IMPACT OF COVID-19 LOCKDOWN ON AIR QUALITY OF CHENNAI

TAMIL NADU POLLUTION CONTROL BOARD

June 2020

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Title:

Impact of COVID-19 lockdown on Air Quality of Chennai
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PREFACE

Novel Corona virus or COVID-19 has shown people world over to unfold a new chapter in the lifestyle of individuals- may be for the first occasion in their life time. The fear of community spread of the virus and its consequent impact on human health and life forced Governments to launch curfew and lockdown of different intensities that imposed severe restrictions in the movement of people and shutdown of most of the economic pursuits of mankind. Most of the important sectors contributing to the socio-economic progress of the nation and the livelihood of its people were locked down during the curfew regimes which spanned for over two months.

The lockdown period noticed near total cessation of air traffic flow, railway transport except cargo, complete shutdown of public transport services like buses, sub-urban electric trains, metro trains, autos and taxis, substantial reduction in volume of private cars and two wheelers. In the industrial sector as well, other than essential category units, the rest were shut down. Entertainment and hospitality industries, educational institutions, private and Government offices, religious and social gatherings were also brought under total lockdown. Such extensive containment measures provided an opportunity for Nature to recuperate. In the midst of lockdown, people in urban centres began to enjoy the benefits of a clean living environment. The brighter side of COVID-19 is seen in the cleaner environmental elements like air and water.

In this context, Tamil Nadu Pollution Control Board launched a study of the impact of COVID-19 lockdown on the Air Quality of Chennai and its surroundings. The data on air quality and the concentration of individual air pollutants obtained from the CAAQM stations of TNPCB and CPCB were compiled and studied to evaluate the quantitative improvements in the quality of Chennai region's air shed. The results and the implications are presented in the present report.

Dr.T. Sekar, IFS (R),
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ACKNOWELEDGEMENTS

The concept and idea for compiling air quality data for Chennai during the COVID-19 lockdown and compare the same with pre-lockdown period was mooted by Thiru A.V. Venkatachalam, IFS, Chairman, Tamil Nadu Pollution Control Board, which is duly acknowledged. The AQI and individual pollutant parameters have been provided from the CPCB website portal on air quality and the CAAQM stations data of TNPCB by the CARE AIR team led by Thiru Sankara Subramanian, Assistant Director (Labs), TNPCB which is gratefully acknowledged.

The data input in respect of calibration and O&M requirement for CAAQM stations were given by Thiru Raghavendran of EnviroTech India Ltd. The authors are thankful for the same. The data and interpretation on the ambient meteorological parameters with reference to AQI data of Chennai CAAQM stations for the month of April 2018, 2019 and 2020 were contributed by Dr. Suresh Kumar, Technical Director, G Lens Innovations Lab, Chennai which deserves appreciation.

I wish to acknowledge the secretarial support provided by the TNPCB in preparation of the report.

Dr. T. Sekar, IFS (R)
Consultant to TNPCB

IMPACT OF COVID-19 LOCKDOWN ON AIR QUALTIY OF CHENNAI

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Introduction

As urban and industrial growth made significant progress, many legislations were introduced to prevent and control pollution and to attain better environmental management. Simultaneously emission and discharge standards for various air and water pollutants were set for different industrial sectors, besides the standards for ambient air and water quality. Presence of various pollutants in emissions and effluents in excess of the prescribed standards will enhance their levels in ambient environment and introduce many risks to environment and consequent health implications.

The State of Global Air 2019 report published by Health Effects Institute[12] identifies air pollution as the fifth leading risk factor for human mortality. The study attributed that air pollution was responsible for over 1.2 million deaths in China and India each based on 2017 data, whereas $PM_{2.5}$ pollution alone contributed to nearly 3 million early deaths in 2017 world over. More than half of this disease burden fell on people living in China and India. Air Pollution collectively is shortening life on an average by 20 months worldwide, a global impact rivaling that of smoking. India is among the high life expectancy loss countries, the study revealed.

The need for strengthening institutional capacity and to integrate scientific analysis with policy actions to control air pollution has been recognized in India since few decades back. In tune with this framework, detailed procedures and protocols have been evolved over time for monitoring the pollutants in ambient air. Such measurements are recorded in manual monitoring stations or Continuous Ambient Air Quality Monitoring (CAAQM) stations. The manual stations provide data on air pollutant parameters for operation periods extending over 8 to 24 hours at selected dates and the data need to be completed manually and presented. If placed in public domain, the data represents manually computed values, which relate to previous dates and not a real time data. CAAQM stations help to overcome this deficiency in air quality monitoring and reporting by facilitating the monitoring of as many air pollutants (parameters) as possible on a near real time and 24x7 basis.

Presenting the raw data sets of individual pollutant parameter and time series plots might not satisfy the general public in terms of understanding the effects of air pollution. It has been increasingly recognized that there is a need for simple, yet effective communication of ambient air quality in urban areas so as to enhance the awareness among the public, especially for those who suffer from illness caused by exposure to air pollution. The Central Pollution Control Board (CPCB) has developed a web-based Air Quality Index dissemination system during 2014 for quick, simple and an elegant looking response to an AQI query[7].

What is Air Quality Index?

Air Quality Index (AQI) is a tool for effective communication of air quality status of an area to people in terms, which are easy to understand and is used for decision making in many countries. It transforms complex air quality data of various pollutants into a single number (index value), nomenclature and colour, which fall in one of the six AQI categories, namely Good, Satisfactory, Moderately polluted, Poor, Very Poor, and Severe with their associated health impacts, which are presented in an easily distinguishable colour scheme (Table 1).

Table 1: AQI categories and associated health impacts

AQI Category	AQI Range	Associated Health Impact
Good	0-50	Minimal Impact
Satisfactory	51-100	Minor breathing discomfort to sensitive people
Moderately Polluted	101-200	Breathing discomfort to the people with lungs, asthma and heart diseases
Poor	201-300	Breathing discomfort to most people on prolonged exposure
Very Poor	301-400	Respiratory illness on prolonged exposure
Severe	401-500	Affects healthy people and seriously impacts those with existing diseases

Each of these air quality category is decided based on weighted values of ambient concentration values of eight air pollutants viz., Particulate $Matter_{10}$ (PM_{10}), Particulate $Matter_{10}$ ($PM_{2.5}$), NO_2, SO_2, CO, O_3, NH_3, and Pb and their likely health impacts (known as health breakpoints). Health Breakpoint concentrations for each of the pollutant vary with reference to the AQI category as furnished (Table 2). The sub-indices for individual pollutants at a monitoring location are calculated using its 24- hourly measured average concentration value of a pollutant (except in case of CO and O_3, where they are 8-hourly data) and health breakpoint concentration range. The sub-index is a linear function of concentration of a particular pollutant (for example, the sub-index for $PM_{2.5}$ will be 51 at concentration 31 μg/m³, 75 at concentration of 45 μg/m³ and 100 at concentration 60 μg/m³). Air Quality sub-index and health breakpoints have been evolved for these eight pollutants, for which short-term (up to 24 hours) and annual National Ambient Air Quality Standards are prescribed[8].

Table 2: AQI Category, Pollutants and Health Breakpoints

AQI Category (Range)	PM_{10} (24hr)	$PM_{2.5}$ (24hr)	NO_2 (24hr)	O_3 (8hr)	CO (8hr)	SO_2 (24hr)	NH_3 (24hr)	Pb (24hr)
Good (0–50)	0–50	0–30	0–40	0–50	0–1.0	0–40	0–200	0–0.5
Satisfactory (51–100)	51–100	31–60	41–80	51–100	1.1–2.0	41–80	201–400	0.5–1.0
Moderately polluted (101–200)	101–250	61–90	81–180	101–168	2.1–10	81–380	401–800	1.1–2.0
Poor (201–300)	251–350	91–120	181–280	169–208	10–17	381–800	801–1200	2.1–3.0
Very poor (301–400)	351–430	121–250	281–400	209–748	17–34	801–1600	1200–1800	3.1–3.5
Severe (401–500)	430+	250+	400+	748+	34+	1600+	1800+	3.5+

The worst sub-index among the computed parameters is responsible for the index for that location. All the eight pollutants may not be monitored at all the locations. Overall AQI is calculated only if data are available for minimum three pollutants, out of which one should necessarily be either $PM_{2.5}$ or PM_{10}. Else, data are considered insufficient (ID) for calculating AQI. Similarly, a minimum of 16 hours' data is considered necessary for calculating sub-index. This can be illustrated with the sample of recorded values for a station on a particular day (Fig 1).

Calculation of AQI

Date	Station	NSIT
DD-MM-YYYY	City	Delhi
	State	Delhi

Pollutants		concentration in µg/m3 (except for CO)	Sub-Index	check	Air Quality Index
PM10	24-hr avg	**98.00**	98	1	
PM2.5	24-hr avg	**42.00**	70	1	
SO2	24-hr avg	**0.00**	0	0	
NOx	24-hr avg	**7.00**	9	1	AQI = **98**
*CO (mg/m3)	max 8-hr	**0.00**	0	0	
O3	max 8-hr	**42.00**	42	1	
NH3	24-hr avg	**32.00**	8	1	

*** Concentrations of minimum three pollutants are required; one of them should be PM10 or PM2.5**

*** The check displays "1" when a non-zero value is entered**

Fig 1: Model calculation of AQI at a particular station for a given day

Even if data are inadequate for determining AQI, the sub-indices for monitored pollutants are calculated and disseminated. The individual pollutant-wise sub-index will provide air quality status for that pollutant.

The web-based CAAQM system, designed to provide AQI on real time basis is an automated system that captures data from continuous monitoring stations without human intervention, and displays AQI based on running average values. For instance, AQI at 6 AM on a day represents data from 6 AM on previous day to the current day.

Ambient Air Quality Monitoring in Chennai

National Air Monitoring Programme (NAMP) is being carried out by the Central Pollution Control Board and the State Pollution Control Boards covering 240 cities in the country with more than 342 monitoring stations. As a part of NAMP mandate, Tamil Nadu Pollution Control Board has been monitoring the air quality in many cities across the State. The Board at present operates 28 numbers of manual air monitoring stations in eight cities and towns, besides nine numbers of CAAQM stations. In Chennai city and its surroundings, the Board has installed operational set ups for both types of monitoring.

- Manual monitoring by the way of collecting air samples by conventional methods at a specified period and analyzed in the laboratory for assessing the pollutants for a particular period of time. Such monitoring is being conducted in five places in Chennai city viz., Adyar, Kilpauk, T.Nagar, Nungambakkam and Anna Nagar.

- Continuous Ambient Air quality Monitoring Station (CAAQMS) that are being operated by TNPCB at six locations in and around Chennai city. They are located at Gummidipoondi, Kodungaiyur, Koyembedu, Mathur (Manali), Perungudi and Royapuram. In addition, CPCB has also been operating three CAAQM stations at Alandur, Velachery and Manali. TNPCB is in the process of establishing 25 CAAQM stations across the State.

For the purpose of the current study, the air quality data received from the CAAQM stations located in and around Chennai has alone been used. The position of the CAAQM stations of TNPCB and CPCB in Chennai are indicated with reference to their latitude and longitude readings in the map as below (Fig 2).

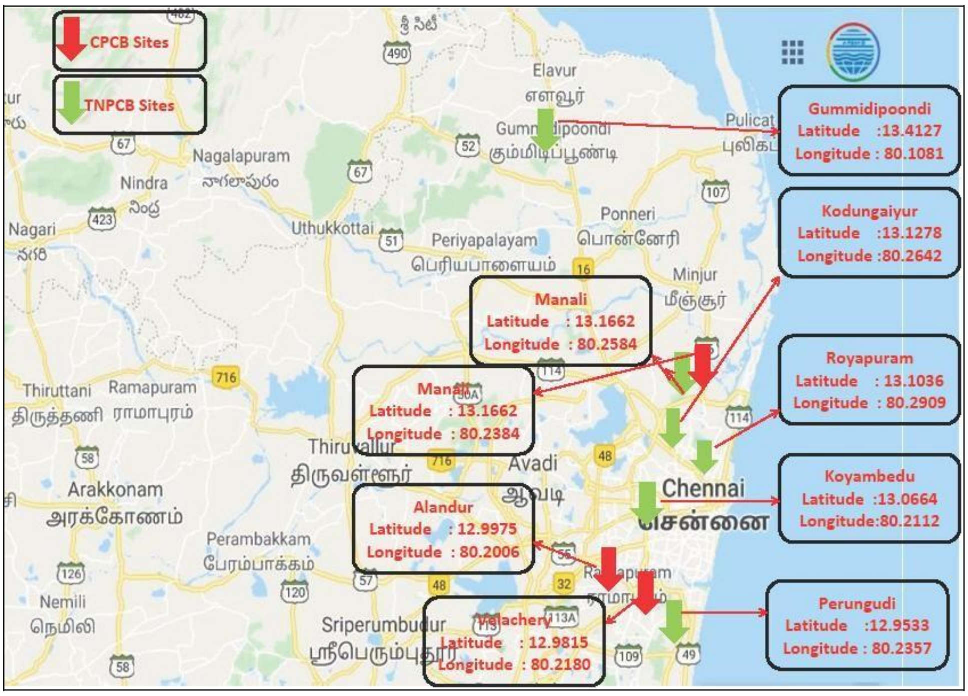


Fig 2 : Map showing the location of CAAQM stations in Chennai

While, locating the air monitoring stations in different parts of the City, the TNPCB has taken into account the type of site with reference to its predominant land use. In the State, the different land use zones recognized are: Primary residential, Mixed residential, Commercial, Industrial, Educational, Public and Semi-Public, Agriculture use zones. Locating the CAAQM stations in representative land use zone is with a view to obtain real time air quality information as influenced by various natural phenomena and human-sponsored activities prevailing in the predominant use zone.

The site classification of the locations of the CPCB and TNPCB CAAQM stations in Chennai are presented as below.

Sl. No	CPCB CAAQM stations	Site classification	TNPCB CAAQM stations	Site Classification
1	Alandur	Traffic Intersection	Gummidipoondi	Industrial
2	Velachery	Residential	Kodungaiyur	Mixed Residential
3	Manali	Industrial	Koyambedu	Traffic intersection cum commercial
4			Manali (Mathur)	Industrial
5			Perungudi	Residential
6			Royapuram	Mixed Residential

Operation of CAAQM stations

Often concerns are expressed by NGOs and citizens' groups about the functional efficiency of the CAAQM stations and the reliability of the data received from the stations. To ensure authenticity of the data on various pollutant parameters obtained from CAAQM stations, stringent operation & maintenance protocols and rigid calibration cycles are adopted by the Tamil Nadu Pollution Control Board. All the CAAQM stations are operated under comprehensive O&M contract with defined functions for the operator. In the stations calibration of various analysers are automatic, assisted by the operator/Engineer. The concerned officers and scientific staff of the TNPCB regularly monitor and review the working of the stations.

O & M Operator's responsibility in the regular upkeep of the station

For all TNPCB CAAQM stations, a comprehensive Operation & Maintenance (O&M) contract is awarded to the O&M operator. The operator has to take care of the following activities as per contract agreement.

- Deputing qualified manpower for individual CAAQM Station
- Supply of consumables like filter tapes for dust monitors, in line dust filters for gas analyzers and scrubbers for smooth operation of zero air generators
- Replacement of faulty of parts in the analyzers (like detectors, UV Lamps and electronic boards and control valves) and sensors on meteorological systems
- Taking care of UPS and Batteries operation
- Taking care of CAAQM station air – conditioners operation
- Paying electricity bills of CAAQM station
- Paying broad band/telephone bills
- Refilling of span gas cylinders whenever required
- Sending daily reports and monthly reports of each CAAQM station to TNPCB

As per the O&M contract, the station operator or Engineer performs the following tasks at a CAAQM Station

- Check the surroundings of the station before entering into it
- Check the CAAQM Station room temperature to be normally at 25 degrees Celsius.
- Check UPS battery voltages and supply voltages (input & output of UPS)
- Check the record of all analyzers for specific parameters, specified by the analyzers manufacturer and copy of the same needs to be sent to the operations manager.
- Attend to manual calibration of analyzers once in a month and send report to head office.
- Maintain station log book by entering daily events including weather condition at CAAQM Station
- Replacement of consumables (filter tapes, dust filters) for analyzers and record in the log book
- Cleaning of PM10 & PM2.5 sampling hoods once in six months.
- Attend to any troubles with the analyzers by getting remote support by a senior service engineer and replace those defective parts in the analyzers. This is recorded in the log book of the station.
- Coordinate with electricity and telephone department for trouble free services, whenever failure arises
- Maintain attendance register in the station

Calibration of instruments in a CAAQM station

Calibration of gas analyzers

Every gas monitoring analyzer in the CAAQM station is working continuously and producing data online. The accuracy or response of the analyzers has their own drift in the measurement/results when it works continuously. The accuracy of analyzers depends on span/zero response of measurement, which in turn due to ageing or internal electronic components or sensors or detectors function.

(a) Zero Calibration: The analyzer has to show zero value in the screen when zero air passes through the sampling line and measuring chamber. Zero air generator, comprising of a small pump, moisture remover and a scrubber removes gas molecules like SO2, CO, NO2 and O3 in the generated air. The operator/engineer has to adjust the offset value to get zero in the screen.

(b) Span Calibration: The ambient air quality measurement of SO_2, NO_x is in the ppb range and that of CO is in ppm range. Assume the instrument set has a measuring range of 500ppb for a particular gaseous pollutant. The operator/engineer will be pumping 400ppb (80% of full scale of measuring range) of the known concentration of the gas to the analyzer. This allows us to check the span response of the analyzer and adjust the span factor or gain value to get the specified span value of 80% or 400 ppb (parts per billion) in the analyzer. The dilution gas calibrator mixes the span gas cylinders concentration with the zero air to produce lower concentration of span values as desired. Normally, the supplied span gas cylinder is in the ppm parts per million) range and it is downsized to ppb range by mass flow controllers inside the gas calibrator. Set up of a typical calibration system is shown in Fig. 3.

