OPEN ACCESS

Volume: 7

Issue: 3

Month: January

Year: 2020

P-ISSN: 2321-788X

E-ISSN: 2582-0397

Received: 23.10.2019

Accepted: 27.11.2019

Published: 01.01.2020

Citation:
Nataraj, Prabhakaran, et al. "Dispersion of Nitrogen Dioxide and Particulate Matter Concentrations in Street Canyons and Open Landscape in Urban Mysore." *Shanlax International Journal of Arts, Science and Humanities*, vol. 7, no. 3, 2020, pp. 36–43.

DOI:
https://doi.org/10.34293/sijash.v7i3.1352

Dispersion of Nitrogen Dioxide and Particulate Matter Concentrations in Street Canyons and Open Landscape in Urban Mysore

Prabhakaran Nataraj, Azis Kemal Fauzie,
P.N.Sandhya Rani and G.V.Venkataramana
Department of Studies in Environmental Science,
University of Mysore, Mysore, Karnataka, India

Abstract
The variation in nitrogen dioxide (NO_2), particulate matter (PM_{10} and $PM_{2.5}$) concentrations and meteorological data were analyzed at different types of urban spaces in Mysore consisting of four street canyons and one open landscape sites. The NO2 and PM levels were measured using a portable monitoring device and respirable dust sampler, respectively. The maximum NO_2 concentration was found at the intersection of both street canyons and open landscape, either in the morning (70-160 µg/m³) or evening (20-60 µg/m³). Results found that the concentration of NO_2 in street canyons was significantly higher than in open landscape sites ($p < 0.001$). The ambient NO_2 levels were also found lower in the crossroads compared to such in the main roads. The high number of vehicles passing through the roads accounts for the higher NO_2 concentration as we found a significant positive correlation between traffic volume and NO_2, SPM, $PM_{10,}$ and $PM_{2.5}$ concentrations, either in the street canyon and open landscape sites. Furthermore, a negative association has been observed between both SPM and NO_2 levels and the wind speed ($p = 0.002$ and $p < 0.05$, respectively). The factors affecting the different dispersion characteristics of air pollutants were found to be the wind speed, vehicular traffic, and site landscape were congested with a high number of tall buildings.
Keywords: Nitrogen dioxide, Street canyon, Particulate matter, Air quality

Introduction

Congested streets and polluted air from traffic volume in urban areas are serious problems, both in central cities as well as in urban spaces (Mally and Ogrin 2015). India's contribution is small compared to global transport emissions, but it is increasing exponentially. The increase in air pollutant concentrations due to vehicular emissions in developing countries like India directly affects the ecological environment and adversely impacts on the human (Aggarwal and Jain 2015). The dispersion of traffic emissions in urban areas is highly influenced by the presence of building structures. Exposure to air pollutants in an urban environment is expected to significantly increase, especially in those areas where population and traffic density are relatively high (Vardoulakis et al. 2013).

It has been reported that $PM_{2.5}$, PM_{10}, and NO_2 concentration has exceeded the exposure limits for urban population due to the increase in traffic volume. High traffic density and poor dispersion cause pollutant concentration to be higher in roadway than non-roadway environment (Acero et al. 2015; Zhang et al. 2013). Due to the rapid increase in vehicle ownership, automobile emission has become the major source of air pollution in large and medium-sized cites.

The high rise building forms a lot of street canyons and also leads to the accumulation of a large number of harmful gases from the motor vehicle in the canyons, which are difficult to disperse and may have serious health effects on the urban population (Zhang et al. 2015). The street-level concentrations of air pollutants depend on wind direction and street canyon aspect ratio (Jeanjean et al. 2017). Climate action also requires an understanding of how emissions vary with spatial context. In Mysuru, the available number of air quality monitoring stations is limited. Hence no sufficient information was available on the distribution of air pollutants within and away from heavy traffic street canyons. Therefore, the present study was set up to determine the spatial distribution of NO_2 concentrations based on the distance from the intersection, vehicular traffic, PM concentration, and meteorological condition in different urban spaces of Mysuru city.

