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"Does Air Quality Influence the Spread of the Sars - Cov2 In Metropolitan Cities? - A Case Study from Urban India"

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Abstract

COVID 19 pandemic has gradually established itself as the worst pandemic in the last hundred years around the world after initial outbreak in China, including India. To prevent the spread of the infection the Government implemented lockdown measure initially from 24th March to 14th April, 2020 which was later extended to 3rd May, 2020. This lockdown imposed restrictions in human activities, vehicular movements and industrial functioning; resulting in reduced pollution level in the cities. This study was initiated with the objective to identify the change in the air quality of seven megacities in India and to determine any correlation between the active COVID cases with the air quality parameters. Air quality dataset of the most common parameters ($PM_{2.5}$, PM_{10}, SO_2, NO_2, NH_3, CO and Ozone) along with air quality index for 70 stations of seven megacities (Delhi, Mumbai, Kolkata, Bengaluru, Hyderabad, Chennai and Chandigarh) were analysed. Comparison was made between AQI of pre lockdown and during lockdown periods. The results obtained indicate sufficient improvement in air quality during the period of the lockdown. For the next part of the study active COVID cases during the lockdown were compared to the air quality change of that period. A significant correlation between active COVID case and change in the air quality was observed for Delhi and Kolkata with 0.51 and 0.64 R^2 values respectively. A positive correlation was also observed between air pollutant parameters and incidents of COVID cases in this study. Thus from the analysis it was identified that air quality index improved considerably as a result of the nationwide lockdown however, there was no significant impact of this improvement on the infection rate of the prevailing pandemic.

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Introduction

The symptoms of the current pandemic were first reported from Wuhan (China) in December 2019, when there was an abrupt increase in the number of fatal pneumonia cases. Gradually as the virus started spreading all around the world through International travel, it was identified to be a novel coronavirus and was nomenclatured as SARS-COV2 due to its homology with the earlier strain of the Severe Acute Respiratory Syndrome (SARS) virus that ravaged the world as an epidemic in the years 2002 and 2003. The disease was named as COVID-19.[1-3] The impact of SARS-CoV-2 has been devastating around the world. So far 213 countries, more than 2.5 million people has been affected till date and more than 150,000 individuals have died.[4] Initially the disease had spread in Wuhan and later on it spread globally within the first four months.[5] Recent data of WHO identify over 2.8 million cases with over 201.000 victims as accessed on April 27, 2020.[6-8] As of 6th July, globally the pandemic caused almost 11 million confirmed cases of infection and more than 2 million deaths.[5] Most of the countries are trying to fight the spread of the virus by halting all social interactions. Social distancing parameters are being revised as continuous research is providing evidences of fomite, droplet and aerosol transmission in closed social environments without proper ventilation and continuous sanitization routines. In India the first confirm case was detected on January 30th, 2020 and the report of infection has rapidly increased from March 16th continuously. Government had declared the first nationwide lockdown for fourteen hours on March 22nd which was followed by 21 days of lockdown from 24th March. All the places of mass gatherings such as academic institutions, shopping malls, theatres, supermarkets and industries were declared to be closed across the country. This lockdown has mandated reduced transportation and industrial productivity which resulted into reduced automobile and industrial emissions.

As various countries had implemented lockdown measure, climate researchers had predicted that this implementation has the potential to positively impact global environment by cutting down greenhouse gas emission.[9] Improved air quality was achieved as a result ofreduced vehicular and industrial pollution due to the closure of majority of workshops and factories. A study showed that in France, Germany and Italy the NO_2 and greenhouse gas has been reduced significantly after lockdown.[10] Europe also reported reduction in air pollution after Government had ordered countrymen to stay at home for preventing the COVID outbreak which halted the factory & industrial work and automobile emissions that showed a drastic reduction in atmospheric NO_2 and Particulate matter proportions.[11] Studies also showed that the air pollution increased the risk of influenza infection.[12] These trends of correlation also have been seen in SARS and MERS.[13]

The world is a polluted place in terms of air quality with 91% of our fellow citizens living in places with poor and polluted air.[14] Each year the global mortality rate due to lack of good quality air has significantly increased.[15] The Global Disease Study showed that outdoor air pollution caused almost 4.2 million premature deaths in 2015.[16] In this regard another report of WHO in the year 2016 indicated that in Europe, Asia and Africa air pollution contributed almost 8 % of total death.

Developing countries such as India and other countries around the world has increasingly sacrificed air quality control in favour of deforestation, industrialization and urbanization. This has resulted in severe health issues such as Chronic Obstructive Pulmonary Disease (COPD) increasing in number and in 2015 nearly one million deaths were corelated to particulate matter pollution.[17] The World Health Organization and Central Pollution Control Board (CPCB) have established standard for ambient air quality, however major Indian cities have flouted the parameters and have consistently being enlisted in the top 20 most polluted cities of the world in the last few years.[18-19]

United States, Environmental Protection Agency (EPA), have identified several severe health and environmental hazards to be caused by “criteria pollutant”, such as carbon monoxide, lead, particulate air pollutants and variations in ground ozone level, which have resulted in smog, acid rain etc. All this are covered under the Clean Air Act of 1963. In India monitoring of air pollutant is performed by Central Pollution Control Board (CPCB) which jurisdiction of the Air (Prevention and Control of Pollution) Act, 1981. According to National Air Quality Monitoring Programme (NAMP), regular monitoring is performed for particulate matter (PM_{10}), sulphur dioxide (SO_2) and nitrogen dioxide

