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Estimation of PM_{10} from Exhaust and Non-Exhaust Emission in Traffic Area, Klang Valley, Peninsular Malaysia Using Air Quality Dispersion Modeling

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Abstract: This paper reviews methods to estimate the concentration of $PM_{10}$from vehicular emission sources (exhaust and non-exhaust) by using AERMOD dispersion model in the Klang Valley region. The ground level concentration was obtained by processing various meteorological parameters, terrain features and source emission inventory data (emission rate) for 2014 were used in simulations within 50 km x 50 km model domain over 24 hours averaging periods. The results showed the maximum concentrations of PM_{10}were revealed in central, southeast and southwest of the model domain. The evaluation of performance of the model was done by comparing observed and simulated PM_{10} concentrations using statistical tools such as correlation coefficient, Normalized Mean Square Error, Factor of two and index of agreement. Therefore, the AERMOD model evaluation resultsrevealed an acceptable model for conducting dispersion modeling from vehicular sources (exhaust and non-exhaust) in the Klang Valley with good model skill for the estimation of PM_{10} concentrations in Shah Alam station. This study considers the first for evaluation PM_{10} using AERMOD dispersion model in the Klang Valley region in Peninsular Malaysia.

Key words: PM_{10} · Emission Inventory · Exhaust and non-exhaust emission · AERMOD dispersion Model

INTRODUCTION

Atmospheric particulate matter is the most important group of environmentalpollutants that affect the air at different concentrations. Furthermore, it affects human health when it enters the respiratory system [1]. Present studies on the health problems associated with exposure to particulate matter (PM) with an aerodynamic diameter of 10 μm or less (PM_{10}) have identified a range of health-related problems including deterioration in lung function, heart disease, chronic pulmonary disease and premature death as well an overall increase in mortality [2, 3].

Traffic emissions which generate air pollutants are either exhaust or non-exhaust emissions. Accumulated road dust is responsible of a major portion of the aerosol mass. In the case of vehicular traffic and non-exhaust emissions should be tightly controlled. Road dust re-suspension, brake and tire are significant sources of non-exhaust emissions [4, 5]. Emissions from heavy traffic areas have been found to generate and contribute substantially to overall concentrations of PM in urbanized areas and exposure to PM from vehicle emissions has been proved to adversely affect human health[6]. AERMOD is a USEPA recommended, steady-state air quality distribution plume model. It uses theeffect of vertical variations in the planetary boundary layer (PBL) to disperse pollutants. The plume growth is established by turbulence profiles that fluctuate with height [7, 8]. This model, which is a steady-state Gaussian plume model is beneficial in calculating pollutantdistributionthat is particularly effective in rural and urban; areas flat and varied land; surfaces and in situations of high level

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emission ; and from several sources (point, area, line and volume) of emissions [9, 10]. AERMOD has been promoted by the USEPA as a desirableair distribution model to replace the ISCST3 (Lee & Keener, 2008).The AERMOD is considered accurate for dispersion modeling at distances of 50 km or shorter from the emission source [8]. Theaims of this study is to present the special concentration maps of PM_{10} from vehicles exhaust and non-exhaust emission source in the Klang valley region within the model domain 50 km^2 and to assess the efficiency of the model based on its simulation of PM_{10}.

MATERIALS AND METHODS

Study Area: The Klang Valley is located in central Peninsular Malaysia (between 3.139003 N and 101.686855 E). It is geographically delineated by the Titiwangsa Mountains and surrounded by hilly terrain creating a bowl-like topography with an opening to the Straits of Malacca [11] (Figure 1). The climate is characterised by average temperature (28^0C), high humidity above 70%,and with wind speed of 3.1 m/s. Precipitation is lowest during the SW monsoon (6.27mm) and highest during the NE monsoon (15.1mm) [12].

Estimation of the Exhaust Particulate Matter (PM_{10}) Emissions: Total emission from different vehicle types was estimated based on emission factor, traffic volumes and length of road segment. This emission was estimated according to USEPA, AP- 42 and [13] and the formula for emission from traffic used in the study is given below:

$$E_i = \sum_k \left[EF_{ik} \times A_k \right]$$

where:

E_i is total emission of PM_{10}/g, EF is Emission factor of PM_{10} g/km, i is type of pollutants, k is vehicle type, k is Activity level for each pollutant source.