Materials and Methods

Study Area

Mysore is one of the largest districts in the state of Karnataka, India. It lies at 12° 18' 25" N latitude and 76° 38' 58" E longitude. The altitude of the city is 765 m above mean sea level (Fauzie and Venkataramana 2017). Five sites were chosen for the air pollutant sampling based on vehicular traffic and street landscape, either street canyon or open landscape. Irwin Road, Gun house, Ramaswamy circle, and Hunsur road was selected as street canyon category due to the sites were packed with high rise buildings, heavy traffic, and constant movement of light and heavy-duty vehicles. The fifth sampling site was RMP layout near Basavanahalli as the control site due to its open landscape, higher elevation, and low traffic and vehicular movement. Nine sampling points were selected in each site for NO_2 measurement consisting of five points in the main road with 50 m distance from each point and four points in the crossroad at the distance of 50 and 100 m away from the intersection. The sampling was performed in the morning from 6-9 am and in the evening from 4-7 pm. At the intersection points of all study sites, the SPM, $PM_{10,}$ and $PM_{2.5}$ concentrations were sampled for ten days (80 hours), each day about 4 hours in the morning and evening (Figure 1).

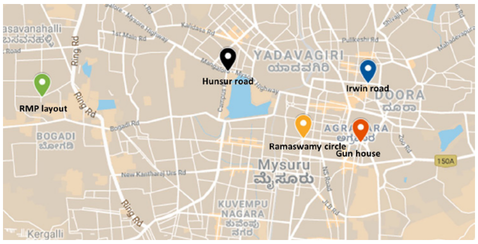


Figure 1 Sampling points for the measurement of air pollutants in street canyons and open landscape sites

Data Collection

The 50m distance between each point in each sampling site was measured accurately using a GPS device, Garmin Montana 650. The NO_2 concentration was measured using a portable air quality monitor, Aeroqual series 500. The meteorological parameters such as outdoor temperature, humidity, wind speed, and heat index were recorded using weather center device, AcuRite model 00615. The particulate matter sampling was done by employing Envirotech's fine particulate sampler APM 550 (for PM2.5) and respirable dust sampler APM 460DXNL (for SPM and PM10).

Statistical Analysis

Data were expressed as mean ± SD. The comparison between sites was done using Student's t-test. The calculated p values were reported in their real values unless they follow this category: $p<0.01$ (highly significant), $p<0.05$ (significant), $p<0.1$ (considerably significant), and $p>0.1$ (insignificant). Linear regression analysis and two-tailed bivariate Pearson's correlation have been prepared to identify the association between NO_2, SPM, PM_{10}, $PM_{2.5}$, number of vehicles, and wind speed. SPSS version 20 was employed for statistical analysis.

Results and Discussion

The variation of NO2 levels with distance along the main road and crossroads in the five areas at low traffic time (morning) and peak traffic time (evening) is given in Table 1. The estimated NO2 levels in the intersection of street canyons (Irwin road, Gun house, Ramaswamy circle, and Hunsur road) were 55.6 ± 2.3, 98.7 ± 5.6, 44.2 ± 2.2, 106.7 ± 5.2 $\mu g/m^3$ in the morning (6-9 am) and 208.1 ± 12.3, 180.7 ± 8.2, 145.1 ± 13.4, 84.6 ± 4.9 µg/m^3 in the evening (4-7 pm), whereas in RMP layout (open landscape) the NO_2 levels of 21.6 ± 2.2 and 66.8 ± 5.1 µg/m^3 were observed in the morning and evening, respectively.

