Report on

Diurnal, Monthly and Annual Variations in Ambient Air Quality in Delhi during 2019

EnviroVigyan

By-

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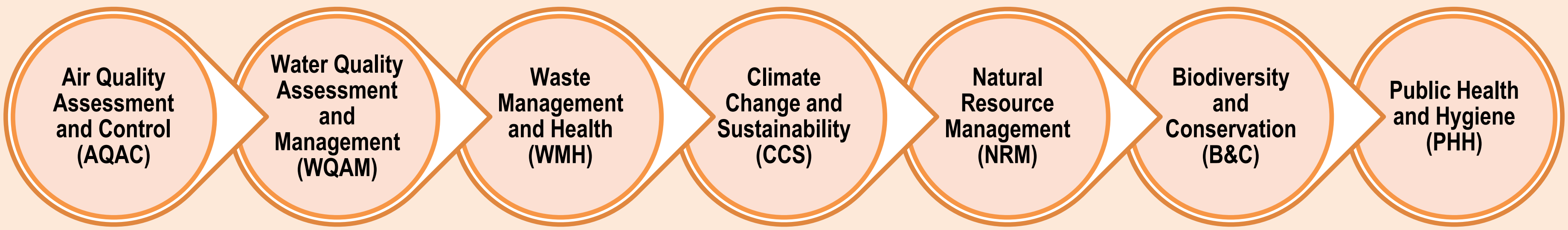
About EnviroVigyan

EnviroVigyan is a registered not-for- profit, non-government organization (NGO), founded by Dr. Anchal Garg in the year 2021. The scientific activities of this organization are supported by a dedicated team of experts drawn from academia and research institutions. The self-motivated dynamic group of experts works in multi-disciplinary areas of societal importance covering different issues of environmental concern. The research, training, and awareness programme focus on the thematic areas ranging from air pollution, waste management, water and sanitation, to climate change, ecosystem restoration, and associated public health.



About Authors

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Dr. Anchal Garg: Dr. Anchal Garg is the Founder at EnviroVigyan since 2021. She is a researcher, consultant, activist, and educator in the field of Environment Management. She completed her Ph.D. in Environmental Sciences (with specialization on Air Pollution Monitoring, Health Risks, and Management) from GGS Indraprastha University. She carried out extensive research on air pollution and its negative implications on climate change and human health. She has expertise of working on monitoring, mapping, emission inventory, and identifying health hazards of Volatile Organic Compounds, Polycyclic Aromatic Hydrocarbons and Particulate Matter. She is Gold Medalist in M.Sc. Environment Management from GGS Indraprastha University. She obtained her B.Sc. in Life Sciences from Hansraj College, University of Delhi, and B.Ed. from Maharshi Dayanand University. She is also DST-INSPIRE Awardee and part of Indian delegation in BRICS Young Scientist Forum-2019 held at Rio de Janeiro, Brazil. She has published 14 research papers in peer-reviewed national and international journals. She has also participated and awarded for her best presentations in various national and international conferences and workshops. She also got the opportunity for being the part of youngest scientific expert for SCO Young Scientist Conclave and Core Member of SCO Forum.

Executive Summary

Ambient air pollution consists of various pollutants including gaseous and particulate matter that are discussed in detail in this report. Delhi's air is always coming into highlights due to its poor quality. In this report, measurements of hourly and daily air quality for various air pollutants ($PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, C_6H_6*) were analyzed for different locations in Delhi divided on the basis of lying in the region of North, West, East, South and Central Delhi. Delhi's air quality data and meteorological data has been analyzed from 1 January, 2019 - 31 January, 2019. Overall study is divided into 3 sub topics - finding out the levels of gaseous and particulate pollutant in Delhi's ambient air, assessing seasonal and diurnal variations in air pollution and identifying the effect of meteorological parameters on air quality.*

The findings shows that East Delhi recorded the highest monthly concentration levels for $PM_{2.5}$*,* PM_{10}*,* NO_2 *and* C_6H_6*. Peaks for* $PM_{2.5}$ *and* PM_{10} *were observed in the month of November and exceeded the National Ambient Air Quality Standards (NAAQS) for most part of the year excluding the months of monsoon season. Peak for* NO_2 *was observed in the month of December.* SO_2 *and* O_3 *levels were always found below their NAAQS. The correlation matrix showed that* $PM_{2.5}$ *and* PM_{10} *possessed a strong positive correlation of +0.88. Negative correlation between air pollutants with ambient temperature and wind speed shows the role of meteorology in the seasonal variation in air pollutants. Through this entire study, we have identified that pollutant levels were not higher throughout year, there are some months when the levels were lower, for example during monsoon season, precipitation occurs and it does not allow the pollutants to rise high up in the air, wind speed is also higher and stronger during monsoon which disperses the pollutants.*

INTRODUCTION

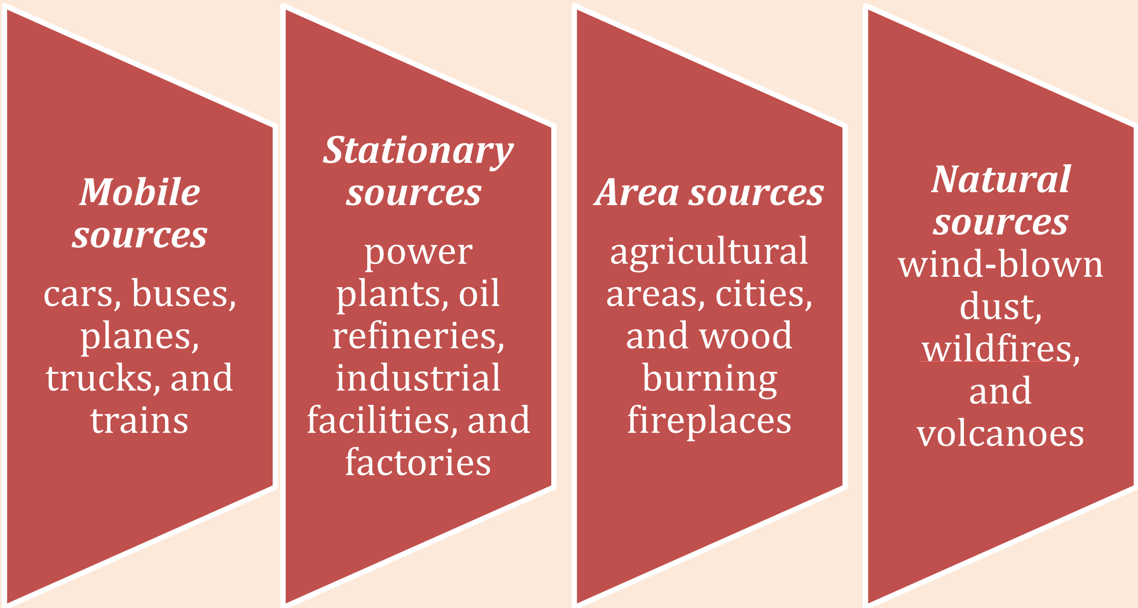
Ambient air pollution (AAP) is a broader term used to define air pollution in outdoor environments. From smog hanging over cities to smoke inside the home, air pollution poses a major threat to health across the globe. While AAP affects developed and developing countries alike, low - and middle-income countries experience the highest burden, with the greatest toll in the WHO Western Pacific and South-East Asia regions. Air pollution in India alone is estimated to kill about 2 million people every year.

Outdoor air pollution originates from natural and anthropogenic means. While natural sources contribute substantially to local air pollution, the contribution from human activities far exceeds natural sources. Burning of fossil fuels, construction and demolition, industrial emissions are some of the leading causes for the same.

WHO states that ambient air pollution accounts for an estimated deaths of 4.2 million per year due to stroke, lung cancer and cardiovascular diseases. It also says that 91% of the population lives in places where the air quality exceeds WHO limits. Pollution burden on air in Delhi has been increasing over years due to rapid urbanization and industrialization. On 25 November 2019, the Supreme Court of India made statements on the pollution in Delhi saying "Delhi has become worse than **narak (hell)".** Supreme Court Justice Arun Mishra said that it is better to get explosives and kill everyone. Being the center of international politics, trade, culture, and literature in India, Delhi is one of the largest metropolises in the country and the world.