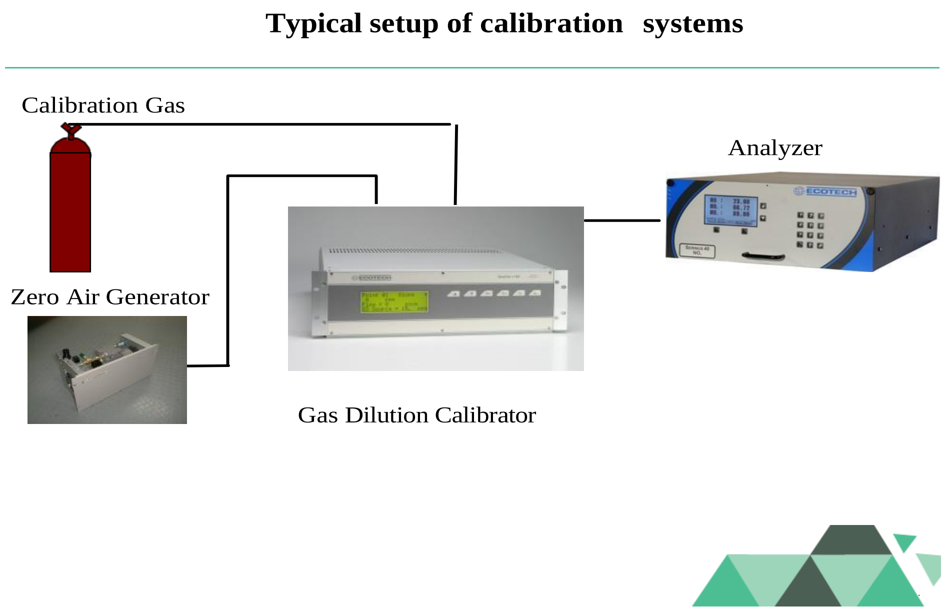


Fig 3: Gas Calibration system

Calibration of Dust Monitors

TNPCB CAAQM stations are installed with SPIRANT BAM1020, where the dust or fine particle sizes concentration is measured through Beta Rays Attenuation method. The SPIRANT BAM1020 does the calibration check by using known dust concentration of membrane, which is normally 80% of full scale of measuring range (1000 microgram) of the instrument. In other words, the concentration refers to the simulation of dust particles applied on the reference membrane. The BAM1020 extends the Reference Membrane between the beta source and the detector, directly above the spot of filter tape that was just measured. The Reference Membrane is an extremely thin film of clear Mylar held in a metal tongue. While calibrating, if the instrument shows more or less of 5% of the reference membrane (800 microgram), we get alarm in the screen of the instrument. The possible cause of the alarm is due to dirty membrane and internal trouble with the instrument like counters, beta source or detector. The picture shows position of reference membrane (Fig. 4).

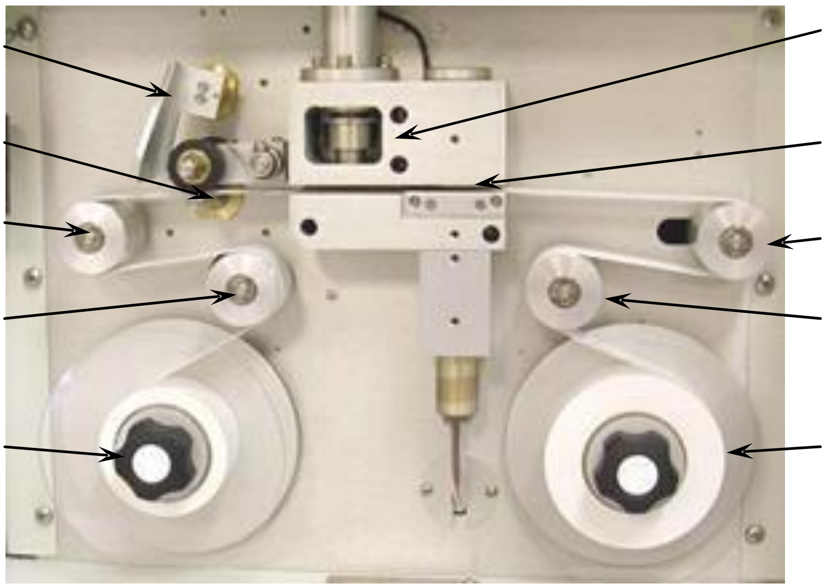


Fig 4: Reference Membrane with motor and two photos sensors (back side)

Background to the Study

COVID 19 or Novel Corona Virus spread its tentacles across the globe, originating from Wuhan, Hubei Province, China in December 2019. On December 31 of last year, Chinese authorities alerted the World Health Organization (WHO) of an outbreak of a novel strain of corona virus causing severe illness[19]. Within the next three months, the virus laid siege in over 70 countries. World Health Organization characterized COVID 19 as a pandemic on 11th March 2020. By April end, it afflicted 30.9 lakh people and caused death of over 2, 17,769 people in form of sporadic cases, cluster cases or community transmission. In India too, the virus showed its first signs of infection during end of January, when the first case was confirmed in Kerala on 31.1.2020 in a student who had returned home from Wuhan, China. By the end of April 2020, about 33,050 people were affected in India, resulting in a casualty figure of 1,074 (WHO Situation Report 101)[18]. In about another month's time by May end, the number of infected people rose five fold (173,763) and those who succumbed to the virus also went up five fold (4,971)[13]. In Tamil Nadu, the first case of COVID-19 was reported on 07.03.2020 and the number of confirmed cases has risen to 21,184 and the casualties were 160 as on 30th April 2020[1].

The virus infection initially started with the people with recent travel history from abroad or from other parts of the country and quickly spread among the persons those who were coming in their contact. The difficulties faced by health care teams include fairly longer incubation period of the virus and proportionately large number of asymptomatic cases in the affected population. In the absence of any vaccine against the virus, the fight over the virus world over has led to many diverse actions. The main strategies for controlling the spread of the virus were contact tracing, enhanced testing, isolation, containment, quarantine, maintaining social distancing, wearing of face mask etc. The lurking threat was that the virus reaches the stage of community spread in the absence of above preventive actions.

However, it was not found to be feasible to enforce the social distancing requirements effectively under the business-as-usual scenario.

Hence nations with high incidence of outbreak and deaths resorted to lockdowns of different intensity. This was done with an intention of breaking the spread chain by restricting the movement of people in a routine manner. In India, a 14 hour voluntary Janta curfew was observed on 22nd March 2020, following which complete nationwide lockdown was announced from the midnight of 24th March till 14th April (Lockdown 1.0). This was subsequently extended for another spell up to 3rd May (Lockdown 2.0). With the view to prevent the community spread of the virus, a third version of the lockdown was continued till 17th May 2020 with considerable relaxations for many activities (Lockdown 3.0).

During the lockdown 1.0 and 2.0 period, all the major transport operations like the road, air and rail services were suspended with exception for transport of essential items like groceries, vegetables, milk services. As a result entire range of bus services, most of the trucks, vans, autos, cars, most of the two wheelers were off the road. Construction activities were put to halt. Hospitals were allowed to function.

Opening of medical stores, grocery shops and vegetable retails were allowed with highly restricted timings.

Educational institutions, industrial establishments, Malls, theatres, IT companies, Government Offices (excluding essential services) commercial and trade centres too were closed. Among the industries, the ones that were manufacturing health care related products & medicines and essentials like milk were permitted to be operated. The hospitality services were also suspended. During lockdown 3.0 days, all industries were permitted to operate with reduced staff and workers' strength. Individual shops were permitted to open. Movement of individuals for non-essential activities in all zones, barring containment areas was allowed between 7 AM and 7 PM. All goods traffic was permitted and no state or Union Territory were free to stop the movement of cargo.

Objectives of the Study

As a result of stringent travel restrictions and curbing of inter-state and intra-district movement of people, all types of vehicular movement got reduced considerably during lockdown periods. Simultaneously all non- essential activities including those of air polluting sectors were shut down. Therefore, it was anticipated that the environmental quality, particularly in urban areas would show considerable improvement.

A study to understand the impact of lockdown on the air quality of Chennai and its sub-urban areas was undertaken by the Tamil Nadu Pollution Control Board with the following objectives.

1) To ascertain the impact of lockdown on the air quality index and the presence of different air pollutants in the ambient air in and around Chennai City by analyzing and comparing the data on air quality index and different pollutant parameters between pre-lockdown, lockdown 1.0, 2.0, and 3.0 periods.

2) To assess the air quality of Chennai during April 2020 lockdown in comparison with air quality in the months of April 2018 and April 2019.

3) To study the influence of air pollutants on the local atmospheric weather parameters and vice-versa by analyzing the recorded meteorological parameters in Chennai that prevailed in the month of April 2018, 2019 and 2020 and comparing the same with the AQI and pollutant parameters for the corresponding period.

Methodology

a) Study of Air quality during pre-lockdown and lockdown periods

Data of Air Quality Index from the six stations of TNPCB and three stations of CPCB in Chennai and its surroundings have been considered for analysis. As the air quality data from the Kodungaiyur monitoring station was reporting ‘insufficient’ (ID) during the entire lockdown period, the same was not included in the study. The TNPCB station located at Mathur village in Manali is not very far away from the Manali station of CPCB. Therefore, data from Manali CPCB station has been included in the study. Thus, for comparing and consolidating the AQI values, seven stations comprising of three CPCB stations viz., Alandur, Velachery and Manali and four TNPCB stations viz., Gummidipoondi, Koyambedu, Perungudi and Royapuram were considered. Data for all these stations have been provided by the Laboratory wing and Care Air Centre of the TNPCB.

The study period has been classified into four spells.

Lockdown status	Period	Duration (days)	Remarks
Pre-lockdown	01-03-2020 to 23-03-2020	23	Normal activities; Janta curfew on 22 March 2020 not separately considered
Lockdown 1.0	24-03-2020 to 14-04-2020	22	Complete lockdown
Lockdown 2.0	15-04-2020 to 03-05-2020	19	Complete lockdown
Lockdown 3.0	04-05-2020 to 17-05-2020	14	Lockdown with certain relaxations

Average AQI for all stations for a single day and Mean AQI from the individual stations for the different periods of lockdown were computed using the daily recorded values.

b) Analysis of individual air pollutant concentration

With regard to analysis of individual air pollutants, namely PM_{10}, $PM_{2.5}$, SO_2 and NO_2 the data sourced from the four TNPCB stations were only analyzed, as the data for individual pollutant parameters of CPCB stations were unavailable. The determinant parameter for the AQI on different dates in each station were obtained and analyzed for the pre-lockdown and different lockdown regimes.

c) Air Quality in April 2020 in comparison to April 2018 and 2019

An attempt was also made to analyze the AQI data for the entire month of April 2020 separately as this was the full month when the lockdown was in force. Data for April 2020 was compared with the air quality that prevailed during the corresponding month of 2018 and 2019. The mean values of AQI for the month of April 2018, 2019 and 2020 were computed from data of individual days for each of the seven CAAQM stations. Then the average values of AQI for all the stations were obtained for all the days and mean value for the month worked out.

d) Study on improvement on environment as reflected in various meteorological parameters due to decrease in greenhouse gases in view of COVID-19 lockdown at Chennai

Various meteorological parameters viz., solar radiation (Watt/metre^2), Dry adiabatic lapse rate (^{0} C/ 1000 metre), temperature inversion height (metre-m), sea breeze strength (miles per hour-mph) and wind speed (miles per hour-mph) were taken up for the study. The data were collected from IMD Meenambakkam as Balloon temperature and calculated adiabatic lapse rate and inversion based on WMO calculations. Data for the dates 1st April to 21st April 2020 and the corresponding dates of 2018 and 2019 were obtained and compared to study the impact of lockdown on these parameters. This part of the study has been taken up by Glens Innovation Lab, Chennai.

Results and Discussion

Results:

a) Impact of Lockdown on Air quality in Chennai

Values of AQI extracted from the daily AQI report for the four different time periods in respect of the seven stations are presented in Tables 3-6. The results reveal that the values of air quality during the pre-lockdown period mostly fell in either “Good” or “Satisfactory” category, except the values registering “Moderately Polluted” status for some days in Gummidipoondi and Manali stations (eleven and six days out of 23 days, respectively) (Table 3). Daily AQI values in all the stations moved to either “Satisfactory” or “Good” category during the Lockdown 1.0 regime, the only exception being two days of “Moderately Polluted” status in Gummidipoondi station alone (Table 4). Data revealed that during Lockdown 2.0, all the stations recorded “Good” category air quality status in all the days except one day and six days out of the total of 19 days in Alandur and Manali, respectively (Table 5). During Lockdown 3.0, AQI values in Velachery, Koyambedu, Perungudi and Royapuram stations registered ''Good'' status, whereas the Alandur, Manali and Gummidipoondi station recorded "Satisfactory" category for three, four and five days, respectively. Rest of the days reported ''Good'' status of air quality. Manali recorded ''Moderately Polluted'' category only on a single day (Table 6). It is inferred that the relaxations in industrial operations (in case of Manali and Gummidipoondi industrial sites) and intra-district and intra zone movement of vehicles during lockdown 3.0 (in case of traffic intersection at Alandur) have increased AQI values in those stations.

Average values of AQI for the different periods in the seven stations and percentage reduction of AQI during different lockdown periods with reference to pre-lockdown were worked out and presented in Table 7.

Table 7: Reduction of AQI during lockdown periods

Period/Station	Alandur	Velachery	Manali	Gummidipoondi	Koyambedu	Perungudi	Royapuram
Pre-lockdown	57.1	56.0	79.3	96.3	50.7	45.5	46.5
Lockdown 1.0	34.1	40.8	58.5	59.3	38.0	33.6	31.5
Lockdown 2.0	23.7	37.8	45.5	33.4	21.0	21.7	23.6
Lockdown 3.0	32.8	38.9	49.9	49.1	23.7	22.9	23.4
Reduction in 1.0 w. r. t PLD* (%)	**40.3**	**28.2**	**26.3**	**39.5**	**25.1**	**25.3**	**25.3**
Reduction in 2.0 w. r. t PLD* (%)	**58.5**	**33.5**	**42.6**	**65.3**	**58.6**	**51.8**	**49.2**
Reduction in 3.0 w. r. t PLD* (%)	**42.6**	**31.5**	**37.1**	**49.0**	**53.3**	**49.1**	**49.7**

* Pre-lockdown period

Table 3: AQI recorded in seven CAAQM stations during pre-lockdown period (01 March- 24 March 2020)

Station/Dates	01-Mar	02-Mar	03-Mar	04-Mar	05-Mar	06-Mar	07-Mar	08-Mar	09 -Mar	10-Mar	11-Mar	12-Mar	13-Mar	14-Mar	15-Mar	16-Mar	17-Mar	18-Mar	19 -Mar	20-Mar	21-Mar	22-Mar	23-Mar	Mean
Alandur	62	70	80	75	89	ND	38	26	44	73	32	43	57	60	77	49	60	53	73	52	46	46	52	57.1
Velachery	56	82	98	63	48	29	109	78	29	26	22	52	55	60	50	51	54	62	53	52	49	58	53	56
Manali	106	101	62	77	54	88	35	25	81	-	62	59	69	93	93	82	122	107	77	89	102	104	57	79.3
Gummidipundi	85	107	125	100	100	91	122	87	78	68	75	82	109	115	153	79	103	120	101	83	89	57	86	96.3
Koyambedu	74	81	76	55	57	31	44	22	31	38	30	37	61	69	55	49	50	60	59	48	43	46	48	50.7
Perungudi	49	76	-	59	47	39	33	25	36	33	30	35	54	65	54	43	39	56	47	42	40	43	46	45
Royapuram	74	81	76	55	57	31	44	22	31	38	30	37	37	57	36	37	40	47	43	34	63	66	33	46.5
Mean	72.3	85.4	86.2	69.2	64.6	51.5	60.7	40.7	47.1	46	40.1	49.3	63.1	74.1	74	55.7	66.9	72.1	64.7	57.1	61.7	60	53.5	61.5

Table 4: AQI recorded in seven CAAQM stations during Lockdown 1.0 period (24 March – 14 April 2020)

Station/Dates	24-Mar	25-Mar	26-Mar	27-Mar	28-Mar	29-Mar	30-Mar	31-Mar	01-Apr	02-Apr	03-Apr	04-Apr	05-Apr	06-Apr	07-Apr	08-Apr	09-Apr	10-Apr	11-Apr	12-Apr	13-Apr	14-Apr	Mean
Alandur	38	26	26	34	47	37	38	39	40	44	44	40	30	23	20	21	21	76	29	24	27	26	34.1
Velachery	49	38	39	39	54	39	48	52	54	37	37	37	37	38	36	37	36	ID	38	37	37	38	40.8
Manali	64	50	71	66	76	60	67	77	90	96	63	46	53	48	38	48	44	40	42	48	50	49	58.5
Gummidipoondi	89	50	43	166	153	65	55	71	65	70	63	54	48	31	35	32	34	32	35	34	37	42	59.3
Koyambedu	40	40	35	40	48	37	44	ID	52	51	55	44	37	33	21	23	31	26	38	28	36	38	38
Perungudi	36	30	32	40	47	35	40	53	51	49	48	45	31	18	21	18	18	20	19	22	34	32	33.6
Royapuram	29	25	29	31	42	32	43	43	47	53	50	41	29	22	21	21	13	21	23	18	28	31	31.5
Mean	49.3	37	39.3	59.4	66.7	43.6	47.9	55.8	57	57.1	51.4	43.9	37.9	30.4	27.4	28.6	28.1	35.8	32	30.1	35.6	36.6	42.3

Table 5: AQI recorded in seven CAAQM stations during Lockdown 2.0 period (15 April – 3 May 2020)

Station/Dates	15-Apr	16-Apr	17-Apr	18-Apr	19-Apr	20-Apr	21-Apr	22-Apr	23-Apr	24-Apr	25-Apr	26-Apr	27-Apr	28-Apr	29-Apr	30-Apr	01-May	02-May	03-May	Mean
Alandur	24	64	16	21	14	13	28	17	24	23	17	28	19	19	21	27	24	ID	28	23.7
Velachery	36	37	39	39	38	38	35	38	37	37	36	41	38	38	38	38	40	38	37	37.8
Manali	44	34	37	34	37	27	49	39	30	42	59	67	62	57	47	41	56	56	46	45.5
Gummidipoondi	38	33	38	28	20	27	29	30	ID	ID	44	20	31	24	29	43	43	47	44	33.4
Koyambedu	30	23	17	13	17	14	17	18	16	19	21	19	18	8	19	30	38	29	33	21
Perungudi	26	22	20	19	18	17	21	18	20	18	19	24	20	17	19	25	32	27	31	21.7
Royapuram	25	19	16	21	33	17	16	20	21	20	27	18	14	20	21	29	39	28	45	23.6
Mean	31.9	33.1	26.1	25	25.3	21.9	27.9	25.7	24.7	26.5	31.9	31	28.9	26.1	27.7	33.3	38.9	37.5	37.7	29.5

Table 6: AQI recorded in seven CAAQM stations during Lockdown 2.0 period (04 May –17 May 2020)

Station/Dates	04-May	05-May	06-May	07-May	08-May	09-May	10-May	11-May	12-May	13-May	14-May	15-May	16-May	17-May	Mean
Alandur	24	52	51	21	32	21	19	20	25	23	75	24	44	28	32.8
Velachery	38	36	34	36	38	36	36	36	34	37	46	48	44	45	38.9
Manali	48	63	41	51	47	38	42	42	44	22	42	71	105	43	49.9
Gummidipoondi	41	34	41	57	56	41	50	59	65	41	41	82	40	40	49.1
Koyambedu	26	17	26	28	26	20	15	15	21	21	25	38	31	23	23.7
Perungudi	24	16	23	22	45	20	19	18	20	22	28	23	22	18	22.9
Royapuram	34	28	26	27	24	23	16	19	26	20	25	15	20	24	23.4
Mean	33.6	35.1	34.6	34.6	38.3	28.4	28.1	29.9	33.6	26.6	40.3	43	43.7	31.6	34.4

Analysis of the data reveal that the lockdown 1.0 and 2.0 brought in significant improvement of Chennai air quality in most of its recorded stations, as revealed from the values of Air Quality Index. While the AQI in the different stations recorded values ranging between 45.5 and 96.3 during the pre-lockdown period, the same ranged from 31.5 to 59.3 and from 21.0 to 37.8 during the lockdown 1.0 and lockdown 2.0 periods, respectively. The same values ranged between 22.9 and 49.9 during lockdown 3.0 regime.

