International Journal of Engineering Applied Sciences and Technology, 2022
Vol. 6, Issue 11, ISSN No. 2455-2143, Pages 15-21
Published Online March 2022 in IJEAST (http://www.ijeast.com)

ASSESSMENT OF AIR QUALITY INDEX IN A MOST POLLUTED MEGA CITY OF ASIA

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Abstract: **A trend analysis of daily $PM_{2.5}$ (aerodynamic diameter <=2.5um) for the period 2013 to 2018 has been carried out over Delhi, which is one of the most populous megacities in the world. The impact of the newly designed India specific Air Quality Index (AQI), which classifies its health implications in 6 categories, has been discussed in this study. An increasing trend in the level of $PM_{2.5}$ is found during the period 2013-2015 when the worst AQI is found to dominate. The impact of policy level shift towards increased awareness leading to soft mitigation is noticed in the trend analysis, and a number of better AQI days started to increase during 2015-2018. The seasonal analysis indicates a uniform trend in each year when AQI is found to be lowest during monsoon due to wash out and highest during the winter season due to a combination of several meteorological factors and landlock geography of Delhi preventing pollutants to disperse under stagnant conditions. The study in detail illustrates how mitigation strategies are effective in controlling the air pollution issues.**

Keywords: **Air quality index; $PM_{2.5}$; Delhi; Mitigation, Air quality days**

I. INTRODUCTION

Air pollution has been a major environmental issue across the world(Azam et al. 2016). Most metropolitan cities in developing countries, including India, face severe air quality issues due to the most significant emissions of particulate matter (PM) and trace gases from anthropogenic activities (Balakrishnan et al., 2019; Fuzzi et al., 2015). The major anthropogenic emission sources include incomplete combustion fossil fuels, agriculture residual burning, construction activities, and emissions from paved and unpaved roads (Beig et al. 2020).

Delhi is one of India's most polluted cities (Beig et al. 2015; Chowdhury et al. 2019). $PM_{2.5}$ is a prominent pollutant in Delhi and neighboring areas, which continuously exceeds the national standards (CPCB 2016). $PM_{2.5}$ exposure is reported to be the largest environmental health risk factor (Tessum et al. 2019). Excess levels of $PM_{2.5}$ (e.g., 65 μg m^{-3} for 24-hours) are found to induce a high risk of respiratory symptoms such as asthma (Guaita et al. 2011). It can also increase multiple oxidative stress levels and cause premature deaths (Dong et al. 2019). High $PM_{2.5}$ exposure can also lead to cardiopulmonary mortality (WHO 2013; Liu et al. 2019a). To control the pollution levels in Delhi, the governments have taken several steps to reduce air pollutants in the city during the last ten years. From 2015 strict implementation of legislative measures was undertaken (Sinha and Kumar 2019). One of the most important initiatives was the launch and implementation of the Air Quality Index (AQI) in 2015, which attempted to provide real-time air pollution levels in common person's understanding to increase societal awareness (Mishra 2019). AQI is suggested by the US Environmental Protection Agency (EPA) and has been used in many cities to estimate the severity of air pollution levels and risk of adverse health effects (Beig et al. 2013; USEPA 2014). Based on the measured ambient concentration of pollutants, AQI can be calculated using eight major pollutants viz. PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, and Pb based on the worst sub-index (http://safar.tropmet.res.in and Sheng et al. 2015).

A scale of AQI is designed to help one understand the air quality around so that protective measures may be taken to avoid polluted air exposure (Beig et al. 2013). The AQI warning also has been designed to provide a one and three-day forecast of pollutant levels in the ambient air (Karuna et al. 2017; Prakash et al. 2017). Therefore, AQI is an easy tool for understanding air pollution levels and their potential health impacts. This paper summarizes the changes in air quality levels before and after implementing legislative measures and AQI in Delhi during the 2012-2018 periods.

