



Policy Interventions and Their Impact on Air Quality in Delhi City — an Analysis of 17 Years of Data

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Received: 7 May 2021 / Accepted: 13 October 2021 / Published online: 4 November 2021
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Abstract Delhi megacity's high level of air pollution is a grave concern and calls for stringent and result-oriented efforts toward its reduction to meet the specified standards. It is necessary to understand the effectiveness of control actions implemented in the past and their response to air quality. The present study attempts to compile the information on the implemented control strategies in the city and evaluate their response in terms of pollution reduction during the years 2003–2019. The pollutant concentrations data are analysed monthly and annually at selected three representative stations being operated for more than two decades. The Respirable Suspended Particulate Matter (RSPM) showed an increasing trend from 2003 to 2019, with an annual average increment in the range of 0.98–3.19%. The increment percentage was found more at Industrial sites compared to residential and commercial sites. The SO₂ showed a decreasing trend with an annual

reduction in the range of 1.49–4.09%. However, NO₂ increased with an annual average of 5.21–6.07%. The reduction observed in the increasing trend of NO₂ and RSPM in recent years after 2015 compared to previous years might be due to various source-specific, short-term and long-term control actions within the city and surrounding regions. The present analysis showed the impact of policy interventions on the air quality of Delhi city. However, there is a need to develop a systematic mechanism to monitor/assess the improvement in air quality (pollutant wise) due to implemented control strategies.

Keywords Policy interventions · Ambient air pollutants · Manual monitoring · Correlation · Trend analysis · Delhi City

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s11270-021-05402-x>.

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1 Introduction

Urban air pollution is one of the significant health concerns in developing countries. Most megacities experience increasing air quality levels exceeding the national ambient air quality standards/guidelines (Krzyzanowski & Schwela, 1999; Gulia et al., 2015; Mannucci & Franchini, 2017). The air quality assessment and management in such megacities is a major challenge due to massive growth in sources and poor implementations of control actions (Gulia et al., 2015). Urban locations are repleted with various

combinations of pollution-generating activities that pose a potential threat and deteriorate air quality levels.

Along with other major cities of developing countries, Delhi, India's capital city, is also facing elevated pollution levels. The city resides a population of about 19 million spread over a 1483 sq km area (Worldatlas, 2018). The population has increased from 13.9 million in 2001 to 16.8 in year 2011 and will increase to 19.6 million in the year 2021 (<https://www.census2011.co.in/census/state/delhi.html>). This rapid population growth further leads to development in associated dependent sectors such as road transport, residential sector, and commercial activities, ultimately increasing energy consumption. Based on an annual economic survey of the city, the Govt. of Delhi observed that energy demand also increased from 2831 MW in 2001–2002 to 6261 MW in 2016–2017 (Govt. of NCT Delhi, 2001, 2018). The per capita consumption of petroleum products in Delhi city increased from 237.1 kg in 2009 to 298.4 kg in the year 2018, which indicates a 25% growth in 9 years. The total consumption of Petroleum products in Delhi during 2017–2018 was 5.0 million Tons (MoPNG, 2018). A significant proportion of petrol and diesel is consumed by the transport sector (Nielsen, 2013). The transportation sector witnessed a tremendous increase in motorized vehicles in the last 15 years in Delhi city, being 34.56 lakh in 2000 and 104.83 lakh in 2017 (Statista, 2020). Also, high growth in commercial activities led to the increase in the number of diesel generator (DG) sets and restaurants/hotels in the city. This tremendous growth in the consumption of petroleum products led to the generation of high air pollution.

CSIR-NEERI has monitored air quality in Delhi and other major cities since 1978, before the Air (Prevention and Control) Act 1981 was enforced in the country. During the year 1978–1979, the annual average value of SO₂, NO₂ and SPM was found in the ranges of 7–61 µg/m³, 23–37 µg/m³ and 296–481 µg/m³, respectively in Delhi. The findings of these monitoring programmes supported the decision-makers to formulate the country's first national air quality standards in the year 1982. These values in the year 1985 were 34–86 µg/m³, 36–51 µg/m³ and 294–488 µg/m³, respectively. It is observed that annual average SPM were more or less similar in the year 1978–1979 and 1985, but values of SO₂ and NO₂ increased

significantly, indicating that the contribution of industrial activities in the city started in the 1980 (NEERI, 1980, 1988). In response to the increasing air pollution level, policymakers tried to manage it for more than four decades by implementing various control actions. The control actions started from 1980 onwards after the enforcement of the Air (Prevention and Control) Act, 1981 and Environmental Protection Act., 1986. Numerous steps were taken during years 1990–2000 to control the air pollution especially on vehicular pollution control such as phasing out of lead from gasoline, introduction of program on sulphur reduction from petrol and CNG fuel in the public transport vehicles in Delhi in 1999. Phasing out of polluting industries from the city was also one of the critical steps by policymakers to tackle the problem during this period. Environment Pollution Control Authority (EPCA) was formulated to control emissions from various sources in Delhi NCR. Later, numerous control actions were introduced after the year 2000 onwards to reduce emissions from various sources. However, their efficacy in air pollution reduction was not evaluated before their implementation and generated lots of questions for debates on the success and failure of these interventions in reducing air pollution. The quantification of the impact of any management practice for pollution control can be done through two approaches; *first* air quality modelling (Gulia et al., 2015, 2018) and *second*, through time series trend analysis of pollution data.