The average AQI computed for each of the station is presented in Fig 5.

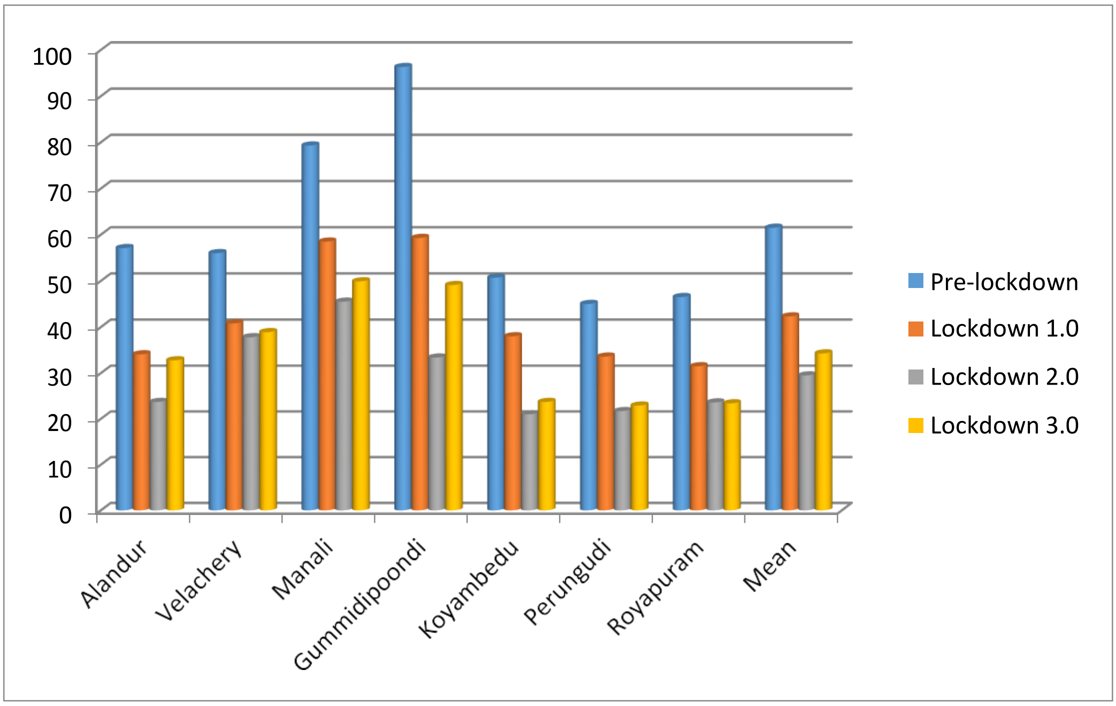


Fig 5: Average Air Quality Index in seven CAAQM stations in Chennai

Mean values for all the seven stations revealed that the AQI fell sharply from 61.5 to 42.3 and 29.5, respectively for the three periods, which represent a fall in the values of AQI by nearly one third (31.2 %) and half (52 %) during the lockdown 1.0 and lockdown 2.0 with reference to the pre-lockdown period (Fig 6).

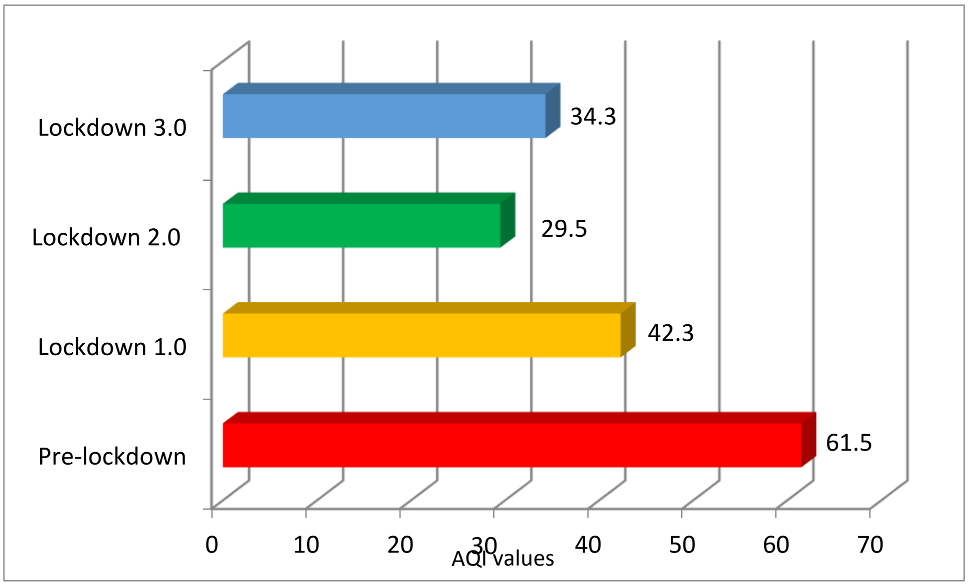


Fig 6: Average AQI values of seven CAAQM stations

With many relaxations in industrial, commercial and trade activities brought into force during the lockdown 3.0 period, the mean AQI values rose to 34.3 (Fig 6).

The improvement in the air quality in various stations during different periods is represented in terms of their standard colour coding as prescribed by the CPCB in Table 8. G represents Good air quality status, whereas S denotes Satisfactory air quality condition.

Table 8: Colour coding of AQI in different stations of Chennai

Period/ Station	TI Alandur	R Velachery	I Manali	I Gummidipoondi	TIC Koyambedu	R Perungudi	MR Royapuram	Mean
Pre-lockdown	S	S	S	S	S	G	G	S
Lockdown 1.0	G	G	S	S	G	G	G	G
Lockdown 2.0	G	G	G	G	G	G	G	G
Lockdown 3.0	G	G	G	G	G	G	G	G

*TI- Traffic Intersection; R-Residential; I- Industrial; TIC- Traffic Intersection cum Commercial; MR- Mixed Residential

The above illustration reveals that in the pre-lockdown time the average quality of air was good (<50 AQI) only in Perungudi and Royapuram stations, while the same for the other five stations and the mean value was satisfactory (50-100 AQI). The quality has improved to good status in Alandur, Velachery, Koyambedu stations during lockdown
1.0 period itself, while the AQI in both the industrial sites viz., Gummidipoondi and Manali continued to be in Satisfactory status. This suggested that certain industrial activities that were exempted from lockdown continued during the lockdown period as well in these industrial estates. However, the AQI values of all seven stations and the mean values moved to Good category during lockdown 2.0 and lockdown 3.0.

Number of days in which the AQI registered varying quality status

An analysis of the number of days out of the total days under each activity regime which registered different average air quality status in the seven stations was made and the per cent figures computed. The results show that the per cent of days in which AQI was in moderately polluted category was 11.7 for the pre-lockdown period, while the same for the lockdown 1.0, lockdown 2.0 and lockdown 3.0 regimes was nil. For the corresponding periods, the AQI moved to Good quality status from 37.4 per cent days to 78.6 per cent, 94.7 per cent and 92.9 per cent days, respectively (Fig 7). Similar positive movement to Satisfactory category has also been recorded during the lockdown periods. Thus, the study reveals that the air quality in Chennai and its surroundings improved significantly during the lockdown periods as compared to the pre-lockdown period.

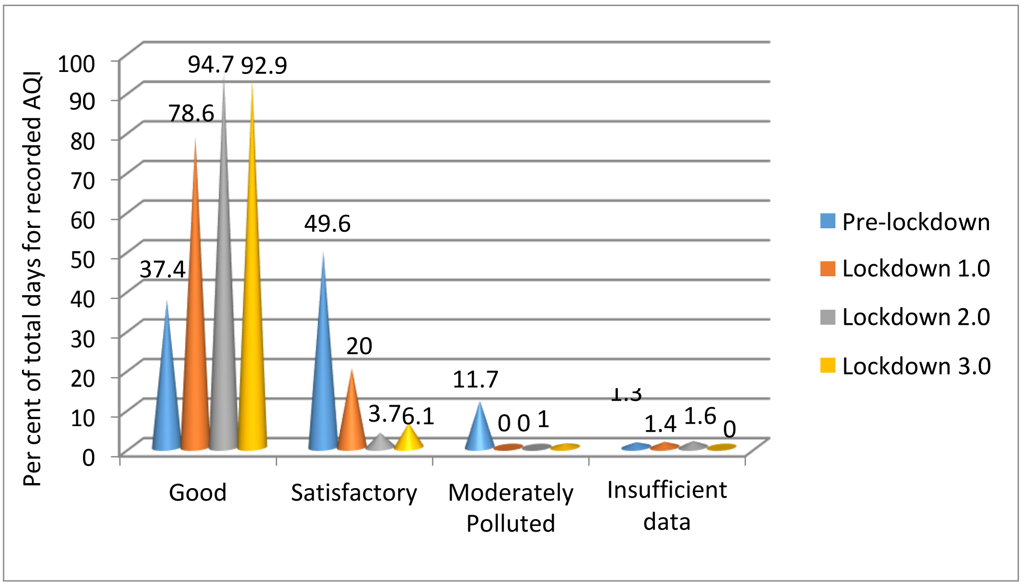


Fig 7: Per cent of total days for recorded AQI

It has been widely recognized that transport, industries, power plants, construction activities, biomass & refuse burning, road dust re suspension and residential activities are the major sectors contributing to air pollution, particularly in urban areas. In addition, certain other activities such as operation of DG sets, restaurants, landfill fires, etc. also contribute to air pollution. From the above finding, it is inferred that the first two lockdown periods had imposed severe restrictions on all transportation involving vehicular movement, industrial activities and construction activities that are the major sources for air pollutants.

As compared to the lockdown 1.0, further improvement in average air quality in all stations was observed during lockdown 2.0, which is reflected in 94.7 per cent of days recording 'Good category AQI' during lockdown 2.0 as compared to 78.6 per cent of days in the lockdown 1.0 regime. This improvement suggests that the people got adapted to various restrictive and regulatory measures imposed by the Government like ban on inter- district movement of people for routine reasons, complete 'off the road' status of high-emission sources like buses, trucks and vans, stringent implementation of the ban on movement of private cars, taxis, auto rickshaws, two wheelers etc., thus resulting in overall reduction in the use of petro products in the transportation sector.

However, as lockdown 3.0 witnessed certain relaxations in movement of people through various activities, a slight reduction in Good air quality status was noticed as compared to lockdown 1.0 and 2.0.

Concurrent reduction in the levels of individual pollutant parameters like PM_{10}, $PM_{2.5}$, SO_2, NO_2 during different lockdown periods is discussed in the subsequent paras.

Site related variation in air quality improvement during lockdown

Improvement in AQ was not felt as much in the Manali industrial site as it was registered in traffic intersections and commercial areas (Table 9).

Table 9: Site related variations in AQI during lockdown

Station	**Mean AQI**			
	Pre-lockdown	Lockdown 1.0	Lockdown 2.0	Lockdown 3.0
Gummidipoondi	96.3	59.3	33.4	49.1
% reduction wrt PLD*		**39.5**	**65.3**	**49.0**
Manali	79.3	58.5	45.5	49.3
% reduction wrt PLD		**26.3**	**42.6**	**37.1**
Mean of seven stations	61.5	42.3	29.5	34.3
% reduction wrt PLD		**31.2**	**52.0**	**44.2**

* Pre-lockdown

AQI showed significant variation in percent reduction between Gummidipoondi and Manali stations. It has been ascertained from the District Environmental Engineer of the concerned area that the continuous operation units such as Chennai Petrochemical Corporation Limited, Madras Fertilizer Limited, NATCO Pharma, Piramal Enterprises and Coromondel International in Manali estate were in operation during the lockdown periods 1.0 and 2.0 also, while all the other industries were not under operation. This has caused relatively lesser improvement in the air quality in Manali industrial area as compared to the average of all stations. As for Gummidipoondi industrial area, higher reduction in AQI value was recorded in both lockdown 1.0 and lockdown 2.0 periods as compared with the seven station average values.

It has been verified from the District Environmental Engineer that all the units in Gummidipoondi SIPCOT complex except four number of vegetable oil manufacturing units (essential products) were not in operation as per Government order and these units were using only firewood as fuel. The reduction per cent of average AQI values during Lockdown 3.0 further dropped in both the industrial sites as compared to the lockdown versions 1.0 and 2.0, as more industries started operations, though at reduced capacity.

Examination of AQI determinants during different lockdown regimes

An assessment has been made for the air pollutants that have determined AQI for different periods, for which the determinant for each of the day from the seven CAAAQM stations were analysed. Number of data points for each pollutant deciding the AQI were computed (Table 10).

Table 10: AQI determinants during different periods

Parameter	Pre-lockdown	Lockdown 1.0	Lockdown 2.0	Lockdown 3.0	Total data points
PM10	82	79	49	50	260
PM2.5	49	48	10	9	116
Ozone	6	0	8	6	20
NOx	5	2	3	1	11
CO	18	19	61	32	130
SO2	1	4	0	0	5
No Data	0	1	1	0	2
Insufficient Data	0	1	1	0	2

It has been informed that PM_{10} is not monitored in the three CPCB stations. It is noticed that during most of the days in the pre-lockdown and lockdown periods in all the TNPCB stations, PM_{10} and $PM_{2.5}$ were determining the AQI, accounting for 48.0 per cent and 21.0 per cent of data points. Carbon monoxide served as the deciding pollutant for AQI in 24.0 percent of the total data points. It is observed that CO became the major determinant for AQI for Velachery and Manali stations during both lockdown 2.0 and 3.0. This might be due to the recommissioning of industrial operations and relaxation of transport regulations during lockdown 2.0, which has possibly resulted in the increase in ambient

CO levels. Ozone and NOx and SO_2 became the determinant pollutants only on very few days in some stations, with 3.7, 2.0 and 0.9 percent of data points accounting for these three pollutants, respectively.

Impact of lockdown on individual pollutant parameters

As explained earlier, most of the eight air pollutants viz., PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, and Pb are monitored in the CAAQM stations. Details of monitored pollutants for their ambient concentration are shown below

Sl.No	CAAQM Station	Parameters monitored
1	Alandur	$PM_{2.5}$, SO_2, NO_X, BTX, CO,O_3
2	Velachery	$PM_{2.5}$, SO_2, NO_X, BTX, CO,O_3
3	Manali	$PM_{2.5}$, SO_2, NO_X, BTX, CO,O_3
4	Gummidpoondi	PM_{10}, PM $_{2.5}$, SO_2, NO_2, NH_3,
5	Koyambedu	PM_{10}, PM $_{2.5}$, SO_2, NO_2, NH_3,
6	Perungudi	PM_{10}, PM $_{2.5}$, SO_2, NO_2, NH_3, CO, O_3
7	Royapuram	PM_{10}, PM $_{2.5}$, SO_2, NO_2, NH_3, CO, $O_{3,}$ Benzene

The individual pollutant values for the four stations of TNPCB were compared for their concentration during different periods taken up for the study.

i) Particulate Matter 10 ($PM_{10)}$:

Daily recorded values of PM_{10} in the four CAAQM stations are presented in Table 11. Data revealed that the average PM_{10} values of at the four sites ranged from 41 to 98, 23 to 66, 12 to 38 and 24 to 39 (all values in µg/m3) during the pre-lockdown and the three lockdown periods, respectively indicating that levels of particulate matter (PM_{10}) pollutant in ambient air subsided during all lockdown regimes as compared to the pre- lockdown period. However, on certain days during lockdown 1.0, all station PM_{10} mean values were higher than the pre-lockdown values on few days. This might have been due to prevailing local conditions on that dates (Fig 8).

Table 11: Mean values of PM 10 (µg/m3) during different days of Pre-lockdown and Lockdown periods in the four CAAQM stations in Chennai

Period/Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Mean
Pre-lockdown	57	85	**98**	74	65	53	55	**41**	46	45	42	51	67	79	72	52	58	73	63	52	56	46	53	60.1
Lockdown 1.0	48	34	35	44	66	42	46	54	**56**	56	53	47	36	24	24	24	24	**23**	26	25	33	34	-	38.8
Lockdown 2.0	30	24	21	18	14	18	19	21	19	16	25	18	18	**12**	21	31	37	33	**38**	-	-	-	-	22.8
Lockdown 3.0	31	24	29	34	32	23	**24**	25	31	26	29	**39**	28	26	-	-	-	-	-	-	-	-		29.0

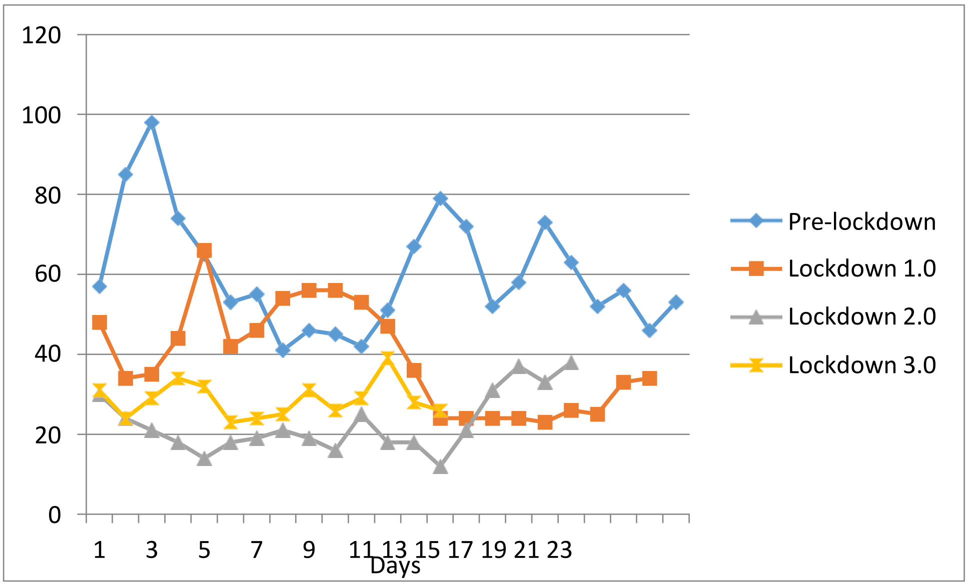


Fig 8: All station mean values of PM_{10} during different lockdown periods

Station wise mean values of PM_{10} of different lockdown periods durations are depicted in Fig 9.