II. METHODOLOGY

2.1 Site description and data analysis

We selected Delhi, which is one of the most polluted city in India, for our study, where $PM_{2.5}$ is a significant pollutant (Roy and Singha 2021). Air quality monitoring stations across Delhi and NCR is shown in Fig.1(The daily mean values of $PM_{2.5}$ from January 2012 to December 2018 from 11 SAFAR monitoring observation network). All the locations are classified based on microenvironment like a residential area, industrial area, traffic intersection, etc. The daily mean concentrations of $PM_{2.5}$ were only calculated when there were more than 16h of valid data.

Arc GIS 10.6 software has been used for spatial analysis. Interpolated maps were generated for $PM_{2.5}$ concentration using ten station data. The Inverse distance weighted (IDW) technique is used for interpolation as this method is simpler to programme and does not require pre-modeling (Dadhich et al. 2018) Compared with other methods.

2.2 AQI calculation

AQI has been calculated as per the Indian Air Quality Index (Ind-AQI) (CPCB and MoEF&CC 2015), using the following equation-

$$I = I_{high} - (C - C_{low}) + I_{low}$$

Where,

I is the (Air Quality) index, C is the pollutant concentration, C_{low} is the concentration breakpoint that is $\leq$ C, C_{high} is the concentration breakpoint that is $\geq$ C, I_{low} is the index breakpoint corresponding to C_{low}, I_{high} is the index breakpoint corresponding to C_{high}.

For the investigation of seasonal variation of the AQI values, 12 months has been break up as follows. As per Indian Meteorological Department, we followed the international standard of four seasons with some local adjustments, which consist of four seasons winter season (Jan- February), pre-monsoon (March-May), monsoon (June-September), and post monsoon (Oct & December).

The AQI measures the overall quality of the air on a scale communicates primarily a number from 1 to 500 that is divided into six levels (between 0 and 50 is considered "good," 51 and 100 "satisfactory," 101 and 200 "moderate," 201 and 300 "poor," 301 and 400 "very poor," and 401 and 500 "severe," as per pollution control authorities (Beig et al. 2013; CPCB 2016). These levels show the impact on human health, which also has ramifications on people's outdoor activities (Liu et al. 2019b).

2.3 Observation Network

The System of Air Quality Weather Forecasting and Research (SAFAR) network was implemented during commonwealth Game (CWG-2010) in Delhi to assess the air quality accurately) as per the World Health Organization (WHO) and USEPA guidelines (Srinivas et al. 2016; Beig et al. 2018; Anand et al. 2019). It consists of 11 monitoring stations that continuously monitor criteria pollutants.Details of the source of $PM_{2.5}$ data, observatory network in Delhi, and other data quality control information is available at http://safar.tropmet.res.in/(Beig et al. 2019). The information on air quality is provided through the installed digital display in most crowded public places. Digital display pays particular attention to people who are sensitive to air pollution and provides them with advice on protecting their health during air quality levels associated with 'low,' 'moderate,' 'high,' and 'very high' health risks. Delhi is a city where air pollutants enter in large volumes, and its removal is less due to its landlocked geography and prevailing meteorological conditions.

III. RESULTS AND DISCUSSION

3.1. Annual and seasonal variation of Air Quality in Delhi (during 2012-2018)

Fig. 2a shows the annual mean concentrations of $PM_{2.5}$ over Delhi from 2012 to 2018. The direct sources of pollutants in Delhi might be due to the traffic and residential pollution sources (Hama et al. 2020a) and the long-range transport from adjacent states such as Punjab and Haryana (Kumar et al. 2015; Kulkarni et al. 2020). During this period, the mean of PM2.5 remains typically of the order of 99-116 $\mu g/m^3$. The lowest annual mean $PM_{2.5}$ was recorded in 2018 (99$\mu g/m^3$) during the observational period.Interestingly, the mean yearly $PM_{2.5}$ concentration exceeded the National Ambient Air Quality Standards(NAAQS)value of 40$\mu g/m^3$, recommended by the Central Pollution Control Board **(**CPCB) during the entire study period. This indicates that further strengthening of legislation and full-scale mitigation measures must improve the AQI over the region.