In the past, numerous studies were conducted on air pollution in Delhi city starting from source apportionment study by NEERI in 2010 (CPCB, 2010), by IIT Kanpur, 2016 (IIT Kanpur, 2016) and latest by TERI, 2018 (TERI, 2018). These are focused studies on the air pollution assessment, contribution of sources and suggestion of management practices for pollution control. However, these studies generated time-bound data on pollution levels, which were unable to evaluate the impact of previously implemented control strategies.

Given the above, the present study is an attempt to analyse the air quality monitoring data of the last 17 years in Delhi city. Further, the management strategies enforced in the city for the reduction of air pollution are compiled in chronological order and compared with the trend of air quality level. The study's outcome will sensitize the policymakers regarding the impact of implemented management strategies

so that future management strategies can be planned appropriately.

2 Evaluation of Air Quality Monitoring Network in Delhi

Delhi has a vast network of air quality monitoring stations, including continuous ambient air quality stations (CAAQMS) and conventional manual stations. At present, 50 monitoring stations are being operated throughout the city of which 40 are real-time and 10 are manual stations (CPCB (Central Pollution Control Board), 2020). Out of 40 CAAQMS, most of them are being operated for the last 2–3 years; however, 11 stations of DPCC (06 number) and CPCB (05 number) stations are being operated from the year 2010 (started during commonwealth games). The situation before the year 2010 was different, and the city's air quality was measured by manual stations only.

Unlike CAAQMS, manual stations are being operated in the city for more than two decades under the national air monitoring program (N.A.M.P.). Air quality monitoring in India was started by CSIR-NEERI, Nagpur, at 10 different cities, including Delhi in the year 1978 for three pollutants i.e., SO₂, NO₂ and SPM. This program has generated data for long-term air quality, which later guided the Central and State regulatory agencies to define the norms of air pollution control at source under the Air (Prevention and Control) Act, 1981. This program was later converted into N.A.M.P in the year 1987 with the addition of more pollutants such as RSPM (PM₁₀). Under N.A.M.P., the monitoring of pollutants is being carried out for 24 h (4-hourly sampling for gaseous pollutants and 8-hourly sampling for particulate matter) with a frequency of twice a week, to have one hundred and four (104) observations in a year.

3 Material and Method

3.1 Site Description

In the present study, pollutant concentration data of three stations in Delhi operated by CSIR-NEERI were analysed and correlated with air quality policies.

Further, time-series analysis of pollutant concentrations was evaluated using monthly and annual data for 17 years (2003–2019) for the selected representative site of residential, industrial and commercial areas. These sites are Sarojini Nagar, Chandni Chowk and Naraina, each characterized by different land use features such as residential, commercial and industrial, respectively. The monitoring is being carried out for both particulate (RSPM/PM₁₀) and gaseous pollutants (SO₂, NO₂). Fig. 1 shows the Google map of the 500 m radius area around each selected site and further compared in Table 1.

3.2 Monitoring Protocol and Analysis

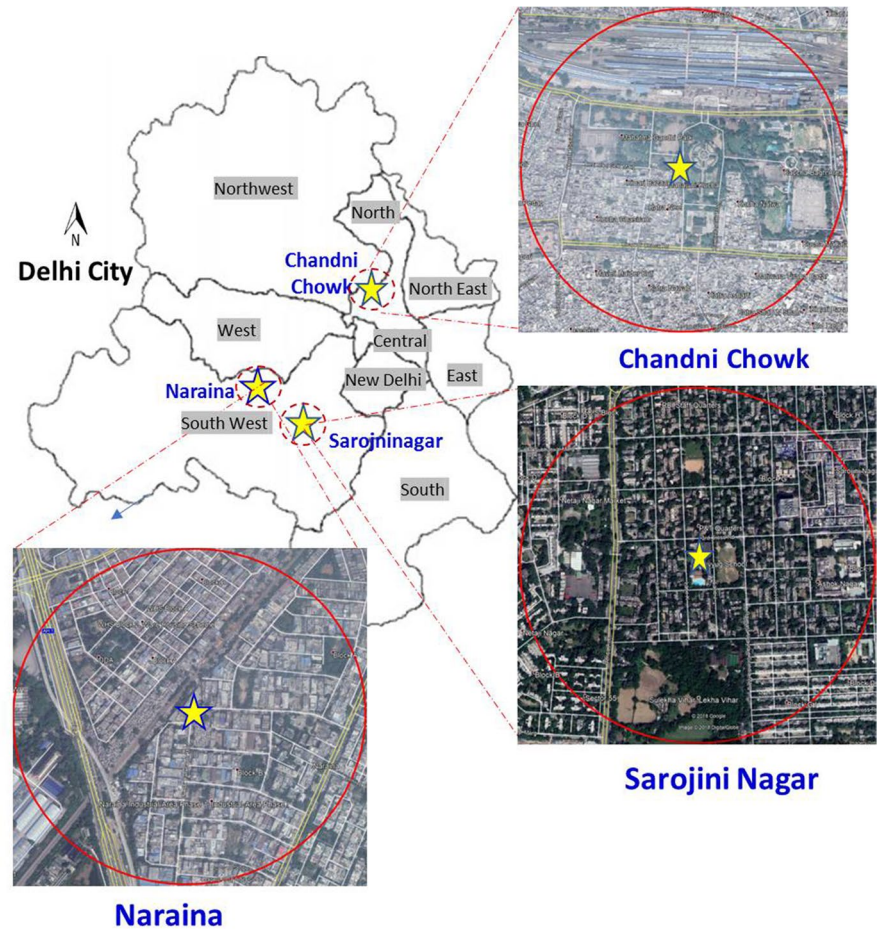
The monitoring is being carried out to meet the requirement of national ambient air quality standards (NAAQS) (MoEFCC, 2009). The collected samples were analysed for both particulate (RSPM) and gaseous pollutants (SO₂ and NO₂) using standard methods prescribed by Central Pollution Control Board and originally described by APHA (1977). The annual and monthly average concentrations have been studied for both particulate and gaseous pollutants from the year 2003 to 2019. The data has been analysed statistically and compared with NAAQS, inter-correlation between sites for a particular pollutant and vice versa.

