Annual and Seasonal Variations in Air Quality Index of the National Capital Region, India

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Abstract**—**Air Quality Index (AQI) is used as a tool to indicate the level of severity and disseminate the information on air pollution to enable the public to understand the health and environmental impacts of air pollutant concentration levels. The annual and seasonal variation of criteria air pollutants concentration based on the National Ambient Air Quality Monitoring Programme has been conducted for a period of nine years (2006-2014) using the AQI system. AQI was calculated using IND-AQI methodology and Maximum Operator Concept is applied. An attempt has been made to quantify the variations in AQI on an annual and seasonal basis over a period of nine years. Further, year-wise frequency of occurrence of AQI in each category for all the five stations is analysed, which presents in depth analysis of trends over the period of study. The best air quality was observed in the Noida residential area, followed by Noida industrial area during the study period; whereas, Bulandshahar industrial area and Faridabad residential area were observed to have the worst air quality. A shift in the worst air quality from winter to summer season has also been observed during the study period. Further, the level of Respirable Suspended Particulate Matter was found to be above permissible limit at all the stations. The present study helps in enhancing public awareness and calls for the need of immediate measures to be taken to counter-effect the cause of the increasing level of air pollution.

Keywords**—**Air quality index, annual trends, criteria pollutants, seasonal variation.

I. Introduction

FROM the beginning of 20th century, rapid industrialization and modernization has filled the earth's atmosphere with toxic pollutants which has created an imbalance in the atmosphere's natural stability. Growing population and economic development is linked to a rapid rise in air pollution resulting in an increasing number of pollutants being released in the ambient air deteriorating its quality. Air pollutants are hazardous to both the environment and our own health.

After decades of industrialization and urbanization, air pollution is becoming a contemplative environmental issue causing public health problem worldwide. Poor air quality has both acute and chronic effects on human health [1], [2]. Massive industrialization in developing countries has led to an increase in environmental problems. The investigation on air pollution (SO_2, NO_2, SPM, Pb, CO and O_3) in mega-cities shows that air pollution is widespread across the mega-cities and is often most severe in cities in the developing countries [3]-[5]. Like other developing nations, India too is facing the challenge of air pollution at an alarming rate due to increasing industrial and other developmental activities. Delhi is considered among the most polluted megacities of the world [6] and offers a first-hand choice to study air pollution problems. According to the air quality report published by the Central Pollution Control Board (CPCB), Delhi has exceeded the annual average Respirable Suspended Particulate Matter (RSPM) concentration limit by more than four times the national annual standards [7]. Increasing vehicular population and the resultant traffic congestion has contributed significantly to air pollution emissions. Various studies have been carried out in the past for air quality assessment based on national ambient air quality monitoring data [5], [8]-[10]. The air quality trend of Delhi was compared with US standards by [8]. An AQI system has been proposed and, in turn, interpreted the air quality of Delhi in few studies [11], [12]. Among air pollutants, RSPM is a ubiquitous and it is especially a major problem due to its adverse health effect, visibility reduction and soiling of buildings [13], [14]. There are few studies based on assessment of ambient air quality AQI, and are limited in scope. An attempt, therefore, has been made for the assessment of ambient air quality by analysing the AQI trends, and annual and seasonal variation in AQI.

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II. Air Quality Index

TABLE I
IND-AQI Categories and Range

Sr. No.	AQI Category	AQI Range
1.	Good	0 to 50
2.	Satisfactory	51 to 100
3.	Moderately-polluted	101 to 200
4.	Poor	201 to 300
5.	Very Poor	301 to 400
6.	Severe	401 to 500

AQI is an index used to indicate the level of severity and disseminate the information on air pollution. It is used as a tool to communicate to the citizens how polluted the air is at present or how polluted its forecast to become. AQI is defined as an overall scheme that transforms weighted values of individual air pollution-related parameters into a single number, or set of numbers. The calculated value varies in between 0 to 500, representing daily measured concentrations of the principal air pollutants for which National Ambient Air Quality Standards (NAAQS) have been established. To present air quality status and its effects on human health, the following description categories have been adopted for IND-

AQI, as described in Table I.