The emission factors (g/km) for pollutant PM_{10} from exhaust emission were obtained from the literature [14-16]. The Traffic volume of different vehicle types and road segment lengths were based on the road traffic volume survey conducted by the Malaysian Public Works Department [17].

Estimation of Particulate Matter (PM_{10}) from the Non-exhaust Emissions: The non-exhaust particulate matter from traffic emissions (E) was estimated using emission factors (EF) and data from vehicular activity (A). The basic equation is:

$$Ei = EF \times A$$

Estimation of Emission Factor for Re-Suspension (PM_{10}): The particulate matter (PM_{10}) emissions factor was estimated from re-suspension dust on a paved road surface by using US-EPA. AP-42 method:

$$EF_{pr} = K \times (SL)^{0.91} \times (W)^{1.02} \times (1 - P/4N)$$

Where:

EF_{pr} is Particulate emission factor for a paved road (g/VKT), K is Particle size multiplier (g/VKT; from AP-42, table 13.2.1-1), SL is Road surface silt loading (g/m^2),

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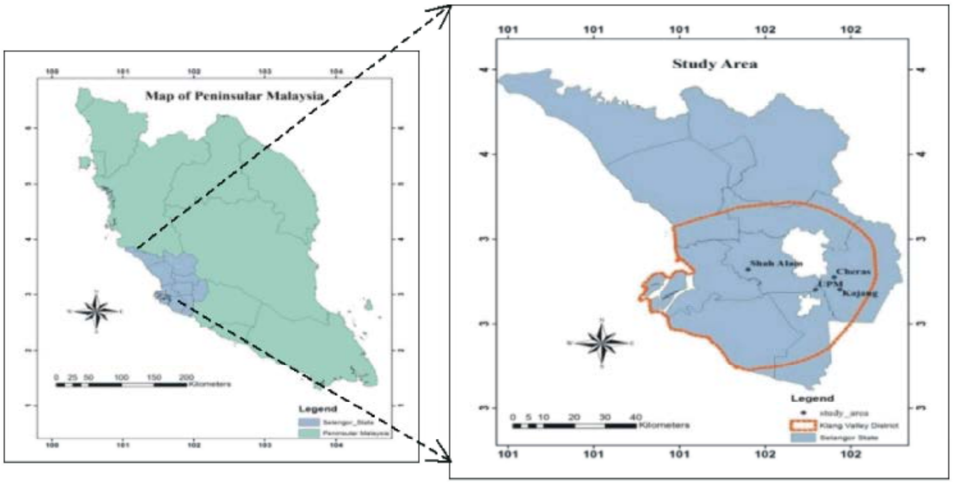

Fig. 1: Study area

W is Average weight of the vehicles using the road (ton), P is Number of wet days with at least 0.254 mm of rainfall during the average period, N is Number of days in the average period (365 for annual). The silt loading on the road surface is a critical factor for the purpose of estimating a paved road which was 0.1 g/m^2 to estimate the particulate emission factor for a paved road [18, 19].

Estimation of Emission Factor for Brake and Tire Wear PM$_{10}$: The particulate emissions factor from brake and tire wear was computed employing [20] formula:

$$E_{sj} = N_j \times M_j \times EF_{sj}$$

where:
E_{sj} is Total emission (g) from pollutant for each grid, N_j is Number of vehicle in defined class in each grid, M_j is Average of milege driven (km) per vehicle in each grid, EF_{sj} is Mass emission factor (g/km), s is Non-exhaust emission source (tire and brake wear), j is vehicle category. The emission factor for tire and brake wear PM$_{10}$ was collected from [20].

AERMOD Meteorological Preprocessor (AERMET) employs meteorological data and surface characteristics to compute boundary layer parameters,namely, mixing height and friction velocity. Surface and upper air were processed every hour in AERMET in the user guide, recommended data from [21] for guidance on the selection of these values. In this study, it is assumed that the land-use is urban area and the weather in Malaysia is similar to condition in summer. Therefore, albedo, Bowen ratio and Surface Roughness values were (0.16, 2 and 1). AERMOD Terrain Preprocessor (AERMAP) used gridded terrain data Digital Elevation Model (DEM) to compute a representative terrain-influenced height in association with each receptor location.