4 Results and Discussion

4.1 Annual Air Quality Trend at the Study Site

The annual average trend was found slightly increasing for RSPM concentrations from the year 2003 to the year 2019. It was found in the range of 164–212 µg/m³ in the year 2003 to 152–248 µg/m³ in the year 2019. The maximum concentrations were recorded at Chandni Chowk with an increase of 30.08% (212 µg/m³ to 264 µg/m³). It is observed that RSPM concentrations were gradually increased from year 2003 to year 2019 with an annual average increment of 0.98–3.19% at all three sites. However, during 2010, the maximum concentrations were recorded at Chandni Chowk site which might be due to an increase in construction activity at the respective site and time. The levels of RSPM were higher during the period

Fig. 1 Map showing differently located manual AQMS in Delhi City



2009–2010 compared to other selected years at most of the sites; however, this annual peak was not observed in SO_2 and NO_2 data. This change might be due to higher and rapid construction activities at various locations in the city to meet the demand of commonwealth games, 2010. The annual average trend indicates a sharp increment in RSPM concentration at Naraina site, but not at Sarojini Nagar and Chandni Chowk, which might be due to an increase in local activities as Industrial site with steel retail shops (Loha Mandi). The road is dusty and high movements of heavy trucks for the transport of iron/steel materials. Further, it is observed that all the stations exceeded the annual average NAAQS of $60 \mu\text{g}/\text{m}^3$ throughout the study period (Fig. 2).

Similarly, the monitored data has been analysed for gaseous pollutants (Fig. 2). In the case of SO_2 , the concentrations were more or less similar from the years 2003–2012. However, there was a

decreasing trend in the concentrations at all the sites from years 2013–2019. Further, SO_2 concentration decreased by 69.51% at Naraina, 66.27% at Chandni Chowk and 59.26% at Sarojini Nagar in year 2019 when compared to the year 2003. The average SO_2 concentrations with annual average decrease by the range of 1.49 to 4.09%. SO_2 level was found decreasing at the Naraina site from the year 2012, which indicates the improvement in fuel quality for industrial use to reduce the pollution level, but no impact was observed at residential and commercial sites. The sulphur reduction program started with 5000 ppm in the year 1996, followed by 500 ppm in the year 2001, 350 ppm in the year 2005, 50 ppm in the year 2010 in both diesel and gasoline fuel. This reduction of sulphur in fuel can be correlated with a reduction in ambient SO_2 level. Also, none of the stations exceeded the annual average NAAQS of $50 \mu\text{g}/\text{m}^3$.

Table 1 Descriptive features of differently located manual AQMS in Delhi City

Sr. no.	Location	Latitude Longitude	Land use	Surrounding land use features	Direction wrt central Delhi
1	Navyug School, Sarojini Nagar	28°34'29.50N 77°11'33.13E	Residential	Govt. Staff Quarters, Bus depot (200 yards away), Sarojini Nagar Market (within 2 km), multi-storey buildings, Major source of local pollution is vehicles, domestic kitchen and market activities etc.	Southwest
2	Town Hall, Chandni Chowk	28°39'29.82N 77°13'36.36E	Commercial	Chandni Chowk market, Old Delhi Railway Station (0.4 km away), Red fort, Shishganj Gurudwara. Major sources are vehicles, tandoors, DG sets,	North
3	NEERI Zonal Centre, Naraina	28°38'02.38N 77°08'05.93E	Industrial	Industries, Diesel Run Railway Line (Delhi-Jaipur Route), garbage dumps, Major source are Vehicles, Industries, Resuspension of Road dust, open burning in slum areas	Southwest

