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Influence of Urbanization on Particulate Matter Pollution in Coimbatore City, India

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ABSTRACT

The spatial-temporal distribution of air pollutants over India's growing cities is still uncertain due to the lack of monitoring data and inadequate knowledge. This study analyzes the temporal and spatial trends of particulate matter in Coimbatore and furthers the influence of urban growth on aerosol concentrations also investigated. The average concentration of $PM_{2.5}$ and PM_{10} was 42.23 and 68.05 µg m^{-3} during the study period and slightly higher than the National Ambient Air Quality Standards. Aerosol concentrations were found to be highest in an industrial site (81.17 µg m^{-3} for PM_{10} and 51.89 µg m^{-3} for $PM_{2.5}$), medium in urban-industrial (69.09 µg m^{-3} for PM_{10} and 42.53 µg m^{-3} for $PM_{2.5}$), commercial (69.99 µg m^{-3} for PM_{10} and 42.31 µg m^{-3} for $PM_{2.5}$), residential (68.39 µg m^{-3} for PM_{10} and 41.21 µg m^{-3} for $PM_{2.5}$) sites, and low in the mixed site (51.59 µg m^{-3} for PM_{10} and 33.19 µg m^{-3} for $PM_{2.5}$). Geographic Information System analysis results indicate that Coimbatore city became more urbanized and more polluted than before. $PM_{2.5}/PM_{10}$ ratio of 0.60-0.65 in the respective locations revealed the dominance of $PM_{2.5}$. Vehicular exhaust emissions and road dust re-suspension are the primary sources of air quality deterioration in Coimbatore city since there are no other significant pollution sources. Our findings provide baseline information concerning the influence of urbanization and transportation on particulate matter pollution in Coimbatore city.

Key words : *Aerosol, $PM_{2.5}$ concentration, Urbanization, $PM_{10}/PM_{2.5}$ ratio.*

Introduction

Ambient air pollution has been recognized as one of the potential threats to the environment and public health. A rapid growth in population, transportation, urbanization, and industrialization are the prime causative agents of deleterious air quality. Over half of the world's population occupies urban space, and by 2050 this share was expected to grow up to 66% (United Nations, 2014). Usually, these urban areas were more polluted than rural due to augmented anthropogenic activities such as motor vehicle transportation, residential heating, cooking, and some industry activities (Guo *et al.*, 2018; Wang *et al.*, 2019). According to the World Health Organization (WHO), over 80% of the urban population is directly exposed to airborne particulates. Even with some improvements in a few regions, globally, urban particulate matter pollution levels increased by 8% from 2008 to 2013 (World Health Organization, 2016). Ambient respirable particulate matters are a complex mixture of solid and liquid particles emitted from the various point and non-point sources, classified into fine ($PM_{2.5}$) and coarse (PM_{10}) particles

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based on their aerodynamic size. The $PM_{2.5}$ and PM_{10} particles differ not only in size but also in chemical compositions (Hsiao *et al.*, 2000). PM is a multifaceted blend of numerous chemical constituents of air, consisting of sulfates, nitrates, ammonium, and organic and inorganic elements together with transition metals (Tiwari *et al.*, 2009; Aldabe *et al.*, 2011). Several studies (Kurt *et al.*, 2016; Cai *et al.*, 2017; Breitner *et al.*, 2019) reported that continual exposure to particulate matter could lead to cardiovascular diseases, pulmonary diseases, cerebrovascular diseases, and endocrine disorders. Recent studies also reveal a link between PM and gastrointestinal diseases, including appendicitis, colorectal cancer, and inflammatory bowel disease (Mutlu *et al.*, 2018).

Being the second most populated country, India becomes an air pollution hotspot and has one of the highest exposures to ambient particulate matter. According to WHO, India has 14 of the 15 top cities with the worst $PM_{2.5}$ pollution, and Delhi tops in PM_{10} pollution. The number of deaths attributable to ambient particulate matter pollution in India was increasing rapidly, and it was projected to be 0.67 million in 2017 (Balakrishnan *et al.*, 2019). Regardless of the several policy measures taken, air pollutants concentration and its impacts on public health follow the growing trend. Several studies were conducted on monitoring, source apportionment, and health impact assessment of the particulate matter. However, most of these studies focused on Indian megacities (Delhi, Mumbai, Bangalore, Kolkata, and Chennai), and there is a lack of detailed studies on ambient air quality and source contributions in tier II cities (Guttikunda *et al.*, 2019). Exhaustion of megacities due to overpopulation and urbanization, tier-II cities became a target of numerous populations and industries. Therefore, these cities are noticed with a significant rise in urbanization, industrialization, on-road/off-road emission sources, changes in land-use patterns, and micro-climatic conditions resulting in air quality deterioration. In fact, several studies reported that urbanization has a positive effect on PM levels (Parrish and Stockwell, 2015; Wang *et al.*, 2019; Wang *et al.*, 2020).

Coimbatore is the third largest and one of the most industrialized cities in Tamil Nadu, India. Coimbatore city covers 4,732 $km^{2,}$ in which 1,628 km^2 of urban and the remaining 3,104 km^2 of rural area. The Coimbatore district's total population was 34,58,045, of which about 75.7% of people were inhabitants of the urban areas. Coimbatore city consists of more than 25,000 industries and textile mills and is well-known for foundries, automobile industries, and manufacturing of textile, industrial equipment, spares, motor pump sets, and wet grinders. In recent times Coimbatore was also emerging as an IT and BPO city and ranked at seventeenth place among the global outsourcing cities. This study estimates the concentration variations due to spatial and temporal changes in ambient particulate matter pollution of tier II city, Coimbatore, India. Moreover, the results were presented concerning the $PM_{2.5}/PM_{10}$ ratio and the influence of urbanization on particulate pollution.