There was a highly significant difference ($p < 0.001$) in the NO_2 concentrations between street canyons and open landscape sites. The maximum concentration was found at the intersection of both street canyons and open landscapes (Figure 2). In case of open landscape site, there was no significant variation in the NO_2 levels with the distance of 50 or 100 meter away from the intersection ($p = 0.391$ and $p = 0.120$, respectively), whereas in street canyons sites the variation ($p = 0.02$) in NO_2 levels was found at the distance of 50 and100 meter away from the intersection. The reason may be the idling of the vehicles, greater traffic density, and lower speed of the vehicles close to the traffic light, thus resulted in higher NO_2 emission (Soltic and Weilenmann 2003).

All street canyons sites, except Hunsur road, had tall and packed buildings in both directions from the intersection compared to the control site; this may restrict the dispersion of NO_2 emitted by the vehicles and cause the NO_2 to concentrate at the ground level of the street canyons (Vardoulakis et al. 2013). The NO_2 concentration in street canyon sites was different between the main road and crossroads in the morning ($p = 0.001$) and evening ($p < 0.001$). A similar trend was found in the control site ($p < 0.05$). However, among the different urban spaces, the most polluted areas are the street canyons.

The concentration of NO_2 in open landscape halves the same in street canyons. As we move away from the intersection, the NO_2 level in control site was very low, mainly due to fewer accounted vehicles. The type of urban space and the number and type of vehicles, as well as their speed, contributed to the pollutant concentration. Therefore, the NO_2 did not show a significant level in the open landscape than that in the street canyons (Mally and Ogrin 2015).

Table 1 Comparison of NO_2 concentration in different types of urban spaces in Mysuru

	Morning					Evening				
Distance, m	**IR**	**GH**	**RC**	**HR**	**RMP**	**IR**	**GH**	**RC**	**HR**	**RMP**
Intersection										
0	55.6 ± 2. 3	84.6 ± 4.9	44.2 ± 2.2	98.7 ± 5.6	21.6 ± 2.2	208.1 ± 12.3	106.7 ± 5.2	145.1 ± 3.4	180.7 ± 8.2	66.8 ± 5.1
Main road										
100m E	49.6 ± 4.7	61.3 ± 3.1	24.8 ± 2.3	65.0 ± 3.0	17.2 ± 1.8	185.5 ± 7.7	98.9 ± 5.2	126.2 ± 9.9	163.2 ± 5.8	52.8 ± 2.0
50m E	51.7 ± 5.5	60.9 ± 2.9	34.8 ± 1.9	72.7 ± 5.8	18.1 ± 1.3	187.6 ± 8.4	89.6 ± 4.8	138.2 ± 4.2	171.2 ± 8.6	63.2 ± 2.8
50m W	58.1 ± 4.5	68.6 ± 3.7	43.2 ± 2.2	79.3 ± 4.2	20.3 ± 1.5	201.3 ± 8.9	92.3 ± 6.0	142.0 ± 4.6	168.0 ± 3.1	65.2 ± 3.9
100m W	47.2 ± 5.6	71.4 ± 3.6	43.0 ± 2.0	62.2 ± 4.1	19.9 ± 1.8	182.9 ± 6.3	66.8 ± 3.7	130.3 ± 9.1	161.6 ± 8.1	51.3 ± 3.1
Crossroad										
100m N	31.9 ± 3.5	39.6 ± 2.2	26.7 ± 4.2	78.4 ± 5.1	11.3 ± 1.7	145.9 ± 5.0	40.7 ± 2.2	111.4 ± 6.2	161.8 ± 7.8	43.9 ± 2.3
50m N	51.3 ± 2.3	72.2 ± 3.9	44.2 ± 2.4	82.5 ± 7.2	15.3 ± 2.9	158.1 ± 4.4	62.2 ± 2.9	122.4 ± 8.1	177.1 ± 9.0	46.8 ± 3.5
50m S	48.6 ± 4.1	71.8 ± 3.9	38.9 ± 2.2	80.3 ± 7.6	18.2 ± 2.1	162.2 ± 8.5	61.7 ± 3.3	119.7 ± 6.4	167.1 ± 7.4	49.3 ± 2.4
100m S	38.9 ± 5.8	68.9 ± 3.6	28.1 ± 1.8	76.5 ± 4.2	12.9 ± 1.8	161.4 ± 8.1	65.5 ± 3.3	113.2 ± 6.3	149.9 ± 9.1	45.9 ± 2.6

Data were presented in mean ± SD; IR = Irwin road; GH = Gun house; RC = Ramaswamy circl; HR = Hunsur road; RMP = RMP layout (control site); E = east; W = west; N = north; S = south.