Importance of healthy air: Air quality is a measure of the suitability of air for breathing by people, plants and animals. On average, a person inhales about 14,000 liters of air every day. Therefore, poor air quality may affect the quality of life now and for future generations by affecting the health, the environment, the economy and the city's livability (CPCB, 2020). Good air quality can provide complementary support for ambitious climate action as air pollutants are known to influence global and local temperature changes and, regional precipitation directly and indirectly.

Sources of Air Pollution: Natural sources of air pollution include volcanic activity, dust, sea-salt, forest fires, lightening, soil out gassing etc. Anthropogenic sources include stationary point sources (e.g., emission from industries), mobile sources (e.g., vehicular emission, marine vessels, airplanes etc.), waste disposal landfills, open burning etc. Common sources of ambient air pollution include combustions from vehicles, solid fuel burning, windblown dusts and industries.



Sources of air pollution unique to Delhi include dust generation during building construction, ash generation from thermal power plants, crop residue burning in neighboring states and burning of fossil fuels for domestic, as well as small scale, industrial use (Khilnani et al., 2014). Major sources of AAP in Delhi include diesel generators and tandoors in restaurants, combustion of fuels (coal, liquefied petroleum gas, and wood) and power plants. Increased combustion of fossils fuel is mainly responsible for the continuous change in the atmospheric composition (Gorai et al., 2018).

“Among all the studied pollutants in Delhi, high levels of particulate matter (PM_{10} and $PM_{2.5}$) and Nitrogen Di-oxide are the pollutants having concentration much higher than their prescribed air quality standard values.”

A 2016 study by IIT-Kanpur found that vehicular emissions contribute to around 9% of the PM10 load and around 20% of the $PM_{2.5}$ load in the national capital. The reasons for this may include high number of vehicles and comparatively higher population in Delhi. According to Dipankar Saha, Former Head of the Central Pollution Control Board’s (CPCB) air quality lab, “The emissions, such as CO_2, are released due to unburnt hydrocarbons. This happens because of various factors such as vehicle speed not being maintained, overloaded heavy-duty vehicles, poor roads and poor management of traffic.”

According to Centre of Science and Environment study, cars emit more $PM_{2.5}$ than several other key pollution sources in Delhi. If cars are estimated to emit 2-3% and diesel cars 1.6% of $PM_{2.5}$ from all sources then cars according to IIT Kanpur report emit equal or more than what solid waste burning (3%), hotel and restaurants (3%), industrial area (2%), C&D waste (2%) and diesel generator sets (2%) emit individually.

Cars also emit more NOx than several other key pollution sources in Delhi. Vehicles at 36% are the second largest contributor to NOx. Only cars emit 6.1% of the total NOx from all sources. This is equal to the third largest contributor of NOx which is diesel generator sets at 6%. The rest including domestic sources (2%), industrial areas (1%), hotels and restaurants (less than 1%), and medical incinerators (less than 1%), emit significantly less than cars. This clearly brings out that Delhi cannot meet its clean air objective if stringent action is not taken on cars.

Day to day variations in pollutant levels at a given location are dictated primarily by changes in the prevailing weather conditions, since day to day changes in emissions are small except for the weekday/weekend differences. When emissions from all sectors are reduced on a regional basis, there is less pollution transported by the prevailing winds from one day to the next. Increased combustion of fossil fuels is responsible for continuous change in atmospheric composition. The size of particles is directly linked to their potential for causing health problems. Small particles less than 2.5 µm in diameter pose the greatest problems because they can get deep into your lungs, and some may even get into your bloodstream. Air pollution data with high spatial and temporal resolution are needed to accurately evaluate the health risks associated with air pollutant exposure.

Change in air quality occurs, especially in urban areas in response to local conditions and dispersion of air pollutants - regional and long rang as well. While air quality is slowly improving in the developed countries, it is rapidly deteriorating in developing countries due to rapid industrialization and increased vehicular traffic (Manju et al., 2018).

"Increased level of air pollutants in urban area is responsible for deficits in pulmonary functions, cardiovascular disease, neurobehavioral effects, and mortality."

While many air pollutants are associated with significant health impacts, O_3, carbon monoxide, sulfur dioxides, and $PM_{2.5}$ are the most studied and commonly used as proxy indicator of exposure to air pollution (WHO, 2005). Scientific reports indicate that excessive exposure to high PM concentrations reduces the expected human lifespan by 1 - 5.5 years. (Huang et al., 2018)

Outdoor suspended particulate matter (SPM) is considered to be the most serious pollutant in metropolitan areas, in view of its adverse health effects as a cause of cardiovascular disease, respiratory irritation, and pulmonary dysfunction.

In addition, biological components such as allergens and microbial compounds are also found. These particles vary in size, composition and origin. Particulate matter with diameter 10 µm can easily penetrate the lung tract and is considered to be the most dangerous pollutant in the urbanized world.

Table 1. Few Studies carried out on Ambient Air Pollution

Study	Study area	Study findings
Gorai et al., 2018	Delhi	Air quality level was worst during winter months (October to January). Most of the area had the moderate to very unhealthy category of $PM_{2.5}$ AQI.
Peshin et al., 2017	Delhi - NCR	O_3 buildup begins when fresh air masses come into the polluted domain and is accumulated during 1-3 days, producing O_3 through photo oxidation processes. Study found out that large scale anthropogenic emissions in the surrounding regions had the strongest influence on O_3 production within the study site.
Das et al., 2021	Delhi, India	Meteorological parameters had close associations with PM concentrations due to lockdown and unlock phases during Covid - 19.
Manju et al., 2018	Coimbatore, Tamil Nadu	PM_{10}, $PM_{2.5}$, and CO were the most serious pollutants. The level of PM_{10}, $PM_{2.5}$, and CO concentrations exceeded the National Ambient Air Quality Standards.
Dadhich et al., 2018	Jaipur, Rajasthan	Concentrations of the air pollutants were high in winter and summer in comparison to the monsoon.
Tella et al., 2021	Malaysia	Temperature, wind speed, and humidity identified as the most critical variables influencing PM_{10} concentration in the study area, in descending order of importance.
Bodor et al., 2020	Transylvania, Romania	Pollutants show lower concentrations during warmer periods, especially during summer, and significantly higher concentrations observed on heating season in winter due to seasonal variations in energy use (biomass burning) and atmospheric stability.
Huang et al., 2018	Beijing, China	Results demonstrate that the deterioration of $PM_{2.5}$ concentration in 2015 is closely related to a set of critical impact factors, including population density, urbanization rate, road freight volume, secondary industry gross domestic product, overall energy consumption and industrial pollutants, such as steel production and volume of sulphur dioxide emission, which are ranked in terms of their contributing powers.
Liu et al., 2021	Germany	Back Propagation Neural Network Model showed that CO and temperature had the greater correlations with $PM_{2.5}$ and PM_{10}. $PM_{2.5}$ and PM_{10} showed a strong positive

		correlation, suggesting that the reduction of $PM_{2.5}$ is essential for reducing PM pollution and enhancing air quality in Germany.
Song et al., 2019	China	Order of traffic-related pollutant emissions was expressway > business zone > industrial zone > residential zone > port. Cars and motorcycles represented the major source of traffic-related pollutant emissions.
Borge et al., 2016	Spain	Analysis of the results showed that the high concentration levels found in urban hotspots depended on extremely complex dynamic processes that cannot be captured by routinely measurements made by air quality monitoring stations used for regulatory compliance assessment. The large influence from local traffic in the concentration fields highlights the need for a detailed description of specific variables that determine emissions and dispersion at micro scale level.
Kuerban et al., 2020	China	Concentrations were generally higher in the north of the country than in the south. In all regions of China, the pollutant level were highest in winter and lowest in summer, except for O_3, which showed an opposite seasonal pattern. Overall, the seasonal mean concentrations of all the pollutants (except for O_3) significantly decreased between the same seasons in 2018 and 2015.