III. Meterial and Methods

A. Study Area Characteristics

India's largest and one of the world's largest conurbation or metropolitan area that borders New Delhi, the capital of India, is designated as National Capital Region (NCR). Five air quality monitoring station have been selected in NCR, India for AQI determination in this study namely, Station-1: HSPCB Office, Sector-16A, Ballabgarh, Faridabad; Station-2: M/s Escorts Research Centre, Mathura road, Faridabad; Station-3: Bulandshahar Industrial Area, Ghaziabad; Station-4: Gee Pee Electroplating Work, Sector-6, Noida; and Station-5: Regional Office, Sector-1, Noida, as shown in Fig. 1. Station-1, Station-3 and Station-4 are located in an industrial area; whereas, Station-2 and Station-5 are located in a residential area.

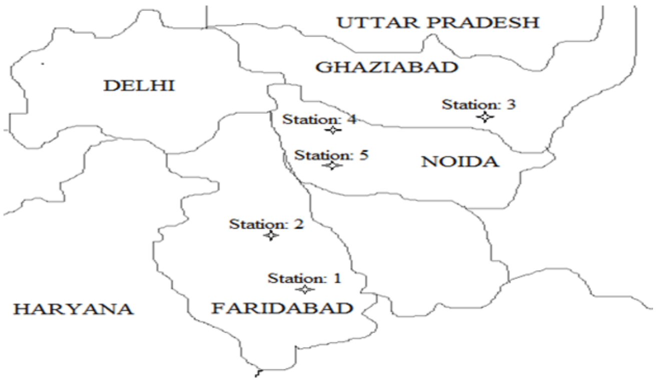

Fig. 1 Location of air quality monitoring stations

TABLE II
NAAQS

Pollutant	Time Weighted Average	Concentration in Ambient Air (μg/m³) Industrial, Residential, Rural and Other Area.
Sulphur Dioxide (SO_2)	Annual	50
	24 hours	80
Nitrogen Dioxide (NO_2)	Annual	40
	24 hours	80
Particulate Matter (size less than 10 μm) or PM_{10}	Annual	60
	24 hours	100

Faridabad is the largest city in Haryana situated in the NCR and is known as a foremost industrial centre. It is one of the biggest industrial cities of Asia with about 200 large and medium scale industries and around 15,000 small scale industries [15]. Faridabad is located at 28.4° N and 77.3° E with an approximate elevation of 198 m. Its climate is classified as tropical steppe and hot semi-arid due to air dryness, apart from monsoon season. Bulandshahar is a city in the state of Uttar Pradesh situated at 28.40° N and 77.84° E with an approximate elevation of 214 m. New Okhla Industrial Development Authority (NOIDA) is emerged as a planned, integrated, modern industrial city in India, which is a part of the NCR. It is located in the state of Uttar Pradesh at the fringes of Delhi at 28.57° N and 77.32° E coordinates spread over 20,316 hectares with an approximate elevation of 213 m.

B. Data Acquisition and Formation

The air quality data for a period of nine years from 2006 to 2014, used in this study is obtained from CPCB and Haryana State Pollution Control Board (HSPCB). The raw data set comprises of 24-hourly average concentration of RSPM, sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). The data is then arranged and statistically computed, as per the requirement of the analysis in the present study. The NAAQS for SO_2, NO_2 and RSPM are listed in Table II.