Source: Own data, measured using Aeroqual portable air quality monitor.

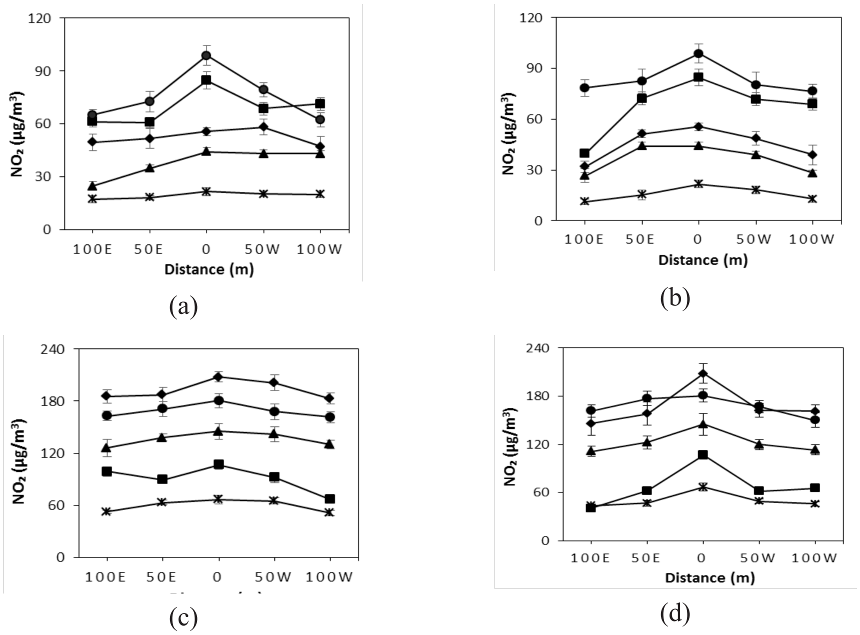


Figure 2: Variation of NO_2 with distance along (a) the main road in the morning; (b) crossroad of in the morning; (c) the main road in the evening; (d) crossroad in the evening; ● Hunsur road, ◆ Irwin road, ■ Gun house, ▲ Ramaswamy, ✱ RMP layout (control), 0 = intersection, E = east, W = west

Statistics of meteorological parameters and air pollutant concentrations in urban Mysuru is given in Table 2. The weekly average concentration of NO_2, PM_{10}, and $PM_{2.5}$ in the intersections of street canyons was 50.6, 93.7, and 52.4 µg/m^3, respectively. The difference in the NO_2 level between each street canyon site is mainly due to vehicular traffic and congested building, but in the case of PM level, no significant different was found. The result found an insignificant relationship between NO2 concentration and SPM, PM_{10}, and $PM_{2.5}$ ($p = 0.236$, 0.576, 0.523, respectively, Figure 3). The reason may be due to the study was conducted during monsoon (June-September) as the rainfall had washed out the particles. Rainwater also reacts with NO_2, which may affect the insignificant correlation between PM concentration and NO_2 level (Kumar and Joseph 2006; Aurangojeb 2011).