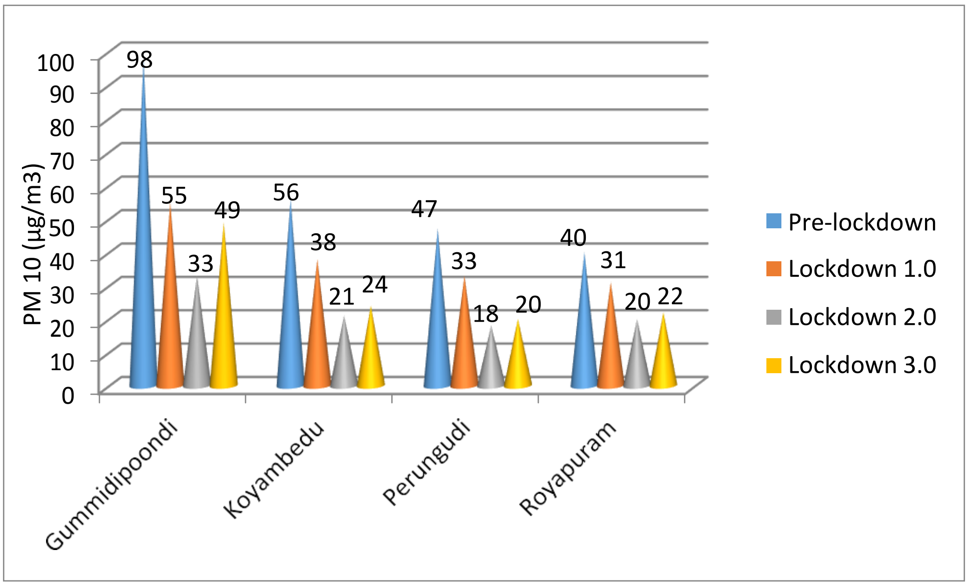


Fig 9 : Station wise mean values of PM_{10} during different lockdown periods

Data revealed that highest reduction in PM_{10} was noticed in Gummudpoondi in both lockdown 1.0 and 2.0 and in Koyambedu during lockdown regime 2.0. Mean PM_{10} concentration fell almost to one third of the pre-lockdown values during lockdown 2.0, indicating substantial reduction in industrial and transport activities in these two stations. The other two stations viz., Perungudi and Royapuram recorded about 38 percent and 50 per cent of pre-lockdown mean PM_{10} concentrations during lockdown 2.0, suggesting that these areas being residential and mixed residential, respectively witnessed considerable movement of local people despite restrictions. The PM_{10} for the 14 days of lockdown 3.0 showed higher values at all stations on all days compared to the lockdown 2.0, indicating that restrictions eased on many fronts of activities in this period.

The whole period average of PM_{10} data for all the four stations put together showed values of 60.1, 38.8, 22.8 and 29.0 for the corresponding periods (Fig 10). The highest drop of 62 per cent in average PM_{10} was observed during lockdown 2.0 from the pre-lockdown values. This data corroborates with the values of AQI in different periods, where too the largest reduction was noticed during lockdown 2.0. Mean PM_{10} concentration jumped by one third during lockdown 3.0 over the corresponding value for lockdown 2.0, revealing enhanced human activities.

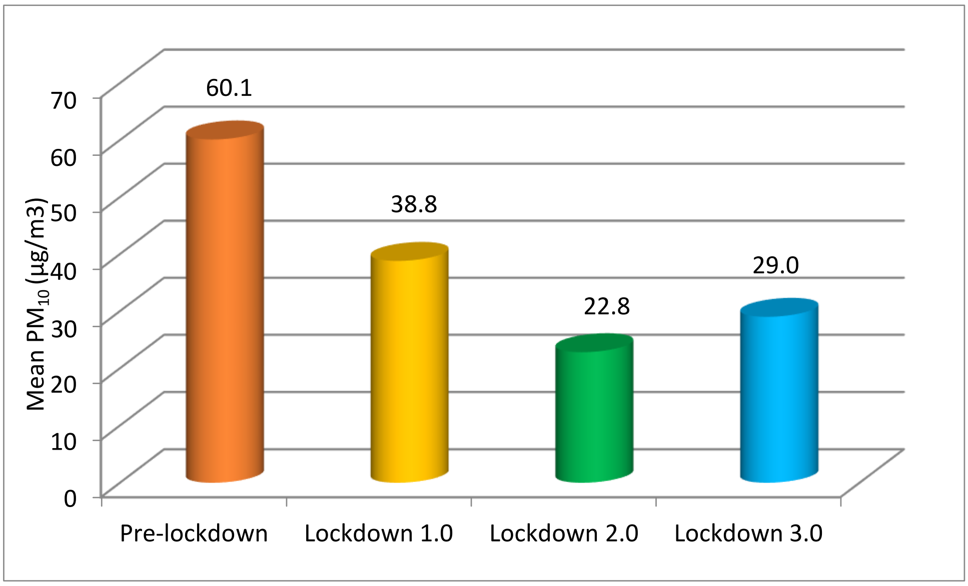


Fig 10: All stations mean PM_{10} values during different periods

ii) Particulate Matter 2.5 ($PM_{2.5}$) :

Table 12 provides data on the daily recorded values of $PM_{2.5}$ in the four CAAQM stations. (landscape) Average $PM_{2.5}$ values at the four sites moved between 13 and 48, 6 and 29, 5 and 20 & 7 and 17 (all values in µg/m3) during the pre-lockdown and the three lockdown periods, respectively indicating that levels of fine respirable particulate matter ($PM_{2.5}$) pollutant in ambient air dropped during the duration of all lockdown regimes as compared to that of pre-lockdown, This trend revealed almost similar pattern as that of PM_{10}. As in the case of PM_{10}, all station $PM_{2.5}$ mean values on certain days during lockdown 1.0, were found to be higher than the pre-lockdown day values. Local activities that prevailed in the vicinity of monitoring stations on those dates coupled with weather conditions could have caused such higher values in the lockdown period (Fig 11).

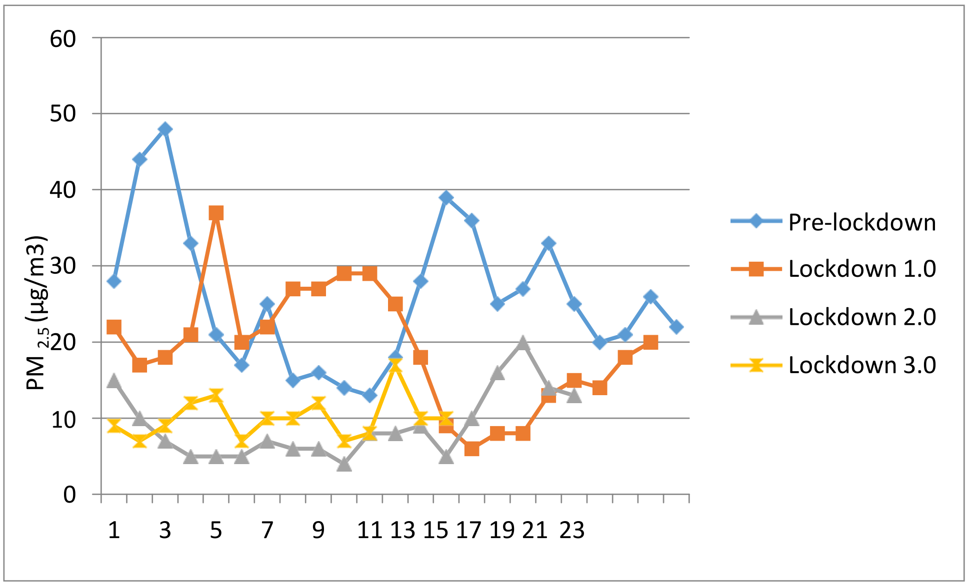


Fig 11: All station mean values of PM $_{2.5}$ during different lockdown periods

Station wise variations in the mean values of $PM_{2.5}$ of during the duration different lockdown regimes are shown in Fig 12.

Table 12 : Mean values of PM 2.5 (µg/m3) during different days of Pre-lockdown and Lockdown periods in the four CAAQM stations in Chennai

Period/Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Mean
Pre-lockdown	28	44	**48**	33	21	17	25	15	16	14	**13**	18	28	39	36	25	27	33	25	20	21	26	22	25.8
Lockdown 1.0	22	17	18	21	**37**	20	22	27	27	29	29	25	18	9	**6**	8	8	13	15	14	18	20	-	19.2
Lockdown 2.0	15	10	7	5	5	5	7	6	6	**4**	8	8	9	5	10	16	**20**	14	13	-	-	-	-	9.1
Lockdown 3.0	9	7	9	12	13	**7**	10	10	12	7	8	**17**	10	10	-	-	-	-	-	-	-	-	-	10.0

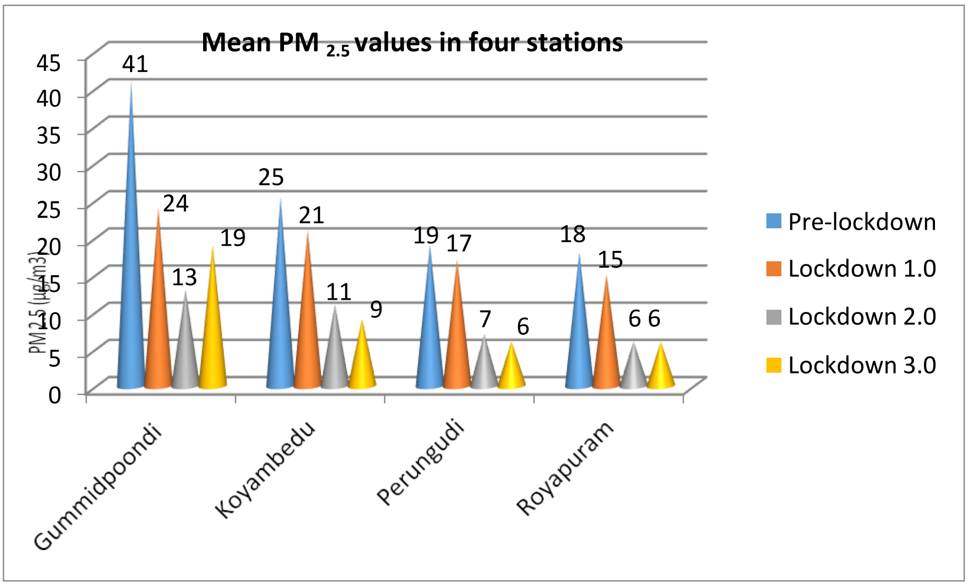


Fig 12: Station wise mean values of $PM_{2.5}$ during different lockdown periods

It is seen from the data that uniformly highest reduction in $PM_{2.5}$ was noticed in all stations during lockdown 2.0. Of all stations Gummudpoondi recorded maximum drop of $PM_{2.5}$ in lockdown 1.0 and 2.0 regimes, accounting for 41.5 and 68.3 per cent fall in $PM_{2.5}$, respectively as compared to pre-lockdown. This follows almost the pattern of PM_{10}. Lockdown brought significant reduction in $PM_{2.5}$ concentration in Koyambedu, Perungudi and Royapuram sites as well particularly during lockdown regime 2.0, registering a drop of 56.0, 63.2 and 66.7 per cent. Overall trend indicates that the restrictions were severer during lockdown

2.0 by which time people got more compliant to COVID -19 lockdown restrictive measures. Though lockdown 3.0 witnessed relaxation of restrictions, no substantial increase of $PM_{2.5}$ as compared to lockdown 2.0 was recorded in the stations except in Gummidpoondi.

The whole period average of $PM_{2.5}$ data for all the four stations put together showed values of 25.8, 19.2, 9.1 and 10.0 for the corresponding periods (Fig 13). While the lockdown regime 2.0 brought the maximum reduction of 64.7 per cent in average $PM_{2.5}$ from the pre-lockdown concentrations, the same was only 25.6 per cent during 1.0 regime.

Again, this trend is in conformity to what has been observed in the AQI values in different periods. Highest reduction in average AQI was recorded during lockdown 2.0. Despite many relaxation of movement regulations during regime 3.0, $PM_{2.5}$ values have not increased significantly over lockdown 2.0.

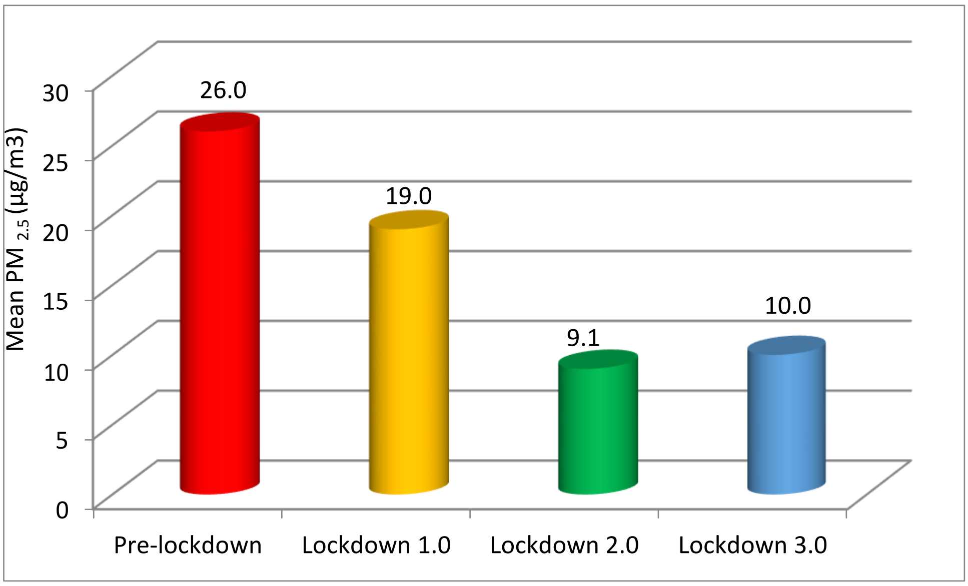


Fig 13: All stations mean $PM_{2.5}$ values during different periods

iii) Sulphur-di-oxide (SO_2) :

Data on the daily recorded values of SO_2 in the four monitoring stations is in Table 13. Average SO_2 values at the four sites were from 5.2 to 8.8, from 2.5 to 4.8, from 2.1 to 4.7 and 3.7 to 7.8 (all values in µg/m3) during the pre-lockdown and the three lockdown periods, respectively indicating that levels of SO_2 pollutant in ambient air reduced significantly during lockdown periods 1.0 and 2.0, as compared to that of pre- lockdown. As in the case of other particulate pollutants, all station SO_2 mean values on certain days during lockdown 1.0, were found to be higher than the pre-lockdown day values. Continuance of certain local activities that prevailed in the vicinity of monitoring stations on those dates coupled with *in situ* weather conditions might be the reasons for such higher concentrations in the lockdown period (Fig 14).

Table 13 : Mean values of SO_2 (µg/m3) during different days of Pre-lockdown and Lockdown periods in the four CAAQM stations in Chennai

Period/Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Mean
Pre-lockdown	**5.2**	7.9	7.9	6.1	6.7	6.5	6.7	7.2	7.1	6.8	5.8	6.3	7.7	8.3	5.8	5.9	**8.8**	8.1	7.5	7.2	6.7	7.1	6.9	7.0
Lockdown 1.0	3.8	3.5	3.3	4.2	3.9	3.1	3.5	5.3	5.4	2.8	**2.5**	4.3	4.3	4.0	3.4	3.7	3.5	4.2	4.1	4.0	4.2	**4.8**	-	4.2
Lockdown 2.0	4.2	3.7	3.3	3.4	3.8	**4.7**	4.1	3.8	4	**2.1**	4.3	4.1	4.2	3.7	3.8	3.7	5.3	4.2	3.4	-	-	-	-	4.0
Lockdown 3.0	4.2	**3.7**	4.9	5.1	4.4	4.0	4.0	4.5	4.8	4.8	5.0	**7.8**	4.8	5.7	-	-	-	-	-	-	-	-	-	4.8

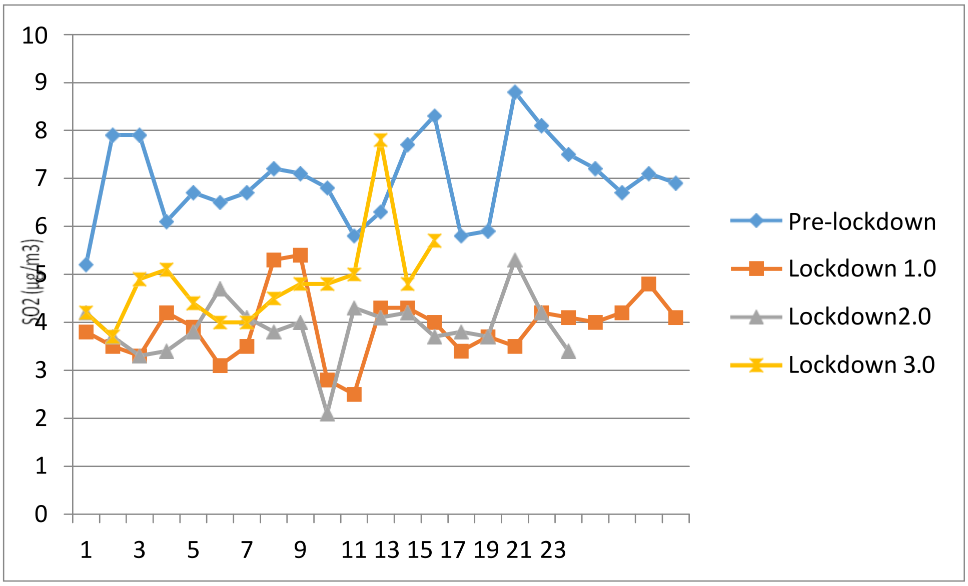


Fig 14: All station mean values of SO_2 during different lockdown periods

Changes in station wise mean values of SO_2 concentration during pre-lockdown and different lockdown periods are presented in Fig 15.