Model Validation: Data for observed ambient air concentrations of heavy metals in particulate matter (PM$_{10}$) were collected for the year 2014 for the average daily concentrations from the four stations of traffic areas in the Klang Valley region. This monitored daily average PM$_{10}$ data were compared with the models' estimated concentrations. Comparison was carried out by measuring some statistical parameters which had been used in earlier studies related to model validation [22-24]which is given by the equation below:

$$R = \frac{\sum_1^N \left(C^S - \overline{C^S}\right)\left(C^O - \overline{C^O}\right)}{\left(\sum_1^N \left(C^S - \overline{C^S}\right)^2 \sum_1^N \left(C^O - \overline{C^O}\right)^2\right)^{0.5}}$$

where:
R is Correlation

$$NMSE = \frac{\overline{\left(C^S - C^O\right)^2}}{\overline{C^S}\,\overline{C^O}}$$

NMSE is normalized mean square error

$$FA2 = \left(0.5 \le \left(\frac{C^S}{C^O}\right) \le 2.0\right)$$

Fa2 is Factor of two is defined as a fraction within a factor of 2

$$IA = 1 - \frac{\sum_1^N \left(C^S - C^O\right)^2}{\sum_1^N \left(\left|C^S - \overline{C^O}\right| + \left|C^O - \overline{C^O}\right|\right)^2}$$

IA is Index of Agreement represents agreement between the average simulated and observed value.

RESULTS AND DISCUSSIONS

Estimation Emission Inventory: The estimation of PM$_{10}$ emission inventory for traffic emissions (exhaust and non-exhaust) was based on the traffic information such as traffic volume, road length and emission factor for PM$_{10}$ of each road in each grid of 1km×1 Km within model domain Table 1.

Table 1: PM$_{10}$ emission from exhaust and non-exhaust (resuspended dust, brake wear and tire wear) according to 1km × 1km grid

Source	Emission g/s
Exhaust	0.000203233
Resuspended dust	0.000114034
Brake wear	7.94557E-05
Tire wear	6.94228E-05

Meteorological Observations: Figure 2 showed wind roses were generated using the WRPLOT and wind classes frequency distribution feature within the AERMET model, which indicated the wind roses of the prevailing winds noted in the study area during the study period showing that the strongest intensities were northeasterly (NE)and west northerly (WN) and the proportion of calm winds was only 16.87 % during the study period.

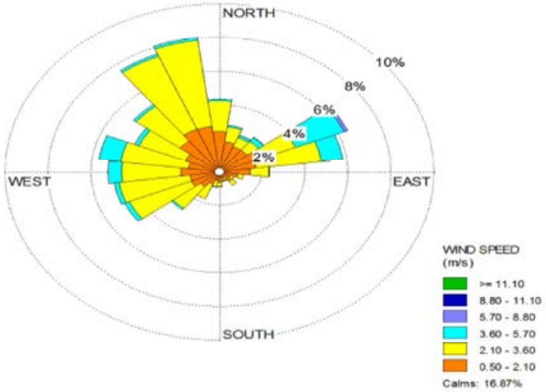

Fig. 2: Wind rose diagram of study area during the study period (blowing from)