Fig.2b shows the percentage of days of AQI in each category. In 2012 maximum percentage of days was found in "satisfactory" (25 %) and minimum (5%) in the "good" AQI category. The city exposed to 16% for "poor" and 22% for "very poor' category. It is noticed that maximum percentage of days (34%) were fallen in the "very poor" AQI category. The percentage of "satisfactory" days were 21% in 2013. This value has drastically fallen to 8 % by 2014. However "moderate" air quality day was increase up to 34% in 2014. Fig. 2b also shows the highest of very poor air quality days (36 %) in 2015 among all years, which may have caused respiratory illness in humans on prolonged exposure (Karuna et al. 2017). However, moderate air quality days were found to decrease (24%) in 2015 compared to 2014 (34%). Although not a single day of "good" air quality category was observed in Delhi during 2016, a significant increase from 15 to 29 % was observed in in "satisfactory" AQI category. In 2017 'moderate' air quality days were 33%, and 'good' air quality days were 1%. "Good" air quality was dominant by reaching up to 8 % in 2018. However, days in the "satisfactory" and "moderate" category was 27 % and 24%, respectively, in 2018. Poor air quality days also reduce to 13% in 2018 compared to 18 % in 2017.

Fig.3 shows the spatial changes in the concentration of $PM_{2.5}$ in Delhi. It is evident from Fig.3a that northeast Delhi is the hotspot of pollution in 2012, whereas in 2018. However, the maximum concentration has decreased, but many areas, including facing severe air pollution problems (Fig.3b). The Northeast area remains in the worst category despite implementing different mitigation measures and policies (Kumar et al. 2015).

The seasonal air quality of Delhi during the 2012-2018 periods is shown in Fig.4. Poor air quality varied from 29 to 51 in the winter season (Jan- February) (Fig. 4a). However, in Delhi city, overall air quality has remained "poor" and ``very poor" category during the winter season. The high pollution levels in the winter season are due to the reduced dispersion on account of low wind velocity and common boundary layer heights (Srinivas et al. 2016). The previous study has also reported similar Delhi features (Peshin et al. 2017; Gulia et al. 2018; Sarika et al. 2018).

In comparison, the reduction has been observed in both these categories during the pre-monsoon (March-May) season (Fig. 4b). A large number of days (71%) in the "satisfactory" category was observed in the monsoon season (June-September) (Fig. 4c), attributed to rain out and washout effects. Monsoon had the best air quality from 2012 to 2018 compared to winter and post monsoon (Oct & December) seasons with increased 'good" and "satisfactory" air quality days (Fig. 4c), associated with the influx of cleaner air from the Arabian Sea and negligible biomass burning during the season. The good air quality day in monsoon is probably due to the significant role of meteorological factors(Dumka et al. 2019; Hama et al. 2020b). "Severe" air quality had not been observed on any single day during the monsoon period. However, good air quality days had increased to 25% compared to all other seasons. The highest 79% of "very poor" air quality was observed post-monsoon (Fig. 4d). It is also observed that the number of days in the "very poor" and "severe" category increases rapidly, leading to worsening air quality in this season. A simultaneously drastic decrease of the percentage of days in the satisfactory category was also observed in post-monsoon compared to monsoon season. The transport of pollutants from nearby Punjab and Haryana during the stubble burning period adds to this deterioration in AQI (Beig et al. 2020). Exposure to very poor AQI may cause respiratory effects even on healthy people and severe health impacts on people with lung and heart disease (Karuna et al. 2017). These high pollution levels are directly evidenced by rising in patients with chronic obstructive airway and respiratory disease in hospitals in winter (Rizwan et al. 2013; Duan et al. 2020).