About Criteria Air Pollutants: Criteria pollutants are a group of air pollutants which are responsible for causing smog, acid rain and other serious health hazards. These pollutants are usually of anthropogenic origin, especially industrial emissions, mining, transportation, electricity generation etc. In majority of the cases, these pollutants originate as a result of the combustion from fossil fuels and industrial processes.

Table 2 Criteria Air Pollutants: its Sources and Effects

Criteria pollutant	Natural sources	Anthropogenic sources	Health effects	Environmental effects
Sulfur oxides (SO_X)	Volcanic emissions	Burning of fossil fuels, metal smelting, petroleum refining etc	Respiratory problems, heart and lung disorders, visual impairment	Acid rain
Nitrogen oxides (NO_X)	Lightning, forest fires etc.	Burning of fossil fuels, biomass and high temperature combustion processes	Pulmonary disorders, increased susceptibility to respiratory infections	Precursor of ozone formation in troposphere, aerosol formation
Particulate matter (PM)	Windblown dust, pollen spores, photo chemically produced particles	Vehicular emissions, industrial combustion processes, commercial and residential combustion, construction industries	Respiratory problems, liver fibrosis, lung/liver cancer, heart stroke, bone problems	Visibility reduction
Carbon monoxide (CO)	Animal metabolism, forest fires, volcanic activity	Burning of carbonaceous fuels, emission from IC engines	Anoxemia leading to various cardiovascular problems. Infants, pregnant women, and elderly people are at higher risk	
Ozone (O_3)	Present in stratosphere at 10-50 km height	Hydrocarbons and NO_X upon reacting with sunlight results in O_3 formation	Respiratory problems, asthma, bronchitis etc.	O_3 in upper troposphere causes greenhouse effects, harmful effects on plants as it interferes in photosynthesis and results in death of plant tissues.
Lead (Pb)		Metal processing plants, waste incineration, automobile exhausts, lead-acid batteries, industrial effluents etc.	Serious effects on central nervous system since it is absorbed rapidly in blood stream, anemia, toxic for soft tissues and bones	

STUDY AREA

Delhi is a city and a union territory of India containing New Delhi, the capital of India. The NCT covers an area of 1,484 square kilometers (573 sq mi). Delhi is one of the oldest cities in the world and has been continuously inhabited since the 6th century BCE. Coordinates of Delhi are 28.7041° N, 77.1025° E. Delhi is jointly administered by the Central and State Government. According to World Health Organization report 2014, One of the country's largest urban agglomerations, Delhi sits astride (but primarily on the west bank of) the Yamuna River, a tributary of the Ganges (Ganga) River, about 100 miles (160 km) south of the Himalayas. The national capital territory embraces Old and New Delhi and the surrounding metropolitan region, as well as adjacent rural areas. To the east the territory is bounded by the state of Uttar Pradesh, and to the north, west, and south it is bounded by the state of Haryana.

Vehicular Growth in Delhi: Increase in number of vehicles in Delhi is far faster than construction of roads. (Economic survey of Delhi, 2020). Tremendous increase of vehicles is a predominant cause of air pollution in Delhi. Road transport in India plays an important role in movement of passengers and transport of goods. Vehicular emissions depend on age of vehicle, emission rate of different vehicle categories. With deteriorating mass transport services and increasing personalized motor vehicle use, vehicular emission is assuming serious dimensions in most Indian cities. Nearly 20% of passenger transport emission is by private automobiles although they only contribute 4% total passenger transport activity in Indian cities (Solanki et al., 2016).

Table 3: Types of registered vehicles in Delhi (Delhi statistical handbook, 2020)

Type of vehicle	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020
Cars and Jeeps	2986579	3152710	3246637	3249670	3311579
Motor Cycles & Scooters/ 2 wheelers	6104070	6607879	7078428	7556002	7959753
Ambulances	2990	3059	3220	2358	2287
Auto Rickshaws (Passenger)	198137	105399	113074	113240	114891
Taxies	91073	118308	118060	109780	122476
Buses	34365	35206	35285	32218	33302
Other Passenger Vehicles	6368	59759	76231	81422	85477
Tractors, Good vehicles, Others	281159	300437	315080	246861	263112

Forest Cover in Delhi: As per the Champion & Seth Classification of Forest Types (1968), the forests in Delhi belong to the Type Group 5, Tropical Dry Deciduous Forest and Type Group 6 Tropical Thorn Forests. Around 67.35% of the total forest cover comes under plantation and 32.65% constitute the natural forest, which covers 57.67 sq km of Delhi's forests. Forest department under the Government of Delhi supervises and monitors various activities such as distribution of seedlings to public, government departments & institutions, plantations on gram sabha lands, along the roads, ridge area, river banks, railway lines etc. To promote the tree plantation activity as a mass campaign and to encourage participation of Residential Welfare Associations, Civil Society, Government organizations, educational institutions etc, the Government of NCT of Delhi, carries out the 'Greening Delhi Campaign' every year (FSI, 2019).

Data Collection: For this study, the zones covered are- North Delhi, East Delhi, West Delhi, South Delhi, and Central Delhi.

The data has been acquired for three monitoring stations per zone. 1 hour and 24 hours daily average concentrations of six pollutants namely $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, C_6H_6 and 24 hour daily average value of various meteorological parameters like wind speed, wind direction, solar radiation, relative humidity and air temperature were downloaded for one complete year from January 1, 2019 to December 31, 2019 from Continuous Ambient Air Quality Monitoring Stations (CAAQMS) of CPCB.

RESULTS

Automatic monitoring was done for recording levels of gaseous and particulate matter pollutants in Delhi's ambient air from 1 Jan, 2019 to 31 Dec, 2019 at different monitoring stations in north, east, west, south and central Delhi. The data analysis includes representation of 3 sites per district. In this manner, the current analysis is the representation of a total of 15 sites of Delhi. The data was retrieved on 24 hrs average of daily from Continuous Ambient Air Quality Monitoring Stations (CAAQMS) of CPCB.

Annual Variations in air pollutants

Table 4 shows the average concentration of various air pollutants for the study period.

Table 4: Average concentration of various air quality parameters from 1 Jan 2019 - 31 Dec 2019

Location	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)	NO_2 (µg/m^3)	SO_2 (µg/m^3)	O_3 (µg/m^3)	C_6H_6 (µg/m^3)
North Delhi	112.08	234.82	40.82	14.97	39.73	2.94
East Delhi	128.18	272.96	88.58	13.38	28.96	4.35
West Delhi	92.37	157.88	30.79	13.62	49.16	1.95
South Delhi	101.22	216.93	52.22	9.80	36.57	4.68
Central Delhi	109.01	172.62	39.87	9.30	22.05	2.09
Average	108.57	211.04	50.45	12.21	35.29	3.20

According to the above table, the average annual concentration of $PM_{2.5}$ ranges from 92.37 µg/m^3 to 128.18 µg/m^3 which is nearly 2 to 3 times higher than the NAAQS prescribed by CPCB. Average concentration of NO_2 remains within the standard value except at East Delhi, where it exceeds the NAAQS concentration level. Average concentration of SO_2, O_3, and Benzene were found to be in safe limit. If we talk about the average concentration of these pollutants throughout the year 2019, it was found to be 108.57 µg/m^3 ($PM_{2.5}$), 211.04 µg/m^3 (PM_{10}), 50.45 µg/m^3 (NO_2), 12.21 µg/m^3 (SO_2), 35.29 µg/m^3 (0_3) and 3.20 µg/m^3 (C_6H_6).

Monthly variations in air pollutants

$PM_{2.5}$: Dust and construction site is the leading source of $PM_{2.5}$ in Delhi followed by the emissions from the transport sector. Dust includes contributions from road dust re-suspension, construction activities, and trans boundary contributions (Sharma, 2017). Summer trans boundary contributors are mainly composed of dust however in winter, contributors add up from biomass burning and industries. NAAQS standard limit for $PM_{2.5}$ (24 hrs) is 60 µg/m^3. As we can see from the graph, the concentration levels are higher than the prescribed standards for most of the year except July, August and September and some parts of June. The reasons for this can be attributed to monsoon season, as during monsoon pollution levels are comparatively lower than rest of the year to some extent due to effect of precipitation. It can also be observed from the graph that peak of $PM_{2.5}$ concentration at east Delhi was four times higher than the NAAQS standards and lowest levels were recorded at west Delhi among them. During three months of monsoon in 2019 i.e., July, August and September, the lowest dip was found in the levels of fine particles at West Delhi and the highest were found at east Delhi, both being below the NAAQS $PM_{2.5}$ standards. Reason for these observations at different locations can be attributed to the industrial area in East Delhi.