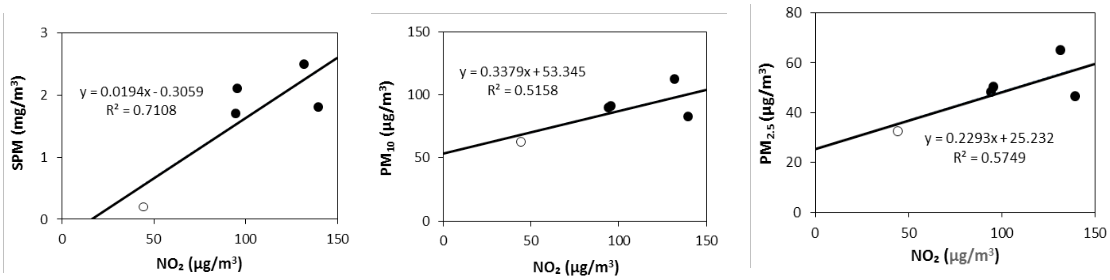
Similar work has been carried out in Mysore and found that the annual average measurement trends in the air quality of Mysore showed that SO_2 and NO_2 concentrations observed in the year 2016 was within the permissible limits of 50 and 40 µg/m^3, respectively (Venkataramana et al. 2018). However, the average concentration of air pollutants in street canyons is higher compared to the open landscape, but it is still within national ambient air quality standard by US EPA with air quality index (AQI) score of 94 (satisfactory).

Table 2 Statistics of Meteorological Parameters and Air Pollutant Concentrations in Urban Mysuru

Parameter	IR	GH	RC	HR	RMP
Temperature, °C	35 ± 0.4	34 ± 0.3	33 ± 0.1	32 ± 0.7	32 ± 0.4
Relative Humidity, %	53.8 ± 0.8	54.0 ± 1.2	53.0 ± 1.1	53.1 ± 0.7	65.0 ± 1.3
Wind speed, km/h	2.3 ± 1.3	2.0 ± 0.4	2.5 ± 0.7	3.0 ± 1.4	5.6 ± 0.8
Temperature variation, °C	0.01 ± 1.2	0.02 ± 0.5	0.03 ± 0.8	0.02 ± 1.6	0.01 ± 0.2
NO^2, µg/m^3	110.7 ± 12.3	120.6 ± 13.4	59.3 ± 5.2	113.7 ± 8.2	40.3 ± 5.1
SPM, mg/m^3	2.5 ± 1.2	2.1 ± 1.4	1.7 ± 1.8	1.8 ± 0.9	0.2 ± 0.6

PM^{10}, µg/m³	112.3 ± 2.2	90.8 ± 2.1	89.6 ± 3.2	82.3 ± 6.2	62.7 ± 5.3
$PM^{2.5}$, µg/m³	64.8 ± 4.2	50.2 ± 2.1	48.2 ± 3.4	46.4 ± 5.4	32.6 ± 2.8

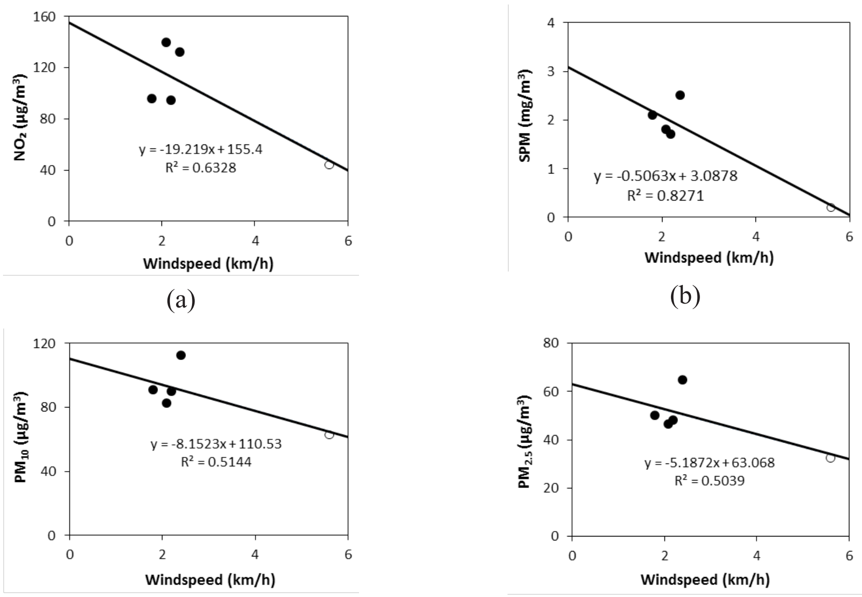
IR = Irwin road, GH = Gun house, RC = Ramaswamy circle, HR = Hunsur road, RMP = RMP layout (control); **Source:** Own data, measured using AcuRite weather center.