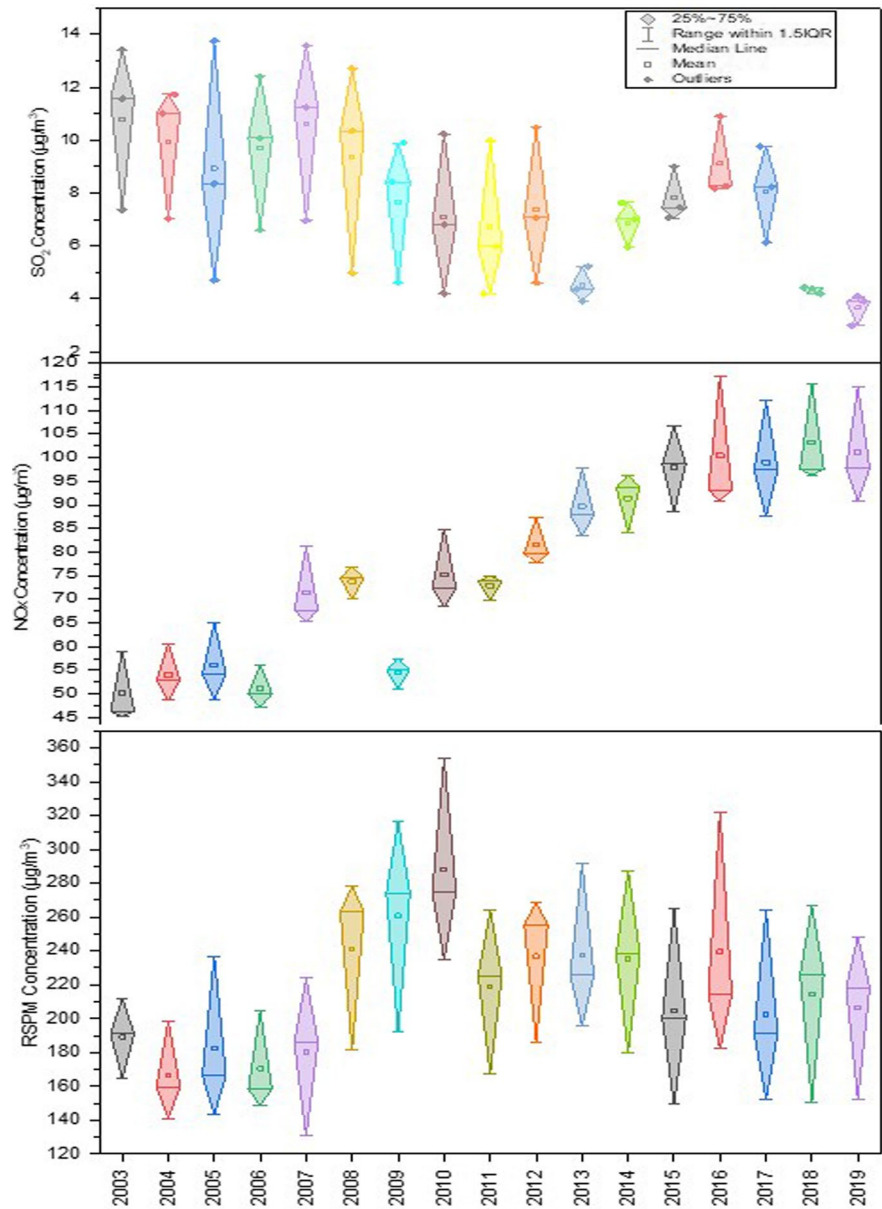
In the case of NO₂, an increasing trend was observed for all the years 2003–2019 at all the locations. The concentrations at Naraina, Chandni Chowk and Sarojini Nagar were increased from 45 µg/m³, 59 µg/m³, 46 µg/m³ in the year 2003 to 98 µg/m³, 115 µg/m³ and 91 µg/m³, respectively in the year 2019 which indicates an increment by 116%, 94% and 96%, respectively. The maximum concentrations were recorded at Chandni Chowk followed by Sarojini Nagar and Naraina. Further, all the stations exceeded the annual average NAAQS of 40 µg/m³. The level of NO₂ is gradually increased with annual average of 5.21–6.07% at all three sites from year 2003 to 2019. Researchers linked the increase in NO₂ concentration with a higher number of CNG fuel based vehicles in the city. For example, Chelani and Devotta (2007) and Khaiwal et al. (2006) have found that no changes were observed in PM₁₀ levels after shifting diesel fuel in to CNG fuel in public transport in the city; however, an increase in NO₂ levels observed during this period is attributed to the introduction of CNG fuel. In view of the above, data on the CNG sale and the total number of CNG registered vehicles in the city were compiled from Indra Prastha Gas Limited (IGL), the agency that was supplying CNG fuel in the city. IGL started its operation to sale CNG in 1999 with only 09 stations in Delhi and now it is operating

at Delhi, Noida, Gr. Noida and Ghaziabad with a total of 426 stations. The sale of CNG increased from 3.76 MMSCM (Million Metric Standard Cubic Meter) in the year 1999 to 1055 MMSCM in the year 2017. The total number of CNG-fuelled vehicles (Buses, Auto, Car/Taxi etc.) increased from 2600 in year 1999 to 1.02 million in year 2017 (IGL, 2018). The correlation coefficient (r^2) between annual average NO₂ concentrations and registered CNG vehicles is calculated to be 0.9, indicating a very good positive correlation between them (Supplementary Information Fig. S1).

4.2 Month-wise Trend Analysis

The monthly variations have been studied at three sites for both particulate and gaseous pollutants for a study period of 17 years. The analysis also included assessment of seasonal variation i.e., winter (December–February), summer (March–June), Monsoon (July–September) and Post-monsoon (October–November). It is observed that for all the three pollutants, the concentrations were maximum in the Post-Monsoon season with a sharp increasing trend from September to November months. The trend further continued with higher concentrations during the winter season. However, the concentrations then

Fig. 2 Annual average trend of pollutant concentrations of last 17 years at three locations in Delhi



decreased slightly in summer and least during the Monsoon season (SI Fig. S2–S4). This change can be correlated with the decreasing ventilation coefficient from September onwards to the whole winter season and then increasing trend during the summer season.

Further, changes in pollutants concentration were compared month-wise between the years 2003 and 2019. The SO₂ concentrations were changed in the range of 4–32% in January, 11–40% in February, 10–33% in March, 2–18% in April, 4–6%

in May, 12–19% in June, 3–21% in July, 8–28% in August, 1–6% in September, 10–27% in October, 17–21% in November and 6–20% in December month.

Similarly, the NO₂ concentrations were changed in the range of 7–9% in January, 4–6% in February, 7–9% in March, 8–10% in April, 8–11% in May, 11–17% in June, 10–14% in July, 9–12% in August, 6–10% in September, 7–14% in October, 5–8% in November and 8–9% in December months.

