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Assessing the Trend and Status of Air Quality in NCT Delhi

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ABSTRACT

In contemporary world, air pollution is one of the major threats to the sustainable prosperity of the population. Expeditious rise in the population, vehicles, industries, construction activities and simultaneous reduction in the green cover, which act as pollution absorber, led to the deterioration of air quality. This rapid rise in above attributes, particularly in the mega cities, had increased the pressure on the physical and social infrastructure which takes heavy toll on the environment and Delhi is no exception to that. Delhi, the National Capital Territory (NCT) of India, is being tagged as the "gas chamber" due to its poor air quality, as Delhi is the most polluted capital of the world according to a study conducted by the Greenpeace. This paper analyzes the trend and pollution level in NCT Delhi, using Exceedance Factor (EF) method, caused by pollutants namely Sulphur Dioxide (SO2), Nitrogen Oxide (NO2), Carbon Monoxide (CO), Respiratory Suspended Particulate Matter / Particulate Matter (RSPM/PM10) and Suspended Particulate Matter (SPM) from 1991 to 2017. Time series analysis (trend line by least square) method is applied to explain the trend and pollution level over the time period and further represented through bar graph to show the trends of pollution in Delhi. Taking National Ambient Air Quality Standards (NAAQS) as a base, trend of pollution in Delhi since 1991 to 2017 has been explained. Exceedance Factor method is adopted to establish temporal variation in air quality of the study area for the period 1991 - 2017. Based on values obtained from EF method, air quality has been classified into four broad categories- low, moderate, high, and critical. The study shows that SO2 is within the prescribed limits established by CPCB (Central Pollution Control Board) in all the years whereas NO2 breaches the NAAQS (National Ambient Air Quality Monitoring Standards) consistently from 2000 onwards except 2007.On the other hand, RSPM/PM10 crosses standard limit throughout the time period of study. Similarly, CO also violates the prescribed limit in almost all the years except 2009, 2014 and 2015.

Introduction

Air Pollution, regardless of being around for several decades, has become one of the riskiest and most widespread environmental problems particularly in urban areas. However, both developing and developed countries are grappling with the problem of polluted air (Abiye et al. 2012**).** It is an invisible menace which is taking heavy toll on the lives of people all over the world. The successive reduction in the date of Earth overshoot day viz September 23, August 8, July 29 in the years 2000, 2010 and 2019 respectively indicates the over exploitation of resources by the people, repercussion of which can be seen in many forms and air pollution is one of them. Globally, the economic cost of air pollution is around USD 2.9 trillion or 3.3% of world's GDP annually and India is losing 5.4% of its GDP (Greenpeace Southeast Asia, 2020). In 2017, 1.24 million or 12.5% of total deaths is due to air pollution and one out of every eight persons died due to noxious air of India (Balakrishanan et al. 2011). According to World Air Quality Report (2019), 21 Indian cities lie in the top 30 world's most polluted cities. The city of Ghaziabad is the most polluted and Delhi stands fifth among them. Delhi is one of the fast-growing economic centers of the Southeast Asia (Shindwani and Goyal, 2014). Delhi, despite being an engine of growth, is struggling from the air pollution from a very long period and this contest is getting troublesome day by day. The air of Delhi is so bad that breathing in Delhi is equivalent to smoking twenty plus cigarettes in a single day (Thakur, 2016**)**. In 2019, the Air Quality Index (AQI) reached a maximum limit of 999 on Diwali night that indicates the rancorous nature of air quality in Delhi. The crisis of air pollution in Delhi, especially the smog, has led to closure of schools many a times, large number of road accidents and flight cancellation are frequent phenomena during winter season (PHFI, 2017). In the year 2015, Ambient PM2.5 was responsible for fifth-ranking mortality risk factor throughout the world and deaths engender by it escalates from 3·5 million in 1990 to 4.2 million in 2015 (Sun and Zhu, et al. 2017). Air Pollution in Delhi is substantially high and consequences of which can be seen in the several disorder like pervasiveness of restrictive, obstructive, and combined (restrictive & obstructive) lungs functioning deficit as studied by (Rizwan et al. 2013). The adulterated air of Delhi increases the risk of cardiac disorders (Balyan et al. 2018). Among many pollutants, the PM10 is the highly lethal and has exorbitant proclivity to perforate in lungs and causes respiratory and cardiovascular disorders and death in worst case (Guttikunda, 2012). Children are more prone to ill effects of toxic air because they need almost double the air required by the adults', similarly aged people are also more vulnerable as their immune system is less resilient as compared to younger ones (Tadano et al. 2014). Children, elderly persons and people with respiratory ailments like asthma, influenza is more susceptible to be affected by the particulate matters (Rizwan et al. 2012). Apart from human beings, it substantially affects the environment and eventually animals, vegetation and minerals (Singh et al. 2015). Furthermore, (Nagpure et al. 2014) evaluated the direct health impacts of various air pollutants in the districts of Delhi. According to their study the North West district has the highest number of morbidity and mortality cases whereas New Delhi district registered the least number of cases.