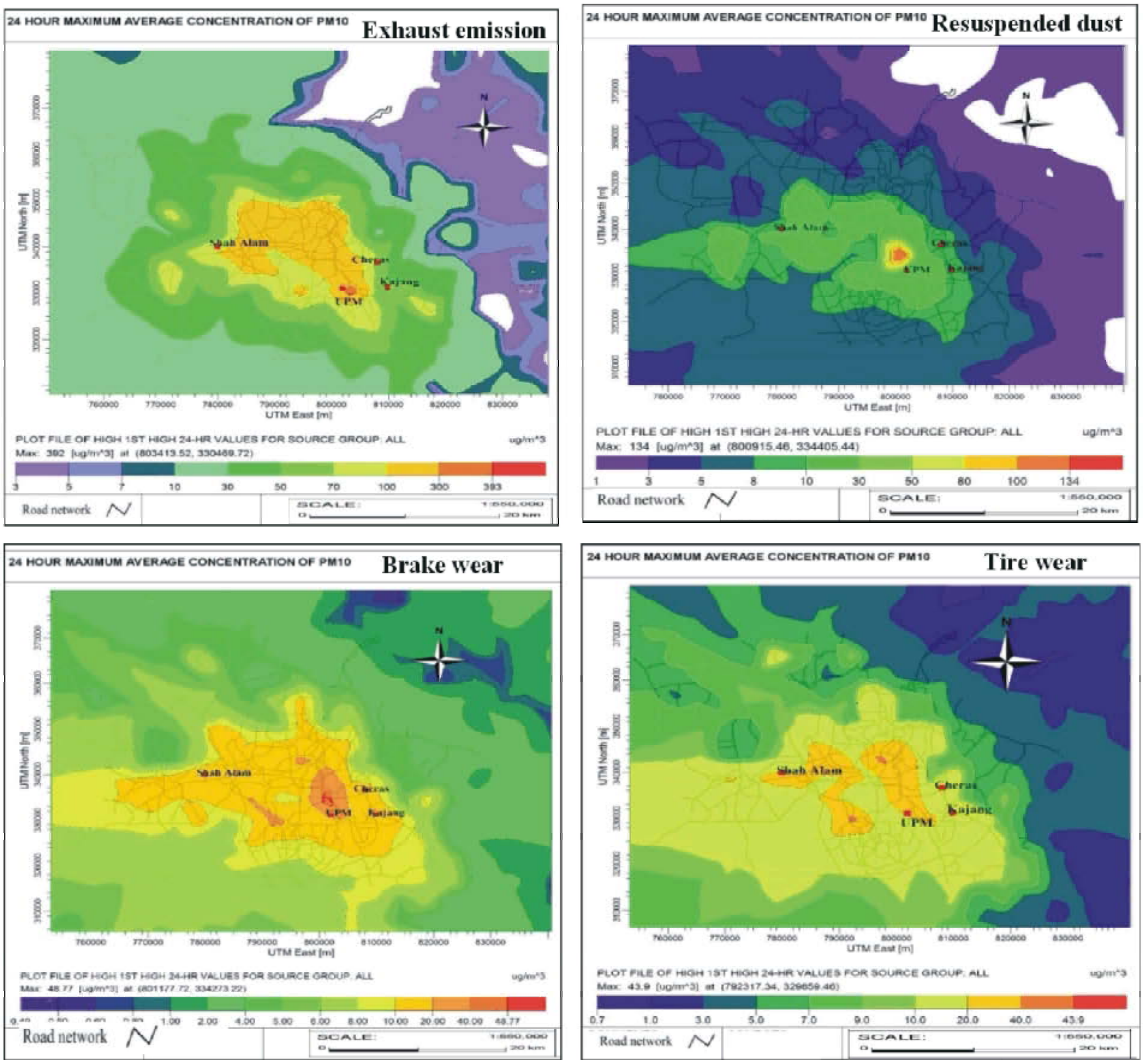

Fig. 3: Spatial distribution of PM_{10} concentration from exhaust emission (year 2014)

Table 2: AERMOD model performance statistics for PM_{10} simulation

Station	R^2	NMSE	F2	IA
Cheras	0.53	0.85	1.01	0.11
Shah Alam	0.64	0.61	1.02	0.54
Kajang	0.7	1.52	1.3	0.2
UPM	0.54	2.25	1.27	0.23

AERMOD Model Simulation of $PM_{10}$from Exhaust and Non-exhaust Emission: The AERMOD model used the hourly meteorological data, emission rate, terrain characteristics and receptor data for the prediction of PM_{10} concentration. The results of AERMOD simulation presented in two parts, spatial concentration maps and statistical analysis for PM_{10} in domain 50 × 50 km in Klang Valley region 2014. The spatial concentration maps of PM_{10} for exhaust and non-exhaust emission were presented in (Figure 3).The spatial concentration maps of PM_{10} for exhaustindicated that the highest PM_{10} concentrations were 393 µg/m^3 located at centre of the domain heading to UPM and Kajang stations, while the second average concentration ranged between 100-300 µg/m^3 which covered all the stations.Generally, most of the domain areas were located at less concentration zones where the amount of PM_{10} is between 3 to 30 µg/m^3. The PM_{10} was dispersed to the west of domain, possibly due to the Northeast monsoon wind which disperses this pollutant to the west. However, the maximum PM_{10} concentrations that emit from non-exhaust namely resuspended dust, brake and tire wear were 134, 48.7 and 43.9µg/m^3 respectively which were found directly to the central, southest and southwest of the domain close to highways of Cheras, Kajang and UPM, likely due to the heaviest traffic emissions from transportation that contribute largely in the center [26] (Figure 5, 6 and 7). Based on the 24 hours simulation results, the concentration of simulated PM_{10} from exhaust emission in Klang Valley region within the domain was higher than the concentration guideline recommended by the DOE Malaysia which is 150 µg/m^3 for 24hours. Whereas, the concentration of PM_{10} that release from non-exhaust was well below than this limits. Singh and Perwez [27] reported the predicted concentration level of SPM varied from 1000 to 2000 µg/m^3 at all the receptor.