C. AQI Determination

In the present study, the AQI was calculated using IND-AQI method specified by [11], [16] and [17]. It has been developed on the dose-response relationship of various pollutants. This index is named as IND-AQI (Indian Air Quality Index) and used for reporting changes in air quality. As all the pollutants are not measured under National Ambient Air Quality Monitoring Programme, computation is based on three criteria pollutants (RSPM, SO_2 and NO_2) only. The maximum value of sub-indices for each pollutant has been taken to represent overall AQI of that location as has been suggested by [17]. The equation for calculating the sub-index (Ip) for a given pollutant concentration (Cp); as based on 'linear segmented principle' is shown as:

$$I_P = \frac{(I_{HI} - I_{LO}) * (C_P - B_{LO})}{(B_{HI} - B_{LO})} + I_{LO} \tag{1}$$

where, I_P = AQI for pollutant P, C_P = Concentration of pollutant P, B_{HI} = Breakpoint concentration greater or equal to given concentration, B_{LO} = Breakpoint concentration smaller or equal to given concentration, I_{LO} = AQI value corresponding to B_{LO}, and I_{HI} = AQI value corresponding to B_{HI}.

A maximum operator system has been adopted for the proposed AQI which is free from ambiguity and eclipsing, as:

$$AQI = Max\,(I_1, I_2, I_3, \ldots\ldots, I_n) \tag{2}$$

AQI of all the five stations was calculated using IND-AQI method for the duration of nine years (2006 to 2014). For studying the seasonal variation of the AQI values, the following break-up of 12 months was used as - Summer season (March-June); Monsoon season (July–September); Post-monsoon (October and November) and Winter (December–February). AQI values computed based on concentration of criteria air pollutants at each of the air quality monitoring stations were used to analyse the seasonal distribution of AQI frequency percentage.

IV. Results and Discussion

A. Annual Variation of AQI

Tables III-VII show the year-wise frequency of occurrence of the AQI from 2006 to 2014 for all the five selected stations. Fig. 2 shows annual averages of RSPM concentration at five monitoring stations of selected sites from 2006 to 2014.

B. Station-1: Faridabad Industrial Area

The best air quality was estimated at Station-1 among all the five stations selected in the study area. A decreasing trend in AQI was observed from 2006 to 2008, but from 2009 onwards air quality starts deteriorating moderately and shows an increasing trend in AQI. From Table III, it can be observed that the overall AQI falls under 'Moderately Polluted' category, which was comparatively better than rest of the study areas. RSPM shows an increasing trend from 2006 to 2014. Annual average concentration of RSPM in 2014 with respect to 2006 shows an increment of 36.20%.

C. Station-2: Faridabad Residential Area

Station-2 is one of the two areas with the worst air quality among all the five stations. A moderate increase in AQI was observed from 2008 to 2014. The worst air quality was seen in 2012 which was followed by 2013. Table IV; demonstrate the year-wise frequency of occurrence of AQI and it can be observed that the value falls under 'Moderately Polluted' category to 'Poor' category for 2012 and 2013. RSPM shows an increasing trend from 2008 to 2012. The annual average concentration of RSPM in 2014 with respect to 2006 shows an increment of 34.60%.

D. Station-3: Bulandshahar Industrial Area

TABLE III
YEAR-WISE FREQUENCY OF OCCURRENCE OF AQI IN EACH CATEGORY AT STATION-1

Year \ AQI Category	1	2	3	4	5	6
2006	0	0	100	0	0	0
2007	0	0	100	0	0	0
2008	0	0	100	0	0	0
2009	0	0	100	0	0	0
2010	0	0	100	0	0	0
2011	0	8	92	0	0	0
2012	0	17	83	0	0	0
2013	0	0	100	0	0	0
2014	0	0	100	0	0	0

TABLE IV
YEAR-WISE FREQUENCY OF OCCURRENCE OF AQI IN EACH CATEGORY AT STATION-2

Year \ AQI Category	1	2	3	4	5	6
2006	0	0	100	0	0	0
2007	0	0	100	0	0	0
2008	0	0	100	0	0	0
2009	0	0	100	0	0	0
2010	0	0	92	0	0	0
2011	0	0	58	0	0	0
2012	0	0	83	42	0	0
2013	0	0	100	17	0	0
2014	0	0	100	0	0	0

Station-3 shows the worst air quality among all the five stations throughout the study period. There was a significant deterioration in air quality in 2008 to 2010 and 2012 to 2013. Highest AQI was found in 2008, which falls under the 'Severe' category. RSPM shows mix trend from 2006 to 2014. The level of RSPM increased up to 452µg/m^3 against the permitted level of 100µg/m^3, which could be due to the growth of the vehicular population, infrastructure development and an increase in the number of industries. The air quality fall under 'Moderately Polluted' category to 'Severe' polluted category, as shown in Table V, concentration of RSPM in 2014 with respect to 2006 shows an increment of 34.60%.