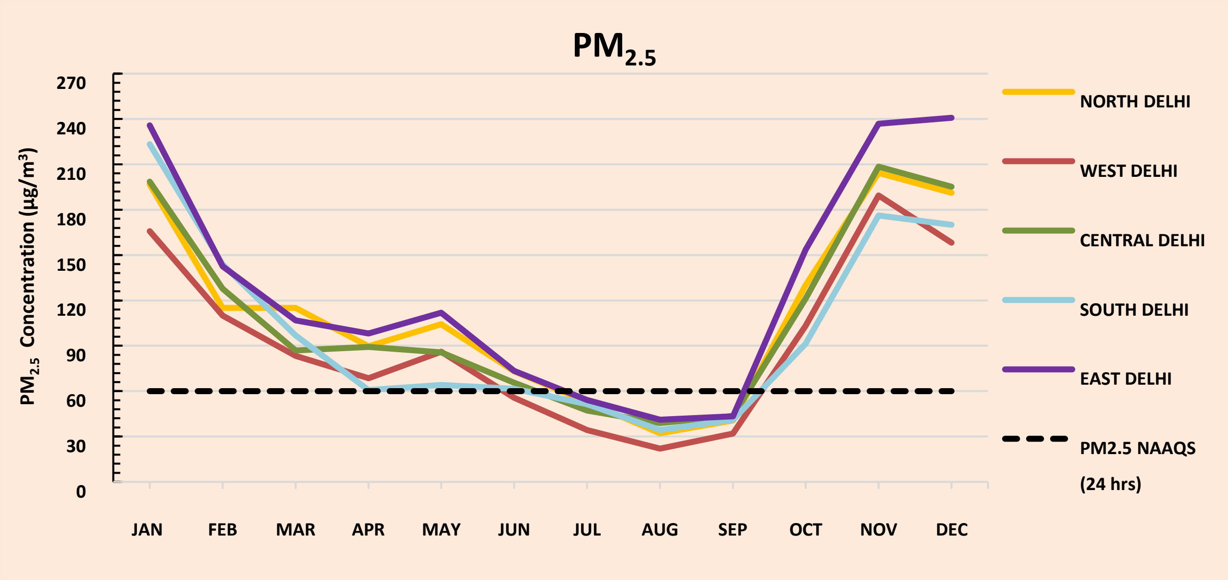


Figure 1: Average monthly variations in $PM_{2.5}$ in Delhi (24 hr)

PM_{10}: Particulate matter size less than 10 µm or PM_{10} concentrations were recorded for three monitoring stations each in, north, east, west, south and central Delhi and the average of these values was plotted in the graph shown below. As it can be seen in the graph that the PM_{10} levels exceeded the NAAQS standards for most of the year 2019 except for July, August and September. NAAQS standard concentration for PM_{10} in ambient air is 100 µg/m^3 (24 hrs), this is highlighted with a black dashed line in the graph. According to a study carried out jointly by, The Automotive research association of India (ARAI) and The Energy and Resources Institute (TERI), the data recorded over a time period of April 2016 to February 2017 showed that seasonal variation of PM_{10} showed higher contribution of dusty sources in summer as compared to winter in Delhi city. The reasons for this were attributed to dry conditions and higher wind velocities resulting in entrainment of dust. It was also found out that vehicular emissions were slightly higher in winter than in summer. Peak of PM_{10} concentration at east Delhi was found to be almost 4 times higher than the NAAQS standards, while comparatively lowest levels were recorded for the monitoring stations at west Delhi throughout the year.

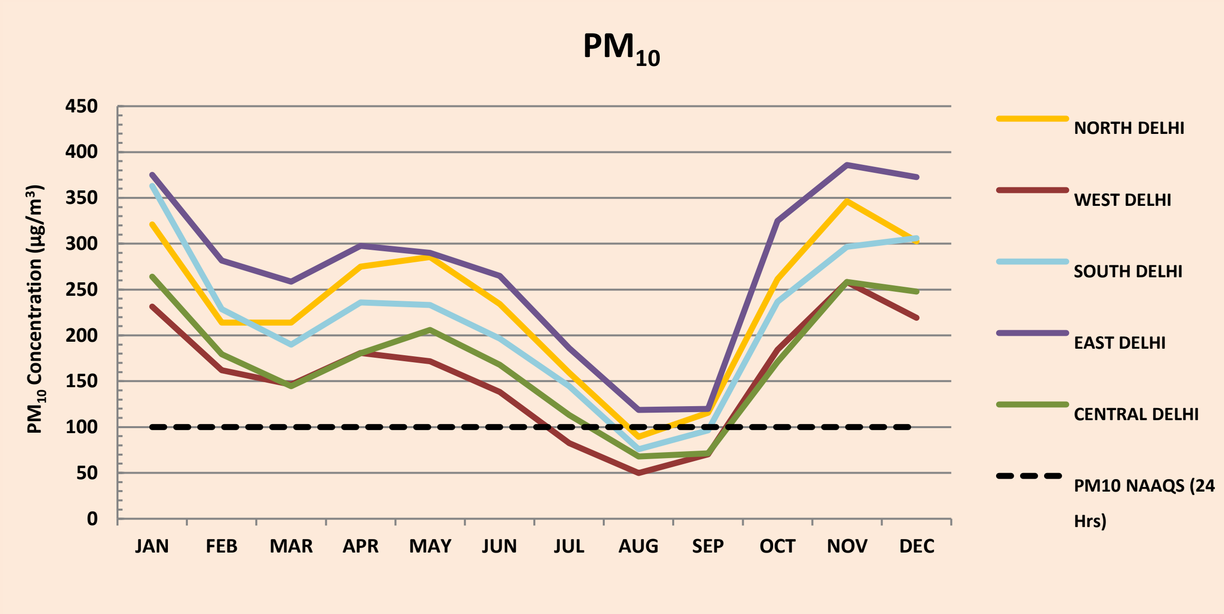


Figure 2: Average monthly variations in PM_{10} in Delhi (24 hr)

NO_2: Motor vehicles coal-based industries are the major drivers of NO_2 pollution in Delhi. Black dashed line represents the NAAQS standards for concentration of NO_2 in ambient air (24 hrs). As it can be seen from the graph that the levels of NO_2 were generally lower for the north, west and south Delhi. However, it can also be seen that concentration levels exceeded in central and east Delhi for a varied months of the year 2019 attaining a peak in east Delhi for the month of December which can be attributed to combined effects of primary emissions from traffic and domestic heating, weak photochemical reactions and adverse diffusion conditions (Hama et al., 2020). East Delhi attracted special attention here too, the peak of NO_2 levels in December was found to be almost 2 times higher than NAAQS standards, while the lowest were recorded for west Delhi throughout. For central

Delhi a bell-shaped kind of peak can be seen which is differentiating it from rest of the graph.

