Vijay, P, Nagendra, SM, Gulia, S, Khare, M, Bell, M, Namdeo, A. (2021) Performance Evaluation of UK ADMS-Urban Model and AERMOD Model to Predict the PM10 Concentration for Different Scenarios at Urban Roads in Chennai, India and Newcastle City, UK. In: Shiva Nagendra S.M., Schlink U., Müller A., Khare M. (eds) Urban Air Quality Monitoring, Modelling and Human Exposure Assessment. Springer Transactions in Civil and Environmental Engineering. Springer, Singapore. https://doi.org/10.1007/978-981-15-5511-4_12. pp 169-181.

Chapter 12
Performance Evaluation of UK ADMS-Urban Model and AERMOD Model to Predict the PM_{10} Concentration for Different Scenarios at Urban Roads in Chennai, India and Newcastle City, UK

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12.1 Introduction

The size of pollutants is linked to their potential of causing effects on human health. Particulate matter, which is derived from traffic and its resulting vehicle emissions, is one among six criteria pollutants and is of more importance due to its capability to penetrate into deep lungs and get deposited, thereby affecting the performance of lungs badly. The term particulate matter refers to the collection of both solid and liquid particles of different sizes. Particulate matter of size less than 10 µm in diameter is inhalable and can accumulate in the respiratory system. Particulate matter of size less than 2.5 µm in diameter, which are generally referred to as fine particles, can penetrate deep into the lungs and are supposed to cause largest health risks. Second reason is due to its synergistic effect with other pollutants present in the air. Air pollution related to particulate matter is now becoming a serious problem in developing as well as developed countries, factors being the vehicles and the resuspension caused by the vehicular movement. From the studies, it has been found that vehicles in major metropolitan cities of India accounts for 70% of CO, 30– 40% of NO_x and 30% of PM of the total load of these cities, of which two-third is contributed by two wheelers alone (Sharma et al. 2005). Source apportionment studies of Chennai (Clean Air Asia: Air quality profile 2010 edition) showed that from the residential monitoring stations, levels of particulate matter in Chennai lies in the range of 51–70 μg/m^3. According to DoT, about 80% of the road emissions in UK are generated from particulate matter due to road traffic even though there is no factors like resuspension in this country.

12.2 Methodology

12.2.1 Domain Definition

The study region in Chennai is Sardar Patel road (SP road) which stretches from Adayar to Guindy. It is flanked by Indian Institute of Technology Madras and Cancer Institute on one side and Central Leather Research Institute on other side. The terrain of the area is flat terrain about 9.0 m above mean sea level. Study area was located at out gate of IIT Madras. The site is surrounded by a number of educational and research institutes. At this site, there is no local stationary emission source; all the emissions are from the traffic data. The instrument was kept at a height of 1.2 m above the ground level and about 7 m away from the centre line of SP road.

The study region in Newcastle is Newcastle City Centre which is the busiest intersection of Newcastle upon Tyne. The Newcastle International Airport is in close proximity to the city centre, about 6 km from the city. Here also all the emissions are from vehicles and there is no stationary sources. About 10,000 car parking spaces are available within the city centre to the Nexus Metro covering the region. The site selected here was 20 m away from city centre. The monitoring station is operated under Automatic Urban and Rural Network (AURN), the main air quality compliance network for DEFRA. The monitored data for both cities are used for the validation of the model.

The study area for both the cities is shown in Fig. 12.1a, b.

12.2.2 Traffic Characteristics

The traffic flow study on Sardar Patel road is based on visual study. The counting procedure involved video recording of the diurnal traffic followed by manual counting. It is very difficult to distinguish the different category of each vehicle.