Materials and Methods

Air Quality Monitoring

Ambient air samples of particulate matter were collected on a monthly basis for a period of one year (July 2018 to June 2019). Respirable particulate matter (PM_{10}) and fine particulate matter ($PM_{2.5}$) were collected using a respirable dust sampler (Model: APM 460 BL, Envirotech, India) and a fine particulate sampler (Model: APM 550, Envirotech, India) at five sampling stations. Fig. 1 shows the sampling sites selected for the current study. The sampling stations were carefully chosen to represent Commercial (Gandhipuram), Urban-industrial (Kavundampalayam), Mixed (PSG CAS), industrial (SIDCO), and residential (Selvapuram) activities. The suspended particulate matter's respirable fraction was collected on a pre-weighed glass microfibre filter paper (MGF/1, 20.3 × 25.4 cm). The glass microfibre filters were dried in a hot air oven at the temperature of 105 °C before and after sampling. The concentration of PM_{10} was calculated by measuring the weight gain after sampling using weigh balance (Shimadzu, model: AUW220D) with an accuracy of 10 µg. All the sampling was conducted for 24 hours at a flow rate of 0.9–1.2 m^3 min^{-1}. $PM_{2.5}$ particles were retained in pre-weighed 47 mm diameter Polytetrafluoroethylene (PTFE) filter papers. Before and after the sampling, PTFE filters were kept at a relative humidity of 50% and a temperature of 25°C for 24 hours. Gravimetric determination of the collected $PM_{2.5}$ mass was carried out using an electronic microbalance (Sartorius, Model: MSA 6.6S-000-DF) with 1 µg sensitivity. The particulate matter size contribution between 2.5 µm to 10 µm ($PM_{2.5-10}$) was determined based on the mass balance approach. Basic meteorological parameters such as minimum, maximum, and average temperature, rainfall, wind speed, and humidity were collected from the Indian Meteorological Department (IMD) from July 2018 to June 2019. The PM and climatological data have been exposed to various statistical investigations to identify and assess trends.

Spatial Analysis

Spatial interpolation has been the most time-efficient and straightforward method to estimate pollutants distribution over a region. In the present study, Inverse Distance Weighted (IDW) interpolation procedure was applied for spatial modeling of the collected particulate matter data as it provides better visualization of air pollutants over the study area. Numerous studies have indicated that the performance of IDW is better than kriging and spline when comparing the correlation coefficient between simulated and observed values. This methodology assumes that the concentrations at a specific site are more affected by adjacent than distant sites. To predict a value at unmonitored sites, IDW uses the available concentrations at the neighboring sites. Weights are calculated by taking the inverse of the distance from a sampling location to the location of the point being estimated. For the study area, the spatial data was first created within a GIS environment using ArcGIS Pro 2.4.3 (Trial version). The monthly mean concentrations of PM data from five monitoring locations were used to interpret PM's distribution within Coimbatore city. Based on these monitoring locations, the interpolated maps were generated and analyzed.

Urban Development

Considering the array of the urbanization process and data collection limits, the present study considers changes in the urban buildup area and vehicle population (gathered from MoRTH) as an indicator of urbanization. Initially, the Land use/Land cover (LULC) analysis of the satellite data was performed using the software package (ArcGIS Pro 2.4.3 trail version). LandSAT 8 satellite data collected from USGS Earth Explorer (https://earthexplorer.usgs.gov) for 2000 and 2019 were utilized to characterize the study area into five categories: Agriculture, Water bodies, Urban fabric, Barren land, and Natural Vegetation. The base map of Coimbatore Corporation was extracted from the survey of India (SOI) toposheet series of 1:25,000 scales. Before land cover analysis, satellite data are pre-processed for geo-referencing. Composite bands

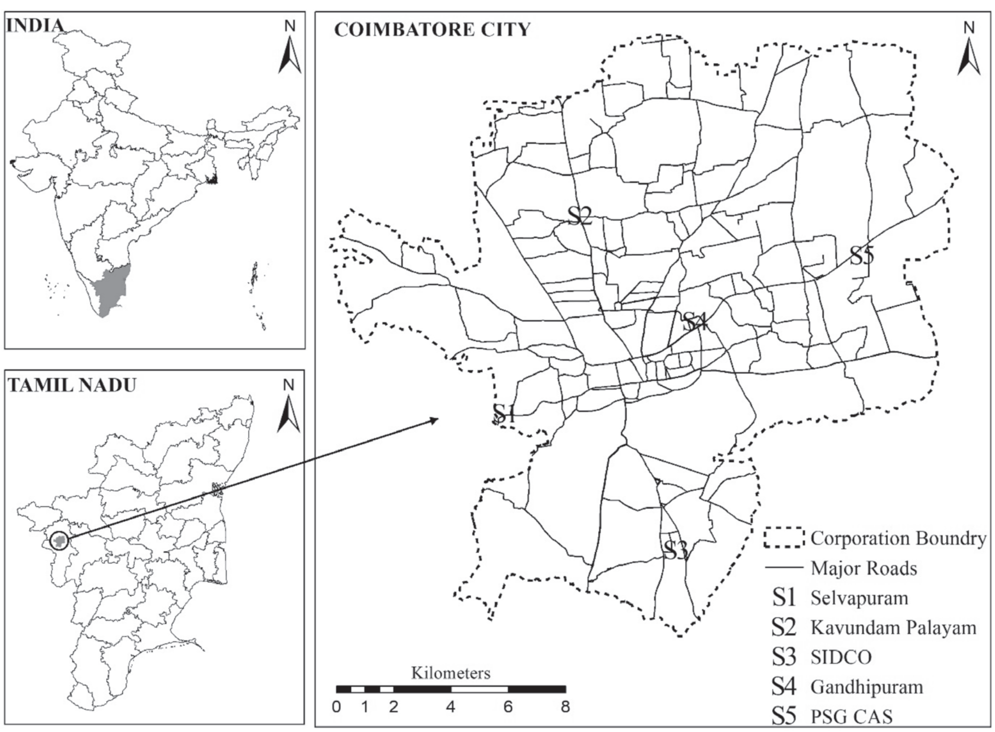

Fig. 1. Sampling sites of Coimbatore city

were generated, and the area of interest was extracted using the mask function. Further, different raster functions were used to improve visualization and identify the objects on the imagery. Finally, the changes in the land cover patterns were calculated from the LULC maps of 2000 and 2019.

Results

Ambient Particulate Matter Pollution

Monthly Variations of PM fractions and meteorology

Table 1 shows the monthly average values of temperature, rainfall, wind speed, humidity, and particulate matter (PM_{10} and $PM_{2.5}$) from July 2018 to June 2019. On average, the values of PM concentrations were found in the range of 26.14–90.49 µg m^{-3} and 16.81 - 61.99 µg m^{-3} for PM_{10} and $PM_{2.5}$, respectively. The lowest concentration of PM_{10} particles was observed during the South-West monsoon period in September (26.14 ± 9.00 µg m^{-3}) and August (28.79 ± 5.98 µg m^{-3}). Simultaneously, the maximum values were observed in February (90.49 ± 28.59 µg m^{-3}), followed by December (85.97 ± 12.40 µg m^{-3}). While considering $PM_{2.5}$ mass, the concentrations were observed to be least in August and September with 16.81 ± 7.43 and 18.69 ± 8.82 µg m^{-3}, respectively. The maximum $PM_{2.5}$ concentration occurs in December (61.99 ± 12.10 µg m^{-3}). By applying the mass balance approach, the monthly mean concentration of $PM_{2.5-10}$ in Coimbatore city is estimated to be in the range of 7.45 to 53.85 µg m^{-3}, with an annual average of 25.82 ± 19.3 µg m^{-3}.