Researchers around the world have undertaken many studies to understand the probable reason behind air pollution. Majority of them agreed upon the fact that moronic human population growth, industrialization and urbanization in the last century have raised the concentration of air pollutants on global scale. However, there are regional factors which contribute to the air pollution of a particular area. As for the Delhi, decadal growth rate is 47% and the consistent rising population has increased the demand for energy to meet their transportation, power and other needs (Kumar et al. 2017). The rampant increase in consumption of petroleum and diesel has significantly contributed to the vehicular pollution. While the particulate pollutants are contributed by non-exhaust particles like wear and tear of road pavements, vehicles components, industrial processes, construction activities. (Firdaus, 2010**).** Meteorological factors are another reason for high concentration of pollutants in Delhi. Delhi is a landlocked state and is therefore unable to receive the moderating effect of water bodies. Moreover, cold dry air and ground-based inversion, in winters, are accountable for high concentration of pollutants (CPCB, 2016). According to the study undertaken by (Deshwal et al. 2009), the concentration of pollutants (except SO_2) in Delhi is not showing declining trend even with the adoption of several air pollution control measures, as it has been witnessing magnanimous growth of population, vehicles, industries, energy consumption since the independence. Apart from the anthropogenic sources the climatic and natural sources also contribute in raising the level of air pollution in Delhi, pre- monsoon dust storms accentuate the already high concentration of suspended particulate matter (Lahiri et al. 2006). Throughout the world Organizations, Agencies, and NGOs notably (WHO) World Health Organization, (USEPA) United Nations Environment Protection Agency, (UN) United Nations, CPCB from India etc. are continuously fighting with the air pollution by making policy interventions, providing scientific solutions, generating awareness by publishing reports, papers etc. (Department of Environmental, Food and Rural Affairs, 2015). Air pollution in Delhi is continuously rising and makes it the most polluted capital city in the world therefore the present study assesses the trends of air pollutants and status of air quality. An attempt is also been made in this study to analyze the trends of certain pollutants particularly SO_2, NO_2, RSPM, SPM, PM10 and CO and finally the status of pollution in Delhi. For the study, data from Central Pollution Control Board (1991-2010), Delhi Pollution Control Committee (2011-2017), Census of India (1991,2001 and 2011) and Economic Survey of Delhi (1999-2006) was used. Here we applied Least Square Method for Trend analysis and Exceedance Factor for Comparison with air quality standards.

This study will help people to understand the level of air pollution from 1991 to 2017 in Delhi and facilitate the policymakers to take appropriate steps in the right direction so that the damaging effect on Environment, Economy and Human health can be controlled.

Materials and methods

Study Area

Delhi is one of the union territories as well as the capital of India. It is the third largest urban center with 16.31 million Population (Economic Survey of Delhi, 2017-18) and is located between the latitudes of 28°24′17″ and 28°52′ north, and longitudes of 76°50′26″ and 77°20′37″ (Figure 1). It covers an area of 1484 km or 573 sq miles at an elevation of 216 meters above mean sea level. It shares its boundary with Haryana from three sides and on eastern side by Uttar Pradesh **(**Economic Survey of Delhi, 2014-15). The foundation stone of Delhi was laid by Emperor George V during the Grand Durbar of 1911. Delhi is primarily divided into two parts Old Delhi and New Delhi; former comprises the modern-day Delhi or Lutyens Delhi whereas the latter signifies the historical and cultural aspect of Delhi. Initially there was only one district in Delhi with it headquarter at Tis - Hazari.

In 1997, Delhi was divided into nine districts (New Delhi, North Delhi, North-West Delhi, West Delhi, South-West Delhi, South Delhi, South-East Delhi, Central Delhi, North-East Delhi) and in 2012 two more districts were added namely Shahdara and South-East. Delhi experiences Humid Sub-tropical Climate (CPCB, 2012)**.** Summers are long and extremely hot (early April to mid - October). Monsoon winds advent from end of June. Reversal in wind direction from north- western direction to the south - western in early March brings hot waves called 'Loo' from deserted part of Rajasthan. Winter starts in late November and peaks in January accompanied by heavy fog. Annual rainfall in Delhi is 714 mm or 28.1 inch.

The River Yamuna flows though the city having huge catchment area distributed at both the banks. Delhi is a well popular Tourist Destination and it attracts people across the world. It also falls under Gurgaon-Delhi-Meerut Region, one of the Major Industrial Regions (NCERT, 2017) of India and comprises several industries like Engineering Goods, Textile, Chemical, Electronics, Steel, Plastic, Rubber, Automobiles, Thermal Power stations (Badarpur, Indraprastha, Rajghat) etc.

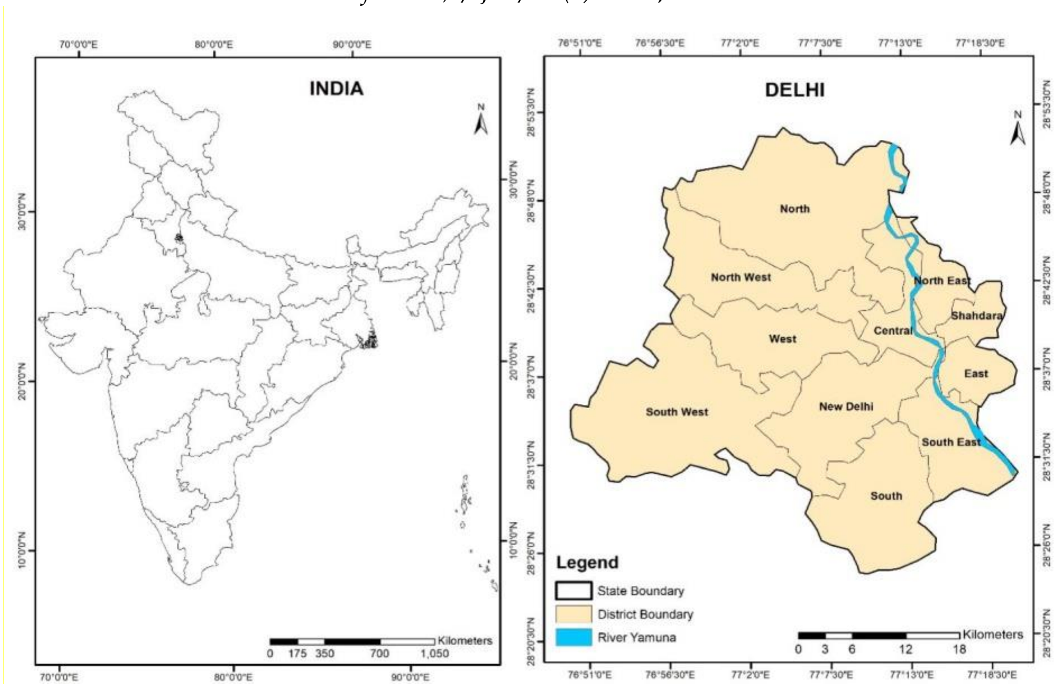

Fig 1: Location Map of Delhi

Material

This paper is quantitative study based on secondary sources of data. The monitored concentration for the pollutants namely Carbon Monoxide (CO), Sulphur dioxide (SO_2), Nitrogen Oxide (NO_2), Respiratory Suspended Particulate Matter (RSPM), Particulate Matter having aerodynamic diameter of 10 microns (PM10) is collected from Central Pollution Control Board (CPCB) for the period 1991 to 2010, as per its National Ambient Air Quality Monitoring (NAAQM) program (Table 1) started in 1984. Initially there were six locations commissioned around mid–1987, gradually the number of monitoring stations was increased and presently there are eleven monitoring stations in Delhi.