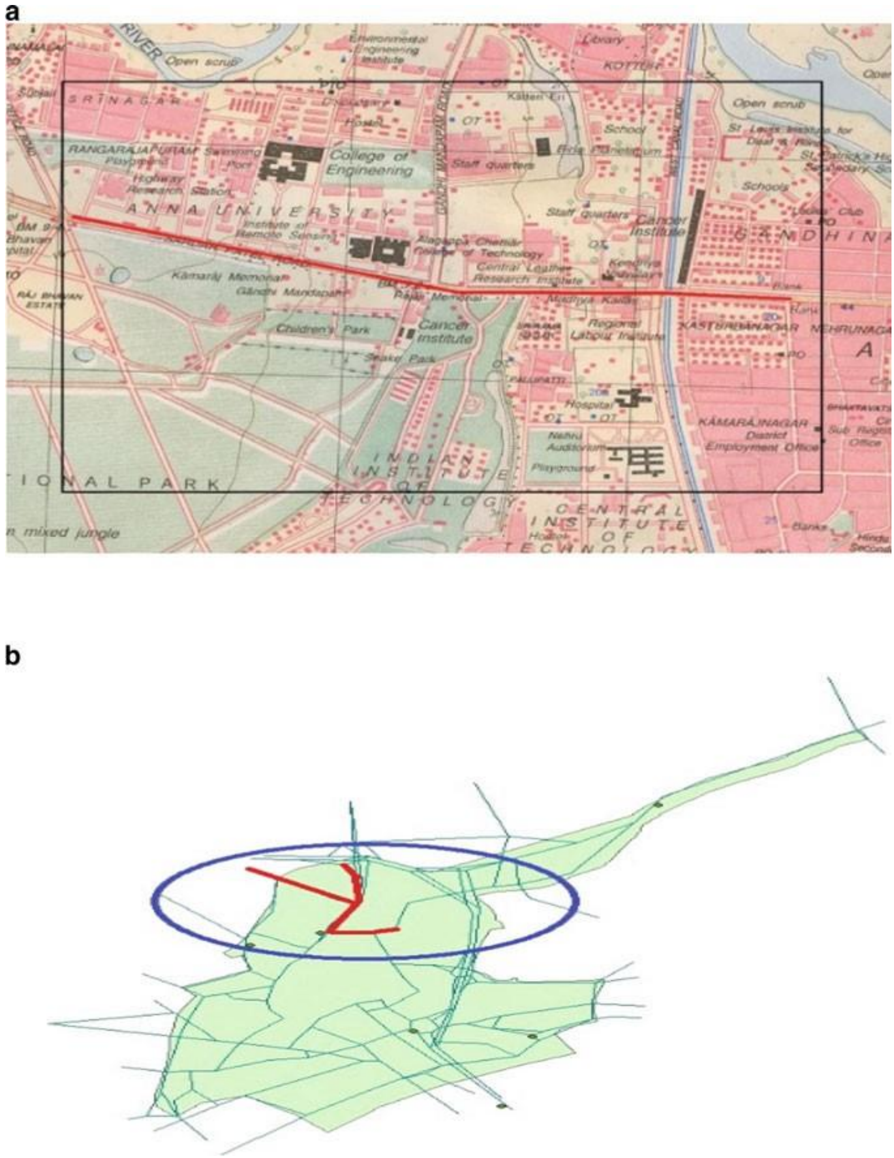

Fig. 12.1 a Study area: Chennai. b Study area: Newcastle City Centre, UK

while counting the traffic volume so there is a need to identify the exact composition of vehicle to predict correct emission factor for each category of vehicles. The vehi- cles are categorized as two wheelers, three wheelers, cars, trucks and buses but it does not represent the exact classification of each vehicle's category. For this reason, the data has been obtained from Chennai Pollution Control Board with different category of vehicles and different emission factors for each category. The peak flow occurs between 8 am–10 am and 5 pm–7 pm as indicated by the peaks as shown in Fig. 12.2a. The vehicle number at weekends and weekdays are 126,099 and 128,622 per day, respectively. The fleet composition is dominated by two-wheelers (about 51%). The second-largest share is held by cars and three-wheelers (34% and 8%, respectively). Bus, lorry and van form a small percentage.

The traffic pattern in Newcastle is somewhat uniform over weekdays and minimum in weekends as compared to weekdays, as shown in Fig. 12.2b. Most of the time we can even see a uniform flow of traffic flow. The maximum number of vehicles in a day is 25,537 which is one-tenth of the traffic flow of SP road. Newcastle diurnal traffic flow shows that morning peak flow occurs between 7 am and 11 am and evening peak occurs between 3 pm and 8 pm. The fleet composition of Newcastle is dominated by petrol car which comprises 60%. The second-largest share is by diesel car (30%). Above data has been obtained from SCOOT profile for the central cordon region of Newcastle City.

The traffic data of the year 2009 was used for both the cities and the analysis was done with the meteorological data of the critical winter period (December 2008 to February 2009).

