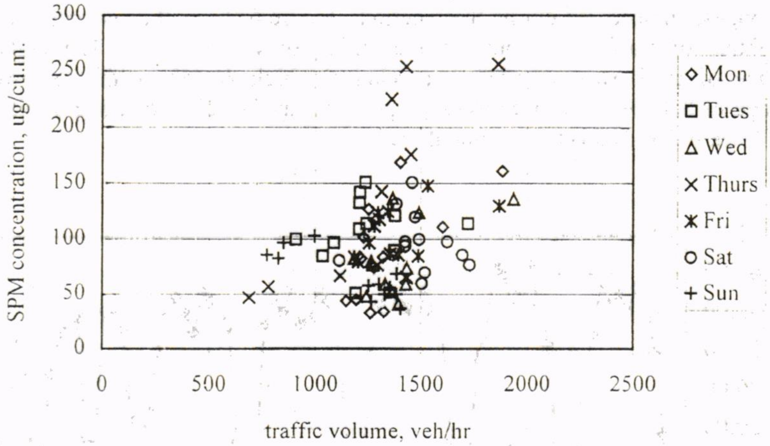

Figure 7. SPM Concentration-Traffic Volume Scatterplot at R-10 Road

4.2 Roadside SPM Concentration Estimation Model

A regression model is developed for the open area land use type that can estimate roadside SPM concentration given the traffic flow and meteorological parameters. Basically, the assumptions in roadside SPM concentration modeling are the following: the pollutant concentration is directly proportional to the traffic volume; traffic volume is classified according to vehicle types; the model specified the number of diesel-engined vehicles as one of the main variables; wind speed is inversely proportional to pollutant concentration; traffic speed, being in general inversely proportional to traffic volume, is likewise assumed to be inversely proportional to the pollutant concentration. A significant factor in the fluctuation of air pollutants is wind direction. Wind direction was accounted for by classifying the data by directional points using the 16 compass-degree points.

In order to investigate the important factors that can explain the variation of roadside SPM concentration, the measured roadside SPM concentration is regressed with respect to independent variables such as traffic flow and meteorological characteristics as shown in Equation 1.

$$SPM = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \quad (1)$$

where $\beta_1, \beta_2, \beta_3, \ldots, \beta_n$ = coefficients
β_0 = intercept
$X_1, X_2, X_3, \ldots, X_n$ = independent variables

The traffic and wind velocity data are used as the potential independent variables of the regression analysis. The natural logarithm of SPM, *ln*SPM, is used as the dependent variable. The following are used as the independent variables: WS (Wind speed in meters per second, m/s), WD (Wind direction, cosine of the angle between the orientation of the receptor and wind direction), VTRUCK (Truck volume in vehicles per hour, veh/hr), VBUS (Bus volume in vehicles per hour, veh/hr), VJEEP (Jeepney volume in vehicles per hour, veh/hr), VCAR (Car volume in vehicles per hour, veh/hr), MC_TC (Motorcycle/tricycle volume in vehicles per hour. veh/hr). TOTALV (Total traffic volume in vehicles per hour, veh/hr) and SPEED (Average speed in kilometers per hour, kph).

Regression analysis involves developing a functional relationship between the established dependent variable and the independent variables. Correlation analysis between variables is conducted in order to assess the adequacy of the factors in the regression analysis. Ten (10) independent variables are considered as factors that influence roadside SPM concentration. Considering the factors contributing to the roadside SPM concentration at R-10 road, nine (9) variables are adopted as shown in Table 1.

Table 1. Correlation Matrix of Potential Modeling Variables of R-10 Road

	*ln*SPM	WS	WD	VTRUCK	VBUS	VJEEP	VCAR	MC_TC	TOTALV	SPEED
*ln*SPM	1	-0.41	-0.51	-0.19	0.05	0.11	0.31	0.27	0.26	0.15
WS		1	-0.07	0.22	0.04	0.24	0.01	-0.01	0.20	0.03
WD			1	0.25	-0.19	-0.20	-0.16	-0.08	-0.09	-0.12
VTRUCK				1	-0.25	-0.36	-0.55	-0.36	-0.11	-0.37
VBUS					1	0.55	-0.11	0.01	-0.07	0.04
VJEEP						1	0.38	0.33	0.48	0.39
VCAR							1	0.78	0.86	0.33
MC_TC								1	0.78	0.24
TOTALV									1	0.24
SPEED										1

From the matrix. VCAR and MC_TC are relatively highly correlated with TOTALV. It can be seen initially from Table 2 that the significant factors influencing roadside SPM concentration for R-10 road are the WS, WD and TOTALV parameters.