Similarly, the RSPM concentrations were changed in the range of 4–14% in January, 0–5% in February, 11–14% in March, 9–12% in April, 11–16% in May, 17–23% in June, 5–25% in July, 1–10% in August, 5–7% in September, -3 -8% in October, -3 -14% in November and 1–19% in December months. Further, the changes in pollutant concentrations over the last 17 years are summarized in Table S1.

The concentration of NO₂ showed an increasing trend for all 12 months from the year 2003 to 2019. The trend clearly indicates a peak during the years 2007 and 2008 in all months and then a sudden decrease in the year 2009 and later gradually increased. The concentration of RSPM was also found higher during the years 2007 and 2008 with the decrease in the year 2009. However, no such trend was observed for SO₂.

Further, the changes in the monthly average concentration of pollutants between the years 2003 and 2019 were carried out as shown in Fig. 3. It is observed that SO₂ concentrations reduced maximum of up to 84% in October. However, NO₂ concentrations increased in the range of 58% (Feb) to 212% (July). The RSPM concentrations were reduced maximum in February (38%) and increased maximum by 86% in July. These huge variations in monthly average pollutant concentrations might be due to short-term policy interventions that are enforced only for selected months such as November to March months. Some of them are ban on DG sets, shutoff of Badarpur power plants, ban on construction activities,

closure of polluting industries, the introduction of green crackers and implementation of GRAP etc.

4.3 Correlation Between Parameter and Sites

The correlation analysis was carried out between pollutants for a particular site and between the study sites for a particular pollutant to evaluate the common possible sources. The correlations between pollutants were categorized as very good ($r^2 > 0.8$), good ($r^2 =$ in the range of 0.6–0.8), moderate ($r^2 = 0.4–0.6$) and insignificant ($r^2 < 0.4$). Fig. 4 describes the month-wise correlation coefficient (r^2) matrix between different pollutants at three sites. It is observed that good correlations exist between NO₂ and RSPM at Naraina site during January, which indicates the presence of common sources. Naraina site is an industrial area and located at near the inner ring road (high traffic movement). The famous Loha Mandi (Iron Market) is adjacent to Naraina site where many heavy-duty diesel trucks travel and are parked on the road. So, diesel vehicles, re-suspension of road dust and emission from industrial activities are the sources of these pollutants.

However, NO₂ trends throughout the year and RSPM during March, April and September months are well correlated between sites i.e., Naraina, Sarojini Nagar and Chandni Chowk, which indicates the possibility of the contribution of vehicles and road dust. For SO₂, there is no significant correlation

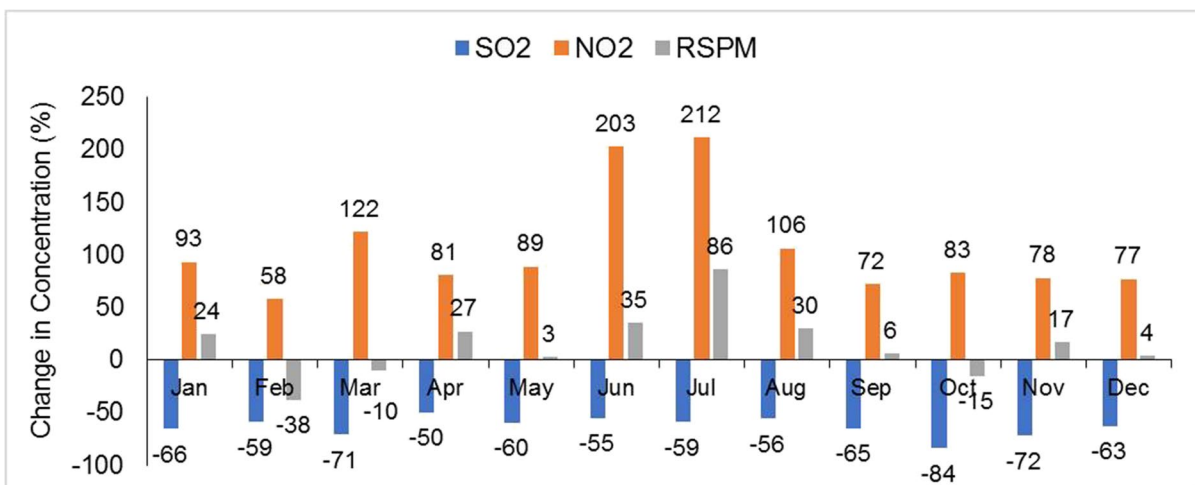
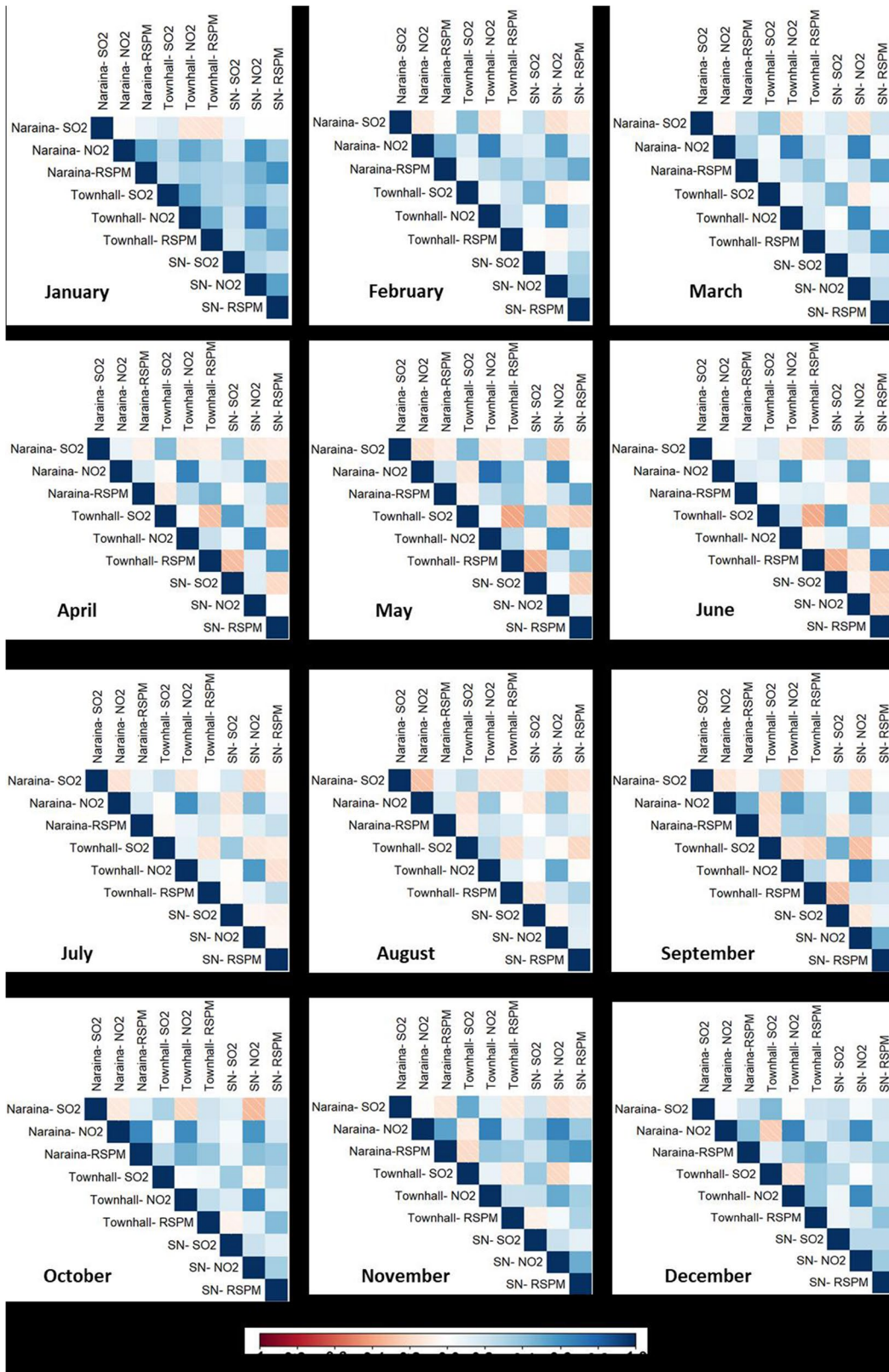