(a) (b) (c)

Figure 3 Correlation between NO_2 and (a) SPM, (b) PM_{10} and (c) $PM_{2.5}$. ● street canyons, ○ control

The variation in NO_2 concentration and wind speed has no regular trend. However, higher NO_2 concentration occurred when the wind speed was between 2-4 km/h. The concentration varies irregularly with increasing wind speed. The meteorological factors differ significantly between the street canyon and the open landscape. On the street canyon sites, the observed meteorological elements were characterized as low wind speed (2.4 km/h), high humidity (53.4%), and high-temperature variation (0.02°C), which may be the reason why NO_2 concentration was not dispersed properly. Furthermore, there was a significant negative correlation between wind speed and concentration of SPM and NO_2 ($p = 0.002$ and $p < 0.05$, respectively). Interestingly, PM_{10} and $PM_{2.5}$ showed insignificant relationship with wind speed ($p = 0.173$ and $p = 0.179$, Figure 4). The wind speed in each street canyon was almost similar, but the NO_2 concentration varied. The reason may be due to the difference in building congestion, which made the pollutants cannot be dispersed properly.



(c) (d)

Figure 4 Correlation between wind speed and (a) NO_2, (b) SPM, (c) PM_{10} and (d) $PM_{2.5}$.
● street canyons, ○ control

The concentration of NO_2 and particulate matter in street canyons are highly influenced by traffic volume. The NO_2 level in some of the canyon sites like Irwin road and Ramaswamy circle exceeded the permissible limit (80 µg/m^3). Conversely, PM_{10}, and $PM_{2.5}$ daily average concentrations were below the national standard in all street canyons. The high number of vehicles passing through the roads attributable to the higher NO_2 concentration as we found significant positive associations between traffic volume and NO_2, SPM, PM_{10}, and $PM_{2.5}$, either in street canyon or open landscape sites (Figure 5).

Table 3 shows the vehicular status during the assessment of air pollutants in the morning and evening. The vehicle population in Mysore has grown rapidly since 2015. It increased significantly from approximately 84 627 in 2015 to 97 069 in 2018, with an annual increase rate of 6 221 vehicles per year. During vehicle count, the two-wheelers were the dominant vehicle type and the dominant source of emission in street canyons. By our study, number of vehicles plays a significant role in controlling the primary and secondary pollutant emissions in Mysuru, particularly the ambient NO_2 levels. Buses and heavy-duty vehicles like trucks emit a relatively higher amount of NOx (Venkataramana et al. 2018; Sindhwani and Goyal 2014). According to US EPA, diesel vehicles contribute about 50% of the NOx and PM emissions to the ambient environment (Kumar and Joseph 2006).