Therefore, the data were obtained for eleven locations viz Ashok Vihar, Siri Fort, Janakpuri, Nizamuddin, Mayapuri, Sarojini nagar, Chandini Chowk, Shahdara, Shahzada Bagh, Pitampura and ITO (Figure 2). In addition to the data of pollutants, meteorological parameters are also measured like wind direction, wind speed, temperature and relative humidity. Delhi Pollution Control Committee (DPCC) was established in 1991 by Central government to control the air pollution in Delhi. It has been delegated all the powers and functions of State Pollution Control Board (SPCB) in relation to NCT Delhi by CPCB under the provisions of section 6 of Air act, 1981, in march 1991. Data for the time period 2011 to 2017 are collected from Delhi Pollution Control Committee (DPCC) for six locations namely R.K Puram, Mandir Marg, Punjabi Bagh, IGI Airport, Anand Vihar and Civil Lines (Figure 2). Data of population are taken from the census of India for the year 1991, 2001 and 2011 and other data related to urbanization, industries, transport and energy are taken from statistical hand book Delhi, economic survey of Delhi, annual reports of CPCB, Journals, newspapers and magazines etc. The collected data of different locations are first organized and hence annual average values are computed for each pollutant.

Table 1: National Ambient Air Quality Standards (NAAQS)

Pollutants	Time weighted average	Concentration (in µg/m³)	Method of Measurement
SO2	Annual average	50	Improved West and Geake Method, Ultraviolet fluorescence
NO2	Annual average	40	Jacob & Hochheiser Modified (Na-arsenite), Gas Phase Chemiluminescence
RSPM	Annual average	2000	RSPM Sampler
CO	8 hourly	60	Non Dispersive Infrared Spectroscopy
SPM	Annual average	360	High Volume Sampling (Average flow rate not less than 1.1m³/minute)

Source: CPCB, 2009

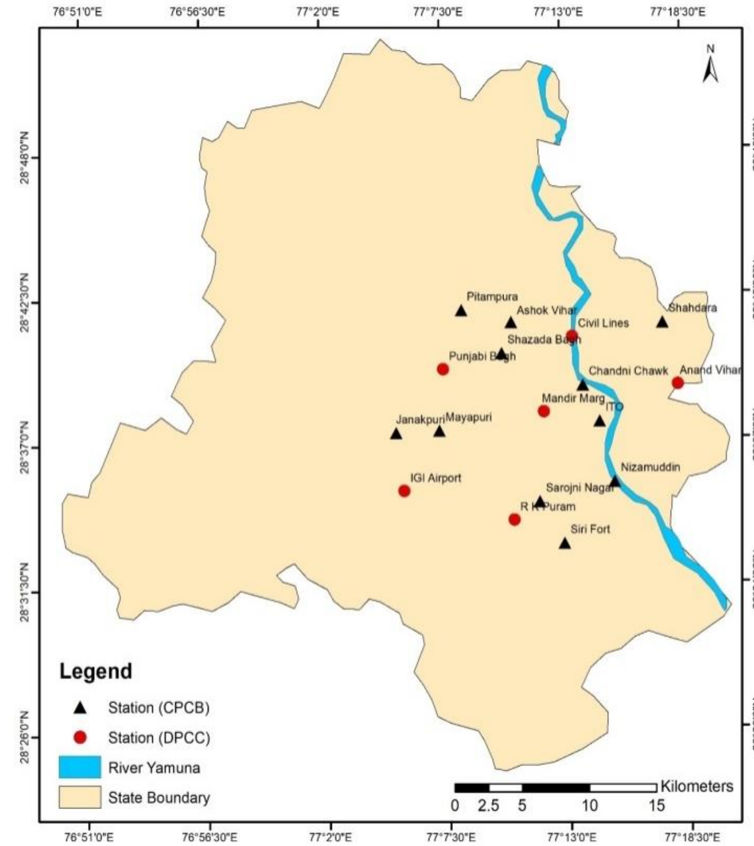

Fig 2: Air Pollution Monitoring Stations of CPCB and DPCC

Methodology

Time series analysis (trend line by least square) method is applied to explain the trend and pollution level over the time period and further represented through bar graph to show the trends of pollution in Delhi. Taking National Aambient Air Quality Standards (NAAQS) as a base, trend of pollution in Delhi since 1991 to 2017 has been explained. Time series analysis is considered as one of the best techniques for obtaining trend value over a time period. With this method, a straight-line trend is obtained. The equation of straight line is Y = a + bX where 'a' and 'b' are constants. This equation of straight line establishes a functional relationship in X and Y series and as such can be used to forecast future value. In addition to trend analysis using least square method, exceedance factor method (Equation 1) is adopted to establish temporal variation in air quality of the study area for the period 1991 - 2017. Based on values obtained from EF method, air quality has been classified into four broad categories- low, moderate, high, and critical. Figure 3 shows the methodology used in this study. CPCB primarily uses this method to assess the quality of air in its annual reports and other publication. Apart from CPCB, researchers like (Firdaus, 2010: Haque et al. 2017) and others used the exceedance factor method to find out the status of air. Data of population, urbanisation, transportation and energy etc have been taken to analyse the relationship between rising air pollution and these factors.

