Assessment of particulate matters from vehicular emission using operational street pollution model at Panjrapole, Ahmedabad (India)

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Abstract
Indian cities are evolving at an ever-increasing rate in terms of economy and infrastructure facilities. Subsequently, the transportation systems have also become robust in addition to become a basic necessity for urban landscapes. This has unraveled numerous problems relating to regional air quality due to increased traffic volumes, especially where the street is not wide enough and is encompassed by buildings creating a canyon effect. This study has been conducted on an identified street (i.e. Panjrapole) of Ahmedabad to assess the vehicular air pollutants i.e. PM_{10} *and* $PM_{2.5}$ *using operational street pollution model (OSPM). To run as well as to validate the model for identified street, primary data like traffic volume count and street configuration along with secondary data which includes meteorologica conditions and background pollution data from reference grade ambient air quality measuring locations deployed by municipal authority, has been analyzed for the month of December.*

OSPM study indicates excess prediction in concentrations of PM_{10} *and* $PM_{2.5}$ *by 2% and 3% respectively as compared to the actual air pollutant concentrations during the study period. However, this can be a useful tool to achieve reliable vehicular air pollutants data using input data only and the same will be useful for decision making authorities including town planners, environmental engineers, urban designers etc. to mitigate and prevent the air pollution.*

Keywords: Vehicular emission, particulate matter, pollution model, Ahmedabad.

Introduction

Air pollution is among the world's most serious threats to the environment and public health. Rapid industrialization and urbanization are the main causes of air pollution in developing nations like India. Hostile meteorological conditions, automobile and industrial emissions mainly contribute to the urban environmental pollution. India has experienced a sharp decline in ambient air quality during the last ten years. Also, air quality management has become a serious concern and significant challenge in recent years. Automobile emissions are commonly recognised to have a substantial impact on local air quality and contribute to higher pollution levels.

Air pollution generated due to automobile emissions is increasing day by day due to the increase in the number of vehicles. Vehicles are the dominant source of air pollution in the atmosphere. Fuel combustion pollutes the atmosphere significantly and emits NOX, CO_2, HC, CO, SO_2 and particulate matter (i.e. PM_{10} and $PM_{2.5}$). In recent times, PM_{10} and $PM_{2.5}$ are the major contributing air pollutants in metropolitan cities such as Ahmedabad, Mumbai, Kanpur, Bangalore, Pune etc. The pollutants' contribution to total air quality is determined by a variety of factors including the number of vehicles, the types of fuel used, traffic management systems, air pollution control measures executed, green belt cover, urban planning, ongoing construction of infrastructural projects etc.[14]

The concerned regulatory authority conducts regular monitoring procedures to evaluate the city's air quality using a wide range of technologies. In major cities worldwide, limit values generally exceeded for major pollutants such as NO_2 and particulate matter (PM_{10} and $PM_{2.5}$ respectively). Continuous regular monitoring involves a limited number of measurement sites as continuous regular monitoring is resource-demanding. Therefore, air pollution modelling can be used as a tool for the assessment of air pollutant levels.

Various approaches and methods have been used to assess and evaluate the ambient air quality[11]. Air pollution modelling is a technique for analysing air quality using mathematical theories in order to comprehend pollutant concentrations and their behaviour in the atmosphere[4]. Air dispersion models are mathematical representations of the physics and chemistry that regulate the movement, dispersion and transformation of pollutants in the atmosphere. Three types of air quality models exist depending on the source of pollution: point, area and line source models[10].

Various Gaussian based mathematical models have been used for the assessment of vehicular air pollutions such as AERMOD, CALINE, EPA HIWAY etc. for mobile sources. STREET, CPBM, CAR, OSPM etc. have been extensively employed for street canyon dispersion modelling[2,8]. Amongst them, the operational street pollution model (OSPM) was developed by Aarhus University and is commonly used to predict the pollution level in urban street canyons on an hourly basis with very short deliberation times[4,8,13,15].

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Overview of Operational Street Pollution Model: OSPM is used to calculate the concentration of exhaust pollutants including gases and particulate matters, using a combination of a simple plume model for direct contribution and a box model for recirculating part of the pollutant in the street. Model assumes that the traffic and emission are uniformly distributed across the canyon. A street canyon is a place where the street is surrounded by buildings on both sides, creating a canyon like environment[3,6,7].