The meteorological parameters directly influence the distribution and transport of ambient particulate matter. The temperature, rainfall, wind speed, and humidity during the study period ranged between 25–33°C, 1.05–313 mm, 7.8–25.6 km h^{-1}, and 46–73%. As expected, the month of January and April showed the minimum and maximum temperature values, accordingly. The average wind speed was found to be a peak in July (25.6 km h^{-1}). After that, the wind speed steadily decreased to reach the mini-

Table 1. Summary of PM and relevant environmental parameters for the period of July 2018 to June 2019

Period	Temperature (°C)	Rainfall (mm)	Average Wind Speed (km h^{-1})	Humidity (%)	PM_{10} (µg m^{-3})	$PM_{2.5}$ (µg m^{-3})	$PM_{2.5-10}$ (µg m^{-3})
Jul-18	27	1.05	25.6	64	54.65 ± 35.04	20.21 ± 6.39	34.44 ± 31.86
Aug-18	26	28.49	23.6	68	28.79 ± 5.98	16.81 ± 7.43	11.98 ± 7.87
Sep-18	28	43.09	15.9	62	26.14 ± 9.00	18.69 ± 8.82	7.45 ± 2.12
Oct-18	28	313	9.3	65	80.32 ± 36.25	45.38 ± 16.88	34.94 ± 27.60
Nov-18	26	210.4	8	73	68.87 ± 22.41	52.49 ± 24.83	16.38 ± 3.55
Dec-18	26	103.7	7.8	71	85.97 ± 12.40	61.99 ± 12.10	23.98 ± 13.12
Jan-19	25	31.4	9.2	61	76.14 ± 9.86	48.11 ± 11.56	28.03 ± 13.95
Feb-19	28	35	10	54	90.49 ± 28.59	36.64 ± 12.36	53.85 ± 19.85
Mar-19	31	14.2	10.8	46	80.95 ± 21.43	45.77 ± 10.39	35.17 ± 20.87
Apr-19	33	79.7	11.6	47	68.05 ± 7.48	49.15 ± 9.14	18.90 ± 3.41
May-19	32	106	19	57	73.06 ± 5.84	54.60 ± 17.21	18.46 ± 9.38
Jun-19	29	39.5	23.3	66	83.13 ± 31.58	56.87 ± 26.48	26.27 ± 11.01

Table 2. Statistical summary of PM_{10}, $PM_{2.5}$, and $PM_{2.5-10}$ in five sampling locations

Location	PM_{10} (µg m^{-3})		$PM_{2.5}$ (µg m^{-3})		$PM_{2.5-10}$ (µg m^{-3})	
	Range	Average ± SD	Range	Average ± SD	Range	Average ± SD
Gandhipuram	18.31–118.30	69.99 ± 30.34	11.28–70.14	42.31 ± 17.46	3.89–82.41	27.68 ± 24.86
Kavundampalayam	29.10–119.43	69.09 ± 29.42	9.62–78.94	42.53 ± 22.69	5.10–87.38	26.56 ± 22.29
PSG CAS	16.40–79.55	51.59 ± 21.85	9.82–60.00	33.19 ± 17.54	3.48–42.80	18.40 ± 10.58
Selvapuram	28.31–115.48	68.39 ± 25.27	10.96–74.74	41.21 ± 20.94	10.82–60.40	27.18 ± 14.98
SIDCO	30.02–140.96	81.17 ± 32.14	15.17–76.52	51.89 ± 21.04	7.73–83.59	29.28 ± 21.43
Overall	18.31–140.96	68.05 ± 28.72	9.62–78.94	42.23 ± 20.30	3.48–87.38	25.82 ± 19.3

mum (around 8 km h^{-1}) in November and December. After December, the wind speed steadily increased to its maximum in May (23.3 km h^{-1}). The annual rainfall of 1005 mm was recorded with the South-West (mid-June to August) and North-East monsoon (October to mid-November), contributing 7.22 and 52.07% of annual rainfall, respectively.

Seasonal variability of PM fractions

Fig. 2 shows the pattern of PM_{10}, $PM_{2.5\text{-}10}$, and $PM_{2.5}$ in four seasons. The mean of PM_{10} was observed to be 84.20 µg m^{-3} in winter, 74.02 µg m^{-3} summer, 58.44 µg m^{-3} in NE monsoon, and 55.53 µg m^{-3} in SW monsoon, respectively. In comparison with PM_{10}, only slight variations were found in the concentrations of fine particulate matter. The order of $PM_{2.5}$ level was found to be summer (49.84 µg m^{-3}) >winter (48.94 µg m^{-3}) >SW monsoon (48.92µg m^{-3}) >NE monsoon (42.23µg m^{-3}). The mean value for the $PM_{2.5\text{-}10}$ was 35.29 and 19.29 µg m^{-3} in summer and winter, respectively. At the same time, it was about 24 µg m^{-3} in both NE and SW monsoon seasons.