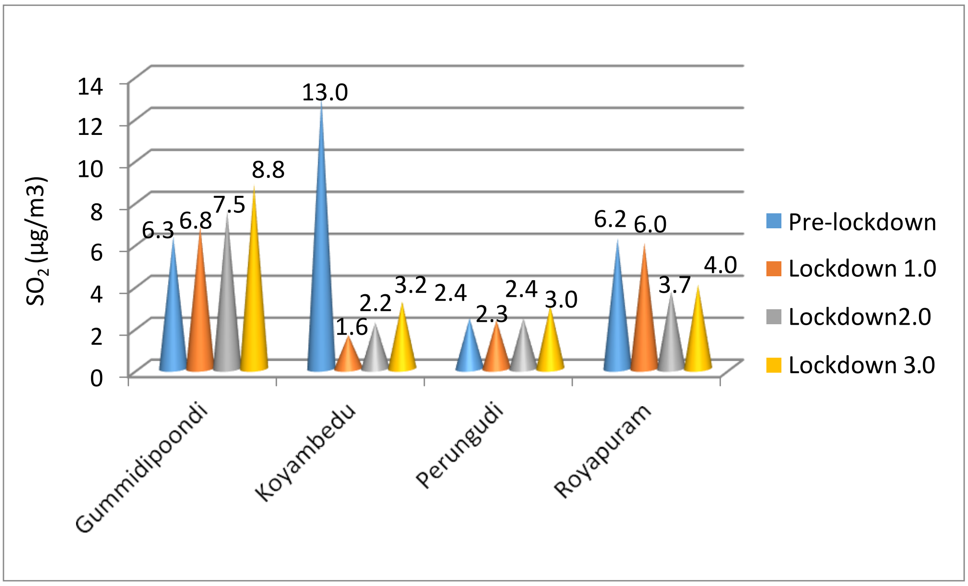


Fig 15 : Station wise mean values of SO_2 during different lockdown periods

Data revealed that maximum improvement in air quality in terms of SO_2 values is recorded in Koyambedu site in all the three lockdown periods. It is seen from the data that there has been no significant reduction in SO_2 concentration in Perungudi station. In fact there has been minor increase in SO_2 values during lockdown 1.0, 2.0 and 3.0 as compared to pre-lockdown in Gummidipoondi, suggesting continuance of some industrial activities in the SIPCOT estate. Maximum drop of 87.7, 82.9 and 75.4 per cent in SO_2 concentration in ambient air has been recorded in Koyambedu station in lockdown 1.0, 2.0 and 3.0 regimes. This trend suggests that complete cessation of transport and consequent shutdown of Chennai Metropolitan Bus Terminal (CMBT) and closure of the wholesale vegetable, fruit and flower market at Koyambedu resulted in the drop of consumption of High Speed Diesel (HSD) and thus improvement in air quality in terms of SO_2.

Average of SO_2 data for the whole study period in all the four stations put together showed values of 7.0, 4.2, 4.0 and 4.8 for the corresponding periods (Fig 16). While the lockdown regime 2.0 brought the maximum reduction of 42.9 per cent in average SO_2 from the pre-lockdown concentrations, the same was only 40.0 per cent and 31.4 per cent during1.0 and 3.0 regimes. The pattern follows the observations recorded for the AQI in different periods, where lockdown 2.0 registered the highest reduction in average AQI.

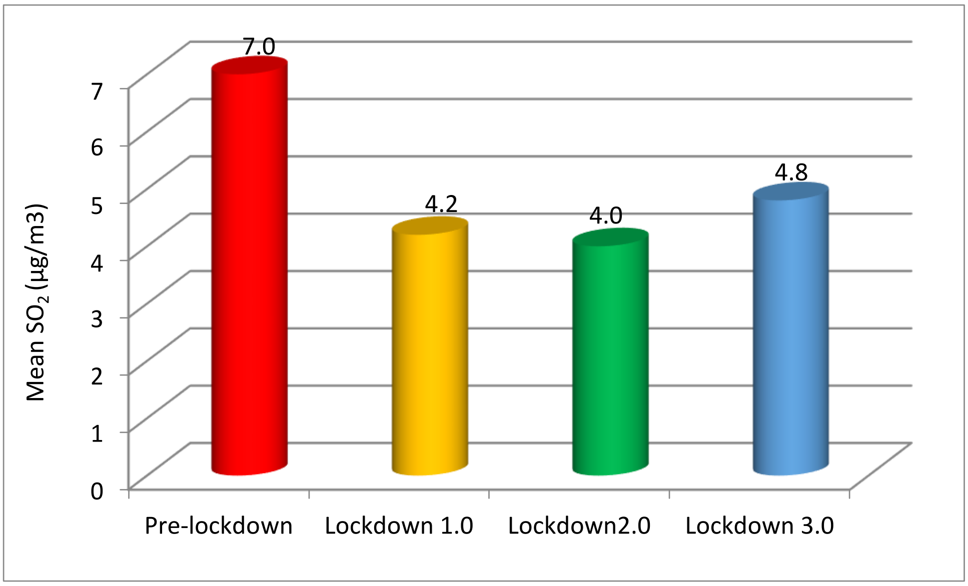


Fig 16 : All stations mean SO_2 values during different periods

iv) Nitrogen-di-oxide (NO2) :

Data on the daily recorded values of NO_2 in the four monitoring stations is presented in Table 14. Average NO_2 values fell in the range at the four sites from 6.5 to 18.0, from 4.0 to 10.0, from 3.8 to 6.5 and from 5.0 to 7.3 (all values in µg/m3) during the pre-lockdown and different lockdown periods, respectively. Results revealed that NO_2 pollutant in ambient air reduced significantly during all lockdown periods as compared to that of pre-lockdown. Lockdown 3.0 showed higher NO_2 values than lockdown 2.0 days on most occasions due to introduction of certain relaxations on industrial and transportation activities (Fig 17).

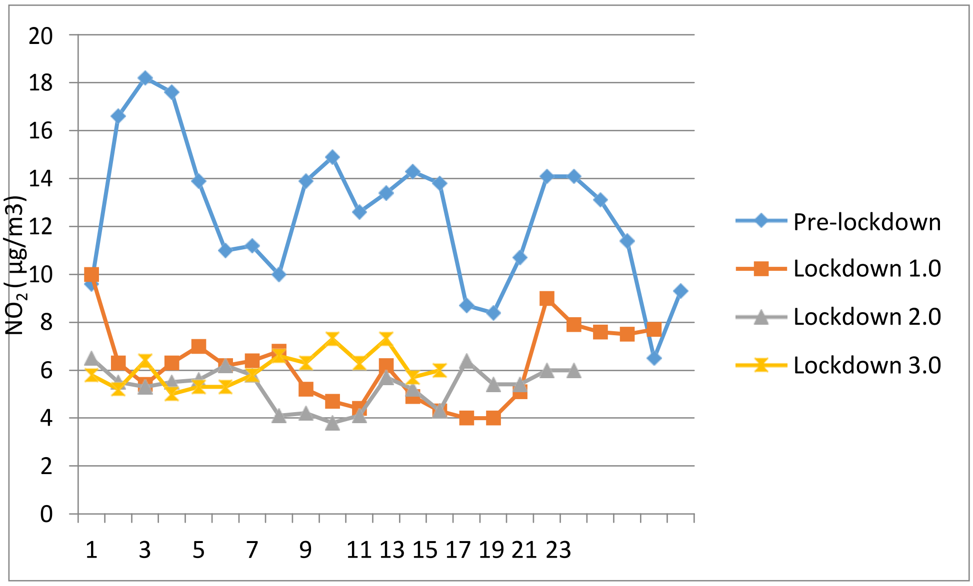


Fig 17: All station mean values of NO_2 during different lockdown periods

The station wise mean values of NO_2 concentration during pre-lockdown and different lockdown periods are furnished in Fig 18.

Table 14 : Mean values of NO_2 (μg/m3) during different days of Pre-lockdown and Lockdown periods in the four CAAQM stations in Chennai

Period/Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Mean
Pre-lockdown	9.6	16.6	18.2	**18.0**	14.0	11.0	11.2	10	13.9	14.9	13	13	14.3	14	8.7	8.4	11	14.1	14.1	13	11.4	**6.5**	9.3	12.5
Lockdown 1.0	**10**	6.3	5.4	6.3	7.0	6.2	6.4	6.8	5.2	4.7	4.4	6.2	4.9	4.3	4.0	**4.0**	5.1	9.0	7.9	7.6	7.5	7.7	-	6.2
Lockdown 2.0	**6.5**	5.5	5.3	5.5	5.6	6.2	5.8	4.1	4.2	**3.8**	4.1	5.7	5.2	4.3	6.4	5.4	5.4	6.0	6.0	-	-	-	-	5.3
Lockdown 3.0	5.8	5.2	6.4	**5.0**	5.3	5.3	5.8	6.6	6.3	**7.3**	6.3	7.3	5.7	6.0	-	-	-	-	-	-	-	-	-	6.0

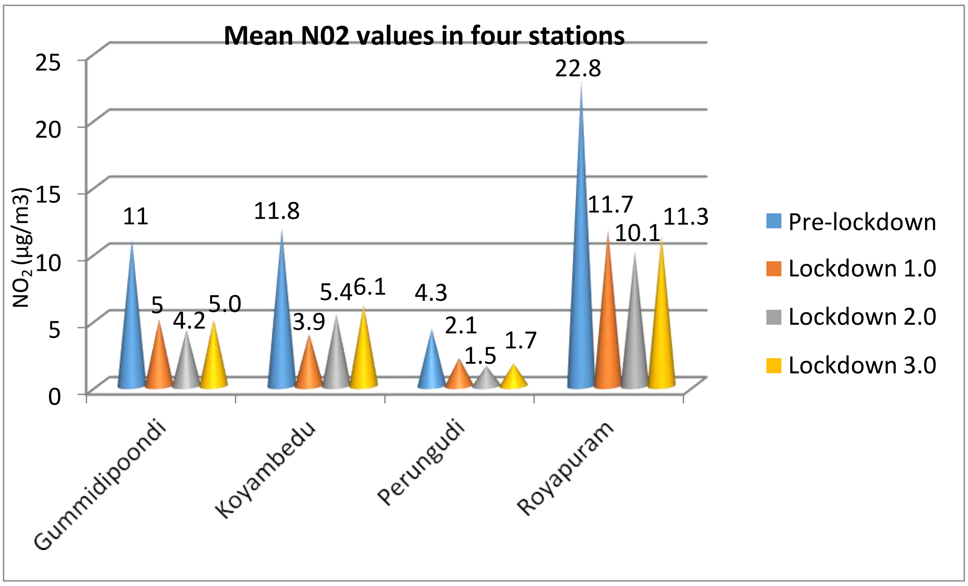


Fig 18: Station wise mean values of NO_2 during different lockdown periods

It has been seen that NO_2 concentration in all stations showed significant reduction in during the lockdown periods. Percent reduction in NO2 levels in ambient air with reference to pre-lockdown period in Gummidipoondi, Koyambedu, Perungudi and Royapuram stations during lockdown 2.0 was 61.8, 54.2, 65.1 and 55.7, respectively. However, all stations registered higher mean NO_2 value during 3.0 over the lockdown period 2.0, which is attributed to the relaxation.

Data on the average NO_2 values for the entire study period in all the four stations put together showed values of 12.5 6.2, 5.3 and 6.0 for the different periods. The lockdown 2.0 period registered the lowest average NO_2 value, as in the case of the other pollutant parameters. Reduction in NO_2 concentration was highest during lockdown 2.0 at 57.6 per cent of the pre- lockdown period (Fig 19). Reduction pattern in NO2 trend corroborates with the trend of values recorded for the AQI in different periods, with lockdown 2.0 registering the maximum reduction in average AQI.

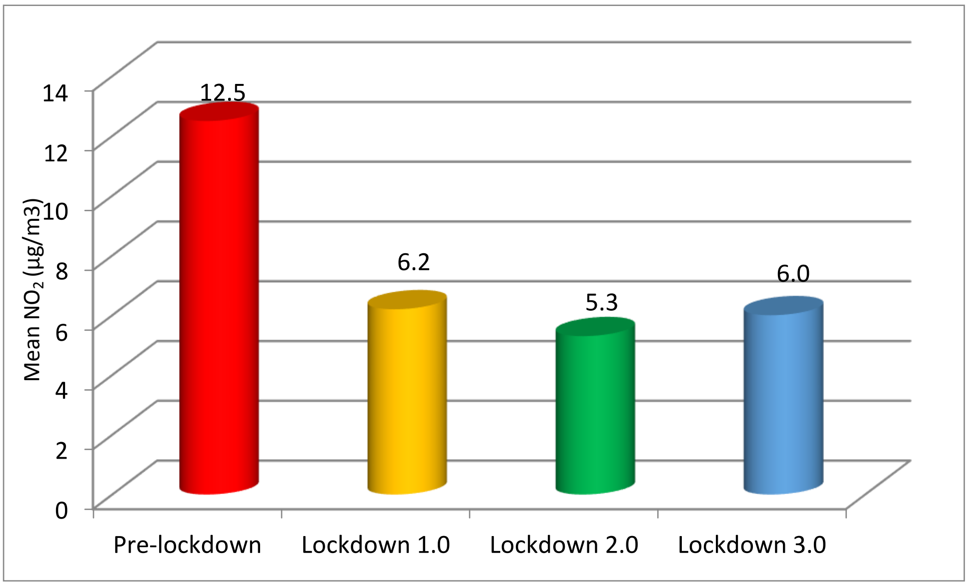


Fig 19: All stations mean NO_2 values during different periods

Comparison of Air quality in Chennai during April 2020 with that of April 2018 and 2018

One of the objectives of the present study is to assess the air quality of Chennai during April 2020 lockdown in comparison with air quality in the months of April 2018 and April 2019 so as to understand the impact of lockdown restrictions on air quality of Chennai and its surroundings. Average of daily values of AQI in the seven monitoring stations during the April month in the years 2018, 2019 and 2020 have been arrived at and furnished in Table 15. Based on the AQI value, relevant colour coding has been also assigned to the individual data point for each day.

Results reveal distinct pattern of air quality during lockdown month of April 2020 as compared to the corresponding periods during 2018 and 2019 (Table 15).

Table 15 : Mean daily AQI for seven CAAQM stations during April 2018, 2019 and 2020

Date	Apr-18	Apr-19	Apr-20
1	70.2	93.2	57
2	59.8	84.6	57.1
3	53.8	85.9	51.4
4	68	57	43.9
5	75.7	62.4	37.9
6	92.5	59.7	30.4
7	63.5	57.6	27.4
8	54.5	59.2	28.6
9	56.5	63.6	28.1
10	48.3	61	35.8
11	52.2	62.8	32
12	51.2	62.9	30.1
13	51.2	60.6	35.6
14	43.2	46.9	36.6
15	34.2	61.5	31.9
16	40.5	63	33.1
17	47.3	58.1	26.1
18	45.8	34.2	25
19	61.2	38.8	25.3
20	56.2	49	21.9
21	53.3	47.6	27.9
22	47.2	43.6	25.7
23	60.7	55.9	24.7
24	64.3	69.3	26.5
25	68.3	76.6	31.9
26	59.2	65.3	31
27	57.8	58.4	28.9
28	49.8	51.3	26.1
29	43.8	50.3	27.7
30	60	71.1	33.3
Mean	56.6	60.7	33

Of the total number of 30 days in April for which data were obtained from the seven stations, average AQI values showed Satisfactory air quality status for 21, 24 and 3 days during 2018, 2019 and 2020, respectively. Air Quality Index registered Good category for 9, 6 and 27 days for the corresponding years (Fig 20).

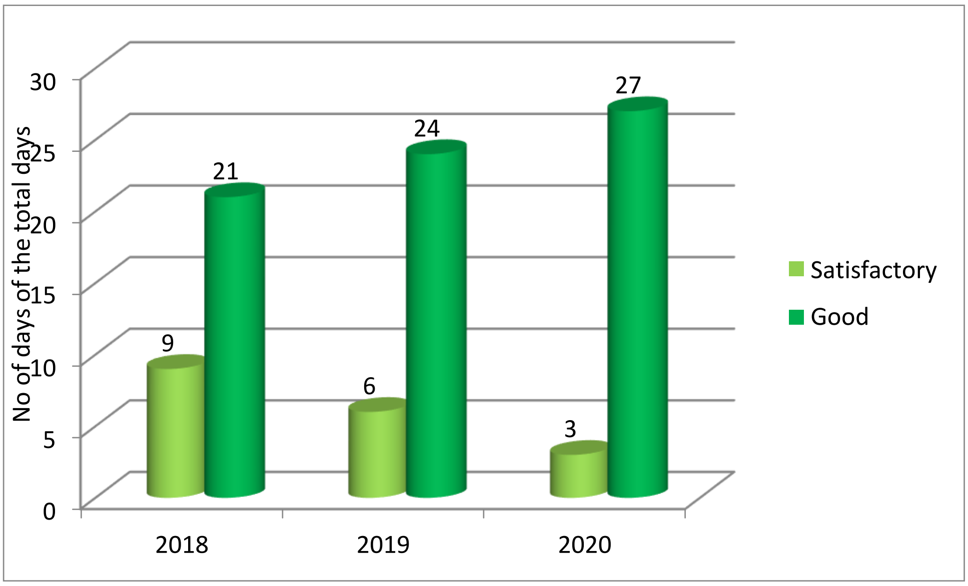


Fig 20: Status of average air quality during April 2018, 2019 and 2020

The daily mean AQI values of all the seven stations are in Fig 21.