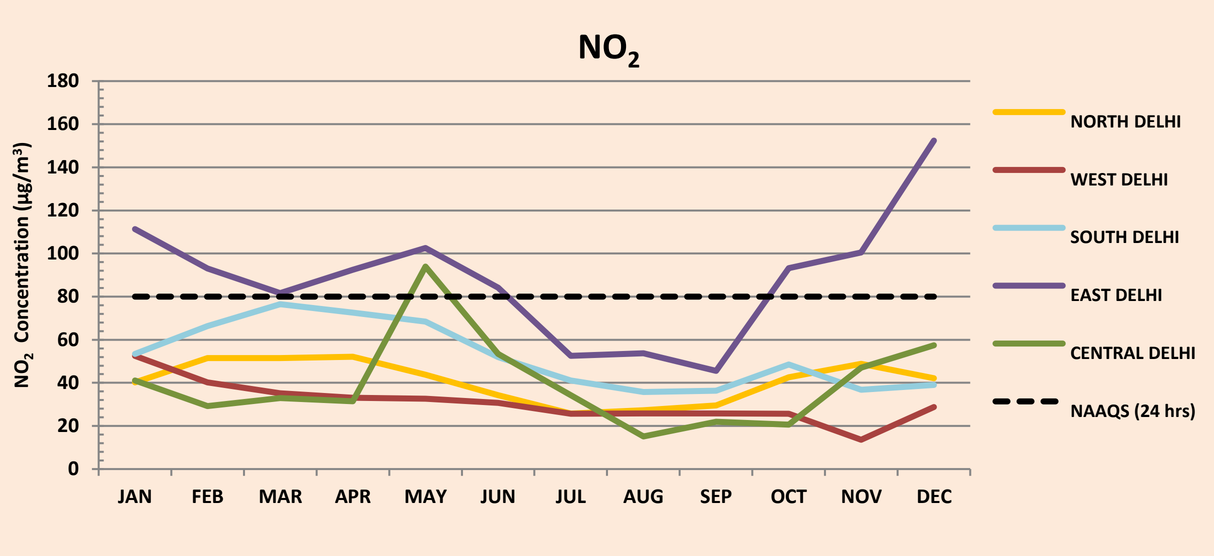


Figure 3: Average monthly variations in NO_2 in Delhi (24 hr)

SO_2: Natural sources of SO_2 include volcanic eruptions however if we talk of anthropogenic sources in urban cities and Delhi specifically, burning of fossil fuels, metal smelting and petroleum refining are some of the major sources. The graph below shows that the SO_2 concentration was always lower than the NAAQS standard of 80 µg/m^3 for the year 2019 throughout the monitoring stations of Delhi that have been taken in account for the data collection and making graph.

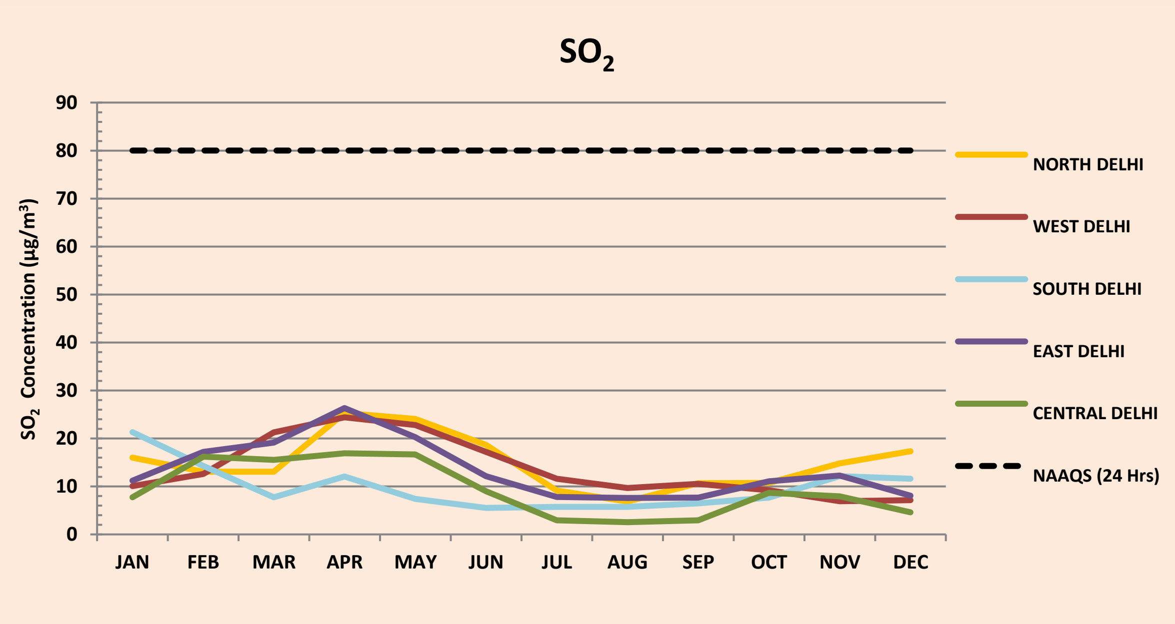


Figure 4: Average monthly variations in SO_2 in Delhi (24 hr)

SO_2 emissions are mainly from combustion of fossil fuels. Peaks of SO_2 concentration in different regions of Delhi was found to be built in the month of April. It can also be observed from the graph that the higher levels of SO_2 were recorded at west Delhi, if we were to compare the concentration levels of other monitoring stations located in Delhi.

O_3: According to Center for Science and Environment (CSE) report (2019), ozone level has increased in Delhi due to severe heat waves. It also says that O_3 is an emerging dominant secondary air pollutant. However, as we can see from the graph given below, the O_3 levels in Delhi were below the prescribed standards for 8 hrs which is represented with a black dashed line and yellow dashed line for 1 hr standards for the year 2019. In the months of April, May and June the concentration level of O_3 exceeded the prescribed standard (1hr) by NAAQS in parts of west Delhi. Here, the highest ozone concentration was recorded for the monitoring stations at west Delhi. Also, the highest concentration during summer has been observed due to heat waves and more photochemical activities of volatile organic compounds and nitrogen oxides to form ozone. It can also be concluded that the peaks for the various regions of Delhi was found to be in the months of April, May, June and July.

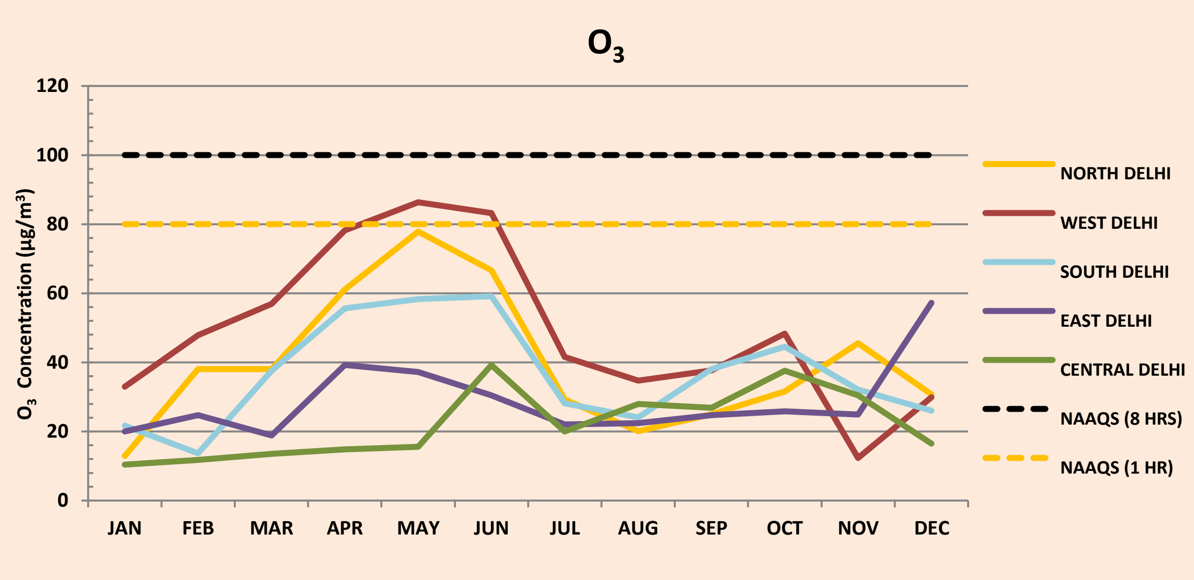


Figure 5: Average monthly variations in O_3 in Delhi (24 hr)

C_6H_6: NAAQS standard for benzene is 5 µg/m^3. Graph below shows that the standards are exceeded the most at monitoring stations east Delhi followed by south Delhi. One of the important monitoring stations in east Delhi was Anand Vihar. There are many iron and steel, chemical and other industries in this area which may account for the benzene emissions as an important source of the pollutant along with the pollution from automobile exhaust. North Delhi also seemed to come close to the black dashed line representing the benzene standards for some months of the year in 2019. Another conclusion that can be drawn from the graph is that benzene concentration levels were found to be higher in the months of January, October, November and December in the year 2019. Its peak concentration is usually seen at night. According to a source apportionment study carried out by scientists at the National Environmental Engineering Research Institute for Delhi, diesel engine exhaust contributes to 26%-58% of total benzene; 14% - 23% comes from vehicle exhaust; 10-18% from evaporative exhaust; and the rest from auto repair, degreasing and natural gas (Joshi, 2018). Also, benzene concentration in the atmosphere was found to be more than 2 times higher than NAAQS in East Delhi and lowest was recorded for west Delhi throughout the year in 2019.