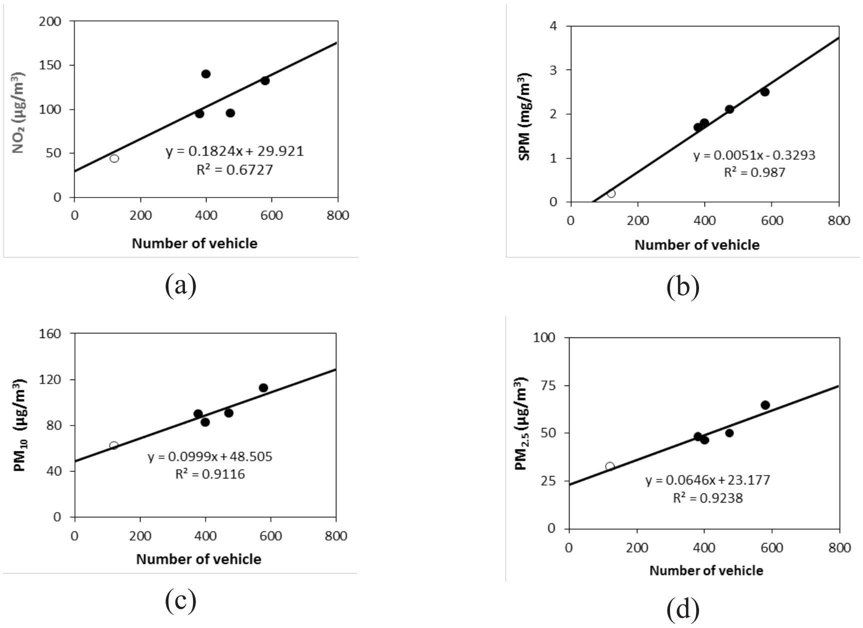


Figure 5 Correlation between number of vehicles and concentration of (a) NO_2, (b) SPM, (c) PM_{10} and (d) $PM_{2.5}$. ● street canyons, ○ control

Conclusion

Measurement of meteorological data, vehicular traffic, and air pollutant concentrations, including NO_2, SPM, PM_{10}, and $PM_{2.5}$, have been conducted at four street canyons and one open landscape during the monsoon period in Mysuru. In general, the measured air pollutant concentrations in the street canyons were higher compared to the open space. The area near the bus station (Irwin road) has the highest air pollutant level in comparison to other street canyons. The concentrations of NO_2 and particulate matter in the crossroad were significantly lower compared to the main road. The factors affecting this difference were found to be vehicular traffic, street landscape, and wind speed. Above all, perhaps, our work could be beneficial for the town planners in organizing the urban transport planning resulting in the reduction of the air pollutant emissions that will further promote the increase in public health quality in the city.

Table 3 Vehicle count during the assessment of air pollutant (a) in the morning (6 to 9 am) and (b) in the evening (4 to 7 pm)

	Main road					Crossroad				
	Two-wheeler	Car	Rick-shaw	Truck	Bus	Two-wheeler	Car	Rick-shaw	Truck	Bus
Morning										
Irwin road	232 ± 24	100 ± 16	212 ± 38	12 ± 4	48 ± 4	40 ± 8	12 ± 3	11 ± 1	9 ± 1	2 ± 1
Gun house	264 ± 27	118 ± 22	100 ± 15	14 ± 4	60 ± 6	72 ± 12	16 ± 4	22 ± 6	6 ± 2	3 ± 1
Ramaswamy circle	170 ± 25	64 ± 12	56 ± 8	11 ± 1	46 ± 9	94 ± 15	8 ± 2	16 ± 2	3 ± 2	6 ± 2
Hunsur road	92 ± 12	82 ± 12	34 ± 6	8 ± 2	42 ± 5	68 ± 18	4 ± 2	12 ± 2	3 ± 2	4 ± 1
RMP layout (control)	31 ± 4	20 ± 2	8 ± 1	9 ± 1	14 ± 6	18 ± 4	9 ± 1	4 ± 2	2 ± 2	1 ± 1
Evening										
Irwin road	604 ± 34	264 ± 24	409 ± 34	34 ± 6	82 ± 11	169 ± 23	34 ± 14	80 ± 8	1 ± 1	1 ± 1
Gun house	560 ± 15	249 ± 18	196 ± 19	33 ± 9	72 ± 12	159 ± 14	38 ± 8	44 ± 4	2 ± 1	4 ± 2
Ramaswamy circle	590 ± 27	149 ± 8	128 ± 10	44 ± 2	68 ± 11	118 ± 12	14 ± 1	32 ± 7	2 ± 1	2 ± 1
Hunsur road	394 ± 38	242 ± 16	124 ± 18	12 ± 1	80 ± 9	96 ± 9	16 ± 2	22 ± 8	4 ± 1	3 ± 1
RMP layout (control)	106 ± 16	44 ± 14	12 ± 2	6 ± 1	26 ± 13	27 ± 6	23 ± 6	12 ± 3	6 ± 2	1 ± 1

Acknowledgments

Authors are thankful to Dr. Amruta Nori Sarma (Yale University, USA) for providing NO2 sampling device, Dr. Rajesh Kumar (JSS University, Mysore) for his valuable suggestion, Anjali, Varshini, Gautam, and Rajan (M.Sc. project students of Mysore University) for helping in sampling and data collection.