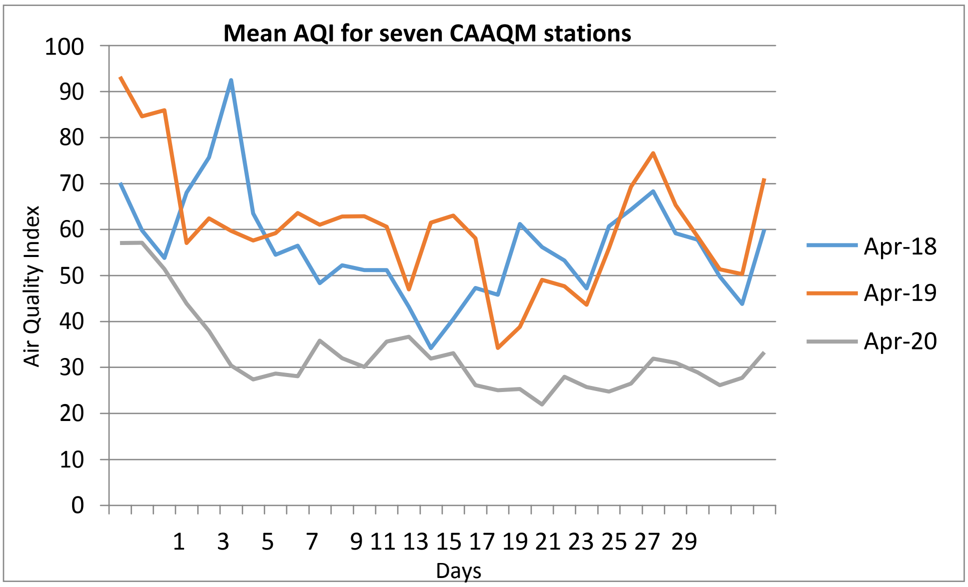


Fig 21: Daily mean average of AQI for the seven stations

Data reveal that average AQI values of all the days in lockdown period (April 2020) were lower than that of the corresponding days during 2018 and 2019. The trend indicates significant improvement in the air quality of Chennai due to lockdown measures.

An analysis of mean AQI values for the month of April 2020 for the individual monitoring stations was made and compared with the corresponding mean values for the months of April 2018 and April 2019.

Results are presented in Table 16 and Fig 22. It is noticed that in each of the seven sites, mean AQI values were significantly lower during 2020 as compared to that of 2018 and 2019. When the results of combined mean values of 2018 and 2019 with that of 2020 were studied, it is observed that drop for all stations worked out to 44.0 per cent. However, different monitoring stations registered reduction in AQI values ranging from a low of 33.0 per cent (Royapuram) to a maximum of 58.9 per cent (Alandur). The entire month of April 2020 covers part of lockdown 1.0 and lockdown 2.0 periods. AQI values in the CAAQM stations at both the industrial sites viz., Manali and Gummidipoondi during 2020 were almost half of what it was in 2018 and 2019 (51.7 and 52.0 per cent, respectively). Results show that the improvement in air quality was felt more significantly in industrial areas and traffic intersection due to complete shutdown of industries and total ban on heavy vehicle movement along the highways in the city. Koyambedu station recorded relatively less reduction in mean AQI (44.6 per cent) probably because the Koyambedu wholesale market continued to receive vegetable, fruit and flower laden trucks through the entire April 2020.The market was shut down towards first week of May, when it got temporarily shifted to Tirumazhisai, another satellite location of Chennai. Likewise, relatively lesser drop in mean AQI in Velachery, Perungudi and Royapuram was more likely because these areas represent residential or mixed residential and some incidence of high density local automobile movement (of two wheelers and cars) continued despite lockdown restrictions (Table 16).

Table 16: Reduction of average AQI values in seven CAAQM stations during April 2020

Month/Year	Alandur	Velachery	Manali	Gummudipoondi	Koyambedu	Perungudi	Royapuram	Mean
Apr-18	No data	56.3	77.3	75.1	48.2	43.3	39.3	56.6
Apr-19	57.0	82.1	79.5	80.5	49.5	40.5	35.8	60.7
Apr-18 and -19 average	57.0	69.2	78.4	77.8	48.9	41.9	37.6	58.9
Apr-20	28.0	38.0	37.9	37.4	27.1	26.3	25.2	33.0
% reduction in Apr-20	58.9	45.1	51.7	52.0	44.6	37.2	33.0	44.0

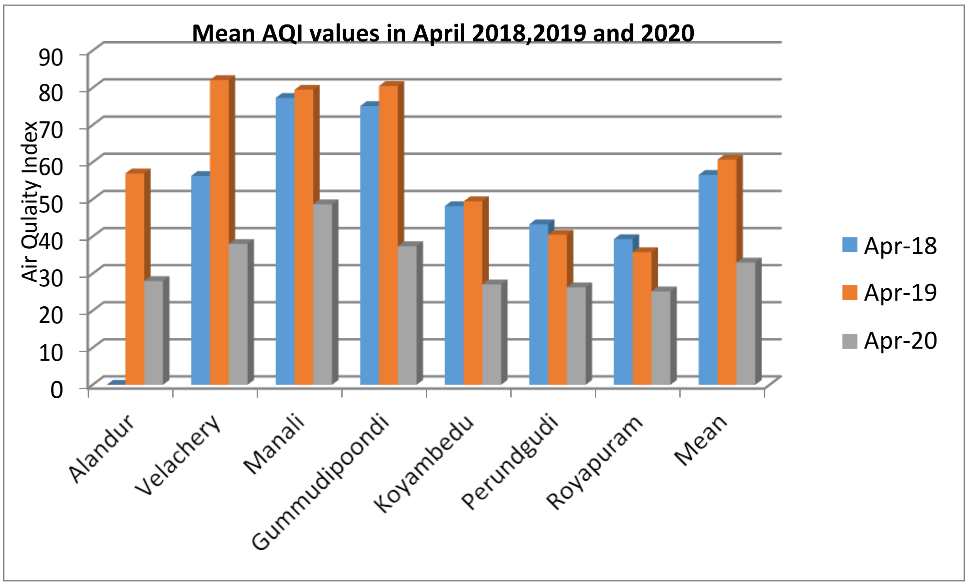


Fig 22: Mean AQI in individual stations during April 2018, 2019 and 2020

Average of AQI data of all the seven stations for the month of April 2018, 2019 and 2020 were worked out and presented in Fig . The AQI values for the years 2018, 2019 and 2020 were 56.6, 60.7 and 33.0, respectively (Fig 23). It is inferred that part of lockdown regime 1.0 (1^{st} April to 14^{th} April 2020 and part of lockdown 2.0 period (15^{th} April to 30^{th} April 2020) cumulatively accounted for considerable drop in the AQI value, bringing the overall average air quality to Good category in 2020 as compared to 2018 and 2019, when the average air quality for April registered Satisfactory quality.

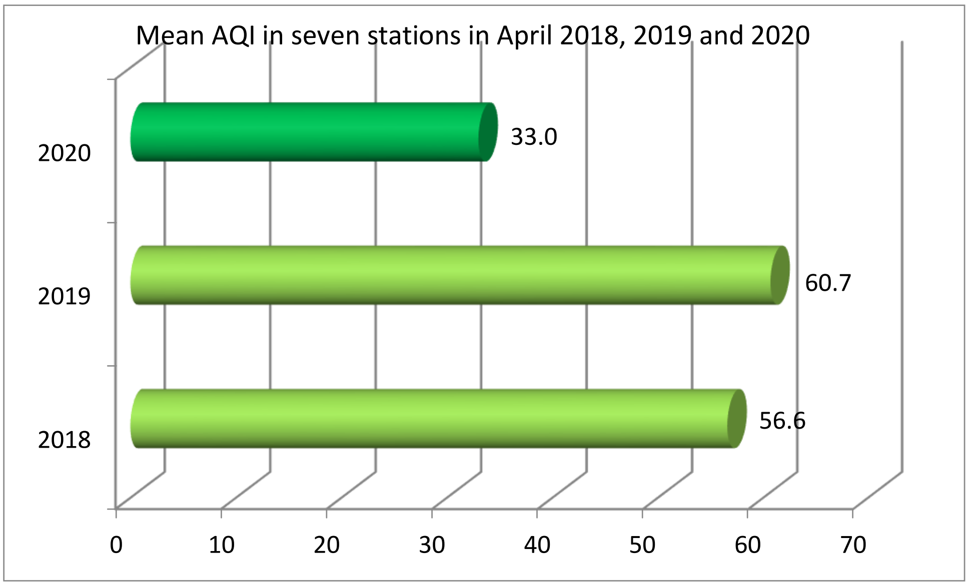


Fig 23: Mean AQI in seven stations in April 2018, 2019 and 2020

Impact of reduction in ambient AQI values on certain meteorological parameters

Results on the improvement of different meteorological parameters viz., solar radiation (Watt/metre^2), Dry adiabatic lapse rate (^{0} C/ 1000 metre), temperature inversion height (metre-m), sea breeze strength (miles per hour-mph) and wind speed (miles per hour-mph) during 1st - 21st April 2020 as compared to the relevant figures during the corresponding days of 2018 and 2019 are computed and presented in the following paras.

a) Solar Radiation

The measurement of solar radiation is being done at atmosphere (6 - 10m height) using a Pyranometer and is expressed in Wm-2 (Watt/square meter).

As the radiation propagates downwards, about 20% (67 Wm–2) is absorbed by the atmosphere, warming it, while 23% (77 Wm–2) is scattered and reflected back to space from the air, clouds and aerosols, 58% (198 Wm–2) arriving at the surface. The top of Atmosphere (TOA) solar radiation is a function of absorbed Solar Radiation (ASR) and Outgoing Long Wave Radiation (OLR) and is represented in the following formula.

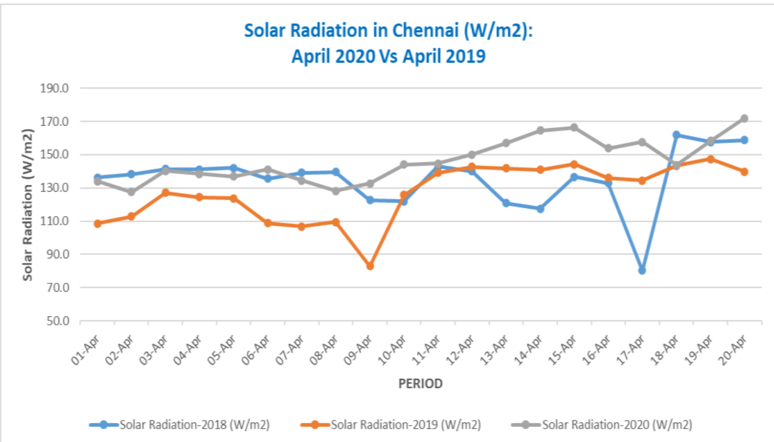
Top of Atmosphere (TOA) Solar Radiation = Absorbed Solar Radiation (ASR) - Outgoing Long wave Radiation (OLR)

In general, higher solar radiation into the land surface leads to increase in the land temperature because of which density and pressure will be reduced. Presently due to lockdown the greenhouse gases mainly CO_2 are reduced drastically (no combustion sources and biological processes) and density of greenhouse gases reduced. As greenhouse gases, including carbon dioxide decrease in the atmosphere, the decrease in radiative forcing results in lesser surface temperatures, decreased water-holding capacity of the atmosphere, decreased evaporation, and lesser water vapour amounts. As water vapour is the dominant greenhouse gas, it results in a decreasing the surface temperature change.

In this condition, the absorbed solar radiation (ASR) in the day time is perfectly reflecting (OLR) back to the atmosphere in the night time. Absorption and refection of solar radiation occurring as natural cycle without much resistance from greenhouse gases since it has been reduced due to lockdown. Solar Radiation during April 2018 is 135.4, April 2019 is 127 W/m^2 whereas on April 2020 is 146W/m^2. (Table 17 and Fig 24)

Table 17 and Fig 24: Solar Radiation

SOLAR RADIATION : CHENNAI			
Date	Solar Radiation-2018 (W/m2)	Solar Radiation-2019 (W/m2)	Solar Radiation-2020 (W/m2)
01-Apr	136.3	108.7	134.1
02-Apr	138.3	112.8	127.7
03-Apr	141.4	127.1	140.2
04-Apr	141.2	124.4	138.5
05-Apr	142.2	123.7	137.0
06-Apr	135.5	108.8	141.2
07-Apr	139.2	106.9	134.5
08-Apr	139.6	109.4	128.2
09-Apr	122.7	82.9	132.6
10-Apr	122.0	125.7	144.1
11-Apr	143.0	139.1	144.6
12-Apr	140.0	142.8	150.1
13-Apr	120.9	141.9	157.0
14-Apr	117.6	141.0	164.6
15-Apr	136.7	144.3	166.4
16-Apr	132.8	136.0	153.9
17-Apr	80.2	134.4	157.6
18-Apr	162.0	143.4	143.8
19-Apr	157.6	147.4	158.4
20-Apr	158.9	139.9	172.0
Mean	**135.4**	**127.03**	**146.23**



b) Dry Adiabatic Lapse Rate

The dry adiabatic lapse rate has been calculated based on the elevation temperature and balloon temperature. It represents the fall in temperature with rise in every 1000 metre and expressed as ^{o}C per 1000m.

Dry adiabatic lapse rate obtained for the study period in April 2018 was 11.8^{o}C per 1000 m, where as it was 10.6^{o}C per 1000 m for April 2019. This has further reduced to 7.8^{o}C per 1000m during April 2020. The adiabatic lapse rate has been reduced by around 2.8^{o}C per 1000m (as compared to 2019) and 4.0^{o}C per 1000m (as compared to 2018). This drop in adiabatic lapse rate is because of reduction in greenhouse gases due to COVID-19 lockdown during April 2020 (Table 18 and Fig 25). Hence the proposition that increasing CO_2 levels will increase the temperature all the way down to the surface.

The average lapse rate of temperature in the lower atmosphere is 0.6 to 0.7 °C per 100 metres, which now exists based on the calculated lapse rate during lockdown period. Lower temperatures prevail with increasing height above sea level for two reasons: (1) because there is a less favourable radiation balance in the free air, and (2) because rising air—whether lifted by convection currents above a relatively warm surface undergoes a reduction of temperature associated with its expansion as the pressure of the overlying atmosphere declines. Because of these effects the adiabatic Lapse Rate during April 2019 is 1.06^{o}C per 100m.

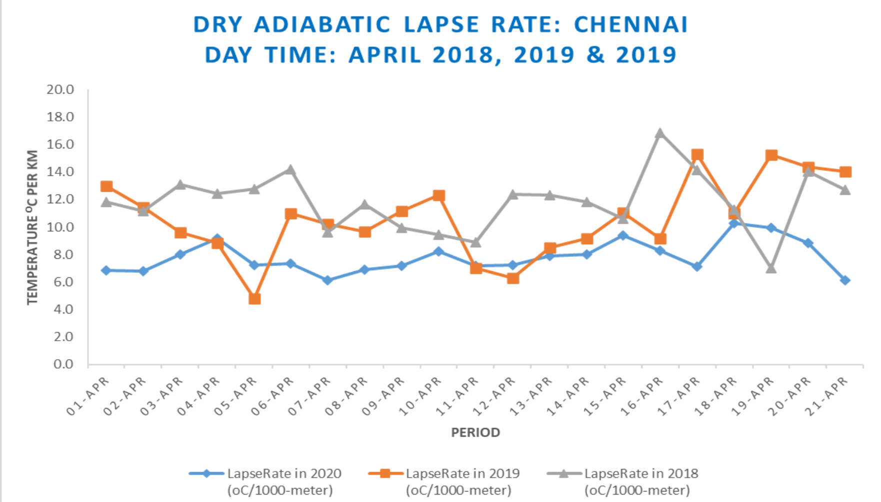
c) Temperature Inversion

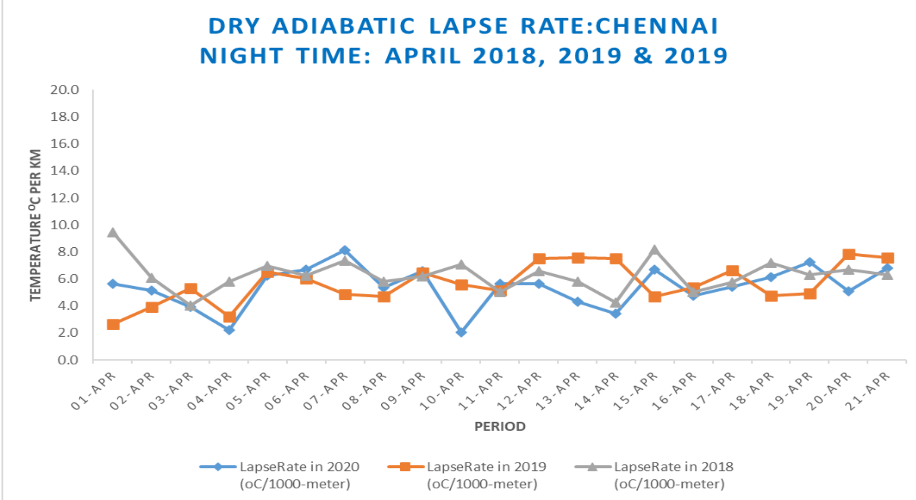
Thermal inversions, atmospheric stability, and mixed layer height are probably the most important meteorological conditions controlling atmospheric pollution dispersion. The inversion is based on the amount of outgoing long-wave radiation.

Lesser the Greenhouse gases is likely to reduce the energy to be trapped near the surface. This is an indication that decreases in surface

DRY ADIABATIC LAPSE RATE - DAY TIME : CHENNAI			
Date	**LapseRate in 2020 (oC/1000-meter)**	**LapseRate in 2019 (oC/1000-meter)**	**LapseRate in 2018 (oC/1000-meter)**
01-Apr	6.9	13.0	11.8
02-Apr	6.8	11.5	11.1
03-Apr	8.0	9.6	13.1
04-Apr	9.2	8.8	12.4
05-Apr	7.3	4.8	12.7
06-Apr	7.4	11.0	14.2
07-Apr	6.2	10.2	9.6
08-Apr	6.9	9.7	11.7
09-Apr	7.2	11.2	10.0
10-Apr	8.2	12.3	9.4
11-Apr	7.2	7.0	8.9
12-Apr	7.2	6.3	12.4
13-Apr	7.9	8.5	12.3
14-Apr	8.0	9.2	11.8
15-Apr	9.4	11.0	10.6
16-Apr	8.3	9.2	16.8
17-Apr	7.1	15.3	14.1
18-Apr	10.3	11.0	11.2
19-Apr	9.9	15.3	7.0
20-Apr	8.8	14.4	14.0
21-Apr	6.1	14.1	12.7
Mean	**7.8**	**10.6**	**11.8**
Variance	**1.2**	**7.2**	**4.2**
Std. Deviation	**1.7**	**2.7**	**2.5**

DRY ADIABATIC LAPSE RATE - NIGHT TIME: CHENNAI			
Date	**LapseRate in 2020 (oC/1000-meter)**	**LapseRate in 2019 (oC/1000-meter)**	**LapseRate in 2018 (oC/1000-meter)**
01-Apr	5.7	2.7	9.5
02-Apr	5.1	3.9	6.1
03-Apr	3.9	5.3	4.0
04-Apr	2.2	3.2	5.8
05-Apr	6.3	6.5	7.0
06-Apr	6.7	6.0	6.2
07-Apr	8.1	4.9	7.3
08-Apr	5.4	4.7	5.8
09-Apr	6.6	6.5	6.2
10-Apr	2.1	5.6	7.1
11-Apr	5.6	5.2	5.0
12-Apr	5.7	7.5	6.6
13-Apr	4.3	7.5	5.8
14-Apr	3.4	7.5	4.3
15-Apr	6.7	4.7	8.2
16-Apr	4.8	5.3	5.0
17-Apr	5.4	6.6	5.7
18-Apr	6.1	4.8	7.2
19-Apr	7.3	4.9	6.3
20-Apr	5.1	7.8	6.7
21-Apr	6.8	7.6	6.3
Mean	**5.4**	**5.7**	**6.3**
Variance	**2.2**	**2.0**	**1.4**
Std Deviation	**1.6**	**1.6**	**1.5**



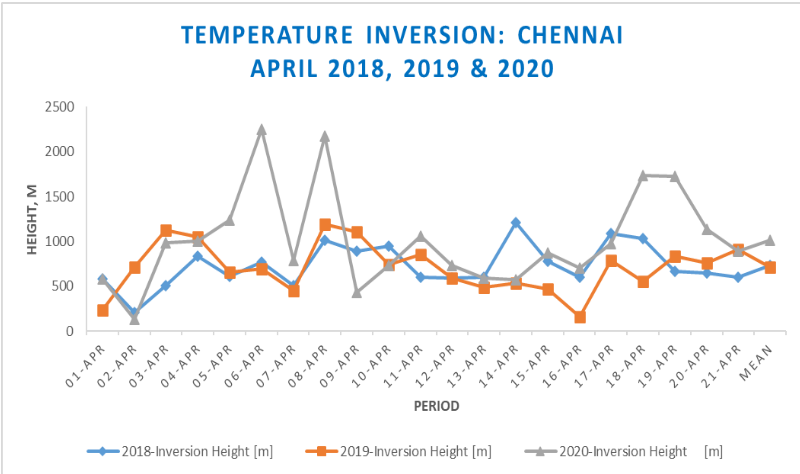


temperatures cause an increase in the inversion layer. So climate changes can be linked to the characteristics of the inversion layer.