3.2. Air pollution mitigation measures and observed results

It is observed that in the summer season, the poor air quality days continuously increased from 2012 to 2015 after that showed a gradually decreasing trend(from 36% to 23% in 2015-2018) (Fig. 4a). To tackle the worsening air quality in Delhi, India's government introduced a major national and local initiative in 2015 (Kumar et al. 2015). Detailed Government measures to control air pollution are depicted in table 1. PM2.5 showed a gradual increase up to 2014 (Fig. 2a). Thereafter from 2015, the $PM_{2.5}$ concentrations were found to decline. The annual $PM_{2.5}$ variations mainly match the diverse emission sources and local meteorology, suggesting that controlling the baseline concentrations can improve air quality (Peshin et al. 2017). Fig. 2b depicts the annual variation of AQI during 2012-2018. The number of "good" days drastically decreased from 5 % in 2012 to nil in 2013. Delhi city did not have a single day of "good" air quality from 2013 to 2015. The increase in" good" days further started from 2016, showing an enhancement of 8 % by 2018. This progress in "good" air days could be associated with the substantial efforts of stringent government policies and public awareness. A considerable decrease in "satisfactory" air quality days was observed in 2014 (8%) compare to 2012 (25%). However, the development comes as a sign of relief for the city as its satisfactory AQI has increased from 2015 to 2018 (up to ~ 25%). The number of "poor" and "very poor" air quality days had an increase of 24% and 36% respectively in 2014 and 2015. The "very poor days" showed a major decrease thereafter from 36% to 25% during 2015-18 periods. The reduction in "severe air quality" days has shown a -1 to 5 % fluctuation during 2015 to 2018. Air quality in post-monsoon deteriorated as very poor days rose and touched to 80% in 2015 (Fig. 4b) compare to 28% and 4% respectively in pre-monsoon and monsoon seasons. It is observed that in the pre-monsoon season, the "poor" air quality days continuously increased from 2012 to 2015, after which showed a gradually decreasing trend (Fig. 4a).

Hence, the reasons for this reduction in air pollution levels could be associated with the strict implementation of government legislation in the baseline sources since 2015, such as providing round-the-clock electricity, imposing hefty fines on violation of construction norms, implementing 'Graded Response Action Plan' and closing of two major thermal power plants operating within the city limits (https://scroll.in/article/939095/delhi-pollution-reduced-by-25-government-claim-is-based-on-hazy-data).

The emissions due to local traffic was regulated with the implementation of " odd-even day" policy, in which vehicles having odd numbers (even numbers) are allowed only in alternate days (Table 1). Apart from these measures, the regular awareness drive in terms of AQI displays in different areas in the city to educate the citizens could be attributed to the said improvement in Air Quality.

As a part of AQI awareness among the public, SAFAR (System of Air Quality and Weather Forecasting and Research) has developed a mobile application (Fig. 5) (Beig et al. 2015). The SAFAR mobile application provides the air pollution warning in advance so that individuals can take up appropriate action to avoid their exposure to air pollution. The same application was used by authorities to generate mitigation policies in different areas. After launching this app, the Immediate effect was observed, as "very poor" air quality days started to decline. It shows that public awareness can create a cleaner environment, where scientists and stakeholders can express the scientific research in simple language on a large scale (Kelly and Fussell 2015). Along with the online applications, the print media also should include efficacy messages for the awareness of air pollution mitigation strategies in the public domain(Ramírez et al. 2017).

IV. CONCLUSIONS

Air Quality changes pre and post-implementation of AQI standards (in 2015) and legislative measures have been analyzed during the 2012-2018 periods. Results show that "good" and "satisfactory" days have increased, and "poor" and "very poor" air quality days have reduced after 2015 due to the implementation of air pollution mitigation strategies. The pollution levels were high in post-monsoon and winter months, associated with meteorology and long range transport. Despite past improvements in air quality, Delhi breathes air that does not meet CPCB or WHO standards. The result showed that many fold highest concentration of $PM_{2.5}$ than the prescribed limit very less distribution of days in the "good" category throughout the seven years. The risk level depends on several factors; however, the government's stringent efforts must be curbed down Delhi's air pollution urgently before it deteriorates more.