TABLE V
YEAR-WISE FREQUENCY OF OCCURRENCE OF AQI IN EACH CATEGORY AT STATION-3

Year \ AQI Category	1	2	3	4	5	6
2006	0	0	42	58	0	0
2007	0	0	100	0	0	0
2008	0	0	50	37	0	13
2009	0	0	42	58	0	0
2010	0	0	42	33	25	0
2011	0	0	100	0	0	0
2012	0	0	67	17	16	0
2013	0	0	42	41	17	0
2014	0	0	60	40	0	0

TABLE VI
YEAR-WISE FREQUENCY OF OCCURRENCE OF AQI IN EACH CATEGORY AT STATION-4

Year \ AQI Category	1	2	3	4	5	6
2006	0	8	83	9	0	0
2007	0	0	92	8	0	0
2008	0	0	100	0	0	0
2009	0	0	100	0	0	0
2010	0	8	92	0	0	0
2011	0	0	100	0	0	0
2012	0	0	100	0	0	0
2013	0	0	100	0	0	0
2014	0	0	100	0	0	0

E. Station-4: Noida Industrial Area

TABLE VII
YEAR-WISE FREQUENCY OF OCCURRENCE OF AQI IN EACH CATEGORY AT STATION-5

Year \ AQI Category	1	2	3	4	5	6
2006	0	0	100	0	0	0
2007	0	0	100	0	0	0
2008	0	0	100	0	0	0
2009	0	0	100	0	0	0
2010	0	8	92	0	0	0
2011	0	0	100	0	0	0
2012	0	0	100	0	0	0
2013	0	0	100	0	0	0
2014	0	0	100	0	0	0

There was a gradual improvement in the air quality in the Noida industrial area (Station-4). The highest AQI was found to be 220, which was comparatively less than both Faridabad and Bulandshahar industrial areas, that is Station-1 and Station-3, respectively. Significant improvement in AQI was observed from 2006 to 2014. Table VI shows that the overall AQI fall under the 'Moderately Polluted' category. The value of RSPM was found to be highest in 2007 and then value decrease moderately up to 2009. From 2010 to 2014 minor increment can be seen in the annual average concentration of RSPM. Annual average concentration of RSPM in 2014 with respect to 2006 shows a decrement of 41.10%.

F. Station-5: Noida Residential Area

A significant improvement in the air quality was observed in Noida residential area (Station-5). 2007 shows improvement in the overall air quality. AQI shows a decreasing trend from 2006 to 2014. From Table VII, it can be concluded that the overall AQI falls under the 'Moderately Polluted' category. The level of RSPM shows the decreasing trend from 2006 to 2010 and mixed trend from 2011 to 2014. Annual average concentration of RSPM in 2014 with respect to 2006 shows decrement of 41.20%.