The vehicular emissions are treated as a number of infinite line sources aligned perpendicular to wind direction and cross wind diffusion emitted at street level. The length of the vortex of air pollution is to be calculated along the wind direction and is 2X the building height upwind. The building configuration along the street may have different heights of the buildings, affecting the vortex and subsequently the modelled concentrations. The leeward side receptor receives the traffic emission within the occupied area of vortex (recirculation zone) and at windward side receives contribution from recirculated pollution and emission (Figure 1). The vertical dispersion of the model assumes the linear growth of the plume with distance from the source[6,8,18].

Various researchers have used OSPM to determine the urban air pollution concentration levels for mobile sources and also the model results have been compared with the actual pollution levels. OSPM has been effectively utilised for various urban canyons as has been presented in table 1.

Lazic et al[9] used an integrated approach for detecting the vertical dispersion trend of PM_{10} (from OSPM) and trace elements (moss biomonitoring). Both the methods display a similar decrease in pollutant concentration with increasing height. Another comparative study in Helsinki reported a 22% over prediction of NO_2 concentration in urban canyons by OSPM whereas the observed and predicted values of CO and NOx had minimal difference[7].

Assael et al[2] reported a fair agreement between observed and modelled values for NOx and NO_2. Furthermore, certain deviations have been explained through the identification of location specific characteristics such as wind gusts, variation in traffic load and resuspended road dust.

According to the research conducted for the Helsinki and Chembur study areas, OSPM has a tendency to under predict for PM and CO[7,8].

This study has been conducted for the identified area i.e. Panjrapole Street, Ahmedabad, Gujarat, India to assess the vehicular air pollutants i.e. PM_{10} and $PM_{2.5}$ using OSPM. To run and validate the OSPM at the identified street, primary data like vehicle density and street configuration have been collected using a survey and secondary data like meteorological data and background pollution data have been collected from the nearest State Government ambient air quality station for the selected winter season period. The winter season has been selected as the highest pollution concentrations have been observed in this season.

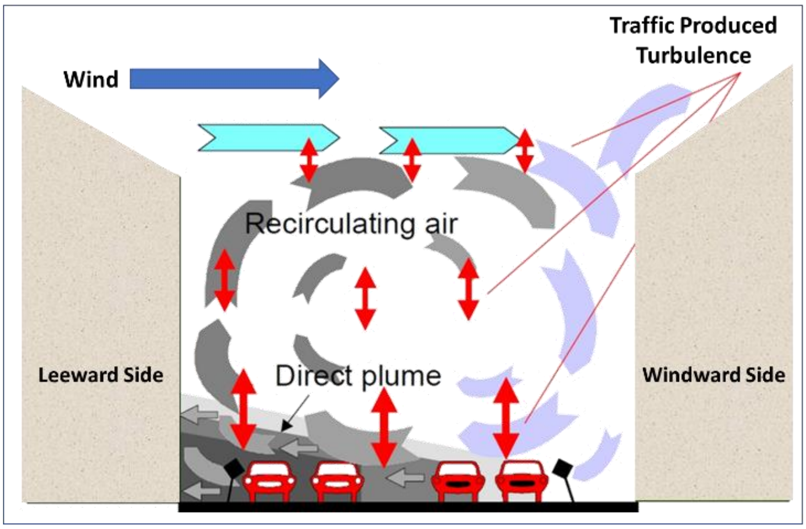

Figure 1: Pollution dispersion inside a street canyon along with wind direction

Table 1
OSPM acquired for various urban street canyons

S. N.	Location/ Country	Modelled pollutants
1	Chembur, India	NO and PM[8]
2	Thessaloniki	PM_{10}[2]
3	Netherlands	NO_2 and PM_{10}[18]
4	Helsinki, Greece	CO, NO_X, NO_2 and O_3[12]
5	Roskilde, Denmark	NO_X and CO[3]

The winter season is significantly worse than the other seasons, which has a major health impact also[1].

Material and Methods

Air pollution control and management depend greatly on air quality modelling methodologies. OSPM is a Gaussian dispersion - based line source model and its adopted methodology is illustrated in figure 2. OSPM is used for hourly prediction of exhaust gases and particulate matter concentrations at different street levels. It employs a combination of a plume model for significant contributions and a box model for the recirculating part of the pollutants in the street to compute pollutant concentrations. A street canyon is formed when a street is enclosed on both sides by buildings, creating a canyon like atmosphere[3,5,7,16].

The air pollution of Ahmedabad for an identified site (Panjrapole) has been analysed using the OSPM model in this study. Aarhus University created the practical street pollution model WinOSPM which is available for free evaluation[8,12,17,18].