Exceedance Factor (EF) of the Pollutants is calculated using the following formula:

$$EF = \frac{Observed\ annual\ mean\ concentration\ of air\ pollutants}{Annual\ air\ quality\ standard\ for\ respective\ pollutants} \qquad \text{Equation 1}$$

The four categories of air pollution based on the values of Exceedance factor are:

1. Critical pollution (C): EF $\geq$ 1.5;
2. High pollution (H): 1.0 $\leq$ EF < 1.5;
3. Moderate pollution (M): 0.5 $\leq$ EF < 1.0;
4. Low pollution (L): EF < 0.5

The concentration of air pollutants is only a numerical value and does not reveal the severity of pollution i.e., low, moderate, high and critical. This inevitable aspect is demonstrated by the Exceedance factor of respective pollutants. From the above categorization of the Exceedance factor, the pollutants in the first three categories (critical, high, moderate) are actually violating the prescribed standards but with varying magnitude and causing significant damage to health of humans and environment and consequently needs immediate attention to combat their repercussion. Pollutants lie in fourth category i.e.; low are meeting the standards as of now by likely to breach in coming future so appropriate steps should be taken to mitigate and restrict them in prescribed limits.

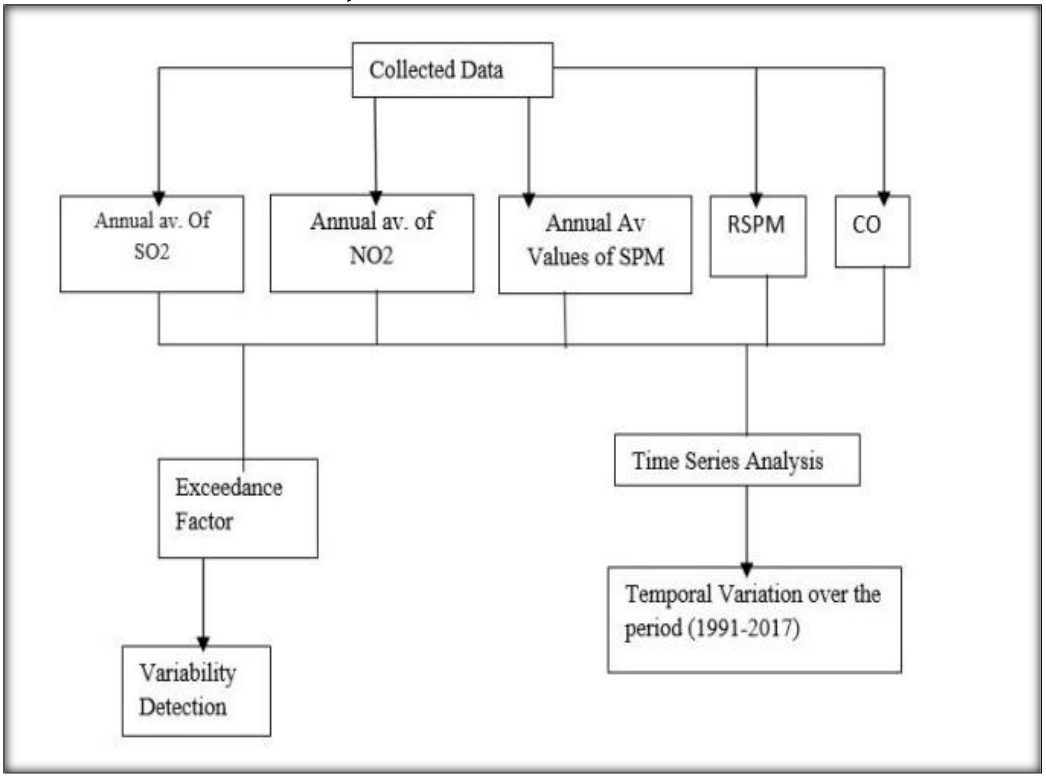

Fig 3: Flowchart of Methodology

Results and Discussion

The year wise trends of annual mean concentration of air pollutants are analyzed using time series analysis method and they are visually represented through bar graphs as shown in figures 4-9 for SO_2, NOx, RSPM/PM10, CO and SPM respectively. Table 2 and Figure 11 show the quality of air which is examined using exceedance factor method.

Sulphur Dioxide (SO_2) is both primary and secondary pollutant. It is primarily originated from the burning of fossil fuels like coal and oil and a significant additive in particulate matter in the environment. Rainfall combined with SO_2 and NOx, which are present in the gaseous form in the atmosphere, to convert the pure rain into acid rain, also referred as "unseen plague**,** which mutilates both living and non-living. It affects the aquatic life by increasing the PH of the water and turning them into lifeless water bodies. Similarly, it hampers the soil, plants, buildings and monuments etc. (Kaushik, 2006). In Figure 5, it is clearly visible that concentration of SO_2 is well below the NAAQS set by CPCB i.e., 50µg/m³. It is also perceptible from (Table 4) that exceedance factor of SO_2 is below 0.5, except in 2017, and reached a maximum concentration of 23.36µg/m³, throughout the monitored years, which indicates that it caused low level of air pollution and did not pose any significant threat to human health. Moreover, the trend line is also showing a decreasing trend. This is due to several initiatives taken by the government like provision of catalytic converter in passenger car (1995), reduction of Sulphur content in vehicle fuel (petrol and diesel) to 0.5%, 0.25%, 0.05% in 1997, 1999, 2000 respectively. Ban on loose supply of 2T engine oil and discontinue use of commercial vehicles older than fifteen years in 1998. Implementation of euro norms Bharat 2000 (Euro 1), Bharat II (Euro 2), Bharat III (Euro 3), and Bharat IV (Euro 4) in 2000,2001, 2005 and 2010 respectively, significantly controlled the emissions from vehicles as a result of this minimum concentration observed in year 2007(4.4µg/m³). However, in a recent study conducted by Greenpeace in 2019, India was found to be the largest emitter of SO_2 in the world. Therefore, appropriate steps should be taken by government to control the SO_2 emissions because it can disrupt functioning of lungs and cause consequent respiratory disorders.