Fig. 3 Change in monthly average concentration (%) from 2003 to 2019



◀ **Fig. 4** Month-wise correlation matrix of pollutants for years 2003–2019

found between sites that can be due to industrial emission at Naraina site compared to other two sites.

5 Pollution Control Strategies in the Last 17 Years in Delhi NCR

Air pollution control strategies are primarily the efforts adopted for maintaining the air quality levels in urban geometries to prevent any further significant deterioration and improve the already degraded air quality. Table 2 describes the control measures that have been adopted in the last 17 years, especially for better air quality in Delhi and surrounding regions and corresponding average pollutant's concentrations. Policymakers have started worrying about increasing air pollution from 1980s onwards resulting in the enforcement of the Air (Prevention and Control) Act, 1981 and the Environmental Protection Act., 1986. After these two acts, the activities related to air quality management increased during 1990–2000s especially on vehicular pollution control such as phasing out of lead from gasoline, sulphur reduction from gasoline and CNG fuels in public transport vehicles in Delhi. Environment Protection Authority (EPCA) to control emission from various sources in Delhi-NCR also formulated during this period. During 2001 to 2003, the Autofuel policy was released that provided a road map for improvement in fuel quality in vehicles (from BS I to BS VI). Honourable Supreme Court of India has ordered phasing out of polluting industries from Delhi city. In years 2003–2005, the number of CNG vehicles was increased significantly and efforts put to improve the pollution control certification from vehicles. During the years 2006–2010, ambient air quality standards were revised with the inclusion of new pollutants such as $PM_{2.5}$, and VOCs. The National Green Tribunal was formulated in the year 2010 to separately deal with the court cases/complaints related environment, including air pollution. From the last 4–5 years, the occurrence of air pollution episode during November month took the attention of policy makers and media that result in the enforcement of regulations/norms/guidelines to reduce air pollution from all possible sectors such

as transport, agriculture residue burning, industries, street biomass burning, DG sets, firecrackers etc.

Further, the control strategies/actions were grouped into different time periods and compared with annual average pollutant concentrations. Also, the changes in average concentrations in selected time interval were calculated with respect to (wrt) its base year average (Fig. 5). The period before year 2005 is considered as the base period that's why showing 0% change. It is observed that SO_2 concentration has reduced from $10 \mu\text{g}/\text{m}^3$ to $6 \mu\text{g}/\text{m}^3$, which can be correlated with the phasing out of sulphur from fuels. SO_2 concentrations decreased significantly during 2006–2010 (10%) and reduced maximum during 2016–2019 (40%). The RSPM concentrations were highest ($228 \mu\text{g}/\text{m}^3$) during 2006–2010 and reduced to $215 \mu\text{g}/\text{m}^3$ during 2016–2019. However, it was still higher than average RSPM levels of base years, i.e., $179 \mu\text{g}/\text{m}^3$ (23%). It is also observed that RSPM concentrations increased gradually during 2006–2010 and 2011–2015 with 27% each wrt to base year period, respectively. The increasing rate of RSPM reduced after 2011–2015. There is no decreasing trend observed in NO_x concentrations during any time interval and concentrations increased from $53 \mu\text{g}/\text{m}^3$ in base years to $101 \mu\text{g}/\text{m}^3$ in 2016–2019 (91%) wrt to its base years.