Selection of Study Area: The street canyon of Panjrapole, Ahmedabad, has been selected for air pollution modelling. The location and various parameters of this street are shown in figure 3 and table 2. Usually, the meteorological conditions in the winter season are unfavourable as they generate inversion conditions characterised by low temperatures, mixing height and reduced wind speed. Therefore, OSPM has been applied in the winter season (i.e. third week of December 2021) for the selected study area.

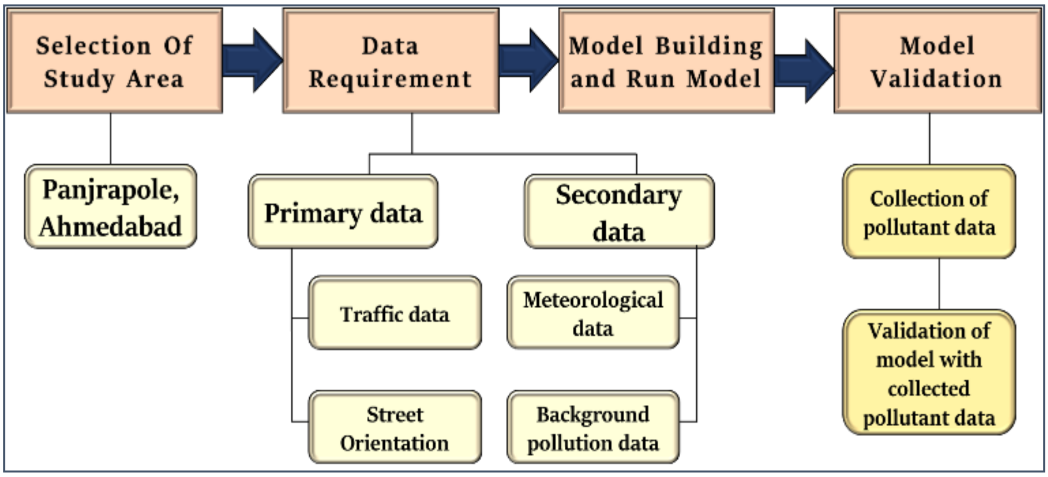

Figure 2: Brief methodology of the study approach

Figure 3: Google map of selected area of Panjrapole, Ahmedabad

Table 2
Various parameters of Panjrapole street canyon

Description	Parameters
Type of Area	Institutional area
Street orientation	39.6 ^{0}North
Road width	42 m
Average building Height	10 m
Height to Width (H/W) ratio	0.2
Numbers of vehicles per day during peak hours (PCU)	69,698 ± 884
Nearest ambient air quality station	Navrangpura, Ahmedabad

Data Requirements to run the OSPM Model: To run the OSPM model, primary and secondary data like hourly traffic, meteorology, street configuration, background pollution, etc. have been collected for the selected street (Figure 4). A traffic survey was performed on both the sides of the street for traffic volume count and street configuration[5]. The building configuration data includes building height, road width and street orientation along with different building heights and road ratio (H/W≥1) has also been gathered by the primary survey.

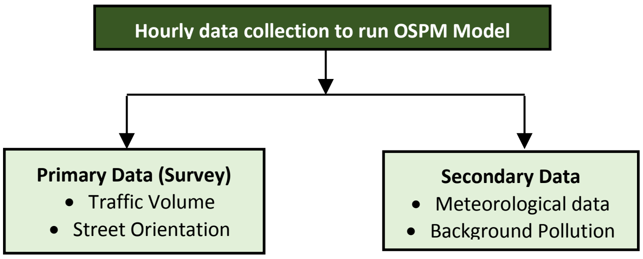

Figure 4: Data requirements to run the OSPM Model

(i) Traffic volume: The data for the number of vehicles was collected by conducting traffic survey on the selected street canyon during peak hours (i.e. 8 am to 11 am and 4 pm to 8 pm) in December and then those were classified based on the fuel input (i.e. petrol, diesel, or compressed natural gas) using the regional transport office data of Ahmedabad. The number of vehicles was categorised into motorcycle, car, auto, bus and truck and further converted into passenger car unit (PCU) which is a traffic flow rate term used in traffic engineering. The vehicle survey and collected data have been presented graphically in figure 5(a). The average number of vehicles per day in passenger car unit is 69,698 ± 884. During the observation period, the number of vehicles reported on Monday was higher than on other weekdays.

Based on the traffic survey carried out during the peak hours, it has also been noted that the density of petrol driven motorcycles, CNG based autorickshaws and diesel based cars were higher during the study period (Figure 5b).