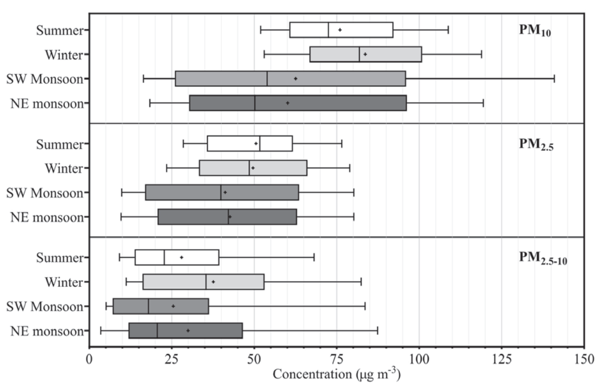

Fig. 2. Seasonal variations of PM_{10}, $PM_{2.5\text{-}10}$, and $PM_{2.5}$

Spatial variations of PM_{10} and $PM_{2.5}$

The results of concentration of $PM_{2.5}$, PM_{10}, and $PM_{2.5\text{-}10}$ measurements in five sites representing Commercial (Gandhipuram), Urban-industrial (Kavundampalayam), Mixed (PSG CAS), Industrial (SIDCO), and Residential (Selvapuram) areas for the study period were summarized in Table 2. The monthly average concentrations at the SIDCO site ranged from 30–141 µg m^{-3} for PM_{10}, 15–76.5 µg m^{-3} for $PM_{2.5}$, and 7.7–83.6 µg m^{-3} for $PM_{2.5\text{-}10}$. Whereas the annual average concentration, was 81.17 ± 32.14, 51.89 ± 21.04, and 29.28 ± 21.43 µg m^{-3} for PM_{10}, $PM_{2.5}$, and $PM_{2.5\text{-}10}$, individually. As presented in Table 2, the annual average measurements were 69.99 ± 30.34, 69.09 ± 29.42, and 68.39 ± 25.27 µg m^{-3} of PM_{10} and 42.31 ± 17.46, 42.53 ± 22.69, and 41.21 ± 20.94 µg m^{-3} of $PM_{2.5}$ for Gandhipuram, Kavundampalayam, and Selvapuram sites, respectively. Overall the concentration of PM fractions was significantly lower in PSG CAS than in the other study sites. The annual mean of PM_{10} and $PM_{2.5}$ in PSG CAS was recorded as 51.59 ± 21.85 and 33.19 ± 17.54 µg m^{-3}.

Airborne aerosol data is spatially assessed to evaluate the influence of the seasonal variations on the buildup of pollutants in different sampling spots and presented in Fig. 3(a) and 3(b). The highest mass concentrations of PM_{10} were observed in Gandhipuram and SIDCO as 94.90 and 90.66 µg m^{-3}, respectively, during the winter season. The results demonstrate that the PM_{10} concentrations were higher in the center and southern part of the city in all the seasons except North-East Monsoon. Similarly, $PM_{2.5}$ levels were also found to be higher in the southern part of the city.

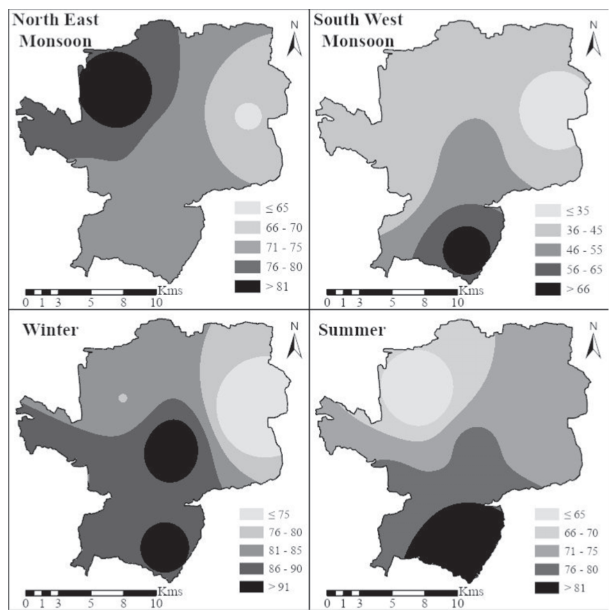

Fig. 3(a). Spatio-temporal variations of PM_{10} in Urban Coimbatore

$PM_{2.5}/PM_{10}$ ratio

The distribution of the $PM_{2.5}/PM_{10}$ ratio in the sampling locations is displayed in Table 3. The mean $PM_{2.5}/PM_{10}$ ratios at the sampling sites ranged between 0.21–0.88 with average and standard deviation of 0.63 and 0.17. Interestingly, the PM ratio for PSG CAS and SIDCO sites were ranged between 0.42–0.86 and 0.41–0.83, accordingly. It specifies that at least about 41% of atmospheric PM_{10} particles were less than 2.5 μm in size in these sampling sites. The lowest value for the $PM_{2.5}/PM_{10}$ ratio was observed in the Selvapuram site (ranged within 0.21-0.84, with an average of 0.59).

Table 3. Distribution of $PM_{2.5}/PM_{10}$ ratio on the sampling sites (July 2018 to June 2019)

Location	*$PM_{2.5}/PM_{10}$ Ratio*	
	Range	Average ± SD
Gandhipuram	0.31 - 0.88	0.64 ± 0.19
Kavundam palayam	0.25 - 0.88	0.62 ± 0.21
PSG CAS	0.42 - 0.86	0.64 ± 0.15
Selvapuram	0.21 - 0.84	0.59 ± 0.19
SIDCO	0.41 - 0.83	0.65 ± 0.15
Overall	0.21 - 0.88	0.63 ± 0.17

Urban Development

Land Use/Land Cover Change

The land cover change analysis approach was selected to evaluate the urban growth of Coimbatore city in the last two decades. Figs. 4, and Table 4 show the pattern of land use/cover in 2000 and 2019. It was observed that in the year 2000, Coimbatore city was covered by 42.71 km^2 of urban fabrication, 87.36 km^2 of agricultural land, 62.69 km^2 of natural vegetation, 65.22 km^2 of barren land, and 1.88 km^2 of water bodies. Coimbatore city corporation limit has redrawn in 2010 due to urban growth. In 2019, over half of the study area (57.39%) was covered by urban constructions. Unfortunately, about 59.82 and 48.37% of the vegetation and agricultural area has been transformed into other land use categories.

Vehicular growth

At present, the most transport-related source of air pollutants is concentrated nearby urban areas. Vehicular growth (between 2001-2018) and vehicle contributions in 2018 were presented in Fig. 5 and its insert. The number of vehicles on the roads of Coimbatore proliferating in the last two decades. According to the Ministry of Road Transport and Highways (MoRTH), in 2001, about 4.09 lakhs of