Further, the pollutants data were compared to its previous years (Fig. 6). It is observed that during the years 2006–2010, the SO_2 concentrations were decreased by 10% while NO_2 and RSPM concentrations were increased by 22% and 27%, respectively. Similarly, during the years 2011–2015, SO_2 reduced by 25% and NO_2 increased by 33% when compared to the years 2006–2010 and no changes were observed in the RSPM concentrations. In recent years (2016–2019), the levels of SO_2 were reduced further by 6% and RSPM by 5% compared to average of years 2011–2015 and NO_2 were increased only by 16%. This change indicates that numerous short-term and long-term control strategies implemented in Delhi NCR in the last few years showed positive response in terms of decreasing the growth rate of NO_2 and reducing the concentrations of SO_2 and RSPM. The short-term impacts are being implemented during mid or end of October months when air quality index reached on very poor or severe category every year from year 2016 onwards. These control actions are (i)

Table 2 Control strategies adopted in Delhi City in the last 17 years

Year	Management strategies: expected pollutants to be reduced	Annual average concentrations ($\mu\text{g}/\text{m}^3$)		
		SO ₂	NO _x	RSPM
Before 2005	<ul style="list-style-type: none"> Hydrocarbon norms introduced for petrol vehicles: <i>RSPM</i> Setting limit values for idle CO and HC for four wheelers with/without catalytic converters Introduced in NCR and 13 more cities: <i>RSPM</i> Sulphur content reduced in diesel to 500 ppm (BSII) in 2001 and 350 ppm and 150 ppm in gasoline in BSIII in year 2005: <i>SO₂</i> Introduced CNG vehicle in Delhi city: <i>RSPM</i> Phasing out of industries outside of Delhi Periphery: <i>RSPM, SO₂, NO_x</i> 	10	53	179
2006–2010	<ul style="list-style-type: none"> Implementation of Lambda Measurement in Pollution Under Control (PUC) Certification Programme: <i>NO_x, RSPM</i> Proposed Automotive CNG fuel specifications: <i>RSPM</i> Revised NAAQS and introduced standards for 12 pollutants included PM_{2.5}: <i>RSPM, SO₂, NO_x</i> Creation of Ambience Air Fund: <i>RSPM, SO₂, NO_x</i> Bharat Stage IV in Delhi NCR and 13 more cities and Nationwide in 2017: <i>RSPM, CO</i> Creation of National Green Tribunal (NGT) to hear and speedup the environment-related court case: <i>RSPM, SO₂, NO_x</i> Strict emission norms were enforced in industries having Furnace, boiler, and captive power plant: <i>SO₂, NO_x & RSPM</i> Sulphur reduced to 50 ppm n diesel and gasoline in 2010: <i>SO₂ in vehicles</i> 	9	65	228
2011–2015	<ul style="list-style-type: none"> Restricted entry of Heavy Vehicles in Delhi and allowed during night time only between 10:00 pm.–07:00 am: <i>RSPM; SO₂ & NO_x</i> A complete ban on open solid waste burning in the city: <i>RSPM; SO₂ & NO_x</i> Ban on registration on diesel cars having engine capacity above 2000c: <i>RSPM & NO_x</i> 	7	87	227
2016–2019	<ul style="list-style-type: none"> Odd-Even Car Scheme implemented in Private Cars in Delhi city which is time-specific strategies: <i>RSPM & NO_x</i> De-registration of diesel cars older than 10 years or more and all 15-year-old vehicles in Delhi city: <i>RSPM & NO_x</i> Introduced Air Pollution Accountability App for citizens to account for Leaves and garbage burning, building and construction dust, unpaved road dust in Delhi city: <i>RSPM, SO₂ & NO_x</i> Enforced Graded Response Action Plan (GRAP) in Delhi and NCR. The plan have 27 control actions and suggested to implement at different pollution level in the city: <i>RSPM, SO₂ & NO_x</i> The Government enforced stringent emission norm for Thermal Power Plants. Delhi NCR has 13 thermal power plants which are going to implement these norms to meet the compliance: <i>RSPM, SO₂ & NO_x</i> Ban on use of Furnace oil and Petcoke fuel for industries in Delhi and NCR. Action has been taken for illegal use of these fuel in industries in the year 2017: <i>SO₂ & RSPM</i> Introduced Bharat Stage VI in all new vehicles in Delhi–NCR: <i>RSPM & NO_x</i> Constructed Eastern-western Periphery Expressway around Delhi city to bypass the non-designated vehicles from Delhi. It is found that almost 50,000 vehicles daily use these periphery road corridors which are supposed to enter Delhi city: <i>RSPM & NO_x</i> MoEFCC has launched National Clean Air Program for 102 non-attainment cities in India, including Delhi city: <i>RSPM, SO₂, NO_x</i> Conversion of Brick-kiln technology in to advance less polluting technology i.e., Zig- Zig in Delhi NCR: <i>RSPM, SO₂ & NO_x</i> Introduction of green crackers in stead of traditional fire crackers in the year 2017–2018: <i>RSPM, SO₂, NO_x</i> 	6	101	215