12.2.3 Emissions

The emissions for the year, calculated using the number of vehicles and its emission factors given by Automatic Research Association of India (ARAI) were used in model calculations. Based on the emission factor for each category of vehicle and the percentage distribution given by CPCB between each category of vehicle, the emission loads are obtained in grams/day or kilograms per day. Emission values for Newcastle were calculated using Simple Emissions Modelling Framework (SEMF) developed by TORG, Newcastle University.

The emission estimate is done by methodology followed by Righi et al. (2009). In this methodology, emissions rate (g/s) assigned to each road based on volume of traffic (vehicles/hour), vehicular emissions factors (g/km) and road length (km) was found and applied to the formula given below.

Emission in g/day = Number of Vehicles × Emission Factor (g/km) × Length of the Road (km).

12.2.4 Meteorological Data

The main input meteorological parameters for ADMS are wind speed and wind direction plus of the following parameters cloud cover, heat flux, temperature, reciprocal of Monin–Obukhnov length, upper air data. The parameter solar radiation will be used if NO_x chemistry has to be used. (CERC 2006a, b). Sequential hourly meteorological data were obtained from Laga Systems. Data characterizing upper air

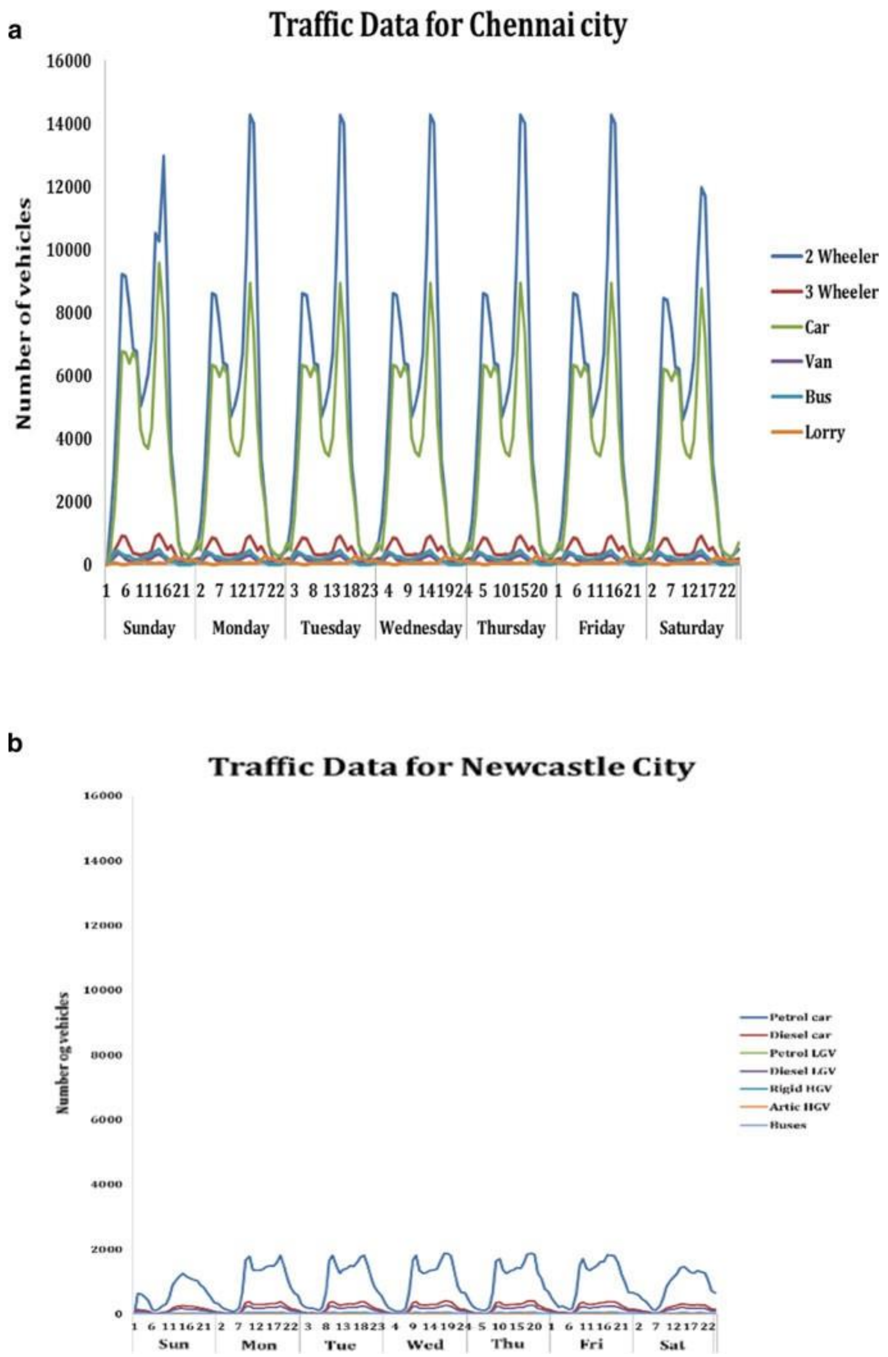

Fig. 12.2 **a** Daily average vehicle count for Sardar Patel Road. **b** Daily average vehicle count for Newcastle City

conditions were acquired from the same data set. The windrose diagram of the study period for Chennai and Newcastle City has been shown in Figs. 12.3a, b and 12.4a, b, respectively.

12.2.5 Monitored PM_{10}

Monitored data for the study period was collected on daily hourly concentrations from the monitoring stations set up at IIT Madras out gate, Chennai and Civic Centre, Newcastle City. The observed values of PM for Chennai was done by using Grimm monitor (Model No: 1.108) and for Newcastle, the observed values were collected from the data