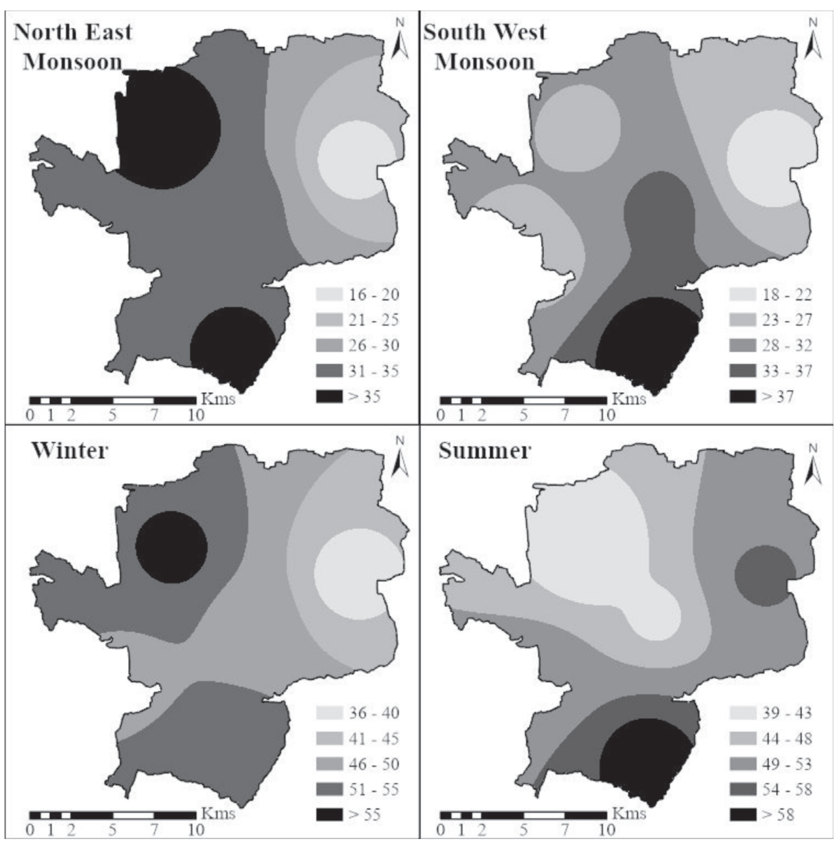

Fig. 3(b). Spatio-temporal of $PM_{2.5}$ in Urban Coimbatore

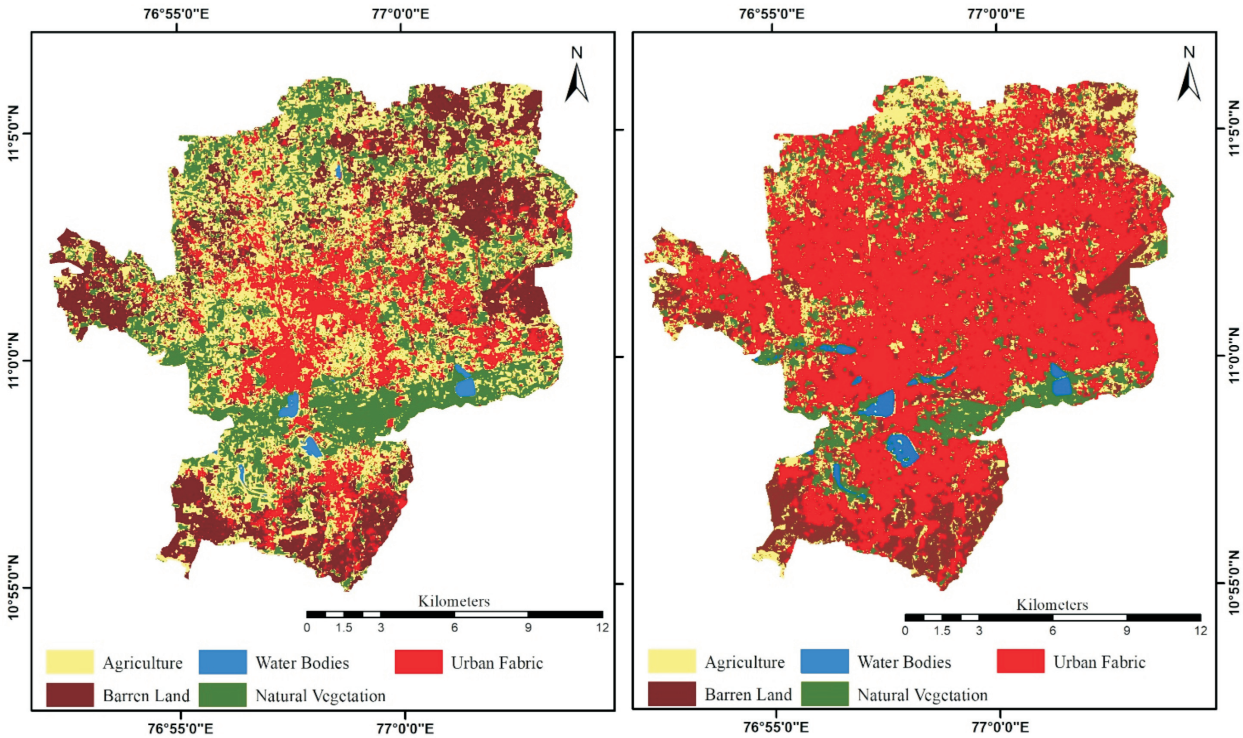

Fig. 4. Land Use/Land Cover classification of Coimbatore city

Table 4. Land Use/Cover change between 2000 and 2019

Land Use/Cover	Area in km²		Change in the area (%)
	2000	2019	
Agriculture	87.36	35.10	-59.82
Water Bodies	1.88	3.59	47.63
Urban Fabric	42.71	149.14	249.49
Natural Vegetation	62.69	32.37	-48.37
Barren Land	65.22	39.66	-39.19

vehicles are occupying the roads of Coimbatore. More than a fivefold increase in the vehicle's population was noticed during the period 2001-2018. As of March 2018, the total number of registered vehicles has grown to more than 24 lakhs, out of which 81.71% contributed by two-wheelers, followed by cars, Jeeps, and Taxis (15.85%).

Discussion

Air pollution has become more aggravating in India due to augmented developmental activities—industrial development, growing cities, swelling road traffic, economic development, and higher consumption of fossil fuel-based energy (Gurjar *et al.*, 2018). In this study, 24-h PM concentrations were well within the limit (100 µg m^{-3} and 60 µg m^{-3} 24-h average for PM_{10} and $PM_{2.5}$) of National Ambient Air Quality Standards (CPCB, 2009) as specified by Central Pollution Control Board, India. However, compared with WHO air-quality guidelines (50 µg m^{-3} and 25 µg m^{-3} 24-h average for PM_{10} and $PM_{2.5}$), the observed values are much higher. The concentration of PM fractions will be varied from place to place, depending on the geographical region, land use type, sources, and metrological parameters. The results showed that the maximum concentration of particulate matter (PM_{10} and $PM_{2.5}$) was higher in the industrial site, followed by commercial and urban-industrial sites. Upstretched PM concentrations in the Gandhipuram and Kavundampalayam are related to the increased transport and road dust re-suspension during the vacation period. Further dust emissions from bridge construction activities also considerably contribute to the total emission load. Apart from the sources, a stable atmosphere may also be why this increased ambient PM concentration. In contrast, vehicles and other anthropogenic activities are the primary cause of pollution load in the Selvapuram region.