Nitrogen Oxide (NO_2) is a poisonous, non-flammable, reddish-orange in color having mild odor smell. It is a precursor of ozone formation in troposphere. It amalgamates with aerosols in environment to form brownish smog, which reduces the visibility in atmosphere, hinders floral growth and causes crop impairment etc. Most important reason of formation of oxides of nitrogen is high temperature of combustion viz internal combustion engines, fossil fuel-fired power station etc. Trend line of NO_2 shows a rising tendency (Figure 6). From 1991 to 1996, although the concentration of NO_2 is within NAAQS (40µg/m³) but the value of exceedance factor is greater than 0.5 which indicates moderate level of pollution caused by it. During 1997 – 2010, it caused high level of pollution as the value of exceedance factor is above 1.0. Similarly, from 2011 onwards and up to 2017, exceedance factor is greater than 1.5 and consequently responsible for critical level of pollution. The rising trend of oxides of nitrogen from 1991 – 2017 and subsequent pollution level has changed from moderate to high to critical level. It is caused due to tremendous growth in the number of registered vehicles (Figure 7) and industrial units, over the years, as both transportation and industrial sectors are significant contributors to high concentration of nitrogen oxides in Delhi. However, in the initial years (1991-1996), concentration of nitrogen oxide adhered to NAAQS but it did not lie in the low-level pollution category of exceedance factor despite the concentrations were less than 40µg/m³. Therefore, rising trend of NO_2 is a cause of concern, as it causes irritation in nose and throat and reduces immunity to lung infection inevitably make the body vulnerable to respiratory illness.

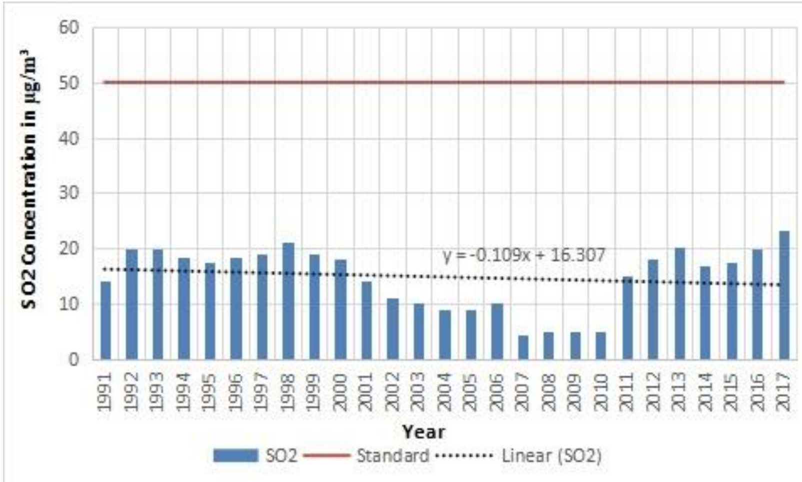

Fig. 4 : Trend of SO_2 in the ambient air of Delhi

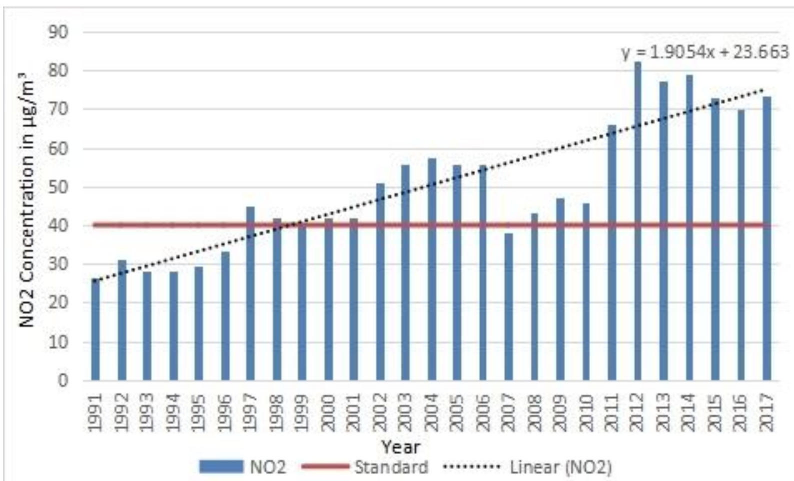

Fig 5: Trend of NO_2 in the ambient air of Delhi

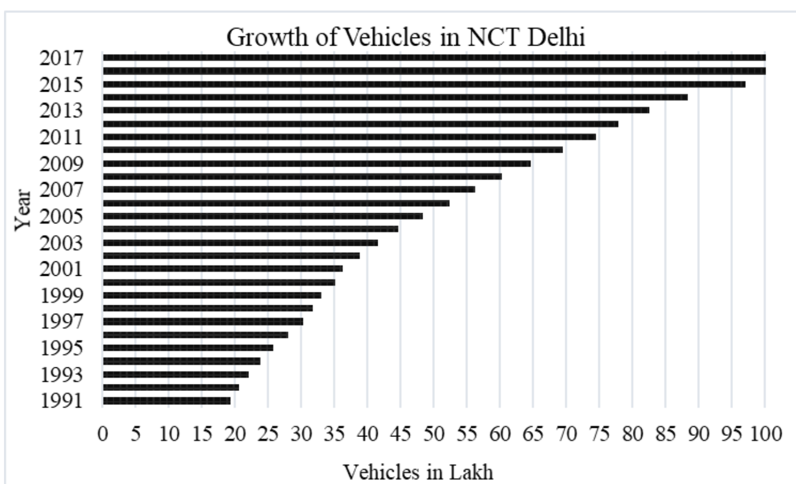

Fig 6: Registered Vehicles in Delhi (1991-2017)

Respiratory Suspended Particulate Matter (RSPM) is the solid particles having aerodynamic diameter less than 10µm or $1/7^{th}$ width of human hair. It is one of the most important pollutants because it is generally used to measure the level of air pollution. RSPM is categorized as primary particle as they are originated from industrial activities, road traffic, road dust, sea spray, and windblown soil, they also contain carbon and an organic compound, metals and metal oxides and ions. The trajectory of RSPM, over the years, shows a steep spike in the trend line from 2001- 2017 (Figure 8) and breached NAAQS in every year (only among all the pollutants). This rising trend can be attributed to the surge in number of vehicles (1991- 19.24 lakh and 2017- 109.86 lakh),increasing industrial units and hike in energy consumption (1991- 1435MW, 2001 - 2831MW, 2011 - 3274MW) thus it reached a maximum value of 318µg/m³ in 2014 (430% greater than the prescribed value) but the most threatening issue is that its exceedance factor lie in the critical level of air pollution category which can be highly fatal as it can cause mild breathing discomfort to lung cancer, shorten life span, cardiovascular ailment therefore it is a pollutant of urgent concern. The main reason for breaching the standard value(60µg/m³) in every year by RSPM is due to the presence of numerous sources like vehicles (exhaust from petrol vehicle and diesel vehicle), physical processes (grinding, abrasion, crushing), power plants, windblown dust, re-suspended road dust, burning of biomass, construction activities, domestic refuse burning etc.