recorded by gravimetric monitor set up at Civic Centre. The same location was used as receptor point for monitoring station in the model so that comparisons between estimated and observed concentrations could be made. The study was done during critical winter period as pollutant concentrations are higher during this period. The outputs of the pilot model, predicted hourly sequential measurements of air pollutant data and dispersion derived from vehicular emissions, were compared against observed data within the study area.

12.2.6 Model Used: ADMS-Urban and AERMOD

The model used here is ADMS-Urban which is highly advanced and complex, allowing the user to define an array of parameters and outputs depending on requirements. Developed by Cambridge Environmental Research Consultants (CERC) Ltd ADMS-Urban is a state-of-the-art advanced atmospheric dispersion modelling software package. It adopts a Gaussian dispersion distribution in stable and neutral conditions and a non-Gaussian distribution in the vertical plane for convective conditions. ADMS-Urban can calculate concentrations of pollutants emitted both continuously from point, line, volume and area sources. The model has been extensively validated by over 70 UK local authorities and it is used to predict the dispersion of pollutants derived from on road traffic (Carruthers et al. 1999; Owen et al. 2000; Colvile et al. 2002; McHugh et al. 2004).

AERMOD is a steady-state plume model developed by American Meteorological Society (AMS) and US Environmental Protection Agency (EPA). This model also adopts a Gaussian approach to dispersion modelling. The basic input requirements can be broadly classified into meteorological data, emission data, geometrical data and pollutant background data. AERMOD is applicable to rural and urban areas, flat and complex terrain, surface and elevated releases and pollutant emissions from point, line, volume and area sources. Both the models mentioned have been used to predict the PM_{10} concentrations in Newcastle City, UK and Sardar Patel Road, Chennai, India.