The observations highlighted in Fig. 2 show the clear pattern of the seasonal influence on concentrations of PM_{10} and $PM_{2.5\text{-}10}$ mass. As anticipated, our observations exhibited higher concentrations of PM_{10} and $PM_{2.5\text{-}10}$ during the winter season. This seasonal variation could be attributed to the synergistic effects of variations in emission rates as well as climatic conditions. It is quite a surprise to find that the mean level of $PM_{2.5}$ in the summer was slightly higher than in the winter. Elevated temperature, greater turbulence, and unstable atmospheric condition during summer encourage re-suspension, and higher residence time of fine dust particles could be the possible reason for this. As shown in Fig. 2, re-

Table 5. Reports on Particulate matter pollution in Coimbatore

Locations	Period	PM10 (µg m^{-3})	PM2.5 (µg m^{-3})	Reference
Gandhipuram	July 2018 -June 2019	69.99	42.31	Present Study
Kavundampalayam		69.09	42.53	
PSG CAS		51.59	33.19	
Selvapuram		68.39	41.21	
SIDCO		81.17	51.89	
Overall		68.05	42.23	
Coimbatore	2018	54	32	CPCB
Poniarajapuram	2017	48	32	
G.D.Matric Hr.Sec.School		43	31	
SIDCO Office/ Kurichi		56	38	
Poniarajapuram	2016	53	33	
G.D.Matric Hr.Sec.School		51	28	
SIDCO Office/ Kurichi		74	44	
Coimbatore	2016	-	26	Guttikunda *et al.*, 2019
Poniarajapuram	2015	47	28	CPCB
G.D.Matric Hr.Sec.School		42	27	
SIDCO Office / Kurichi		52	36	
Townhall	December 2013 -	73.6	42.3	Manju *et al.*, 2018
Gandhipuram	November 2014	65.5	27.6	
Thudiyalur		73.1	41.2	
Ganapathy		70.2	38.9	
SITRA		71.9	33.7	
DB Road		68.5	34.6	
Thekkalur		98.7	56.9	
Sundharapuram		92.4	48.8	
Coimbatore	2011-2015	62.5	-	Guttikunda *et al.*, 2019
SIDCO	March 2009 -February 2010	-	92	Mohanraj *et al.*, 2012
Kuniyamuthur		-	58	
KavundamPalayam		-	90	
100 Feet Road		-	60	
Lakshmi mills		-	80	
Railway station	March 1999 –February 2001	84.24	-	Mohanraj and Azeez, 2005
Gandhipuram		84.4	-	
Saibaba colony		59.7	-	
SIDCO		77.37	-	
Peelamedu		71.3	-	
Kuniyamuthur		51.73	-	
Coimbatore	1998	-	14.1	Guttikunda *et al.*, 2019

spirable and fine dust particle concentration was lower during the monsoon season than in the winter and summer seasons. This could be attributed to the rapid dispersal due to higher wind speed as well as the wet deposition of dust particles during monsoon. Generally, precipitation leads to removing particles from the atmosphere due to the washout effect (Morawska *et al*., 2008). Numerous studies reported that mean PM concentration tends to be higher in winter seasons, in which the ventilation capability is lower, owing to low temperatures, high relative humidity, and decreased atmospheric mixing height (Kulshrestha *et al*., 2009; Saxena *et al*., 2017). Similar observations were recorded by studies conducted in Agra (Kulshrestha *et al*., 2009) and Chennai (Srimuruganandam and Shiva Nagendra, 2010).

$PM_{2.5}$ and PM_{10} levels were at the peak in the industrial site in all the seasons. In contrast to other study sites, the PM_{10} levels were nearly equal during winter and summer in SIDCO, which may be due to the continual vehicular emission from the nearby roads and the emissions from surrounding industries. Reduction $PM_{2.5}$ and PM_{10} were observed all over the city during SW and NE monsoon seasons. A comparative diminution of PM during monsoon periods results from the washout of air pollutants due to precipitation. Nevertheless, a different trend was observed in the Kavundampalayam site in the case of PM_{10} measurement. Relatively, a higher concentration of PM10 was recorded in NE monsoon (88.53 µg m^{-3}) than winter (79.93 µg m^{-3}) and summer (59.24 µg m^{-3}). This irregular drift may be due to a lack of rainfall and road construction activities nearby sampling sites.

Compared with previous observations (Table 5), the values were much lower for $PM_{2.5}$ concentrations concerning those reported by Mohanraj *et al.* (2012) for Coimbatore from March 2009 to February 2010. Noticeably, fine and coarse particulate load at the mixed site (PSG CAS) is significantly lower than the other sites during the study period. The monthly average concentration of coarse particulate matter ranged from 16.40 to 79.55 µg m^{-3}, with an annual average of 51.59 µg m^{-3}. The particulate matter concentrations found in the present observation were substantially higher than earlier observations by CPCB and Guttikunda *et al.* (2019). The concentration of coarse particles was 68.05 µg m^{-3} during the study period, which was slightly higher than the average value reported by Guttikunda *et al.* (2019) as 62.5 µg m^{-3} for the period 2011-2015. Data published

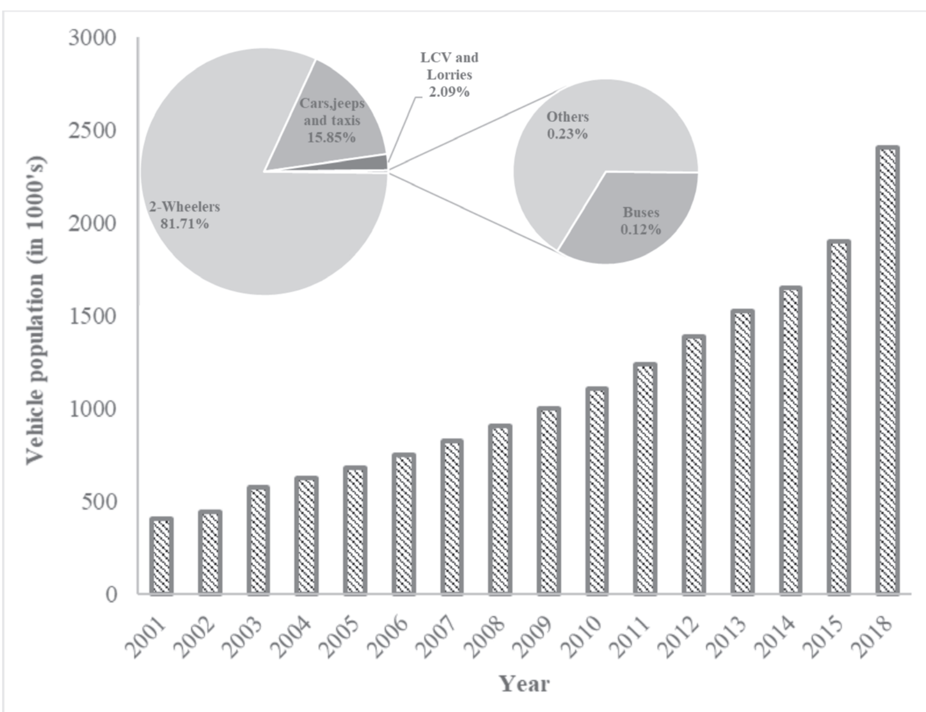

Fig. 5. Growth of automobile population between 2001-2018 in Coimbatore

by CPCB based on the results obtained from manual air quality monitoring stations shows that the annual average concentrations of PM_{10} and $PM_{2.5}$ were 54 and 32 µg m^{-3} in 2018 (Table 5).