The italic bold text indicates that expected pollutants to be reduced due to respective management strategy

Fig. 5 Change in pollutant concentrations (%) wrt base year period

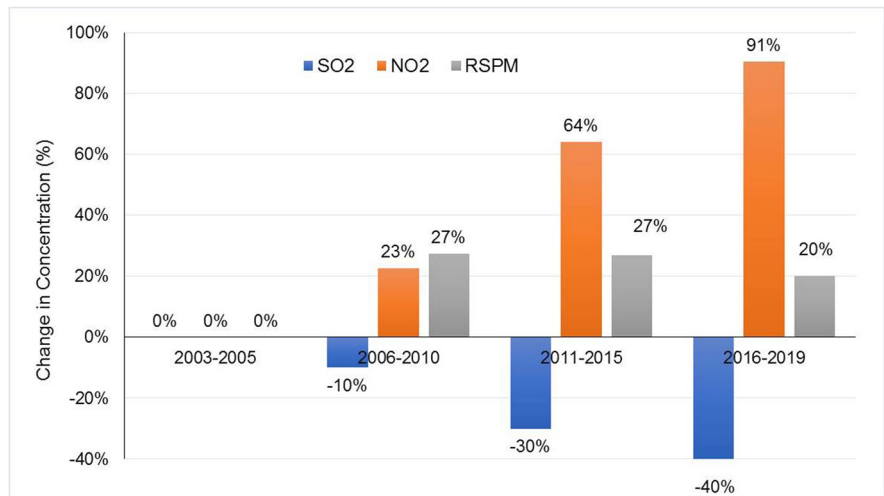
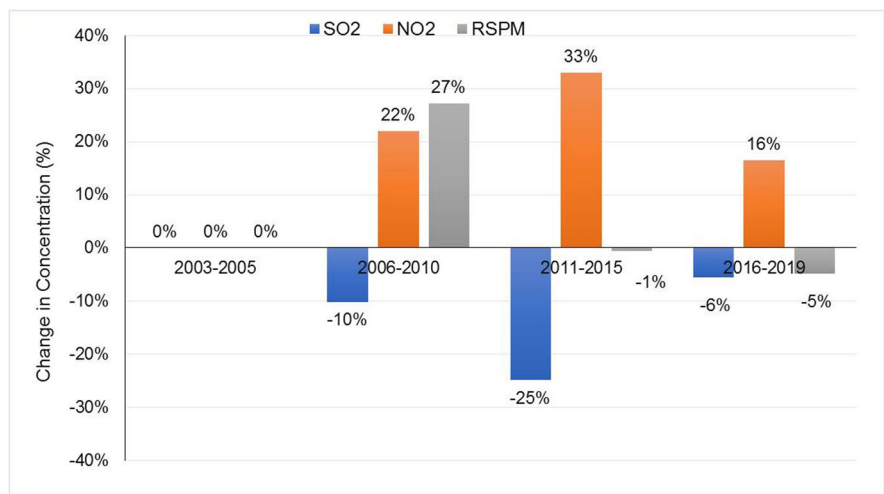


Fig. 6 Change in pollutant concentrations (%) wrt previous year period



ban on operations of DG sets, (ii) closing operation of major and minor Industries, (iii) closing of brick kilns, (iv) awareness to public to stop biomass burning; and (iv) odd-even car trial scheme among others to reduce the emission of both gaseous and PM in the ambient air. Additionally, the increase in the frequency of road dust cleaning and a ban on construction activities reduced the PM emission at local level.

6 Conclusion

The present study has analysed the past 17 years data on air quality at three different locations in Delhi and tried to develop correlation between pollutants

and between sites. Further, control action/strategies enforced/implemented in Delhi NCR cities are discussed and correlated with overall air quality trend during the study period. The outcomes of the study are:

1. The study has discussed the history of air quality monitoring in India and presented the air quality trend of last 17 years in Delhi city.
2. It is observed that RSPM concentrations are gradually increased from year 2003 to year 2019 with an annual average increment of 0.98 to 3.19 % while NO₂ concentrations increased maximum with annual average of 5.21 to 6.07%. However, SO₂ concentrations trend changed in the range of -1.49 to -4.09 %.

3. It is observed that daily and annual average RSPM and NO₂ concentrations are found exceeding the specified standards throughout the study period; however, SO₂ concentrations are far below the specified standards.
4. There were no correlation between pollutants for a respective site expect RSPM and NO₂ at Naraina during January which indicates the possibility of vehicular and industrial sources at Naraina Industrial area and nearby ring road.
5. There was good correlation between sites for RSPM during March, April and September months and NO₂ throughout the year which again indicates the possibility of natural/road dust (most common in dry hot weather) and vehicular emission, respectively at all three sites.
6. Concentrations of RSPM and NO₂ are found higher when compared to base year 2003 which might be due to an increase in sources activities (vehicles numbers, energy consumption demand, among others) in the city. However, the comparison of pollutant concentrations wrt its base year showed increment, but increasing rates that gradually decreased as number of control actions amplified, reflecting the impact of control strategies for the purpose they implemented.
7. Numerous control strategies were introduced/enforced by policymakers in the past and found that numbers of actions are increasing every year starting from the 1980s onwards. This increasing trend in a number of control actions/policies showed the seriousness of policymakers about air pollution.
8. The present analysis gives an idea about the impact of policy interventions on the air quality of Delhi city; however, there is a need to develop a systematic mechanism to monitor/assess the improvement in air quality (pollutant wise) as a result of implementing various control strategies.

Data Availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of Interest The authors declare no competing interests.

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