(ii) Street configuration: The ratio of building height to road width and the street orientation of the particular study area are referred to as "street configuration". It denotes a street canyon with the height of the buildings and the width of the road. The average building height is about 10 metres and the road is 42 metres wide including the mass transit facility viz. Bus Rapid Transit System (BRTS) route and street orientation (41.4 ^{o}North) with respect to the north direction of Ahmedabad (Table 3 and figure 6). The front view and top view of the selected street canyon are depicted in figure 6 (a) and figure 6 (b) respectively.

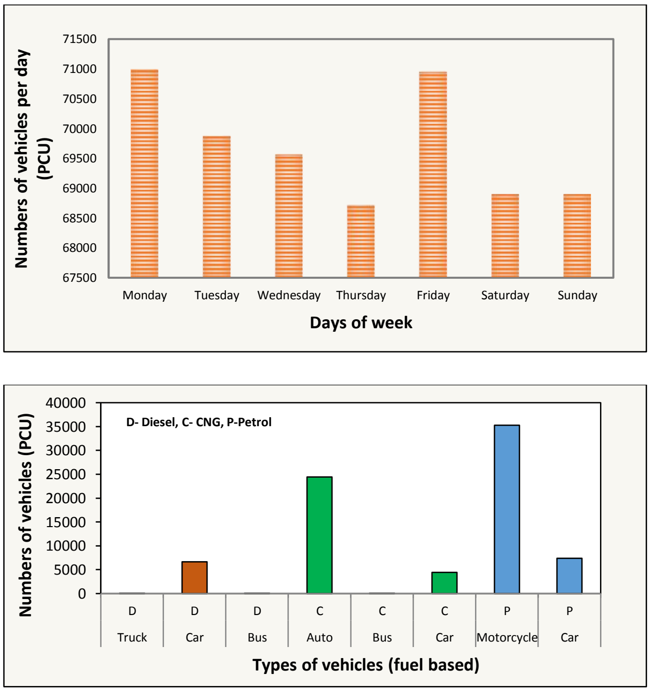

Figure 5: Traffic data for the Panjrapole street canyon (a) Average number of vehicles (PCU) in weekdays (b) Fuel based number of vehicles

(iii) Meteorological data: The meteorological data for the study area includes wind speed, temperature, wind direction, global radiation, precipitation and relative humidity. The data has been collected from the nearest ambient air quality station for the identified study period. Figure 7 shows the wind rose diagram using Lak**es** **e**nvironment WRPlot software of the collected meteorological data. During the study period, it is reported that the average wind speed is 5.63 m/s and the wind blows from east-north and east-south. During the day, temperatures ranged from 20 to 32°C, dropping to 5 to 6 °C at night. Relative humidity has been noted at between 30 and 55% in the study area.

(iv) Background pollution data: Background pollution data is essential to understand pollution resulting from the recirculation of air pollutants during different activities. Background pollution data in the study period (peak hours) was collected from a nearby ambient air quality monitoring location (installed by local authority), Ahmedabad and presented in figure 8. It is observed that PM_{10} and $PM_{2.5}$ concentrations have been reported to range from 155 ug.m^{-3} to 172 ug.m^{-3} and 102 ug.m^{-3} to 111 ug.m^{-3} respectively during the peak traffic hours.

Table 3
Height, Width and Orientation data of Panjrapole street canyon

Street name	Building height		Total road width of Street (m)	Street orientation (Degree)
	Receptor -1 S_1 (m)	Receptor - 2 S_2 (m)		
Panjrapole	10.0	10.0	42.00	39.6° North