Urban growth is interrelated with economic development, population growth, and the surrounding environment. The changes in the land cover patterns affect the microclimatic and environmental conditions of the area. The findings of the current study suggested that the Coimbatore city's urban fabrication has attained rapid growth in the last two decades, whereas the area concealed under agricultural and natural vegetation was declining faster (Table 4). It was noteworthy that the area under urban settlements has shown about 249% of growth in the last two decades, which ultimately results in the aggregation of the human population, transport vehicles, commercial and industrial sectors around and within a smaller area.

Moreover, the impact of urbanization can be better explained by the $PM_{2.5}/PM_{10}$ ratios presented in Table 3. Concerning the overall measured values, $PM_{2.5}$ makes up the majority of $PM_{10.}$ Generally, fine particulate matter deposit very slowly and has a long atmospheric lifetime. Whereas coarse particles deposit relatively quickly with an atmospheric lifetime of less than two days. Hence, $PM_{2.5}$ accounts for most of the suspended particulate matter in the atmosphere (Brook *et al.*, 2003). The ratio of $PM_{2.5}/PM_{10}$ is directly dependent on traffic emissions and turbulence. The contribution by re-suspension of coarse road dust during the vehicle movement was significantly higher for coarse particles than the fine particulate matter (Ketzel *et al.*, 2007; Srivastava *et al.*, 2008). For instance, Querol *et al.* (2001) have shown that the $PM_{2.5}/PM_{10}$ ratios were 0.60-0.65 during traffic hours and about 0.75-0.85 during non-traffic hours.

Similarly, a study by Tiwari *et al.* (2009) in the urban site of New Delhi observed that the $PM_{2.5}/PM_{10}$ ratio in June month was 0.18 due to the dominance of natural mineral dust. In contrast, in February, it was found to be 0.86 due to fine particle's anthropogenic emissions. In the present investigation, the $PM_{2.5}/PM_{10}$ was lowest (0.59 ± 0.19) in the residential site, which implies that the coarse particles, primarily due to road dust re-suspension and biomass burning, are the primary contributor. Whereas the same was ranged between 0.62-0.65 in the Commercial, Urban-industrial, Mixed and Industrial sites where traffic exhaust and industries are the prime pollution sources impacting air quality.

Observations of this study showed the dominance of industrial and vehicle exhaust emissions in the PM concentrations of Coimbatore city. About 14,100 and 23,900 tons of $PM_{2.5}$ and PM_{10} particles were emitted in 2015, out of which transport-related sources directly contribute about 18.3% of the total $PM_{2.5}$ emissions. Furthermore, on-road re-suspension and construction activities account for another 13.7% of $PM_{2.5}$ emissions (Guttikunda *et al.*, 2019), and it was expected that the share of transport and on-road dust might reach up to 19% and 16%, correspondingly, by the year 2030 (APnA, 2017).

Conclusion

One-year ambient respirable (PM_{10}) and fine ($PM_{2.5}$) particulate matter pollution monitoring studies conducted in Coimbatore city have outlined the inducement effect of the urbanization and transport sector on the particulate concentrations. Our study results suggested that the pollution associated with particulate matter is a serious and widespread concern in urban areas of Coimbatore. The overall average concentration of PM_{10} (68.05 µg m^{-3}) and $PM_{2.5}$ (42.23 µg m^{-3}) concentrations observed during the measurement period was found to be exceeding the annual NAAQS standard limit. As regards spatial distribution, a different pattern among and within sampling sites was observed, and the monthly average patterns of PM_{10} and $PM_{2.5}$ show an apparent seasonal variation. It was evident from this study that the particulate matter concentrations remained at a higher level when compared with previous studies. The annual average ratio of $PM_{2.5}/PM_{10}$ was 0.63, indicated that vehicular emissions are the prime source of airborne aerosols. Meanwhile, urban buildup increased rapidly from 16.43 to 57.39% between 2000 and 2019, and a fivefold increase in the vehicle population was noticed in the same period. Given these linkages, the expected growth of urban space and the number of automobiles becomes a severe challenge, leading to increased PM to a harmful level.

References

Aldabe, J., Elustondo, D., Santamaría, C., Lasheras, E., Pandolfi, M., Alastuey, A. and Santamaría, J. M. 2011. Chemical characterisation and source apportionment of $PM_{2.5}$ and PM_{10} at rural, urban and traffic sites in Navarra (North of Spain). *Atmospheric Research*. 102(1-2) : 191-205.

APnA. 2017. The Air Pollution Knowledge Assessment (APnA) City Program. Retrieved November 27, 2020, from http://www.urbanemissions.info/india-apna/coimbatore-india/

Balakrishnan, K., Dey, S., Gupta, T., Dhaliwal, R. S., Brauer, M., Cohen, A. J. and Sabde, Y. 2019. The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study 2017. *The Lancet Planetary Health.* 3(1): e26-e39.

Breitner, S., Peters, A., Zareba, W., Hampel, R., Oakes, D., Wiltshire, J. and Kane, C. 2019. Ambient and controlled exposures to particulate air pollution and acute changes in heart rate variability and repolarization. *Scientific Reports*. 9(1): 1-12.

Brook, R. D., Brook, J. R. and Rajagopalan, S. 2003. Air pollution: the" Heart" of the problem. *Current hypertension reports*. 5(1) : 32-39.

Cai, Y., Hansell, A. L., Blangiardo, M., Burton, P. R., BioSHaRE, De Hoogh, K. and Mbatchou, S. 2017. Long-term exposure to road traffic noise, ambient air pollution, and cardiovascular risk factors in the HUNT and lifelines cohorts. *European Heart Journal*. 38(29): 2290-2296.