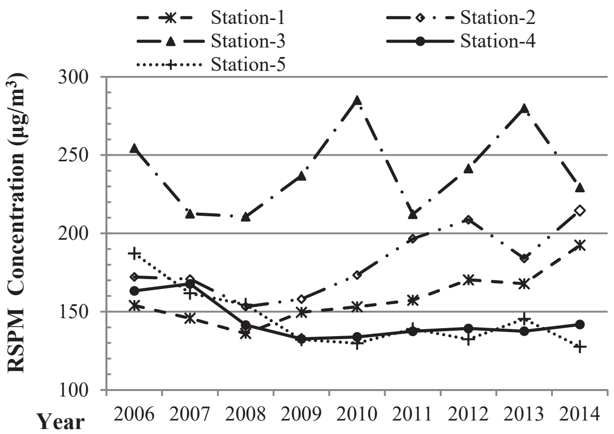

Fig. 2 Variation of annual averages of RSPM concentration

TABLE VIII
SEASONAL VARIATION OF THE AQI

Area	2006	2014
Station-1	winter > summer > monsoon = post monsoon	summer > monsoon = post monsoon > winter
Station-2	winter > summer > post monsoon > monsoon	summer > post monsoon > monsoon > winter
Station-3	winter > summer > monsoon > post monsoon	post monsoon > winter > summer > monsoon
Station-4	winter >post monsoon > summer = monsoon	summer > winter > post monsoon > monsoon
Station-5*	winter > post monsoon > summer > monsoon	winter > summer > post monsoon > monsoon

**The AQI values are of 2007instead of 2006.*

G.Seasonal Variation of AQI

AQI trends for 2006 and 2014 in the four seasons (summer, monsoon, post monsoon and winter) are shown in Table VIII.

H.Station-1: Faridabad Industrial Area

In 2006, the AQI at Station-1 was comparatively worse in winter and better in the monsoon and post monsoon seasons. The AQI depicted the following sequence: winter > summer > monsoon = post monsoon. In 2014, the AQI was comparatively worst in summer and better in winter. The AQI depicted the following sequence: summer > monsoon = post monsoon > winter.

I. Station-2: Faridabad Residential Area

In 2006, the AQI of Faridabad residential area (Station-2) was comparatively worse in winter and better in the monsoon season. The AQI followed the following sequence winter > summer> post monsoon > monsoon. In 2014, the AQI was comparatively worse in summer and better in winter. The AQI depicted the following sequence: summer > post monsoon > monsoon > winter.

J. Station-3: Bulandshahar Industrial Area

In 2006, the AQI of Bulandshahar industrial area was comparatively worst in winter and better in post monsoon. The AQI followed the following sequence winter > summer > monsoon > post monsoon. In 2014, the AQI was comparatively worse in the post monsoon and better in the monsoon season. The AQI depicted the following sequence: post monsoon > winter > summer > monsoon.

K.Station-4: Noida Industrial Area

In 2006, the AQI of Noida industrial area was comparatively worse in winter and better in the monsoon and summer seasons. The AQI followed the following sequence winter > post monsoon > summer = monsoon. In 2014, the AQI was comparatively worse in summer and better in the monsoon season. The AQI depicted the following sequence summer > winter > post monsoon > monsoon.

L. Station-5: Noida Residential Area

In 2007, the AQI of Noida residential area (Station-5) was found to be worst in winter and better in the monsoon season. The AQI followed the following sequence winter > post monsoon > summer > monsoon. In 2014, the AQI was comparatively worse in winter and better in the monsoon season. The AQI depicted the following sequence winter > summer > post monsoon > monsoon.

Figs. 3 and 4 depict seasons having the worst air quality during 2006-2009 and 2010-2014, respectively. Increase of worst air quality during the summer season from 30% to 40% and decrease in winter from 70% to 24% shows the tendency of worst air pollution changed from winter to summer season in the specified duration. The possible reason for worst air quality from winter to summer could be due to increase in the photochemical reaction during the summer season, may be due to change in the emission patterns or due to the shortening of winter period and extension of the summer period, as has been witnessed during the last decade in northern India. An increase in post monsoon season having worst air quality up to 24% could be due to higher percentages of accumulation of coarse particles than those of summer periods, high values of mixing height and solar radiation which facilitate photochemical activity. The changing pattern of seasons may be attributed to global warming and changing global climate patterns.