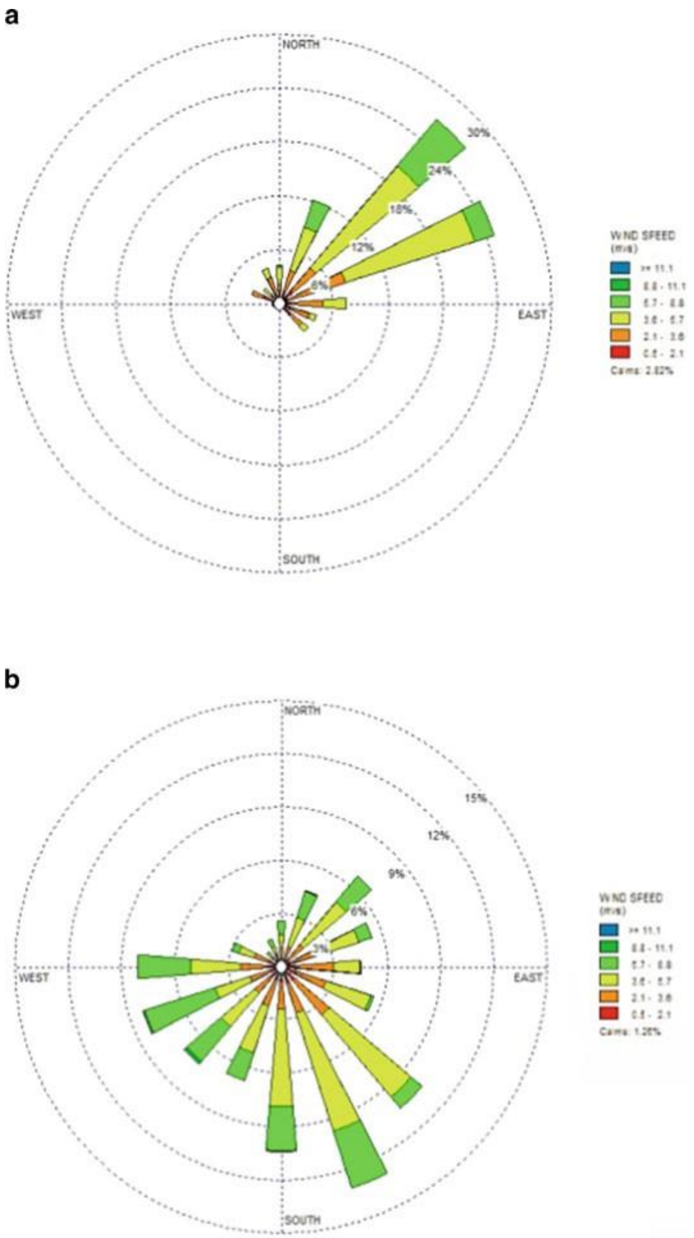

Fig. 12.3 a Windrose for Chennai for December 2008. b Windrose for Chennai for January– February 2009

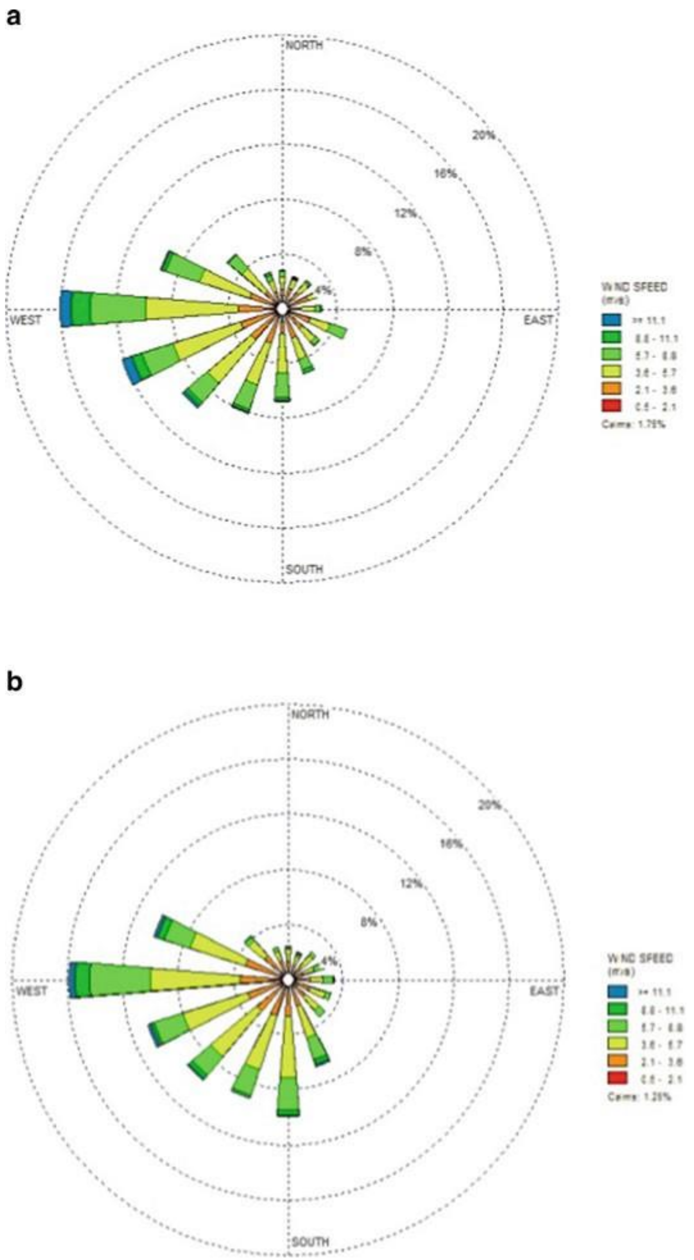

Fig. 12.4 a Windrose for Newcastle for December 2008. b Windrose for Newcastle for January– February 2009