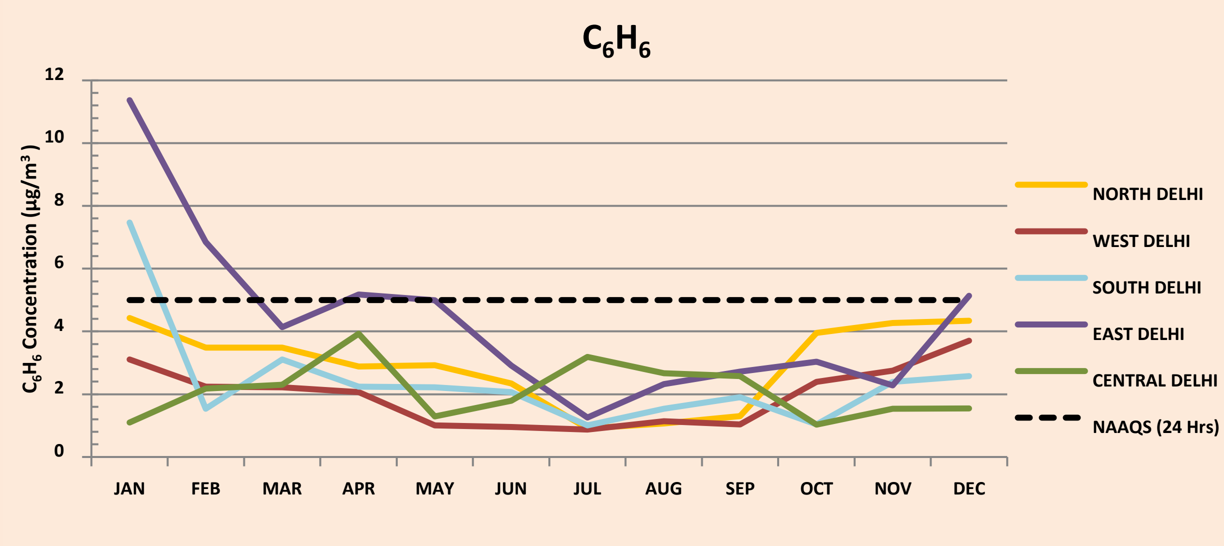


Figure 6: Average monthly variations in C_6H_6 in Delhi (24 hr)

Diurnal Variations

$PM_{2.5}$: Graph below shows the diurnal variations in concentration of $PM_{2.5}$ for a week in the month of March in the year 2019 for the monitoring station in Anand Vihar. Solid orange line represents the concentration levels. It can be seen that higher levels are recorded during the early hours of the day. Peak was recorded at 180 µg/m^3 at around 9 am in the morning while the lowest point recorded was found to be slightly more than 60 µg/m^3. From this we can infer that the peak levels were found to be almost 3 times higher than the lowest recorded during late afternoon hours. Then again a drastic change in levels can be seen at late night hours. It can also be inferred that peak of the graph during early hours was 3 times higher than the NAAQS standard for $PM_{2.5}$ of 60 µg/m^3.

Real time monitoring of particulate matter concentration was carried out by Center for Science and Environment (CSE) in 2015 and it showed that there was a difference in the moisture levels of parks and intersections. Green spaces tend to have a higher accumulation of moisture, which traps the pollutants close to the ground and contributes to higher $PM_{2.5}$ concentrations. Secondly, open areas such as arterial roads and spaces near them are windier and see the dispersal of pollutants due to a constant movement of vehicular traffic and high turbulence. In comparison, green spaces see less dispersal of pollutants and act as sinks where the particulate matter tends to settle down and accumulate (Mukherjee, 2015 Down to Earth).

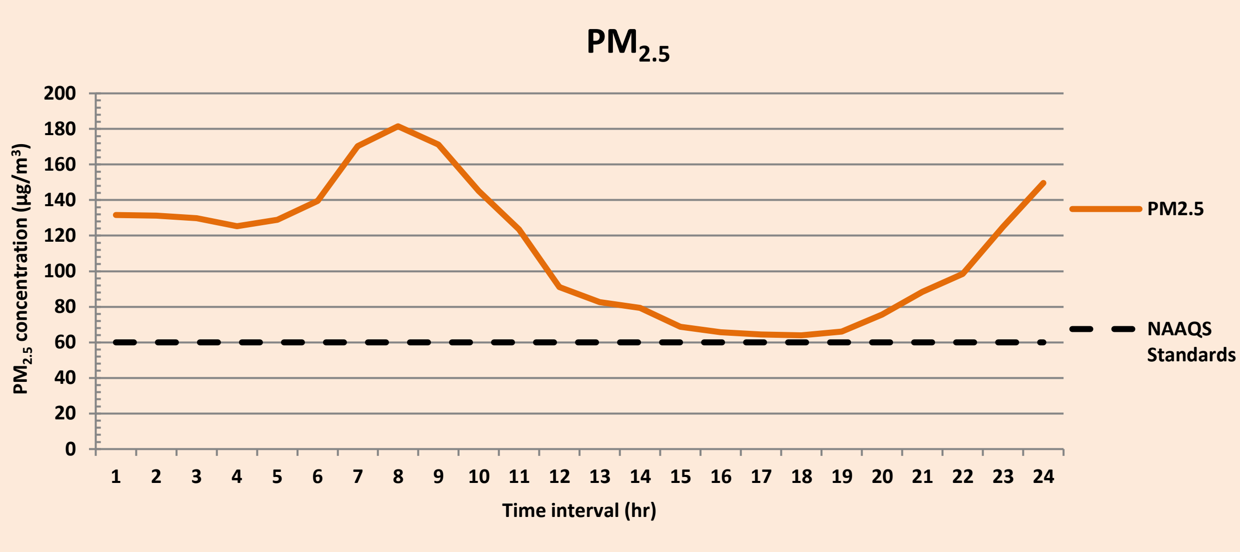


Figure 7: Diurnal variations in $PM_{2.5}$ throughout the day (1 hr)

PM_{10}: Graph for PM_{10} concentration levels shows a similar pattern to that of the $PM_{2.5}$. Peak of the graph can be found at the early hours of the day. Black dashed line represents the NAAQS standard for PM_{10} of 100 µg/m^3. Peak of the day can be seen to be more than 3 times higher than NAAQS standards. The diurnal variation of PM_{10} concentrations indicates a significant correlation with human activities; higher concentrations in densely populated areas with a large volume of traffics and vice versa (Kim and Kim., 2020).