The correlation matrix presented provides valuable basic information on the nature of problems to be encountered in formulating the model. The correlation matrix further shows inter-correlations among the potential independent variables. The next step would be to determine whether all ten independent variables are required for the prediction model. The stepwise regression procedure essentially develops a sequence of regression models, at each step adding or deleting an X variable. The criterion for adding or deleting an X variable can be stated equivalently in terms of error sum of squares reduction, coefficient of partial correlation, or F statistic.

Table 2 summarizes the R-10 Road model estimation result. The generated regression coefficients are obtained from the stepwise regression procedure with the corresponding t-values. The table shows the result of the 4-factor R-10 Road Model for the roadside SPM concentration estimation.

From the table, the models show a low parameter intercept. Theoretically, models with lower intercepts are better since intercept accounts for the relative error in the value contributed by the parameters. The assumptions in the roadside SPM modeling are found to be validated by the parameter relationships, such as the inverse relationships of wind speed and the wind direction away from the receptor with respect to roadside SPM concentration and the direct proportional relationship of traffic with the roadside SPM concentration.

Table 2. R-10 Roadside SPM Concentration Model Estimation Result

	R-10 Road Model	
variable	parameter	t-value
intercept	3.786075	15.66226
WS	-0.21201	-6.73777
WD	-0.33593	-6.90327
TOTALV	0.000665	4.211268
VTRUCK	0.000347	1.206718
Number of Samples	82	
Regression Coefficient	0.5637	

The t–test for the R-10 road model came up with significant values for the modeled variables and the variables indicated by the signs validated the assumptions. Although the VTRUCK variable for the R-10 road model resulted to an insignificant t-value, the stepwise procedure considered this as a significant factor having high volume as compared to other vehicle types. The generated model, having a coefficient of multiple determination, R^2 of 0.5637, indicates that about 56% of the exponential roadside SPM concentration in an open space land use type can be explained by the significant variables: wind speed, wind direction, total volume and truck volume. The most prevalent wind direction of NNE away from the receptor may have affected the roadside SPM concentration thereby establishing a low regression and correlation coefficients.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study implemented an ambient air quality and traffic flow monitoring in Metro Manila and measured actual conditions of roadside suspended particulate matter (SPM) concentration levels. Traffic flow and meteorological parameters are then analyzed and their relationships with roadside SPM concentration established a model for an open space land use type.

The daily average SPM concentration measured at roadsides occasionally exceeded the proposed national air quality standard of 150 $\mu g/m^3$ especially at arterial roads with relatively high truck traffic volume as validated in the R-10 road monitoring site. The findings reinforced the previous observational studies though actual monitoring concentration values were found to be relatively lower.

There is a positive correlation between arterial road traffic volume and the roadside SPM concentration especially at open space land use types. There is a negative correlation between the wind velocity and the roadside SPM concentration. These validated the assumptions that roadside SPM concentration is inversely proportional to wind speed while directly proportional to traffic volume.

Regression models of roadside SPM concentration as a function of arterial road traffic volume and wind velocity is developed for an open space land use type. Significant variables found to influence emission levels of the roadside SPM concentration are traffic volume and wind velocity.

5.2 Recommendations

In line with the objectives of the anti-smoke belching campaign of the Philippine Clean Air Act of 1999, it is recommended that motor vehicle inspection and emission tests be implemented on trucks. It can be noted that many of the trucks passing through the arterial roads of Metro Manila are poorly maintained and have high SPM emissions specifically the black smoke, which is due to the emission from second hand diesel engines.

Due to the positive correlation of traffic volume and roadside SPM concentration, it is recommended that vehicle traffic be minimized at roads inside residential areas that are of the open-space land use type: Short-term measures include consideration of alternative routes and implementation of the concept of road hierarchy. Long-term measures include construction of by-pass roads, change in land use or re-zoning and the institutionalization of vehicle emission testing and inspection system for all vehicle types.

There is a further need to validate the regression model by applying the developed model in other roadside environments.

ACKNOWLEDGMENTS

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