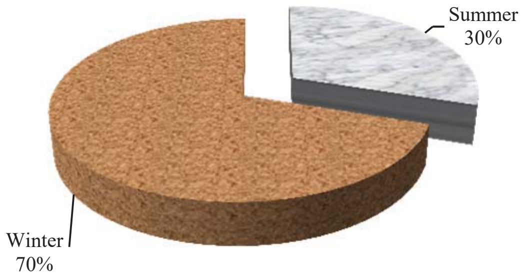

Fig. 3 Season wise percentage distribution of air quality from 2006 to 2009

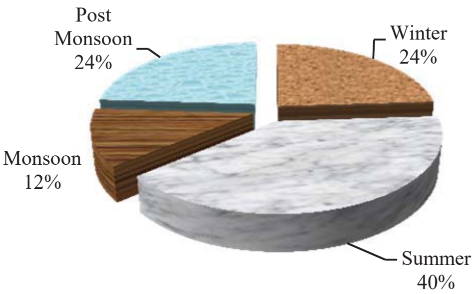

Fig. 4 Season wise percentage distribution of air quality from 2010 to 2014

Overall, the following interpretations can be drawn from the above analysis:

- In 2006, the winter season has worst air quality for all the stations (2007 for Station-5); whereas, in 2014 mostly summer shows worst air quality at Faridabad industrial area (Station-1), Faridabad residential area (Station-2) and Noida residential area (Station-5). Change of season for worst AQI from winter to summer at these stations in a span of nine years maybe due to an increase in photochemical reactions, along with change in nature of emissions imposed because of different control measures, such as promotion of CNG in vehicles, strict imposition of laws. etc. Whereas, the reason worst air quality recorded in Bulandshahar industrial area (Station-3) in the post-monsoon season may likely be due to the fact that this season was associated with low precipitation, low wet day frequency, low cloud cover but high diurnal temperature range, because of which, temperature stability increases, and hence the severity of air pollution.
- Bulandshahar industrial area (Station-3) shows the worst air quality among all the other selected stations. The highest AQI was reported as 402 in 2008 which falls under the 'Severe' category. The possible reasons for this could be the exponential increase in vehicular population, engine gensets, use of diesel vehicles (beyond 10 years of registration periods), re-suspension of traffic dust, commercial and domestic use of fuels, sugar mill and emission from various large and small scale industries beyond the prescribed standard in nearby areas.
- Improvement in air quality at Noida industrial and Noida residential areas, Station-4 and Station-5 respectively, from 2006 to 2014 may be due to traffic decongestion by the operation of metro-trains for public transportation, use of CNG vehicles, strict imposition of laws, shifting and closing of industries emitting pollution beyond the permissible limit (as these stations are closer to Delhi, and are under strict supervision of various pollution control agencies), less dust storms, etc.

V. Conclusions

The conclusions drawn from the present study, along with the recommendations, are:

- It is observed that there is no significant difference between the monthly mean NO_2 and SO_2 concentrations, for both industrial and residential areas selected for this study, throughout the study period. However, the levels of RSPM are a cause of concern, as its level is substantially higher than the NAAQS for residential and industrial areas. Thus, it is concluded that RSPM is a critical pollutant at all the five selected sites/areas.
- AQI is a valuable tool for both data interpretation and accessibility of air quality information by the public. However, since it is site-specific and is based on the levels of only few criteria pollutants and gives equal weightage to the all pollutants, it does not account for variation in possible health impacts. Hence, in future studies IND-AQI should be revamped by considering more parameters, like non-criteria pollutants which impact the air quality of a particular location and weightage aspect should be revised to decide the responsible pollutants to give better idea about the pollution level and its health impacts on a particular population.
- As there is no single solution to environmental problems, more attention should be paid in environmental policy-making and further studies of the issues related to air pollution should be carried out in these areas to determine responsible pollutant to help focus on pollution control strategies. Measures should be taken to counteract the effect of air pollution, like improved emissions standards, capped age of commercial vehicles, cut in power plant emissions, diversion of substantial heavy-traffic and ban on open burning.
- In order to improve air quality of the area more distinctively through declination of point source and fugitive emission, it is necessary to install appropriate highly efficient pollution control devices like scrubbers, electrostatic precipitator, gas cleaning plants, pulse jet bag filters, cyclone separators, etc., in industries in manufacturing processes.

This study calls for an immediate need of actions for air pollution control measures, and initiatives are urgently required so as to bring down the levels of RSPM at a much faster rate, so as to improve the health of citizens, as well as to reduce resulting economic losses.

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