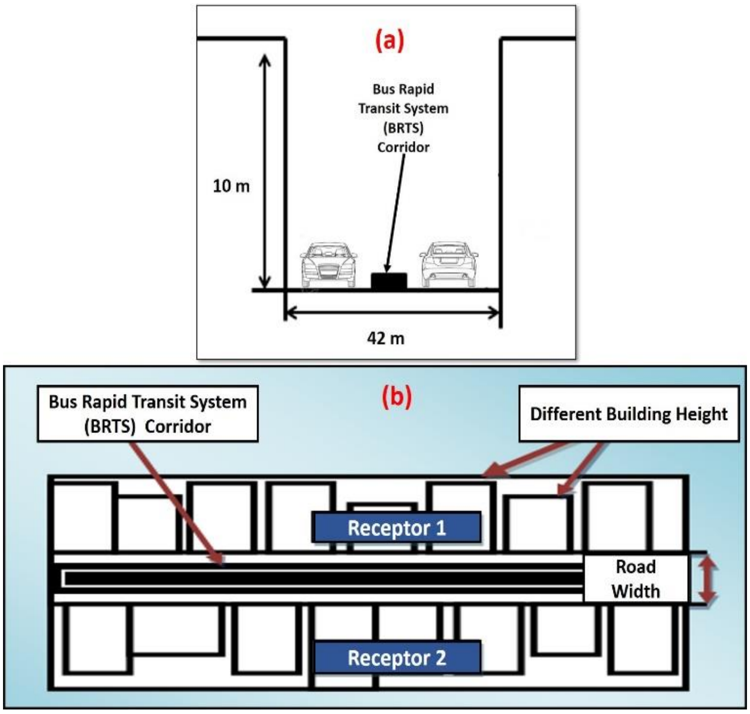

Figure 6: Panjrapole street (a) front view and (b) top view

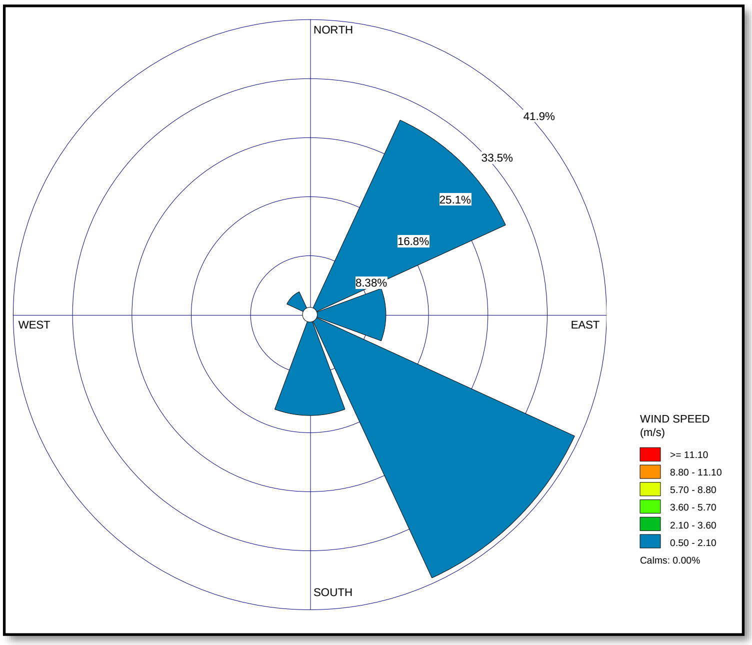

Figure 7: Wind rose graph represents meteorological conditions during the study period

Vehicular emission rate calculations: An emission factor (EF) is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. The vehicular emission rates have been calculated with vehicle emission factors based on the types of fuel and engine. The emission factors provided by the Automotive Research Association of India (2008) were used to compute the hourly emission rate (Table 4).

Emission factors for cars are computed using a number of fuels including diesel, gasoline and natural gas. Similarly, for buses, emission factors are operated on basis of CNG fuel and diesel fuel. Air pollutant concentrations in the street canyon have increased due to the dispersion of vehicular emissions into the street. The estimation of emission rate method is described in figure 9.

An estimated emission rate for different vehicles at selected study area has been presented in figure 10. Previous research[1] has obtained emission rates for PM ranges between 50 and 900 µg/m.sec which are comparable with the estimated values (95 to 172 µg/m.sec).

Results and Discussion

The OSPM model has been used to simulate the winter season i.e. the third week of December. Wind speed, wind direction and temperature all influence air pollution dispersion. Wind speed as well as direction create voids in the street canyon, with changing the weather patterns[5,8]. The findings of the OSPM model at both curb sides with various receptor heights are shown in the table 5.

According to India's national ambient air quality standards provided by the central pollution control board, the maximum 24-hour average concentrations of PM_{10} and $PM_{2.5}$ are 100 $\mu g.m^{-3}$ and 60 $\mu g.m^{-3}$. OSPM results noted the higher level of PM_{10} and $PM_{2.5}$ concentrations than the maximum allowable concentrations in the identified period of the study area. Therefore, appropriate PM_{10} and $PM_{2.5}$ control strategies are needed for the identified street.