Table 2 demonstrates the results of AERMOD simulation at Cheras, Shah Alam, Kajang and UPM stations for 24-hour PM_{10} concentrations. The correlation coefficients for the simulated versus observed 24-hour PM_{10} concentrations were high and moderate. The statistics also revealed NMSE of 0.85 and 0.6, suggesting approximately close to ideal value for Cheras and Shah Alam stations respectively (NMSE=1), while 24-hour PM_{10} concentration declined to within a factor of two (FA2). The index of agreement showed good agreement between observed and simulated values for Shah Alam. These results in line of study carried out by Gulia, Shrivastava, Nema and Khare [28] evaluated the quality of air in the vicinity of a heritage site in Amritsar city in India employing AERMOD. The AERMOD performance was estimated for the forecast of PM_{10} and the results exhibited that predicted pollutant levels were within acceptable limits and the estimated IA values for PM_{10} was 0.50, which showed the performance of AERMOD was acceptable.

CONCLUSION

AERMOD model was used to predict the meteorological conditions, Traffic emissions and air pollution dispersions in the Klang Valley region. The spatial distributions revealed the maximum concentrations of PM_{10} observed in central, west and southeast of the domain heading to Cheras, UPM, Kajang and Shah Alam stations, which are suitable for studying the high concentration of contributions by the prevailing wind direction during the Northeast monsoon season.Evaluation of AERMOD model showed there was good agreement between the simulated and observed concentrations of PM_{10}in Shah Alam.

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REFERENCES

1. Das, R., B. Khezri, B. Srivastava, S. Datta, P.K. Sikdar and R.D. Webster, 2015. Trace element composition of PM 2.5 and PM 10 from Kolkata–a heavily polluted Indian metropolis. Atmospheric Pollution Research, 6(5): 742-750.
2. Xie, Y., B. Zhao, L. Zhang and R. Luo, 2015. Spatiotemporal variations of PM2. 5 and PM10 concentrations between 31 Chinese cities and their relationships with SO2, NO2, CO and O3. Particuology, 20: 141-149.