The average temperature inversion during April 2018 was 727.3 m, during April 2019 it was 708.5 m, whereas due to lockdown the temperature inversion during April 2020 was 1014 m (Table 19 Fig 26). A strong and low height inversion will lead to high pollutant levels, while a weak inversion will lead to lower levels. This clearly indicates that the decrease in greenhouse gases reduces trapping energy and increases temperature inversion. Higher temperature inversion will reduce atmospheric pollution due to the trapping at higher altitude.

Table 19 and Fig 26: Temperature Inversion

TEMPERATURE INVERSION : CHENNAI			
Date	2018-Inversion Height [m]	2019-Inversion Height [m]	2020-Inversion Height [m]
01-Apr	583.5	233.5	580.5
02-Apr	206	713.5	127.5
03-Apr	508	1123	985.4
04-Apr	835.5	1047.5	998.5
05-Apr	613	660	1240
06-Apr	768	690	2254.5
07-Apr	503.8	450.5	789.5
08-Apr	1013	1190.5	2174.5
09-Apr	888.5	1103	427
10-Apr	949	736.5	732.5
11-Apr	599	857	1055.5
12-Apr	591.5	591.5	735
13-Apr	602.5	488.5	593
14-Apr	1207	532	568.5
15-Apr	776.4	464.5	875
16-Apr	597.5	158	703.5
17-Apr	1086	787	971
18-Apr	1034.5	555	1735
19-Apr	666.5	833.5	1729.5
20-Apr	645.5	756.5	1131
21-Apr	598.5	908	886.5
Mean	727.27	708.54	1013.97

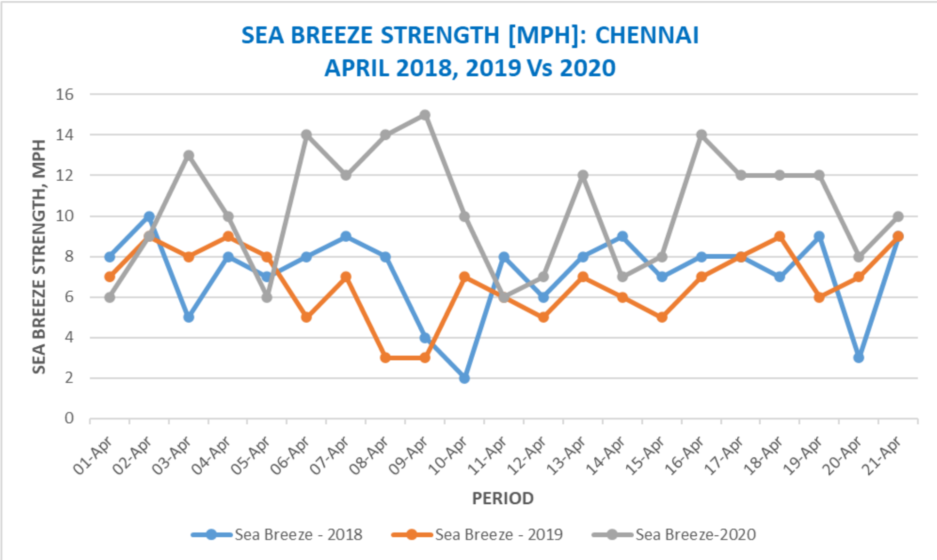


d) Sea Breeze Strength

The strength of the sea breeze is directly proportional to the temperature difference between the land and the sea. The presence and strength of high-level inversions play an important role in the higher strength of the sea breeze circulation. A higher inversion tends to increase the vertical extent of the heating to a shallow layer, which increases the strength of the sea breeze. The Sea breeze strength during April 2018 and April 2018 were 7.2 and 6.7 mph, respectively. The same in April 2020 (during lockdown period) was 10.3mph. Increase in the sea breeze strength is due to increase in surface temperature, higher inversion, vertical mixing and wind speed (Table 20, Fig 27).

Table 20 and Fig 27: Sea Breeze strength

SEA BREEZE STRENGTH [MPH]: CHENNAI			
Date	Sea Breeze - 2018	Sea Breeze - 2019	Sea Breeze- 2020
01-Apr	8	7	6
02-Apr	10	9	9
03-Apr	5	8	13
04-Apr	8	9	10
05-Apr	7	8	6
06-Apr	8	5	14
07-Apr	9	7	12
08-Apr	8	3	14
09-Apr	4	3	15
10-Apr	2	7	10
11-Apr	8	6	6
12-Apr	6	5	7
13-Apr	8	7	12
14-Apr	9	6	7
15-Apr	7	5	8
16-Apr	8	7	14
17-Apr	8	8	12
18-Apr	7	9	12
19-Apr	9	6	12
20-Apr	3	7	8
21-Apr	9	9	10
Mean	7.2	6.7	10.3

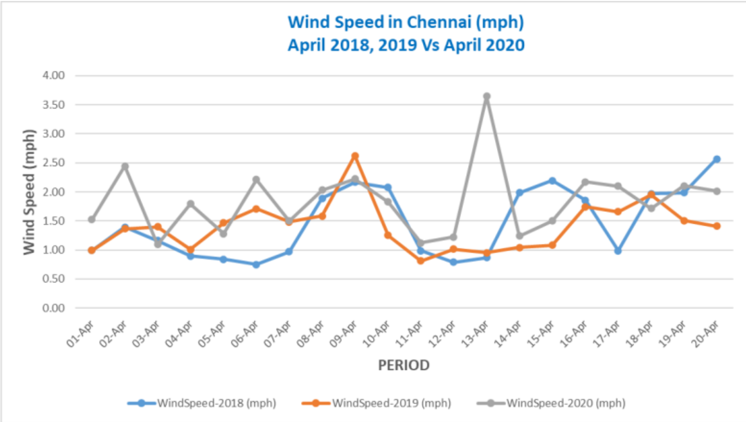


e) Wind Speed

Surface friction plays an important role in the speed and direction of surface winds. Due to increase in the solar radiation the surface temperature increases in the day time and reflecting back the absorbed solar radiation in the night time so the land is cooling up. The average wind speed during April 2018 was 1.47 mph, was 1.40mph during April 2019, whereas during April 2020 the average wind speed was 1.84mph. The wind speed has been increased 24% when compared to April 2018 and April 2019 (Table 21 Fig 28).

Table 21 and Fig 28: Wind Speed

WIND SPEED COMPARISON			
Date	WindSpeed-2018 (mph)	WindSpeed-2019 (mph)	WindSpeed-2020 (mph)
01-Apr	0.99	0.99	1.52
02-Apr	1.39	1.36	2.44
03-Apr	1.16	1.40	1.09
04-Apr	0.90	1.01	1.79
05-Apr	0.84	1.47	1.28
06-Apr	0.75	1.71	2.21
07-Apr	0.97	1.49	1.50
08-Apr	1.89	1.59	2.03
09-Apr	2.17	2.62	2.22
10-Apr	2.07	1.25	1.83
11-Apr	0.99	0.81	1.12
12-Apr	0.79	1.01	1.22
13-Apr	0.87	0.95	3.64
14-Apr	1.99	1.04	1.24
15-Apr	2.20	1.08	1.50
16-Apr	1.85	1.74	2.17
17-Apr	0.98	1.66	2.10
18-Apr	1.97	1.95	1.71
19-Apr	1.98	1.51	2.10
20-Apr	2.57	1.41	2.01
Mean	**1.47**	**1.40**	**1.84**



To corroborate the changes in the meteorological data during the part of lockdown regime in April 2020 in comparison to 2018 and 2019 as a consequence of apparent reduction in various green house gases in the ambient air of Chennai and surroundings, AQI for the period 1st April to 21st April of 2018, 2019 and 2020 for all the seven monitoring stations have been taken for analysis. Daily average AQI data for the seven stations are presented in Fig 29.

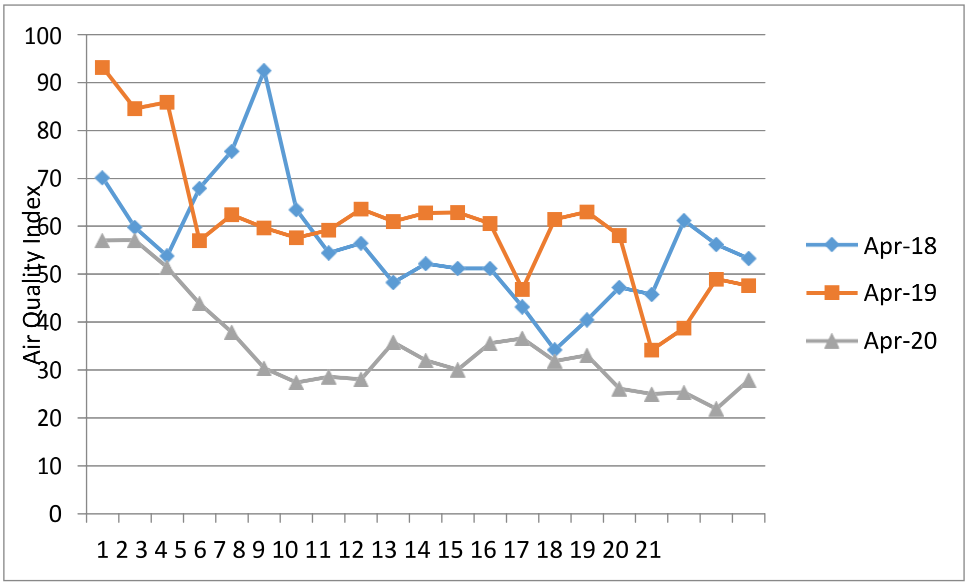


Fig 29: Average AQI in Chennai during 1st April-21st April 2018, 2019 and 2020

It is seen that the average AQI for all the dates of 2020 were considerably lower during 2020 as compared to 2019 and 2020. This trend is also reflected in the reduction of most of the monitored green house gases during the lockdown period as explained elsewhere in the study report.

The mean of AQI values for the entire period of 21 days in all the seven stations for the three years is presented in Fig 30.

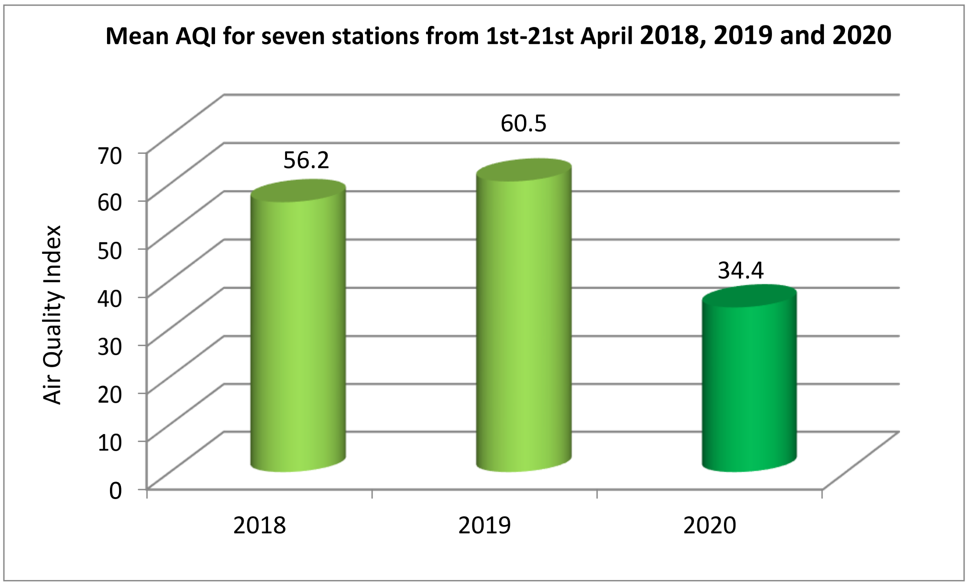


Fig 30: Mean AQI values during 1st-21st April 2018, 2019 and 2020

The values were 56.2, 60.5 and 34.4, respectively during 2018, 2019 and 2020. This suggests that there was 38.8 and 43.1 per cent drop in AQI during 2020, when compared with the index of 2018 and 2019, respectively. It is inferred that the lockdown brought in substantial reduction in the air emission and consequent reduction in various air pollutants.

Discussion and Summary

AQI of different categories have varying health implications. Higher the index, severer are the associated health impacts for the people exposed to the polluted air. While Good category represents the best air quality with minimal health concern, the severe category could affect even healthy people and seriously impact those with existing diseases. As the worst among the AQ sub-index of monitored pollutants determines the value of AQI, both the contributing air pollutants and the AQ index are relevant. Moreover, the short-term (up to 24 hours) and annual National Ambient Air Quality Standards are prescribed for the individual air pollutants only. Therefore, conformity to or exceedence of the ambient concentrations of individual pollutant over the prescribed standard for the same assumes importance.

Present study showed substantial improvements in air quality in Chennai City and its surroundings, which is reflected in significant drop in the mean AQI values of the seven stations. The AQI fell sharply from 61.5 during the pre-lockdown to 42.3 and 29.5, 34.3, respectively for the three lockdown periods 1.0, 2.0 and 3.0. Fall in the values of AQI represent nearly one third (31.2 per cent), half (52 per cent) and 44.2 per cent during these lockdown versions. Certain relaxations in the form of recomissioning of industrial, commercial and trade activities and associated transport regulations might have caused the marginal increase in AQI during the lockdown 3.0.

Analysis of the quality of air indicated that before the lockdown was imposed average AQI was good (0-50 AQI) in Perungudi and Royapuram stations only, while the same for the other five stations was in the satisfactory category (51-100 AQI). The quality has improved to Good status in Alandur, Velachery, Koyambedu stations during lockdown 1.0 period itself, while the AQI in both the industrial sites viz., Gummidipoondi and Manali continued to be in Satisfactory status. This was probably due to continuance of certain industrial activities that were exempted from lockdown in these industrial estates. However, the AQI values of all seven station values moved to Good category during lockdown 2.0 and lockdown 3.0.

While on an average 37.4 per cent days only registered Good category AQI during pre-lockdown period, this status increased to 78.6 per cent of days during the lockdown 1.0 and 94.7 per cent of days during lockdown 2.0. This improvement suggests that the people got adapted to various activity restrictions and regulatory measures imposed by the Government like ban on inter-district movement of people for routine reasons, complete 'off the road' status of high-emission sources like buses, trucks and vans, stringent implementation of the ban on movement of private cars, taxis, auto rickshaws, two wheelers etc., thus resulting in overall reduction in the use of petro products in the transportation sector. As lockdown 3.0 witnessed certain relaxations in movement of people through various activities, 92.9 per cent of the days recorded Good air quality status.

At many places voluntary compliance to curfew prohibitory orders were not forthcoming. Most of them related to local movement of individuals in two wheelers in connection with purchase of daily needs. Police force has been rigidly enforcing the prohibitory orders during the

lockdown period throughout the State. Many people found violating the regulatory measures on movement of vehicles were imposed with fine and seizure of vehicles besides novel methods of punishment. A total number of 5.53 lakh violators had been booked in 5.18 lakh cases, involving the seizure of 4.33 vehicles across the State up to 30th May 2020. In this period, Chennai City police alone booked 85,000 cases.[14]

Despite enforcement, certain location specific violation of lockdown compliance is evident. Based on their work on mobility data mapped from face book users and then integrating with data from the crowd sourced portal of covid19 india.org since March 22, a team of researchers from IIT Madras showed how the lockdown was witnessing increased mobility, particularly in Chennai especially during weekends. For instance, on the 4th May 2020 i.e the first day of lockdown 3.0, report showed a 17 per cent increase in mobility in the State compared to during April 26-29 lockdown. Increase in mobility was observed during weekends, particularly in Chennai, Kancheepuram and Tiruvallur. The report also noted that overall mobility has increased in lockdown 3.0.[17]

Similarly, a comparison of the AQI values in the seven stations for the month of April during the years 2018, 2019 (normal months) and 2020 (lockdown month) revealed that the average AQI for all the stations were 56.6, 60.7 and 33.0, respectively during 2018, 2019 and 2020. This indicates a drop of about 41.7 per cent and 45.6 per cent in AQI values during April 2020 as compared to corresponding month of 2018 and 2019, respectively. Such reduction in AQI is quite explainable as the consumption of different petro products registered considerable slump during April 2020 due to drop in their demand.

Lockdown regimes 1.0 and 2.0 witnessed near total cessation of air traffic flow and railway transport except cargo, complete shutdown of public transport services like buses, sub-urban electric trains, metro trains, autos and taxis, substantial reduction in volume of private cars and two wheelers.