CPCB. Selected State/City/Location-wise Status of Ambient Air Quality (Annual Average) under National Air Quality Monitoring Programme (NAMP) in India (2015-2018). Retrieved January 6, 2021, from https://www.indiastat.com/table/environment-and-pollution-data/11/air-pollution/45/1031988/data.aspx

CPCB. 2009. National Ambient Air Quality Standards. *Central Pollution Control Board, Government of India.* 1–4.

Guo, H., Kota, S. H., Chen, K., Sahu, S. K., Hu, J., Ying, Q. and Zhang, H. 2018. Source contributions and potential reductions to health effects of particulate matter in India. *Atmospheric Chemistry and Physics*. 18(20) : 15219-15229.

Gurjar, B. R., Ohara, T., Khare, M., Kulshrestha, P., Tyagi, V. and Nagpure, A. S. 2018. South Asian Perspective: A Case of Urban Air Pollution and Potential for Climate Co-benefits in India. In *Mainstreaming Climate Co-Benefits in Indian Cities*. (pp. 77-98). Springer, Singapore.

Guttikunda, S. K., Nishadh, K. A. and Jawahar, P. 2019. Urban Climate Air pollution knowledge assessments (APnA) for 20 Indian cities. *Urban Climate*. 27(August 2018) : 124–141.

Hsiao, W. W., Mo, Z. Y., Fang, M., Shi, X. M. and Wang, F. 2000. Cytotoxicity of $PM_{2.5}$ and $PM_{2.5-10}$ ambient air pollutants assessed by the MTT and the Comet assays. *Mutation Research/Genetic Toxicology and Environmental Mutagenesis.* 471(1-2): 45-55.

Ketzel, M., Omstedt, G., Johansson, C., Düring, I., Pohjola, M., Oettl, D. and Berkowicz, R. 2007. Estimation and validation of $PM_{2.5}/PM_{10}$ exhaust and non-exhaust emission factors for practical street pollution modelling. *Atmospheric Environment*. 41(40): 9370-9385.

Kulshrestha, A., Satsangi, P. G., Masih, J. and Taneja, A. 2009. Metal concentration of $PM_{2.5}$ and PM_{10} particles and seasonal variations in urban and rural environment of Agra, India. *Science of the Total Environment.* 407(24) : 6196-6204.

Kurt, O. K., Zhang, J. and Pinkerton, K. E. 2016. Pulmonary health effects of air pollution. *Current Opinion in Pulmonary Medicine*. 22(2) : 138.

Manju, A., Kalaiselvi, K., Dhananjayan, V., Palanivel, M., Banupriya, G. S., Vidhya, M.H. and Ravichandran, B. 2018. Spatio-seasonal variation in ambient air pollutants and influence of meteorological factors in Coimbatore, Southern India. *Air Quality, Atmosphere and Health*. 11(10) : 1179-1189.

Mohanraj, R. and Azeez, P. A. 2005. Urban development and particulate air pollution in Coimbatore city, India. *International Journal of Environmental Studies*. 62(1) : 69-78.

Mohanraj, R., Dhanakumar, S. and Solaraj, G. 2012. Polycyclic aromatic hydrocarbons bound to $PM_{2.5}$ in urban Coimbatore, India with emphasis on source apportionment. *The Scientific World Journal*. 2012.

Morawska, L., Ristovski, Z., Jayaratne, E. R., Keogh, D. U. and Ling, X. 2008. Ambient nano and ultrafine particles from motor vehicle emissions: Characteristics, ambient processing and implications on human exposure. *Atmospheric Environment.* 42(35): 8113-8138.

MoRTH. 2017. Category-wise Total Number of Registered Motor Vehicles in Million Plus Cities of India (As on 31.03.2018). Retrieved January 8, 2018, from https://www.indiastat.com/transport/30/registeredvehicles/16443/registeredmotorvehiclesinmetropolitancities19962015/452565/stats.aspx

Mutlu, E. A., Comba, I. Y., Cho, T., Engen, P. A., Yazýcý, C., Soberanes, S. and Budinger, G. S. 2018. Inhalational exposure to particulate matter air pollution alters the composition of the gut microbiome. *Environmental Pollution*. 240 : 817-830.

Parrish, D. and Stockwell, W. 2015. urbanization and air pollution: Then and now, Eos, 96, doi:10.1029/2015EO021803.

Querol, X., Alastuey, A., Rodriguez, S., Plana, F., Ruiz, C. R., Cots, N. and Puig, O. 2001. PM_{10} and $PM_{2.5}$ source apportionment in the Barcelona Metropolitan area, Catalonia, Spain. *Atmospheric Environment.* 35(36) : 6407-6419.

Saxena, M., Sharma, A., Sen, A., Saxena, P., Mandal, T. K., Sharma, S. K. and Sharma, C. 2017. Water-soluble inorganic species of PM_{10} and $PM_{2.5}$ at an urban site of Delhi, India: seasonal variability and sources. *Atmospheric Research.* 184 : 112-125.

Srimuruganandam, B. and Nagendra, S. M. S. 2010. Analysis and interpretation of particulate matter–PM_{10}, $PM_{2.5}$ and PM_1 emissions from the heterogeneous traffic near an urban roadway. *Atmospheric Pollution Research*. 1(3): 184-194.

Srivastava, A., Gupta, S. and Jain, V. K. 2008. Source apportionment of total suspended particulate matter in coarse and fine size ranges over Delhi. *Aerosol Air Qual. Res*. 8(2): 188-200.

Tiwari, S., Srivastava, A. K., Bisht, D. S., Bano, T., Singh, S., Behura, S. and Padmanabhamurty, B. 2009. Black carbon and chemical characteristics of PM_{10} and $PM_{2.5}$ at an urban site of North India. *Journal of Atmospheric Chemistry*. 62(3): 193-209.

United Nations. 2014. World's population increasingly urban with more than half living in urban areas. *Department of Economic and Social Affairs*, pp. 2014–2016. Retrieved from https://www.un.org/en/development/desa/news/population/world-urbanization-prospects.html

Wang, Q., Kwan, M. P., Zhou, K., Fan, J., Wang, Y. and Zhan, D. 2019. The impacts of urbanization on fine particulate matter ($PM_{2.5}$) concentrations: Empirical evidence from 135 countries worldwide. *Environmental pollution*. 247: 989-998.

Wang, S., Gao, S., Li, S. and Feng, K. 2020. Strategizing the relation between urbanization and air pollution: empirical evidence from global countries. *Journal of Cleaner Production.* 243 : 118615.

WHO. 2016. WHO's Urban Ambient Air Pollution database-Update 2016. *World Health Organization*.1–7. https://doi.org//entity/phe/health_topics/outdoorair/databases/cities/en/index.html