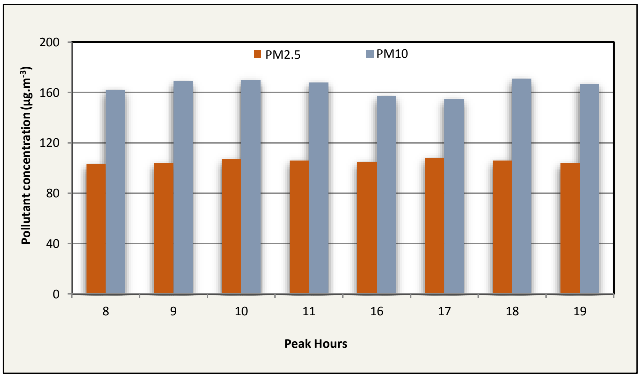

Figure 8: Background Pollution data for Panjrapole, Ahmedabad

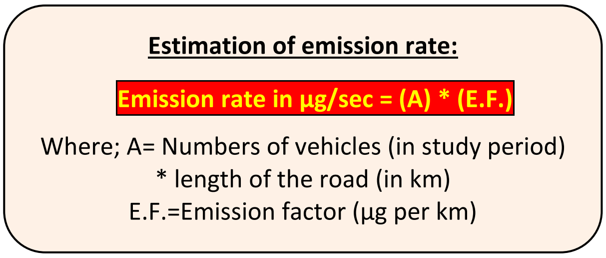

Figure 9: Formula for estimation of emission rate

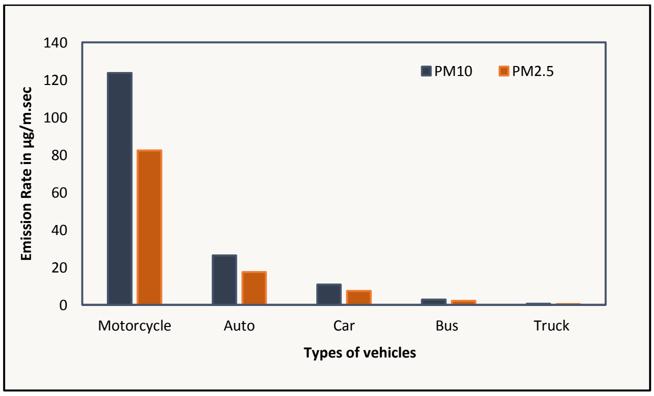

Figure 10: Average estimated vehicle's emission rate at Panjrapole street canyon

Table 4
Emission factor for various kinds of vehicles

Vehicle Type	Type of fuel	Emission Factor for PM_{10} and $PM_{2.5}$ (µg per km)
Two wheelers	Petrol	0.057
Auto	CNG	0.015
Car	Petrol	0.002
	Diesel	0.015
	CNG	0.004
Buses	Diesel	0.300
	CNG	0.004
Truck	Diesel	1.240

Table 5
Panjrapole OSPM model results at receptor-1 and receptor-2

Receptor Height	Receptor-1		Receptor-2	
	PM_{10} (µg.m^{-3})	$PM_{2.5}$ (µg.m^{-3})	PM_{10} (µg.m^{-3})	$PM_{2.5}$ (µg.m^{-3})
Z=0	175.2	116.8	173.8	115.5
Z=3	172.8	114.8	171.4	113.8
Z=6	167.8	111.3	167.1	110.9
Z=9	166.8	110.7	166.8	110.6