Suspended Particulate Matter is a broad term which comprises particulate matters of different sizes PM10, PM2.5 and PM1. It can be classified into categories coarse SPM (PM10) and fine SPM (PM2.5). It is a complex mixture of suspended solid particles in semi equilibrium with surrounding gases. Like RSPM, SPM are also innumerabley sourced from – basic agricultural activities to hospital waste incinerator. Trend of SPM (Figure 9) shows minimum variation in initial years and then a sudden surge in 2008 and reaching a maximum concentration of 494.9µg/m³ in 2010. Although the trend line shows declining tendency, nevertheless, Exceedance factor of most of the years falls under the critical level of air pollution category except few years like 1991, 2005, 2012 etc. This is due to the rising population (1991 – 94.21 lakh, 2001 – 138.51 lakh, 2011 – 167.88 lakh) and urbanization (1991 - 89.93%, 2001 – 93.18%, 2011 – 97.50%).

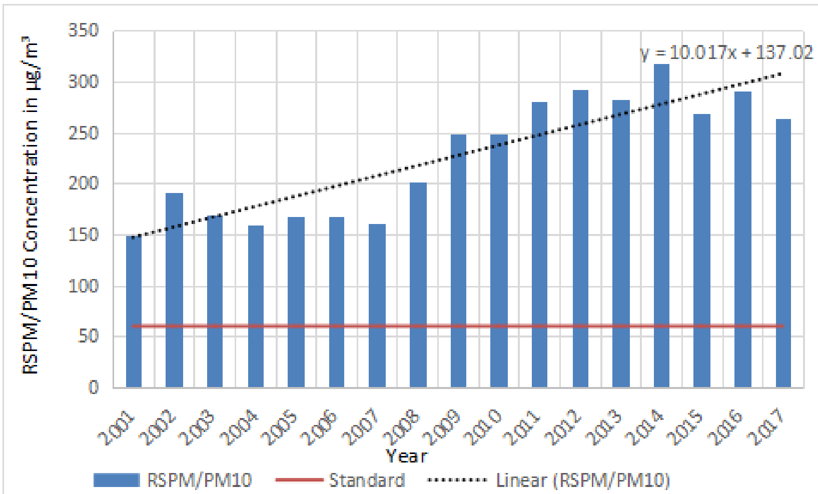

Fig 7: Trend of RSPM/PM10 in the ambient air of Delhi

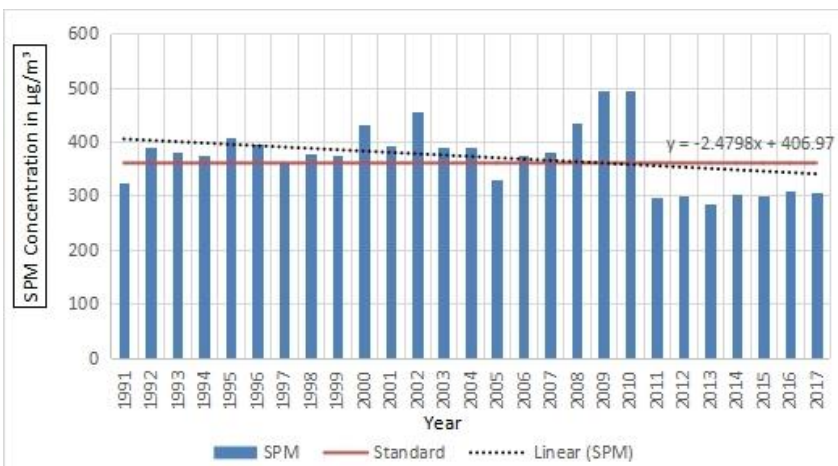

Fig 8: Trend of SPM in the ambient air of Delhi

Carbon Monoxide (CO) is also known as "Silent Killer" because it is odorless, colorless, tasteless and non-irritating in nature. It naturally occurs in the atmosphere due to volcanic eruption, forest fires etc. Anthropogenic sources of CO include automobile emissions, industrial activityies like steel manufacturing and iron smelting, tobacco smoke (prime source of indoor CO emission) etc. The trend graph (Figure 10) of CO shows a decreasing trend in general with reaching minimum value of 1618µg/m³ in 2015 and maximum value of 5450µg/m³ in 1998. CO level curbing down caused due to various controlling measures taken by government like closure of several hazardous industries from time to time and operation of Delhi Metro in 2002 decreased the population of vehicles plying on road which reduced the traffic congestion and consequent emissions. But the exceedance factor given in table 2 presents the grim picture according to which the concentration of CO crosses the 1.5 mark of exceedance factor in all the monitored years, except in 2009, 2014 and 2015, which indicates the critical level of air pollution caused by it. Thus, CO emission is a matter of concern and serious steps should be taken to control emission as it is readily combined with hemoglobin (because it has, 240 times, high affinity for Hb as compared to oxygen) in RBC and form carboxyhemoglobin leading to tissue hypoxia.