The governmental efforts alone are not enough to control or reduce pollution issues. Policymakers and government need to focus on disseminating information to involve people in reducing their exposure to harmful air pollution levels by implementing corrective strategies for improving ambient air quality and using regional language to overcome technical barriers to reach information. A more comprehensive evaluation of different mitigation strategies' health and economic benefits would greatly help Indian decision-makers, and the framework provides a strong foundation (Chen et al. 2017; Li et al. 2020). However, further tightened legislation, control measures in emissions, and awareness is necessary to bring the Delhi pollution levels to NAAQS standards.

Acknowledgments: This work has been financially supported by the Indian Institute of Tropical Meteorology (IITM), Pune. The authors are grateful to Director, IITM, Pune. IITM is supported by MoES, Govt. of India.

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Table 1: Government initiatives from 2015 to control pollution in Delhi

Year	Government Initiatives
2015	The 'Odd-Even' measure Launch of SAFAR awareness app
2016	The mass rapid transport system, catalytic, convertor, public awareness and phasing out of old commercial vehicle and tightening of a mass emission standard for new vehicles.
2017	Graded Response Action Plan (GRAP)
2018	Comprehensive Action Plan (CAP)
2019	Implementation of National Clean Air Program
2020	Plans to pave all the roads in Delhi-NCR

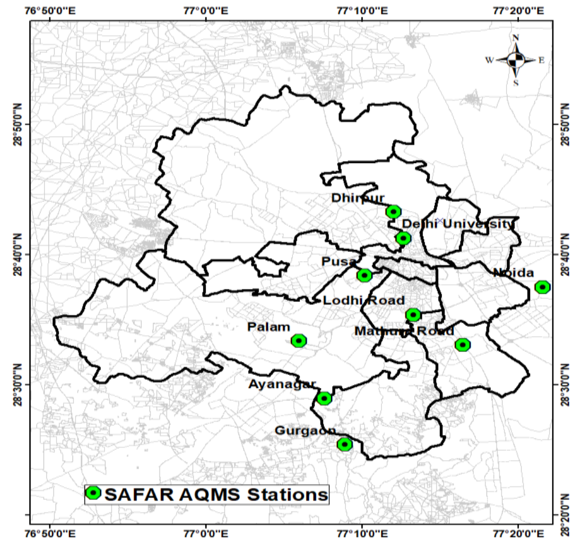

Fig.1: Air Quality Monitoring Station (AQMS) under SAFAR Project in Delhi.

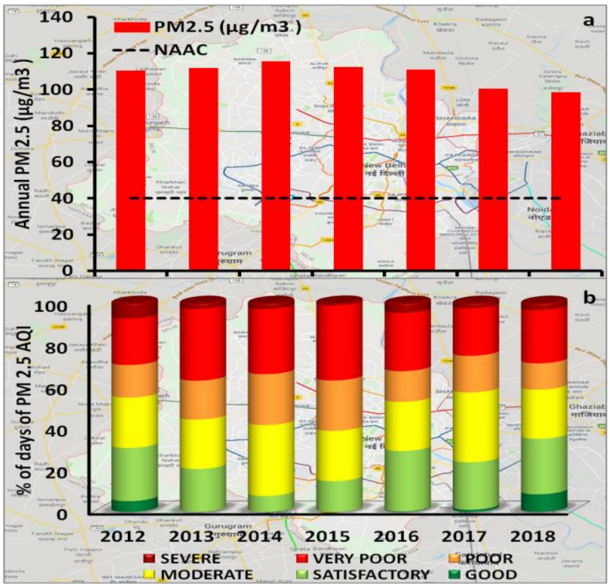

Fig.2: The annual mean of $PM_{2.5}$ mass Concentrations over Delhi based on 8-10 AQMS during 2012-2018 (a). Trend analysis of Air Quality Index (days in percentage) during 2012-2018 over Delhi (b).