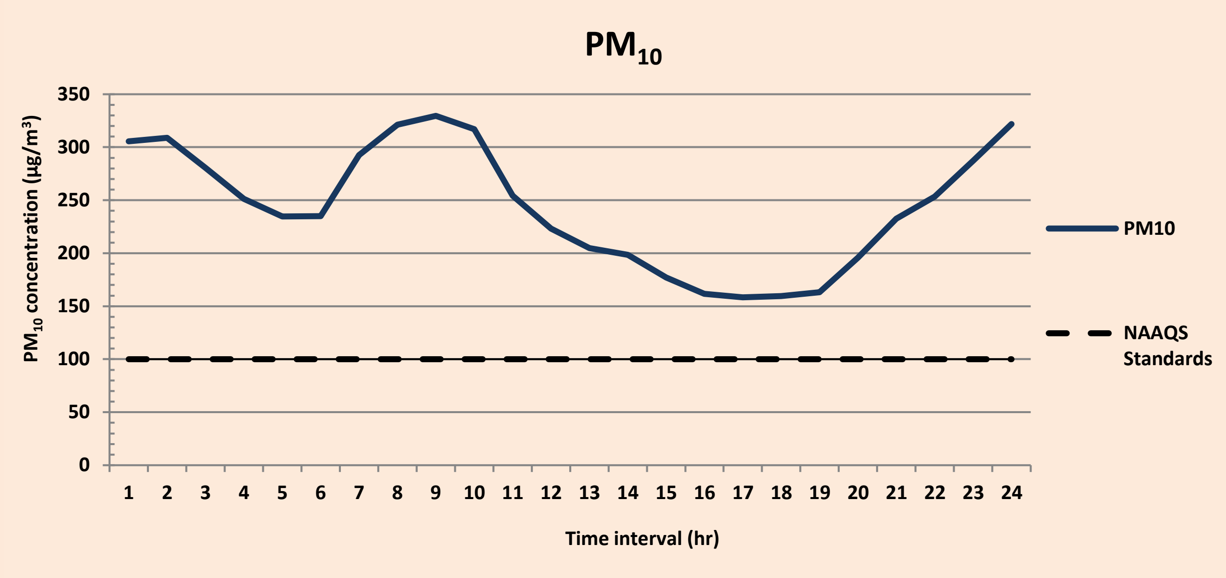


Figure 8: Diurnal variations in PM_{10} throughout the day (1 hr)

NO_2: Graph below represents the NO_2 concentrations throughout the day. It can be seen that the levels were above the NAAQS standard (80 µg/m^3) for most part of the day. Highest level recorded was found to be slightly more than 100 µg/m^3 which can be observed from the graph to occur at the mid day. Lowest levels recorded, below the NAAQS standards were for the late night and early morning, between 1 am to 6 am.

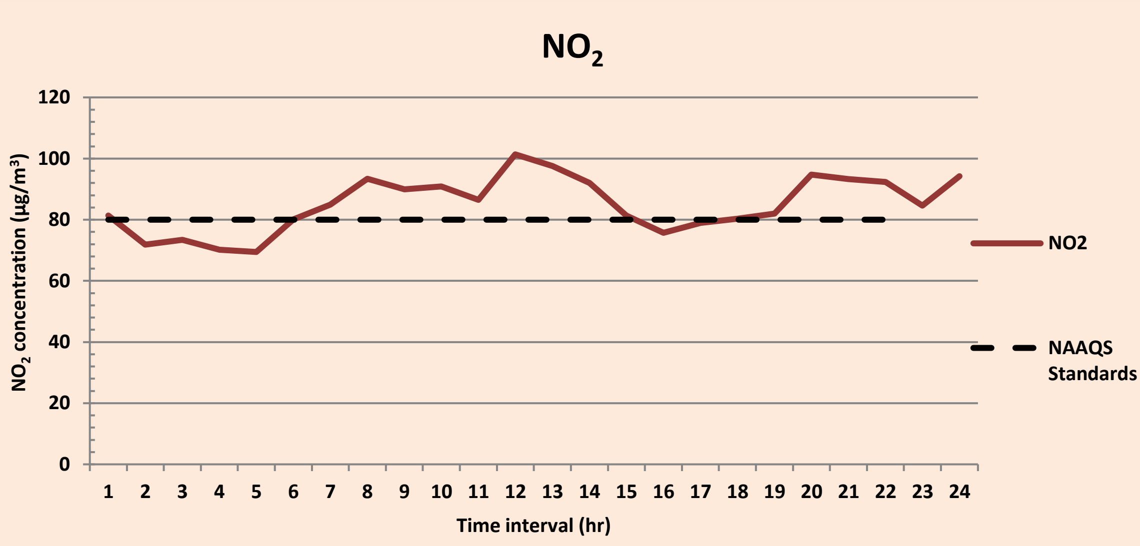


Figure 9: Diurnal variations in NO_2 throughout the day (1 hr)

SO_2: Concentration levels were very well below the NAAQS standards throughout the day for a recorded week in March 2019 as it can be seen from the graph given below. Peak of the graph formed below the NAAQS standard that is represented with a black dashed line, shows that the peak was formed during the early hours of the day while a second highest peak formed can be seen to be formed during late at night.

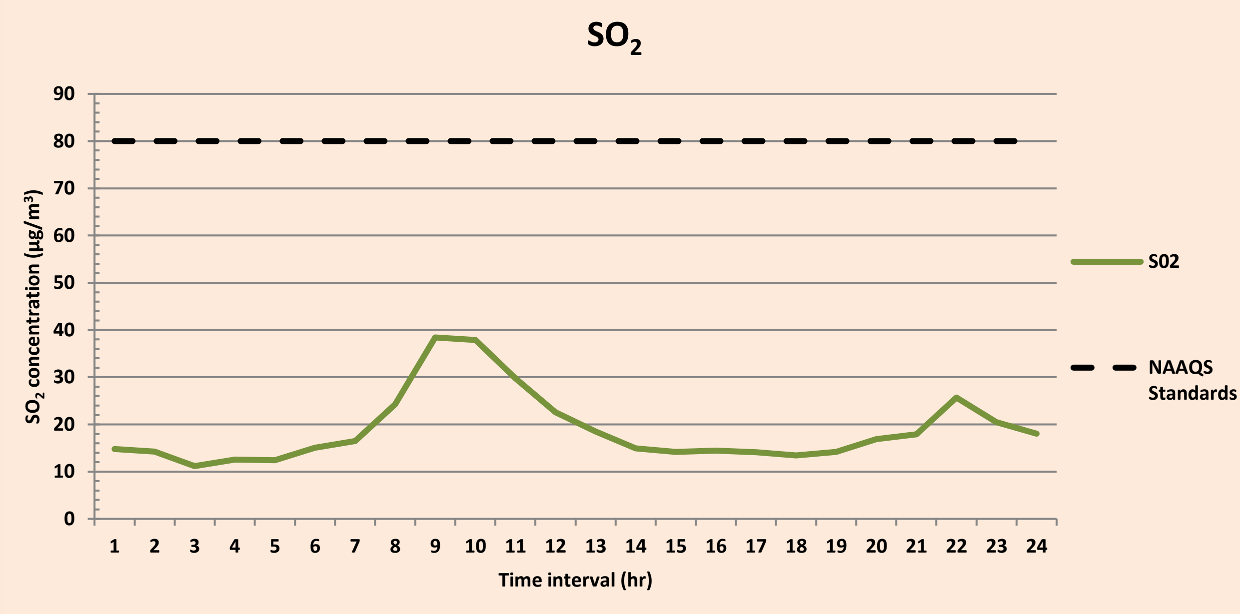


Figure 10. Diurnal variations in SO_2 throughout the day (1 hr)

O_3: It can be inferred from the graph that O_3 levels were well below the NAAQS standards throughout the days in the week of March 2019 under observation. Peak below the NAAQS standards can be observed between 4 pm to 5 pm.