3. Zúñiga, J., M. Tarajia, V. Herrera, W. Urriola, B. Gómez and J. Motta, 2016. Assessment of the Possible Association of Air Pollutants PM10, O3, NO2 With an Increase in Cardiovascular, Respiratory and Diabetes Mortality in Panama City: A 2003 to 2013 Data Analysis. Medicine, 95(2): e2464.
4. Thorpe, A.J., R.M. Harrison, P.G. Boulter and I.S. McCrae, 2007. Estimation of particle resuspension source strength on a major London Road. Atmospheric Environment, 41(37): 8007-8020.
5. Kam, W., J. Liacos, J. Schauer, R. Delfino and C. Sioutas, 2012. Size-segregated composition of particulate matter (PM) in major roadways and surface streets. Atmospheric Environment, 55: 90-97.
6. Masiol, M., A. Hofer, S. Squizzato, R. Piazza, G. Rampazzo and B. Pavoni, 2012. Carcinogenic and mutagenic risk associated to airborne particle-phase polycyclic aromatic hydrocarbons: a source apportionment. Atmospheric Environment, 60: 375-382.
7. Cimorelli, A.J., S.G. Perry, A. Venkatram, J.C. Weil, R.J. Paine and R.B. Wilson, 2005. AERMOD: A dispersion model for industrial source applications. Part I: General model formulation and boundary layer characterization. Journal of Applied Meteorology, 44(5): 682-693.
8. USEPA, Federal Register, Part -III, 40 CFR Part 51, Revisions to the guideline on air quality models: adoption of a preferred general purpose (Flat and Complex Terrain) dispersion model and other revisions; final. 2005.
9. Perry, S.G., A.J. Cimorelli, R.J. Paine, R.W. Brode, J.C. Weil and A. Venkatram, 2005. AERMOD: A dispersion model for industrial source applications. Part II: Model performance against 17 field study databases. Journal of Applied Meteorology, 44(5): 694-708.
10. Hadlocon, L., L. Zhao, G. Bohrer, W. Kenny, S. Garrity and J. Wang, 2015. Modeling of particulate matter dispersion from a poultry facility using AERMOD. Journal of the Air & Waste Management Association, 65(2): 206-217.
11. Azmi, S.Z., M.T. Latif, A.S. Ismail, L. Juneng and A.A. Jemain, 2010. Trend and status of air quality at three different monitoring stations in the Klang Valley, Malaysia. Air Quality, Atmosphere & Health, 3(1): 53-64.
12. MMD, Malaysian Meteorological Department 2014.
13. Lin, M.D. and Y.C. Lin, 2002. The application of GIS to air quality analysis in Taichung City, Taiwan, ROC. Environmental Modelling & Software, 17(1): 11-19.
14. Kannari, A., Y. Tonooka, T. Baba and K. Murano, 2007. Development of multiple-species resolution hourly basis emissions inventory for Japan. Atmospheric Environment, 41(16): 3428-3439.
15. Oanh, N.T.K., W. Thiansathit, T.C. Bond, R. Subramanian, E. Winijkul and I. Paw-armart, 2010. Compositional characterization of PM 2.5 emitted from in-use diesel vehicles. Atmospheric Environment, 44(1): 15-22.
16. Tung, H., H. Tong, W. Hung and N. Anh, 2011. Development of emission factors and emission inventories for motorcycles and light duty vehicles in the urban region in Vietnam. Science of the Total Environment, 409(14): 2761-2767.
17. RTVM, Road Traffic Volume Malaysia, Ministry of Work Malaysia. 2014.
18. Beltran, D., L.C. Belalcazar and N. Rojas, 2012. Spatial distribution of non-exhaust particulate matter emissions from road traffic for the city of Bogota–Colombia. in International Emission Inventory Conference, Tampa, FL. 2012.
19. Escobar, J., 2007. Actualización del inventario de emisiones de contaminantes atmosféricos en la región metropolitana 2005. DICTUC, Pontificia Universidad Católica de Chile. Santiago: Commisión Nacional Del Medio Ambiente Región Metropolitana,
20. EMEP/EEA, EMEP/EEA air pollutant emission inventory guidebook d 2009, EEA, Technical report No 9/2009, URL: http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009 (accessed 15.11.11.). 2009.
21. Paine, R.J.M.a.E., B.A Atmospheric Turbulence: Models and Method for Engineering Application. 1987.
22. Mohan, M., S. Bhati, A. Sreenivas and P. Marrapu, 2011. Performance evaluation of AERMOD and ADMS-Urban for total suspended particulate matter concentrations in megacity Delhi. Aerosol and Air Quality Resarch, 11(7): 883-894.
23. Rood, A.S., 2014. Performance evaluation of AERMOD, CALPUFF and legacy air dispersion models using the winter validation tracer study dataset. Atmospheric Environment, 89: 707-720.

24. Zou, B., F.B. Zhan, J.G. Wilson and Y. Zeng, Performance of AERMOD at different time scales. 2010. Simulation Modelling Practice and Theory, 18(5): 612-623.
25. Bukowiecki, N., P. Lienemann, M. Hill, M. Furger, A. Richard and F. Amato, 2010. PM10 emission factors for non-exhaust particles generated by road traffic in an urban street canyon and along a freeway in Switzerland. Atmospheric Environment, 44(19): 2330-2340.
26. Zhang, Q., Y. Wei, W. Tian and K. Yang, 2008. GIS-based emission inventories of urban scale: A case study of Hangzhou, China. Atmospheric Environment, 42(20): 5150-5165.
27. Singh, G. and A. Perwez, 2015. Air Quality Impact Assessment with Respect to Suspended Particulate Matters in Iron Ore Mining Region of Goa.
28. Gulia, S., A. Shrivastava, A. Nema and M. Khare, Assessment of urban air quality around a heritage site using AERMOD: A case study of Amritsar city, India. Environmental Modeling & Assessment, 20(6): 599-608.