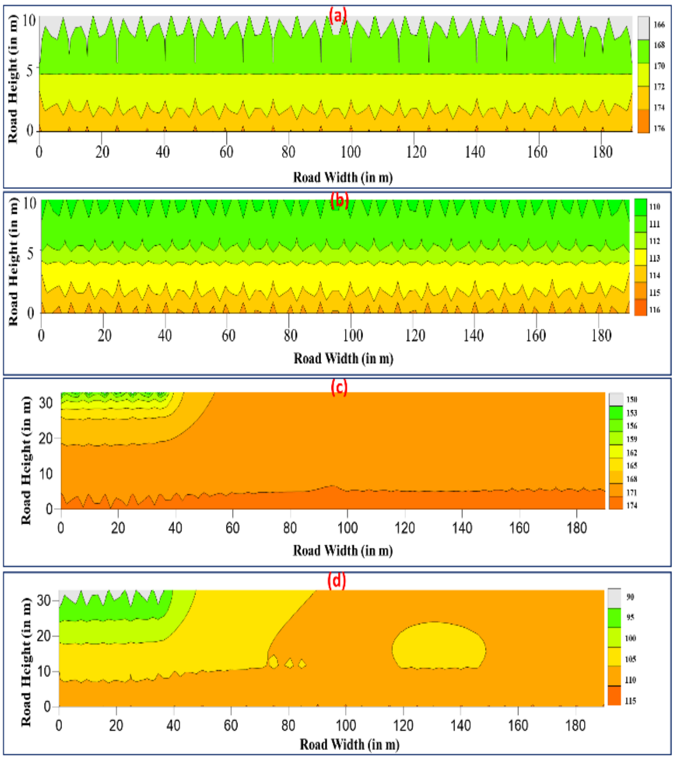

Figure 11: Pollutant dispersion contour maps: (a) Receptor-1 for PM_{10} (b) Receptor-1 for $PM_{2.5}$, (c) Receptor-2 for PM_{10} and (d) Receptor-2 for $PM_{2.5}$

At Panjrapole street canyon, the graphical representation of predicated concentrations of PM_{10} and $PM_{2.5}$ with varied building heights at receptor-1 and receptor-2 is shown in figure 11. The pollutant dispersion contour map was created using Surfer 14 software. Looking at the adjacent building geometry, the considered heights for pollutant dispersion mapping at receptor-1 and receptor-2 are 10 m and 30 m respectively.

Compared to the streamlines and air pollutant concentration dispersion pathways, it is clearly noticeable that the decrease in pollutant concentration from the ground level is to the top of the building. It is because of the air flow pattern changes with the wind directions (vertical upwards) and the traffic pollutants that contribute near the ground level (horizontal upwards)[19]. It is shown that at receptor 1, on an average, PM_{10} and $PM_{2.5}$ concentrations decreased from 176 µg.m^{-3} to

166 $\mu g.m^{-3}$ and 116 $\mu g.m^{-3}$ to 110 $\mu g.m^{-3}$ with receptor height increasing from ground level to 10 m building height as shown in (Figure 11a and figure 11b).

Higher $PM_{2.5}$ concentrations were found at both the receptors. At receptor-2, the maximum $PM_{2.5}$ concentration (116.5 $\mu g.m^{-3}$) was analysed at the ground level (i.e. traffic emission pathways). Air pollutant concentration firstly increases and then decreases as the floor number increases from ground level to 30 m at receptor-2 (Figure 11c and figure 11d). The suspension of air pollutants around the traffic emission points during the primary survey was also observed. This might be happening due to poor meteorological dispersion conditions (inversion) in the winter season.

OSPM result validation: In the present study, OSPM for PM_{10} and $PM_{2.5}$ concentrations have been assessed during peak traffic hours for the identified street canyon of Panjrapole (Ahmedabad city, Gujarat, India). The OSPM results have been further validated with the pollution data collected from the nearest ambient air quality station which is located 0.9 kilometres away from the identified street canyon (i.e. Pinjrapole). Collected data has been used to validate the OSPM.

To compare the nearest ambient air quality station data, the actual field air quality monitor i.e. a High Volume Air Sampler (HVS) at a pre-defined street canyon (i.e. at receptor 1 and receptor 2) and used. However, the results obtained from the nearest ambient air quality station data were found to be similar to the measured data with HVS. HVS data has provided the pollutant concentrations on a 24-hour average whereas OSPM requires hourly pollutant data as input values. Therefore, hourly ambient air quality data collected from the nearest ambient air quality station has been used for OSPM validation.

To validate the model results, 6 m height results have been chosen as the ambient air quality monitoring station located at 6 m above the ground level. The OSPM study indicates over prediction in concentrations of PM_{10} and $PM_{2.5}$ by 2% and 3%, respectively, as compared to the actual air pollutant concentrations during the study period (Table 6).

Finally, figure 12(a) and figure 12(b) show the predicated PM_{10} and $PM_{2.5}$ model concentrations with the actual concentrations in the Panjrapole street canyon for the selected study period (last week of December). The dotted lines are the linear regression graphs acquired with the mathematical equation. The difference between the actual data and the model data was calculated using the mean absolute percentage error (MAPE). The MAPE obtained for PM_{10} and $PM_{2.5}$ is 3.0% (R^2=0.972) and 1.9% (R^2=0.931) respectively, being suitable to predict the PM_{10} and $PM_{2.5}$ pollutant concentrations.

In the present study, the authors also concluded that the OSPM was most suitable for predicting PM_{10} and $PM_{2.5}$ concentrations in congested, busy areas surrounded by tall buildings, urban street canyons.