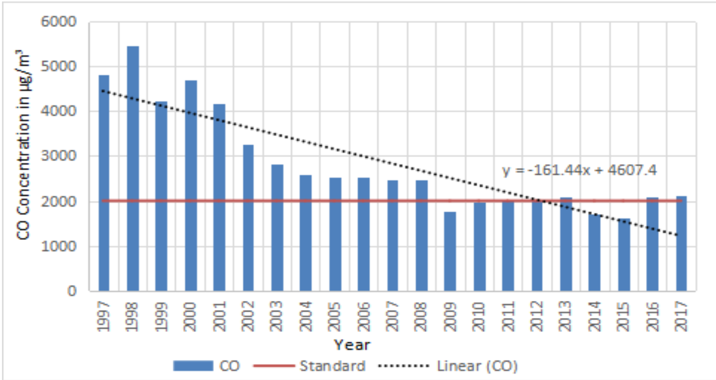

Fig 9: Trend of CO in the ambient air of Delhi

The exceedance factor is a measure of fraction of air pollution that is potentially exposed to ambient air (1) the concentration of air pollutants and (2) in excess of CPCB NAAQS set for the protection of human and environment. The results of exceedance factor are given in Table 4 for each pollutant. Along with the value of exceedance factor, in the table, respective category (Low, Moderate, High and Critical) is also mentioned and resultant bar graph (Figure 10) is made to gauge the change in the quality of air during the concerned time period. The bar graph (Figure 11) of exceedance factor of air pollutants from 1991 to 2017, shows an increasing trend of values of exceedance factor throughout the time period. In other words, it indicates the quality of air changing from sparingly polluted to critically polluted from Table 2 and Figure 11, it is clear that all pollutants in most of the years, except SO_2, lie in the critical and high categories of exceedance factor. Among them, the concentration of RSPM was very high since 2001 to 2017 falling under critical categories of air quality measurement. It has reduced the purity level of ambient air. Concentration of CO was at critical level from 1997 to 2001 and then onward its emission level kept fluctuating between the high and critical category till 2017. NO_2 level remained trending between medium and high category till 2010 from 1991 and it reached to critical level from 2011 onwards. Thus, the deteriorating air quality of Delhi is a direct outcome of skyrocketing concentration of RSPM, CO, NO_2 and SPM in the ambient air.

Table 2: Exceedance Factor of Air Pollutants (1991-2017)

Year	SO_2	NO_2	RSPM/PM10	SPM	CO
1991	0.3 (L)	0.7 (M)	-	0.9 (M)	-
1992	0.4 (L)	0.8 (M)	-	1.1 (C)	-
1993	0.4 (L)	0.7 (M)	-	1.1 (C)	-
1994	0.4 (L)	0.7 (M)	-	1.0 (C)	-
1995	0.4 (L)	0.7 (M)	-	1.1 (C)	-
1996	0.4 (L)	0.8 (M)	-	1.1 (C)	-
1997	0.4 (L)	1.1 (H)	-	1.0 (C)	2.4 (C)
1998	0.4 (L)	1.1 (H)	-	1.0 (C)	2.7 (C)
1999	0.4 (L)	1.0 (H)	-	1.0 (C)	2.1 (C)
2000	0.4 (L)	1.1 (H)	-	1.2 (C)	2.3 (C)
2001	0.3 (L)	1.0 (H)	2.5 (C)	1.1 (C)	2.1 (C)
2002	0.2 (L)	1.3 (H)	3.2 (C)	1.3 (C)	1.6 (C)
2003	0.2 (L)	1.4 (H)	2.8 (C)	1.1 (C)	1.4 (C)
2004	0.2 (L)	1.4 (H)	2.7 (C)	1.1 (C)	1.3 (C)
2005	0.2 (L)	1.4 (H)	2.8 (C)	0.9 (M)	1.3 (C)
2006	0.2 (L)	1.4 (H)	2.8 (C)	1.0 (C)	1.3 (C)
2007	0.1 (L)	1.0 (H)	2.7 (C)	1.1 (C)	1.2 (C)
2008	0.1 (L)	1.1 (H)	3.4 (C)	1.2 (C)	1.2 (C)
2009	0.1 (L)	1.2 (H)	4.1 (C)	1.4 (C)	0.9 (M)
2010	0.1 (L)	1.2 (H)	4.2 (C)	1.4 (C)	1.0 (C)
2011	0.3 (L)	1.7 (C)	4.7 (C)	0.8 (M)	1.0 (C)
2012	0.4 (L)	2.1 (C)	4.9 (C)	0.8 (M)	1.0 (C)
2013	0.4 (L)	1.9 (C)	4.7 (C)	0.8 (M)	1.1 (C)
2014	0.3 (L)	2.0 (C)	5.3 (C)	0.8 (M)	0.9 (M)
2015	0.4 (L)	1.8 (C)	4.5 (C)	0.9 (M)	0.8 (M)
2016	0.4 (L)	1.8 (C)	4.8 (C)	1.1 (C)	1.0 (C)
2017	0.5 (M)	1.8 (C)	4.4 (C)	1.2 (C)	1.1 (C)