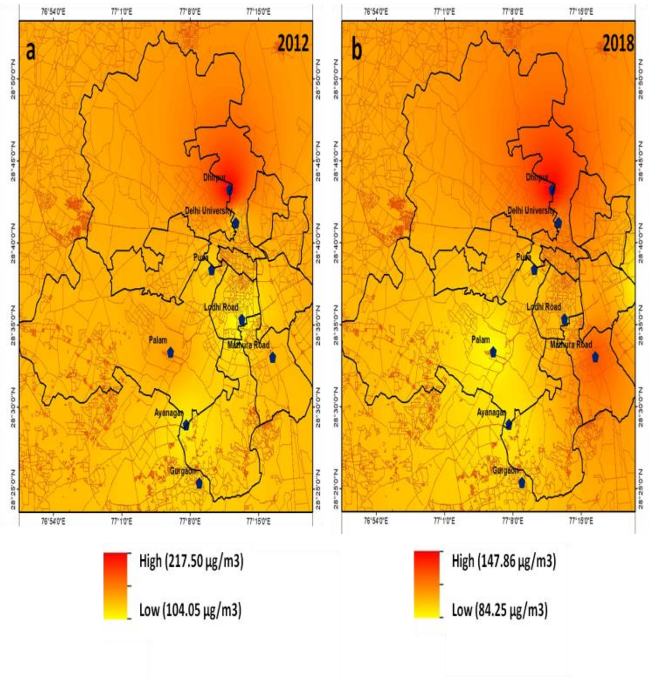

Fig.3: Stationwise spatial changes of $PM_{2.5}$ in 2012(a) and 2018(b)

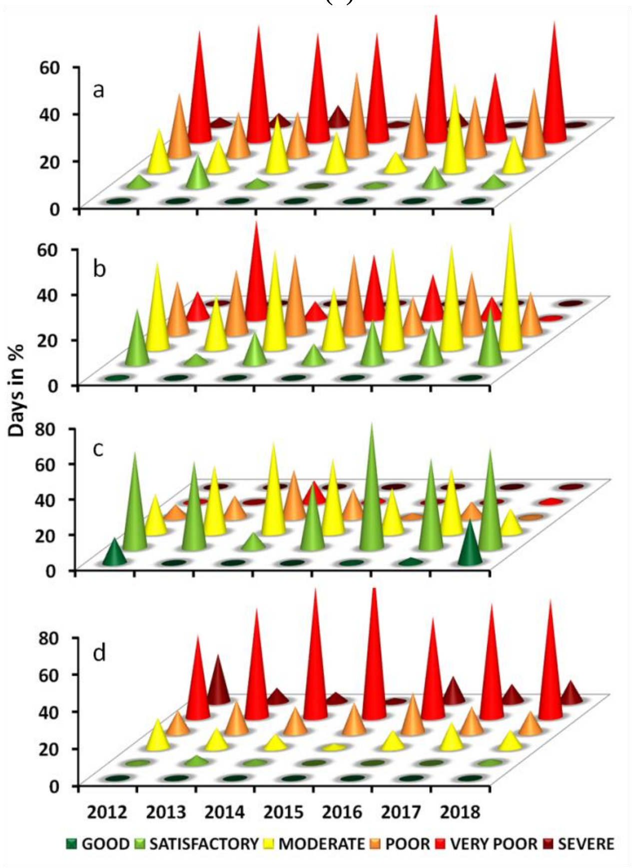

Fig.4: The % variations of days in the year of Air Quality Index during the different seasons (a) winter (b) pre-monsoon (c) monsoon d) post-monsoon during the study period

Fig.5: The communication tool "SAFAR mobile app."