Table 6
OSPM model result comparison with nearest ambient air quality station data

Receptor Height (m)	Results	PM_{10} ($\mu g.m^{-3}$)	$PM_{2.5}$ ($\mu g.m^{-3}$)
Z=6	OSPM Model	167.8 ± 4.5	111.3 ± 6.1
	Nearest Ambient Air Quality Station Data	164.6 ± 3.1	109.1 ± 5.2
	% Over prediction (avg)	3	2

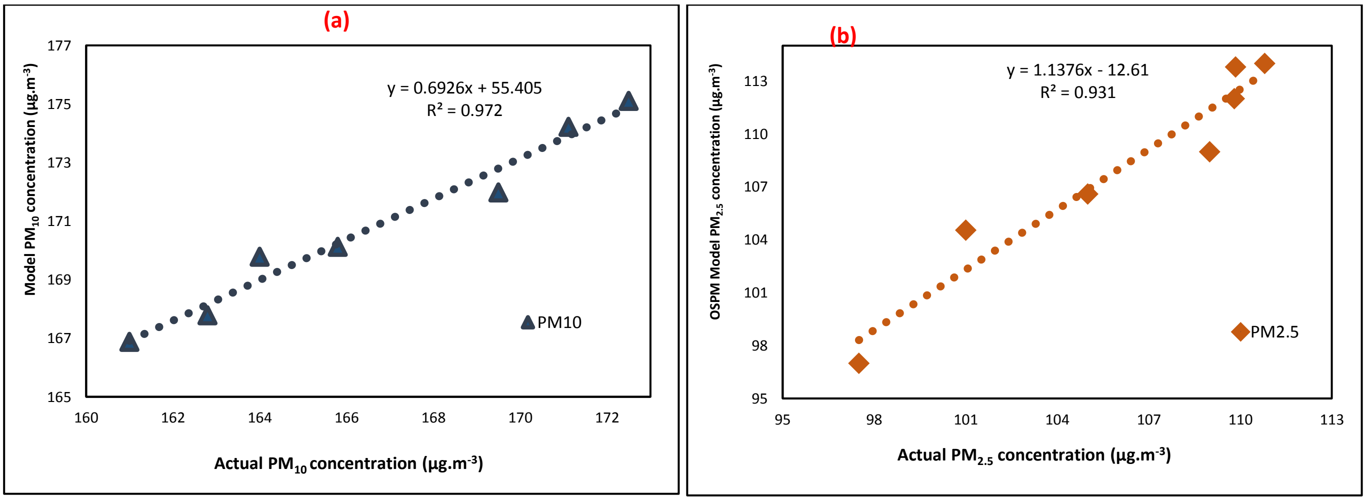

Figure 12: Comparison between actual concentration with OSPM model concentrations: (a) PM_{10} (b) $PM_{2.5}$

Conclusion

The OSPM has been applied for the third week of December 2021 in an identified area (i.e. Panjrapole, Ahmedabad), which is an indicator of the worst ambient air conditions due to lowered temperature and poor pollutant dispersion. The model OSPM result depends on meteorological data, number of vehicles and height to width ratio. In instances of higher height to width (H/W) ratios, traffic producing turbulence (TPT) is generated within the street canyon. Pollutant recirculation is high in such urban street canyon.

The OSPM runs with different building heights to assess the air quality in the street canyon of Panjrapole, Ahmedabad city. 190 m road length was selected of Panjrapole. At 6 meter height, concentration particulate matter was 164.6 ± 3.1 µg.m^{-3} of PM_{10} and 109.1 ± 5.2 µg.m^{-3} of $PM_{2.5}$. The result of OSPM is over predicted than the government monitoring station: PM_{10} 3% and $PM_{2.5}$ 2% at Panjrapole. Finally, it is concluded that the OSPM can be applied to assess the ambient air quality during the presence of line source emissions using an hourly concentration of pollutants with the TPT at different building heights and varying meteorological conditions.

Recommendations

From the present study on air quality assessment of vehicular pollution using OSPM for the Panjrapole street, the following recommendations can be given:

For newly developing Areas:

The ratio of street canyon height to width should be maintained for the efficient dispersion of the vehicular air pollutant in newly developing and constructing street areas of Ahmedabad city.

For developed areas:

The area of urban green space in the city should be increased by carrying out more tree plantation and social afforestation to improve the air quality.

The traffic must be reduced by promoting more public transport like AMTS, BRTS and METRO instead of private vehicles.

The flyovers and bridges should be constructed so that the pollutant can dispersed easily at the height instead of congesting the street lanes.

Acknowledgement

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