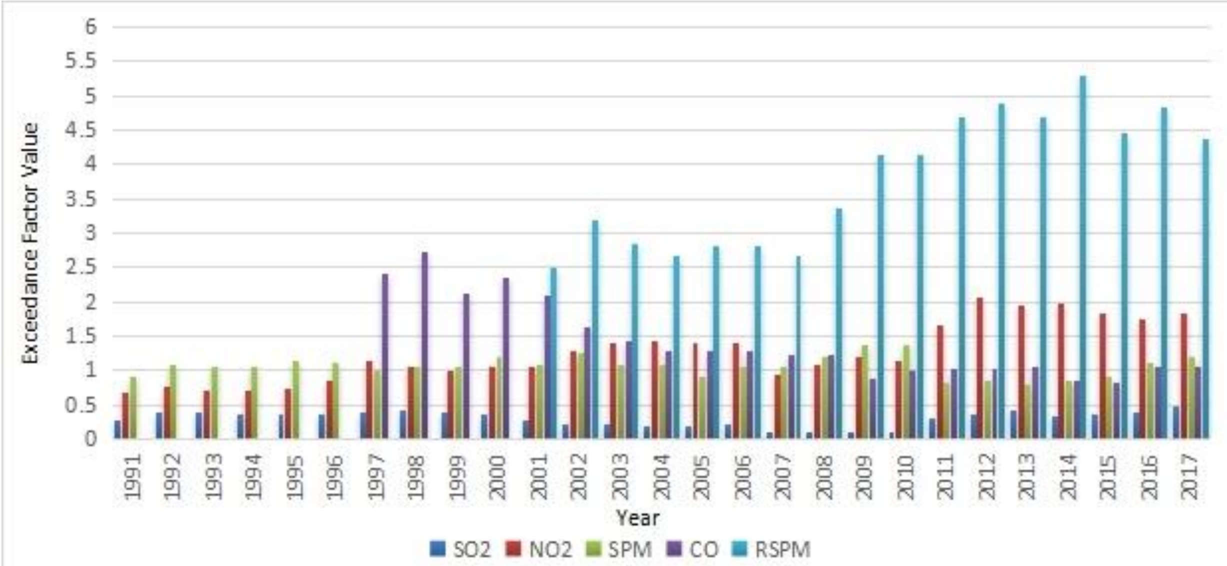

Fig 10: Level of air pollutants, Delhi (1991-2017)

The human factors such as increasing human population, rapid urbanization and increasing energy demand are important factors contributing towards rising levels of studied air pollutants. This is evident from the Table 3, which shows the statistics of population, urbanization and energy demand from 1951- 2011. It is clearly visible that there is continuously rise in population throughout the time period. There is more than 862% rise in 2011 as compared to the population of 1951. Similarly, urbanization in Delhi, in 1951, was merely 15% which is substantially low as compared to the year 2011(75.1%). The rising population accompanied with increasing urbanization urging more resources and affects the consumption pattern. This is evident in the energy demand (table 3) and in the number of registered vehicles (Figure 7).

Table 3: Decadal population, urbanisation and energy demand (1951-2011)

Data	1951	1961	1971	1981	1991	2001	2011
Population (in lakh)	17.44	26.59	40.66	62.20	94.21	138.51	167.88
Urbanization (in %)	15	22	30	40	46.21	62.35	75.1
Energy Demand (in MW)	27	86.6	259.6	563.8	1435	2831	3274

Source: Census of India and Economic survey of Delhi.

Conclusion

In general, several variations were observed in the concentration of pollutants and hence in the trend and status of air quality during 1991 – 2017.These variations are results of interplay between several factors like, rising urbanization, population, per capita consumption, concretization of land with simultaneous efforts to combat air pollution like increasing green cover, more focus and stress on electric and CNG vehicles, shifting towards alternate sources of energy. Anthropogenic activities are the major contributor for the perpetual air pollution but Climatic & meteorological factors (wind direction, wind speed, precipitation, temperature, Humidity) also provide filip to air pollution. Wind governs the course of air pollutants particularly in the upper atmosphere, for example, Wind direction is responsible for carrying the adulterated air, due to stubble burning, from Punjab and Haryana towards Delhi. Insolation is inevitable in the formation of smog during photochemical reaction. Humidity is another important factor which directly affects the pollution levels, notably, High humidity increases the holding capacity of air to hold air pollutants in the air for longer period of time. Precipitation has a dissolving effect on the pollutants like SO_2 and NO_2 and fell on the earth as acid rain. However, another aspect of precipitation is scavenging effect, i.e it boost the visibility by sweeping out the particulate matters suspended in the air.

It is clear and unambiguous from the above discussion that the overall pollution level in Delhi is strikingly high as all the pollutants, except SO_2, breaching the NAAQS and their exceedance factor value is substantially high and causing them to fall in the Critical, Moderate and High category of air pollution. From the analysis through least square trend method and exceedance factor method, it was observed that SO_2 is low in Delhi because vehicles are mostly run on CNG, where as the burning of fossil fuels increases the level of SO_2. The most minacious among all the pollutants is RSPM/PM10 followed by SPM, CO, NO_2. Although concentration of SO_2 is well within the NAAQS during the monitored years but studies in recent times show a grim picture with respect to the concentration of sulphur dioxide. Therefore, while taking pertinent steps for the pollutants of urgent concern SO_2 should not be neglected. Most importantly the clean air and environment forms the integral part of UNEP's Sustainable Development goals (SDG 3.9 and SDG 11.6) and Article 21 of Indian constitution also made the Right to healthy environment as a Fundamental right. Thus, a comprehensive strategy should be chalked out to fight against this invisible menace.

Suggestions

1. Delhi is the metropolitan city where commuters are primarily dependent on road transportation and this has caused rise in number of vehicles. Vehicular emission is the chief culprit in the total pollution load as it releases large number of the pollutants like CO, SO_2, NOx, Lead, HC etc. Thus, measures like- improving the deteriorated condition of roads and fixing the non - performing traffic lights will reduce the traffic congestion and resultant pollution level, replacement of old commercial and private vehicles, subsidy on electric vehicles, mechanical sweeping with water wash, retro-fitment of Diesel Particulate Filter (DPF) which have PM emission reduction efficiency of 60-90%.
2. Power plants are another sponsor of ascending air pollution. The main pollutants source is stack emissions, fly ash generation and fugitive emission in coal handling. These can be controlled by increasing the stack height and use of emission control devices. Thermal Power Stations can examine the possibility of installing Bag House Filters as it can control emission of particles between the size of PM 2.5 to PM10.
3. Burning of waste in open should be discouraged and Monitoring and Action against such persons should be taken to reduce this habit of public.
4. Regular Inspection of industries and penal action should be taken against violators of pollution norms.
5. Smog tower and Anti-Smog Gun can be fruitful for areas having high population density and space paucity.
6. Increasing the green cover and growing pollutant tolerant tree species like Mango, Peepal, Neem, Babool, Snake plant, Spider plant etc.
7. Mass awareness drive will also be a remarkable step at the root level because if people understand the sources and causes of air pollution then they will significantly pitch in to counter the air pollution.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest. All the authors have equally contributed to the present work.

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