In the industrial sector as well, other than essential category units, the rest were shut down. All these restrictions have in turn brought down the demand for different petro products during the lockdown periods, particularly 1.0 and 2.0. In this regard, a comparison between consumption of various petroleum products for the months of March, April 2019 and the corresponding months of 2020 has been made. Results are in Table 22.

Table 22: Petroleum products consumption during lockdown period[10]

Petroleum products	**Consumption in million metric tones**			
	March 2019	**March 2020**	**April 2019**	**April 2020**
LPG	2262	2306	1900	2132
Naptha	1198	1386	949	859
MS (Petrol)	2578	2156	2459	973
ATF	716	484	645	56
SKO	291	152	254	129
HSD	7459	5651	7323	3250
LDO	46	49	45	28
Lubricants & Greases	455	296	255	212
FO & LSHS	538	482	499	297
Bitumen	890	525	691	196
Petroleum coke	2160	1680	2254	1135
Others	972	917	1045	662
Total	19564	16083	18320	9929

**Source:* https://www.ppac.gov.in

Analysis revealed that certain drop in demand has been noticed during March 2020, as compared to the same month of 2019. Per cent reduction of petroleum products consumption between March 2019 and March 2020 was 17.8 per cent. It is understandable, as the country faced seven days of lockdown in March 2020. Between March 2020 and April 2020, the country consumed 38.3 less petro products, as the nation was under lockdown during entire month of April 2020. India consumed only about 54.2 per cent of the quantity of petroleum products during April 2020, as compared to the quantity in the same month the previous year, indicating a drop in demand for petro products to almost half. In the category of Motor Sprit (MS) and High Speed Diesel (HSD), which are among the mass consuming items in surface transport sector and industrial sector, reduction was 61.4 and 55.4 per cent, respectively between April 2019 and 2020, thus representing substantial control in the movement of vehicles and reduced operation of industries (Fig 31). Diesel finds its use in agricultural sector and in generators that kept up its demand in comparison to petrol.

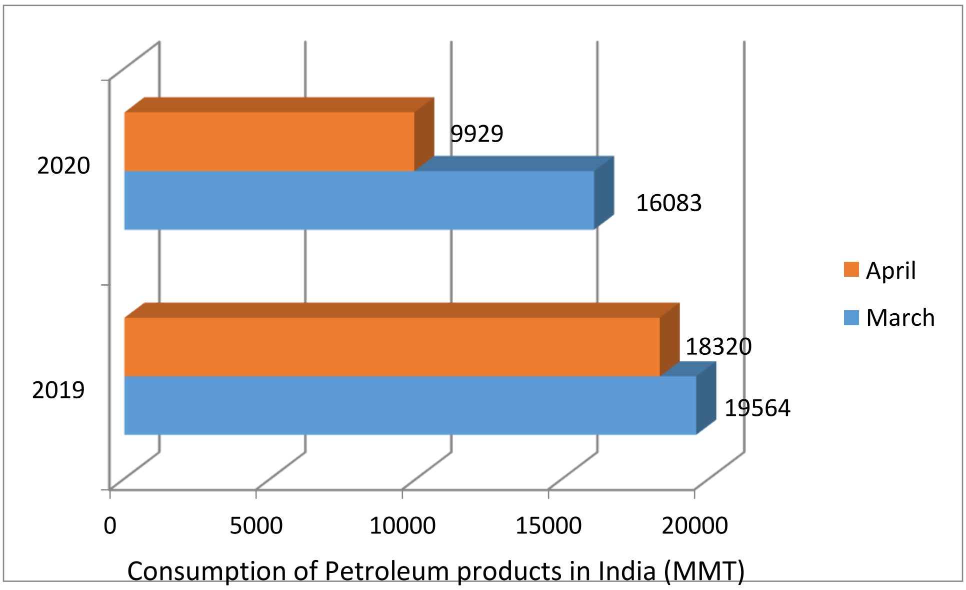


Fig 31: Consumption of petroleum products during March, April 2019 and 2020

This trend is corroborated by the sale figures of the State retailers' viz., Indian Oil Corporation, Hindustan Petroleum Corporation and Bharat Petroleum, who own 90 per cent of the retail fuel outlets in the country.

Cumulatively, they registered 61 per cent and 64 per cent decline in the sales of petrol and diesel, respectively in first half of April 2020 in comparison with the corresponding fortnight of 2019[5].

The lockdown measures have also resulted in significant reduction in the power demand in India. On the front of overall power consumption, there has been sizeable decrease in the consumption of electricity during the lockdown period. COVID 19 lockdown has seen 9 per cent drop in power consumption across the country between March 2019 and March 2020[15]. Power Ministry reported that the country's power consumption in April 2020 was 85.05 billion units (BU) as compared to 110.11 BU in the same month of 2019, a dip of 22.8 per cent, mainly due to lower commercial and industrial demands amid the lockdown to combat COVID-19[6].

With more number of commercial and industrial consumer connections, situation in Tamil Nadu was more pronounced than the national figure. For the month of March 2020, power demand in the State dropped by 14 per cent as compared to March 2019 with virtually no demand for power from industries and commercial establishments since 24 March lockdown. Tamil Nadu's power demand further crashed by 28.6 per cent in April 2020, as against corresponding month last year, largely due to decline in consumption by commercial and industrial consumers. According to data from the Central Electricity Authority, the State's peak demand slipped to 11,398 MW in April 2020 from 15,972 in the corresponding period last year.[15] In case of offices, the power demand during April lockdown fell by 40-50 per cent, when compared to last year as most employees were asked to work from home.

To match with the reduced power demand, electricity managers across the country had to cut down on the production front. Thus during the lockdown, power generation has been adjusted to compensate for reduced consumption. Most of this reduction in consumption has

been met by reduced coal power generation. Coal based power generation reduced from an average of 2,511 MU between March 1 and March 24 to 1,873 MU between March 25 and April 19, a fall of about 25 per cent. As a result, the contribution of coal in total power generation reduced from an average of 72.5 per cent to 65.6 per cent between these two periods[3]. Like in most other States, TANGEDCO has stopped electricity production in its thermal power stations.

Trends suggest that the reduction in consumption of petro-products and electricity and consequent drop in thermal power generation during the lockdown period has resulted in quantifiable improvement in air quality in Chennai. This has been reflected from the analysis of trends in the individual pollutant concentrations viz., PM_{10}, $PM_{2.5}$, SO_2 and NO_2 in the four stations of TNPCB. Of the four parameters, Particulate Matter (PM) is particle of fine solid or liquid suspended in a gas.

Summary of evaluation reveals that average PM_{10} data for all the four monitored stations showed values of 60.1, 38.8, 22.8 and 29.0 (microgram/m^3) for pre-lockdown, lockdown 1.0, 2.0 and 3.0 periods, respectively. The highest drop of 62 per cent in average PM_{10} was observed during lockdown 2.0 from the pre-lockdown values, which is in tune with the lowest AQI values in this period. As for the $PM_{2.5}$ data, whole period average values were 25.8, 19.2, 9.1 and 10.0 (microgram/m^3) for the corresponding periods. Again, lockdown regime 2.0 brought the maximum reduction of 64.7 per cent in average $PM_{2.5}$ from the pre-lockdown concentration. It is seen that $PM_{2.5}$ are emitted directly from sources like unpaved roads, construction sites, or fires and are formed in the atmosphere due to complex chemical reactions between oxides of nitrogen and sulphur that are emitted from sources like power plants, automobiles and industries. The overall two-third reduction of $PM_{2.5}$ levels during lockdown 2.0 in Koyambedu, Perungudi and Royapuram stations are most likely a result of halt in construction activities and vehicular traffic.

Average of SO_2 data for the whole study period in all the four stations put together showed values of 7.0, 4.2, 4.0 and 4.8 (microgram/m^3), respectively for the corresponding periods. Data on the average NO_2 values for the entire study period in all the four stations put together showed values of 12.5 6.2, 5.3 and 6.0 (microgram/m^3) for the different periods.

However, reduction in different pollutant concentrations during the various lockdown versions varied between different locations. For instance, highest reduction in PM_{10} was noticed in Gummudipoondi in both lockdown 1.0 and 2.0 and in Koyambedu during lockdown regime 2.0. This might have arisen due to substantial reduction in industrial and transport activities in these two stations. Likewise, of all stations Gummudipoondi recorded maximum drop of $PM_{2.5}$ in lockdown. Complete cessation of vehicle movement in the industrial estate and sub-urban areas of Gummidipoondi would have caused this variation.

Data revealed that maximum improvement in air quality in terms of SO_2 values is recorded in Koyambedu site in all the three lockdown periods. Shutdown of Chennai Metropolitan Bus Terminal (CMBT) and closure of the Koyambedu wholesale market complex might have been the drivers for the maximum improvement in air quality in terms of SO_2. It is seen from the data that there has been no significant reduction in SO_2 concentration in Perungudi station. In fact there has been minor increase in SO_2 values during lockdown 1.0, 2.0 and 3.0 as compared to pre-lockdown in Gummidipoondi, suggesting continuance of certain industrial activities in the SIPCOT estate. Percent reduction in NO_2 levels in ambient air with reference to pre-lockdown period in Gummidipoondi, Koyambedu, Perungudi and Royapuram stations did not however register much variation among the stations.

As a part of the study to ascertain the impact of lockdown in view of COVID-19 pandemic (25st March to 15th April 2020) on air quality trends over the pre-lockdown period (16th March to 21th March), CPCB analysed the data generated from continuous ambient air quality monitoring (CAAQM) network across the country. These included thirty-eight (38) stations in Delhi, four (4) stations each in the neighbouring major NCR towns i.e. Faridabad, Gurugram, Noida and Ghaziabad. Further, CAAQM data from a few major metropolitan cities viz., Mumbai and Bengaluru with ten (10) stations each, Kolkata with seven (7) stations, Chennai with four (4) stations, Indore with one (1) station and Patna with six (6) stations for the same period was studied. Analysis showed that the nationwide Lockdown in force since the midnight of 24th March has resulted in significant improvement in air quality in the country, as revealed by data analysis and comparison of data for the time before enforcement of restrictions.[4]

Overall, 46 per cent reduction in $PM_{2.5}$ and 50 per cent reduction in PM_{10}, 56 per cent reduction in NO_2 levels, 19 per cent reduction in SO_2 levels, 37 per cent drop in CO levels and 47 per cent reduction in Benzene levels were observed in Delhi during the lockdown period largely because of the restrictions on the two major emission sources, namely the transport sector and industrial operations. As transport sector contributes to 81 per cent of Delhi's NO_x (as per TERI Emission Inventory, 2018), maximum reduction in NO_2 levels during lockdown is understandable. However, only 19 per cent reduction was seen in SO_2 levels which might have been due to the fact that over 70 per cent of Delhi's SO_2 originates from power plants located around Delhi (as per TERI Emission Inventory, 2018) and power plants were operational during lockdown period.

The CPCB study also revealed that Chennai witnessed over 36 per cent reduction in $PM_{2.5}$, while the drop in SO_2, NO_2 and CO levels was around 43 per cent, 5 per cent and 29 per cent, respectively. Higher reduction in $PM_{2.5}$ and SO_2 is seemingly due to restriction on vehicular activities and reduced combustion activities.

Studies have reported that while transport sector is the prominent source for CO, industries contribute majorly to NO_x levels. Since two of the CAAQM stations studied by CPCB are located in Manali (one of CPCB and the other of TNPCB), Chennai, which is an industrial area having significant presence of chemical and petrochemical industries, it is possible that some of the industrial operations in the area that continued during lockdown period might have influenced lesser average per cent drop in NO_2 levels in Chennai.

The CPCB study compared a relatively shorter pre-lockdown period of six days with the lockdown 1.0 period of 22 days for the pollutant parameters and out of four stations studied by CPCB two are industrial sites. Hence the extent of variation in per cent reduction of various pollutant parameters is explainable. Present study involves computation of pollutant parameters for a longer pre-lockdown period of 23 days.

PM_{10} and $PM_{2.5}$ in ambient air comes from various sources, of which the contribution of industries, road dust re-suspension and transportation are the most significant. In case of SO_2 and NO_2, major sources are from industrial and transport emissions. In this connection, reference to the air quality study conducted by urbanemissions.info for Greater Chennai region for the year 2015 will be relevant. As per the study, Chennai region with a population of about 10 million has thirteen per cent of households owning a car and 47 per cent of households owning a motor cycle. Auto manufacturing centres in Chennai account for 30 per cent of India's auto industry in the country.

In the study, satellite data derived concentrations have been estimated using satellite feeds and global chemical transport models. In this method, a combination of satellites provide a cache of measurements that are interpreted using global chemical transport models (GEOS-Chem) to represent vertical mix of pollution and estimate ground-based concentrations with the help of previous ground based measurements. As per the study, annual PM 2.5 concentrations for Chennai district from 1998 to 2014 indicated that the values ranged between 24.5 (2012) and 37.1 microgram/m^3 (2000).

As a part of the study, air emission inventory for the Chennai region for SO_2, NO_x, CO, Non methane VOCs, CO_2 and PM was compiled for the year 2015 (Table 23). The emissions inventory was based on the local available activities and fuel consumption estimates for the Chennai urban air shed and has not included natural emissions like dust storms, lightning and seasonal open (agricultural and forest) fires.[16]

Table 23: Total Estimated emissions by sector in Chennai region for 2015

Sector/ Pollutant	**Units million tonnes/year for CO_2 and tons/year for the rest**					
	$PM_{2.5}$	**PM_{10}**	**SO_2**	**NO_x**	**CO**	**CO_2**
Transport*	11800	12400	1050	20,900	176750	5.40
Residence	1450	1450	450	1300	13750	1.53
Industry	65700	71600	23350	174900	81100	2.10
Dust	5750	37200	-	-	-	1.00
Waste	5100	5350	150	100	24450	0.03
DGST	800	850	50	7350	1950	0.33
BRIC	3450	3500	1550	2850	47550	0.37
Total	94050	132350	26600	207400	345550	9.76

*Transport-Transport emissions from road, rail, aviation and shipping; Residence- residential emissions from cooking, heating and lighting activities; Industry- Industrial emissions from small, medium and heavy industries including power generation; Dust- Dust emissions from road re-suspension and construction activities; Waste- Open waste burning emissions; DGST- Diesel generator set emissions; BRIC- Brick kiln emissions (not included in industrial emissions)

The top three sources for different air pollutants in the region is presented in Table 24.

Table 24: Major sources of air pollutants in Chennai region

Sl.No	Air pollutant	Major sources in the descending order
1	PM_{10}	Industry, Dust, Transport
2	$PM_{2.5}$	Industry, Transport, Dust
3	SO_2	Industry, Brick kilns, Transport
4	NO_x	Industry, Transport, Diesel Generator sets
5	CO	Transport, Industry, Brick kilns
6	CO2	Transport, Industry, Residence

From the study, it becomes clear that the industry, transport and dust that include dust emissions from road re-suspension and construction activities are the chief sources of particulate matter, both PM_{10} and PM $_{2.5}$. SO_2 is contributed by industry, transport and brick kilns, while NO_x is accounted for by industry, transport and Diesel Generator sets. Carbon monoxide is chiefly contributed by transportation, industry and brick kiln sectors as they involve primarily fuel combustion activities.

Drawing inference from the above study report, the significant reduction in all four pollutant parameters in the four monitored stations due to lockdown can be attributed to total cessation or partial cut in the above emission generating activities. CPCB has fixed 24 hour and annual standards for different air pollutants, considering the health implications from short term and long-term exposure to specific pollutant (Table 25)[8].

Table 25: Ambient permissible standards for air pollutants

Pollutant	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural and Other Area	Ecologically Sensitive Area (notified by Central Government)*
Sulphur Dioxide (SO_2), $\mu g/m^3$	Annual	50	20
	24 hours	80	80
Nitrogen Dioxide (NO_2), $\mu g/m^3$	Annual	40	30
	24 hours	80	80

Particulate Matter (size less than 10 µm) or PM_{10} µg/m^3	Annual	60	60
	24 hours	100	100
Particulate Matter (size less than 2.5µm) or $PM_{2.5}$ µg/m^3	Annual	40	40
	24 hours	60	60

*None of the studied site falls in this category

The study also indicated that concentration of the above four air pollutants in Chennai area were well below the time weighted average standards prescribed under the National Ambient Air Quality Standards.

Way Forward

COVID-19 lockdown and its impact on ambient air quality across the nation's cities and towns have many lessons to offer us. Firstly, the shutdown of various economic activities coupled with different intensities of relaxation during various versions of the lockdown regime help the analysts to pinpoint as to what are the sources of the consortia of air pollutants. The lockdown episodes have become an important opportunity to identify the key drivers of air pollution in regional air sheds. However, the gradual reversal of the improvement in air quality status with each progressive lockdown only compels the experts to feel that the clean air phase in the country might be short lived and temporary. They argue that once the environmental restrictions are loosened to bounce back from the COVID 19 related economic losses, achieving better air quality will become tougher than ever.

Secondly and most importantly, scientists will have to inevitably seize the curfew window to understand the background levels of air pollutants when the emissions from the most important sectors including transport, industry and construction have significantly decreased. Thirdly, it is common knowledge that poor air quality makes the people vulnerable to respiratory diseases like the one caused by COVID-19. Some of the underlying conditions like asthma, Chronic Obstructive Pulmonary

Disease (COPD) that make certain people high risk to corona virus complications are caused or made worse by exposure to air pollution. Poor air quality increases societal vulnerability in many ways.

It will be ideal to keep the Air Quality Index, registered during the lockdown at different land use zones of Chennai city as the bench mark values for those locations and strive to maintain the future air pollution levels within that bench mark. Of course, the proposition will be tougher to attain under a business-as usual-scenario. For achieving clean air conditions on an enduring basis, dynamic modeling of source contributions of air pollutants and the non-point sources of pollution to the urban air shed will have to be taken on priority. Such modeling must help to apportion the contribution of various key point sources like transport (including on road dust), industries (including coal fired power plants), construction activities and open burning of waste etc to the primary pollutant levels in ambient air. The modeling should also account for the pollutant load into the air shed from possible non-point sources, generation of secondary air pollutants and should be in a position to forecast air pollution levels in the near term and long term basis. Once done in an objective manner, all out effort should be made to keep the "Pollution under check' by implementing strict air pollution control norms and installing new technologies and methods to reach the goal.

From the lessons learnt out of the present lockdown and consequent improvement in the air quality, environmentalists may clamour for a periodical lockdown regime for certain length of a period- may be ranging from a fortnight to a month- every year so that the community provides an opportunity for the polluted urban environment to rejuvenate itself. The length and format of such a curfew could be a matter of detail but if implemented without compromising on the economic growth and livelihood opportunities of people, that will give an occasion for the urban people to rejoice over their own initiative in protecting their environment.

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