Table 12.1 Emission factors for different category of vehicles for both the cities

Vehicle type	Chennai city
Petrol-cars	0.032
Diesel-cars	0.020
2W-2S	0.011
2W-4S	0.013
3W-P	0.004
3W-D	0.085
Trucks	1.443
Bus	0.755
Vehicle type	**Newcastle City**
Petrol-cars	0.023
Diesel-cars	0.047
Petrol LGV	0.034
Diesel LGV	0.072
Rigid HGV	0.149
Artic HGV	0.228
Bus	0.182

12.3 Results and Discussion

The meteorological data was analysed for three months (December 2008, January and February of 2009). The wind rose for the three months has been shown in Fig. 12.3a, b for Chennai and Fig.12.4a, b for Newcastle City. There is a consistency in wind speed and wind direction for the Newcastle City as compared to Chennai city. The results of the analysis indicated an average wind speed of 4.82 m/s and wind direction 230°. For Chennai, the wind speed averaged 3.66 m/s and wind direction 115°. The predominant wind speed, wind direction and the calm conditions (wind speed <1 m/s) (Table 12.2) are summarized in table below:

Table 12.2 Predominant wind speed, wind direction and the calm conditions (wind speed <1 m/s)

Month	Predominant wind direction	Calm period (%)	0.5–2.1 (%)	2.1–3.6 (%)	3.6–5.7 (%)	5.7–8.8 (%)	8.8–11.1 (%)	>11.1 (%)
December 2008	West	1.8	9.1	24.6	38.1	19.9	0.6	2.1
January–February 2009	West	1.3	9.1	25.2	39.8	19.6	0.5	1.3
December 2008	North-East	1.4	12.6	24.4	41.7	19.4	0.6	0.0
January–February 2009	South-East	1.3	10.9	21.1	42.5	23.9	0.5	0.0

12.3.1 Variation of PM_{10} Model Results with Monitored and Meteorological Data

The weekly modelled ground level concentrations for Sardar Patel road Chennai and Newcastle City Centre road were calculated for line sources for a particular week. The variation of modelled and monitored concentration with meteorological parameters like wind speed, wind direction, temperature and relative humidity is shown in Fig. 12.5. It is seen from the figure that meteorological parameters are more or less positively correlated with pollutant concentrations. The concentrations are more when the wind is towards the receptor location. The concentrations are high when the humidity is almost constant. For high wind speed, the concentration is lower and vice versa. This is due to the reason that pollutants get diluted by dispersion.

The figure shows the weekly average of PM_{10} over the two study regions and the relation between the observed and predicted values.