Funding

The work was funded by the Science and Engineering Research Board (SERB), Department of Science and Technology, New Delhi, and the Department of Studies in Environmental Sciences, University of Mysore.

Competing Interest

The authors declare no competing interests.

References

Acero, J.A. et al. "Impact of Local Urban Design and Traffic Restrictions on Air Quality in a Medium-sized Town." *Environmental Technology*, vol. 33, no. 21, 2012, pp. 2467-2477.

Aggarwal, P. and Jain, S. "Impact of Air Pollutants from Surface Transport Sources on Human Health: A Modeling and Epidemiological Approach." *Environment International*, vol. 83, 2015, pp. 146–157.

Cheng, N. et al. "Ground-level NO_2 in Urban Beijing: Trends, Distribution, and Effects of Emission Reduction Measures." *Aerosol and Air Quality Research*, vol. 18, 2018, pp. 343-356.

Fauzie, A.K. and Venkataramana, G.V. "Characterization of Particulate Matter Collected at Mysore City Roadways in Association with Urban Traffic Condition." *Archives of Current Research International*, vol. 10, no. 1, 2017, pp. 1-17.

Jeanjean, A. et al. "Air Quality affected by Trees in Real Street Canyons: The case of Marylebone Neighbourhood in Central London." *Urban Forestry & Urban Greening*, vol. 22, 2017, pp. 41-53.

Mally, K.V. and Ogrin, M. "Spatial Variations in Nitrogen dioxide Concentrations in Urban Ljubljana, Slovenia." *Moravian Geographical Reports,* vol. 23, no. 3, 2015, pp. 27-35.

Soltic, P. and Weilenmann, M. "NO_2/NO Emissions of Gasoline Passenger Cars and Light-duty Trucks with Euro-2 Emission Standard." *Atmospheric Environment,* vol. 37, no. 37, 2003, pp. 5207–5216.

Vardoulakis, S. et al. "Modelling Air Quality in Street Canyons: A Review." *Atmospheric Environment*, vol. 37, no. 2, 2003, pp. 155-182.

Venkataramana, G.V., Fauzie, A.K. and Naveen. S. "The Status of Air Pollution Attribution to Automobile Emission in Mysuru: Implications for Urban Transport Planning." *Climate Change,* vol. 4, no. 16, 2018, pp. 715-722.

Zhang, H. et al. "Study on the Influence of the Street side Buildings on the Pollutant Dispersion in the street Canyon." *Procedia Engineering,* vol. 121, 2015, pp. 37-44.

Zhang, L. et al. "Estimating Daily Nitrogen Level: Exploring Traffic Effects." *The Annals of Applied Statistics*, vol. 7, no. 3, 2013, pp. 1763-1777.

Author Details

Prabhakaran Nataraj, *Department of Studies in Environmental Science, University of Mysore, Mysore, Karnataka, India,* ***Email ID****: prabhavatar@gmail.com*

Azis Kemal Fauzie, *Department of Studies in Environmental Science, University of Mysore, Mysore, Karnataka, India,* ***Email ID****: aziskemal@envsci.uni-mysore.ac.in*

P.N.Sandhya Rani, *Department of Studies in Environmental Science, University of Mysore, Mysore, Karnataka, India*

G.V.Venkataramana, *Department of Studies in Environmental Science, University of Mysore, Mysore, Karnataka, India,* ***Email ID****: venkataraman_1970@yahoo.co.in*