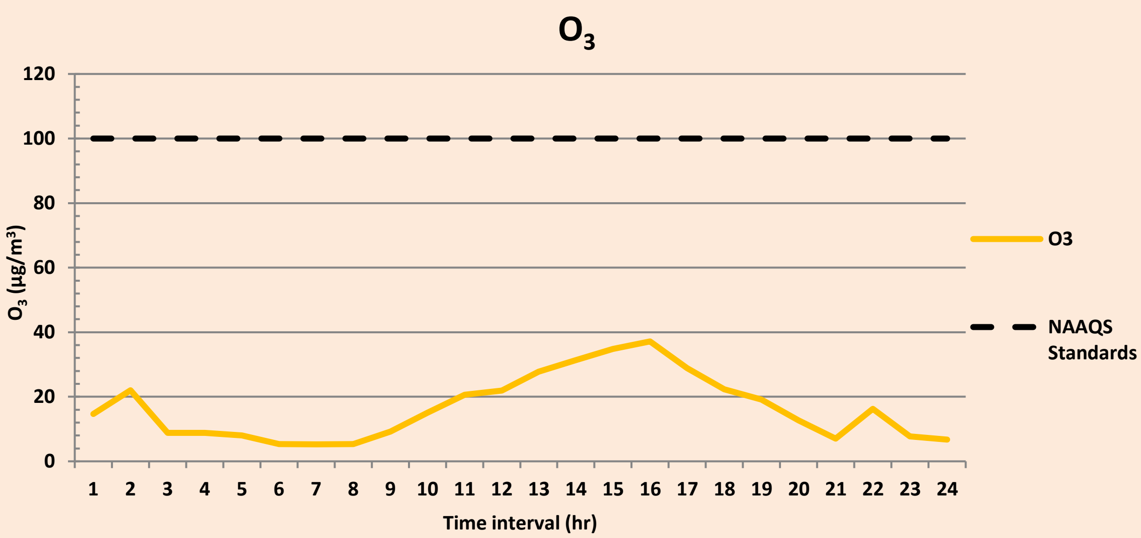


Figure 11. Diurnal variations in O_3 throughout the day (1 hr)

C_6H_6: Graph below represents the C_6H_6 concentration throughout the day for a week in

March 2019. Peak can be observed during late hours of the day around 11 pm to 12 am which can be seen to be extending above the NAAQS standard for C_6H_6. Dip in concentration can be seen to occur during late afternoon or early evenings.

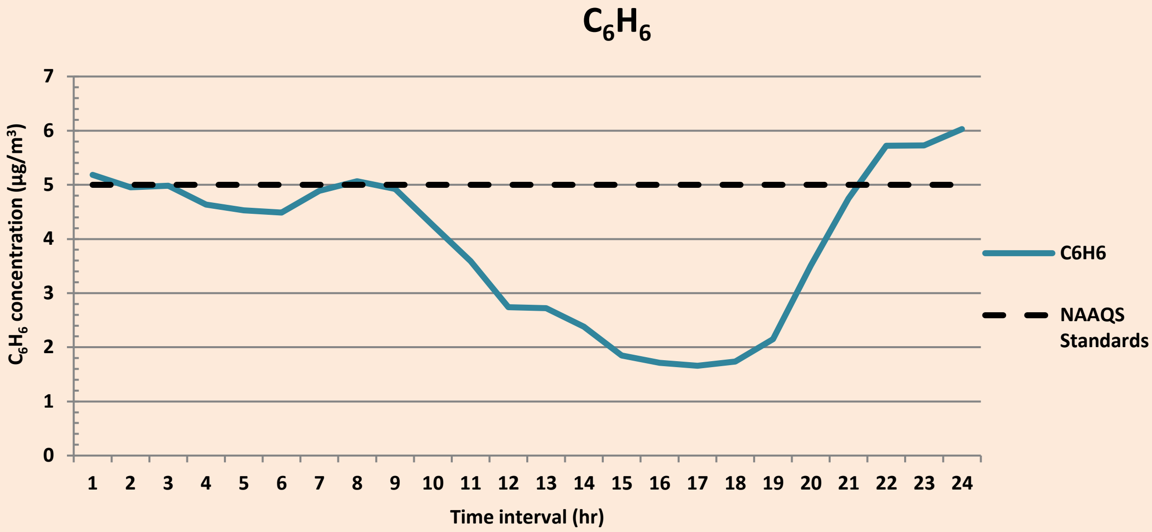


Figure 12: Diurnal variations in C_6H_6 throughout the day (1 hr)

Correlation between air pollutants and meteorological parameters

Correlation coefficients are indicators of the strength of the linear relationship between two different variables, x and y. A linear correlation coefficient that is greater than zero indicates a positive relationship. A value that is less than zero signifies a negative relationship. Finally, a value of zero indicates no relationship between the two variables x and y.

$PM_{2.5}$ and PM_{10} have a correlation coefficient of +0.88. The relationship between $PM_{2.5}$ and PM_{10} have a strong correlation since the value is close to 1. So, if the concentration of $PM_{2.5}$ increases, concentration of PM_{10} also increases and vice versa. It can also be said that both of these are emitted from similar sources. NO_2 has a correlation coefficient of +0.65 with $PM_{2.5}$ and PM_{10} both which denotes a fairly strong positive correlation of NO_2 with $PM_{2.5}$ and PM_{10}. CO and C_6H_6 also show a fairly positive correlation greater than +0.5 with $PM_{2.5}$ and PM_{10}.

	$PM_{2.5}$	PM_{10}	NO_2	SO_2	O_3	CO	C_6H_6	RH	WS	WD	SR	AT
$PM_{2.5}$	1.00											
PM_{10}	0.88	1.00										
NO_2	0.65	0.65	1.00									
SO_2	0.20	0.36	0.25	1.00								
O_3	0.16	0.16	0.37	0.22	1.00							
CO	0.57	0.59	0.40	0.17	0.09	1.00						
C_6H_6	0.59	0.58	0.46	0.32	0.08	0.50	1.00					
RH	0.23	-0.02	0.03	-0.53	-0.04	0.01	-0.08	1.00				
WS	-0.43	-0.38	-0.43	-0.06	-0.03	-0.30	-0.28	-0.25	1.00			
WD	0.23	0.33	0.40	0.06	-0.09	0.16	0.19	-0.20	-0.30	1.00		
SR	-0.35	-0.13	-0.21	0.19	-0.16	-0.09	-0.17	-0.55	0.20	0.09	1.00	
AT	-0.44	-0.24	-0.36	0.10	-0.02	-0.23	-0.45	-0.47	0.16	-0.18	0.50	1.00

Positive	**Negative**
1 to 0.8	0.5 - 0.8
0.8 to 0.5	0.3 - 0.5
0.5 to 0.3	0 - 0.3
0.3 to 0	

Figure 13: Correlation matrix between pollutants

CONCLUSIONS

- The report presents the analysis of various criteria pollutants. Average of various air pollutants from 1-01-19 to 31-12-19 were found to be 108.57 µg/m^3, 211.04 µg/m^3, 50.45 µg/m^3, 12.21 µg/m^3, 35.29 µg/m^3 and 3.20 µg/m^3 for $PM_{2.5}$, PM_{10}, NO_2, SO_2, O_3 and C_6H_6 respectively.
- East Delhi recorded the highest monthly concentration levels for $PM_{2.5}$, PM_{10}, NO_2 and C_6H_6.
- Peaks for $PM_{2.5}$ and PM_{10} were observed in the month of November and exceeded the NAAQS standards for most part of the year excluding the months of monsoon season. Peak for NO_2 was observed in the month of December. SO_2 and O_3 levels were always below the NAAQS standards for SO_2 (24 hrs) and O_3 (8 hrs) respectively.
- $PM_{2.5}$ and PM_{10} levels gave a peak during the early hours of the day, both exceeding the NAAQS (1 hr) by three times. SO_2 and O_3 were always below the NAAQS standards (1 hr) throughout the day.
- Results obtained using correlation matrix showed that $PM_{2.5}$ and PM_{10} possessed a strong positive correlation of +0.88.
- Through this entire study, we have identified that pollutant levels were not higher throughout year, there are some months when the levels were lower, for example during monsoon season, precipitation occurs and it does not allow the pollutants to rise high up in the air, wind speed is also higher and stronger during monsoon which disperses the pollutants.
- Also, in a day as well, the pollutants exhibit diurnal variations, with maximum concentrations during rush-hours.

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EnviroVigyan's 6E Working Framework

We EDUCATE People

We ENGAGE Community

We EMPOWER Women

We EXPLORE Solutions

We conduct EXPERIMENT

We ESTABLISH Facts

Working Areas:

Air Quality Assessment and Control (AQAC)
Water Quality Assessment and Management (WQAM)
Waste Management and Health (WMH)
Climate Change and Sustainability (CCS)
Biodiversity and Conservation (B&C)
Natural Resource Management (NRM)
Public Health and Hygiene (PHH)

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