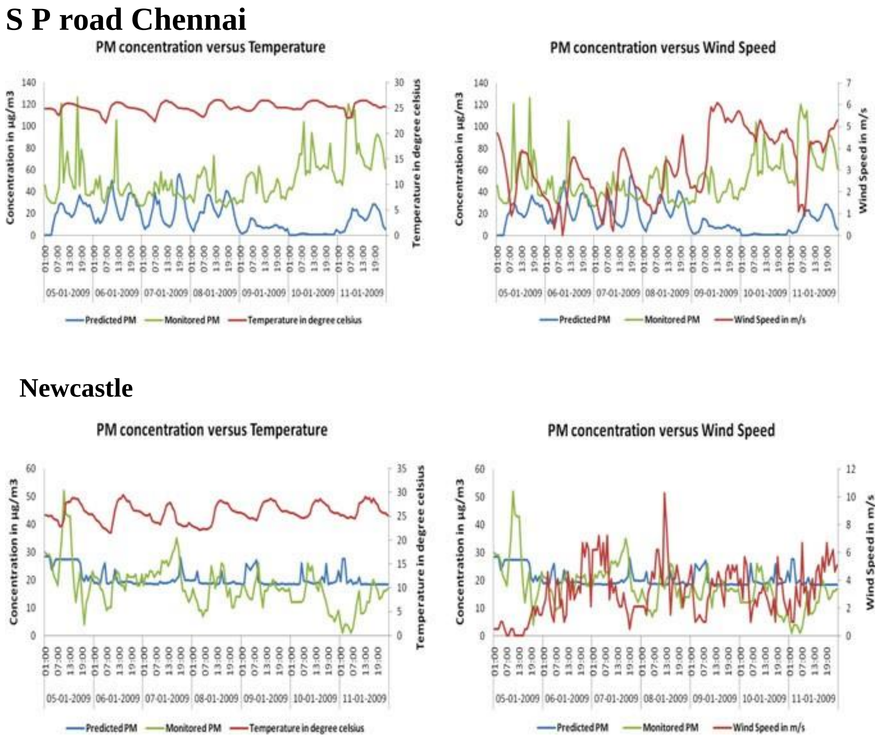

Fig. 12.5 Average of the predicted values and observed values for PM for both the cities

12.3.2 Statistical Analysis for the Model Performance of PM_{10}

Monitored data from the monitoring stations were used for evaluating the model performance. The statistical descriptors index of agreement (IA), fractional bias (FB), normalized mean square error (NMSE), geometric mean bias (MG) and geometric mean variance (VG) were used to evaluate the model performances.

Index of agreement (IA): Index of agreement indicates how much the predicted value departs from observed values. It has a theoretical value between 0–1. 1 indicates perfect agreement.

Normalized Root Mean Square Error (NRMSE): Normalized root mean square error is an estimator of the overall deviations between the observed and predicted values (Kumar et al. 2006). Smaller values of NRMSE indicate better performance and are not biased towards model that over predicts or under predict.

Fractional Bias (FB): The fractional bias or FB represents the relative difference between observed and modelled values in a bounded range (Cooper 1999). It is a symmetrical measure and a dimensionless number. It compares different concentration levels and FB value lies between −2 and +2, −2 indicates extreme over prediction and +2 under prediction.

Geometric Mean Bias (MG) and Geometric mean variance (VG): Geometric mean bias (MG) and geometric mean variance (VG) are measures of dispersion which find application when values in a set follow a log normal distribution. A perfect model will have both MG and VG equal to 1.0.

The criteria set by Kumar et al. (1993) were used for understanding the model performance. According to him, the model will be deemed acceptable if NMSE ≤ 0.5; $-0.5 \leq$ FB ≤ 0.5; $0.75 \leq$ MG ≤ 1.25; $1 \leq$ VG ≤ 1.25. The model performance is deemed perfect by the statistical analysis according to Righi et al. (2009) that the predicted values match the observed values, then fractional bias (FB), normalized mean square error (NMSE) will be zero and index of agreement (IA), geometric mean bias (MG) and geometric mean variance (VG) will be one. Table 12.3 shows the statistical analysis for the model performance of PM_{10}.

12.4 Conclusions

The performance of two Gaussian-based air quality models, namely ADMS and AERMOD models have been evaluated for Chennai city and Newcastle City. ADMS model performed fairly better for PM_{10} predictions for both the cities when compared with AERMOD which is indicated by the degree of agreement values. The IA values for ADMS are found to be 0.39 for Chennai city and 0.48 for Newcastle City.

Table 12.3 Statistical analysis for the model performance of PM_{10}

Pollutant PM10	ADMS	AERMOD	Measured concentration
For Newcastle City			
IA	0.48	0.44	
MG	1.07	1.14	
VG	1.14	0.98	
FB	−1.19	−1.27	
NRMSE	0.09	0.11	
Mean (μg/m^3)	4.44	3.72	16.38
Maximum (μg/m^3)	28.10	24.74	59.00
Minimum (μg/m^3)	18.30	16.30	1.00
Pollutant PM10	ADMS	AERMOD	Measured concentration
For Chennai city			
IA	0.39	0.37	
MG	1.12	1.19	
VG	1.04	1.01	
FB	−1.03	−1.15	
NRMSE	0.17	0.20	
Mean (μg/m^3)	41.33	20.68	130.39
Maximum (μg/m^3)	120.11	86.34	343.16
Minimum (μg/m^3)	25.61	25.61	25.61

Acknowledgments

The research work was a part of UKIERI funded research project titled "Evaluation of Quantitative Dispersion Models for Urban Air Quality Assessment". We wish to thank UKIERI New Delhi. We also acknowledge CERC, UK who provided the ADMS for academic and research purpose; and Laga systems Hyderabad for providing the meteorological data.

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