(NO_2) at all the monitoring stations. Real time monitoring of air quality is achieved by calculating the Air quality index (AQI) which takes into account various pollutants such as Pb, NH_3, SO_2, NO_2, CO, O_3, PM_{10} and $PM_{2.5}$ and (Table 1). Particulate matter (PM), SO_2, NO_2, NH_3, CO and O_3 are considered as classical air pollutants to calculate air quality under the programme of NAMP. Few recent studies have reported the importance of air quality and its impact during the period of lockdown in India as a result of the prevalent pandemic.[20-23] In India, Delhi and other metropolitan cities have caused severe air pollution in last few years which was very clear from the recorded air quality previously.[24]

Table 1: List of air pollutants and their sources

Serial Number	Pollutant	Source	Remarks/Source
1	$PM_{2.5}$ and PM_{10}	Primary sources are incomplete combustion, automobile emissions, dust and Cooking exhaust. Chemical reactions in the atmosphere also act as a secondary source.	https://doi.org/10.1016/j.atmosenv.2013.01.032[25]
2	NO_2	Outdoor source- Traffic emissions. Indoor source- (Appliances used for cooking), (Gas, Oil, Wood etc).	https://www.ncbi.nlm.nih. gov /books/NBK138707/[26]
3	NH_3	Principal source- Ammonia based fertilizer used in agriculture and livestock maintenance.	https://doi.org/10.1007/s 013-2051-9[27]
4	SO_2	Principal source- Fossil fuel burning in thermal power plant and other industry.	https://www.epa.gov/so2-pollution/sulfur-dioxide-basics[28]
5	CO	Principal source- Vehicular emissions and. burning of fossil fuel	https://www.epa.gov/co-pollution/basic-information-about-carbon-monoxide-co-outdoor-air-pollution[29]
6	Ozone	Sunlight mediated formation of ozone (ground level) by reaction between nitrogen oxide and emitted volatile organic compounds from various urban and industrial sources.	https://www.epa.gov/ground-level-ozone-pollution/ground-level-ozone-basics[30]

This work focused on the change in AQI and ambient air pollutants during lockdown in selected cities to construct a correlation between the air quality and outbreak of the COVID infection in search of the impact of air pollutants on viral invasion.

Materials and Methods

Study Design

Seven metropolitan cities viz Delhi, Mumbai, Kolkata, Bengaluru, Hyderabad, Chennai (Fig. 1) and over 74 monitoring stations were sampled in this study for a period of three months.

The span of 1st February to 20th March was chosen as there was no lockdown imposed by the government and the data could provide clear picture of air pollution in city specific manner. This time span was designated as the pre lockdown period for this analysis. The Government had ordered total lockdown from 22nd March to the end of April, when there was significantly restricted emission of industrial and vehicular pollution. Later in the month of May (Unlock 1) and June (Unlock 2) there were gradual relaxation of the lockdown norm declared by the government. Thus for this analysis, data up to the month of April was considered appropriate for the post lockdown period (Table 2).

Data Collection

Data was collected from The Central Pollution Control Board (CPCB) database (https://app.cpcbccr.com/AQI_India) which is under National Air Quality Monitoring programme (NAMP). Pollutants are monitored for a period of twentyfour hour (gaseous pollutant at 4-hour interval and particulate matter at 8-hour interval). This is done twice a week and 104 observations are achieved for a year.[31] This study monitored certain pollutants namely particulate matter ($PM_{2.5}$ & PM_{10}), Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2), Ammonia (NH_3), Carbon monoxide (CO) and Ozone from the month of February to April to evaluate the alterations in air quality. AQI values were also taken into consideration city wise keeping in mind pre-lockdown phase and implemented lockdown phase. Finally, we accumulated all the data (average values with reference to observation days) of three months (Table 3).

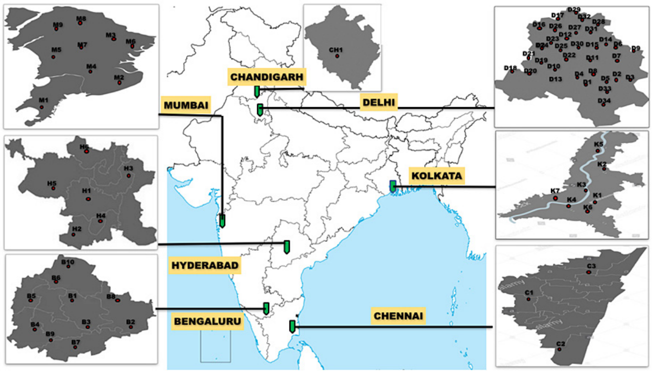


Fig. 1: Data collection sites (Air quality parameter measuring stations in seven megacities)

Table 2: Description of datasets and periods of pre and post lockdown considered in the study

Serial Number	Nomenclature	Period	Explanation
1	Pre-Lockdown	February-Mid March	Before the enforcement of complete lockdown.
2	Post-Lockdown	Mid-March-April	During the period of complete lockdown without any relaxation activity

Table 3: City specific AQI average of respective stations

¬Cities	Observation Sites	Prelockdown AQI	Postlockdown AQI
	Alipur	190.214	103.5
	Anand Vihar	218.857	104
	Ashok Vihar	212.857	99.4
	Aya Nagar	136.785	70.1
	Bawana	243.785	122.4
	CRRI Mathura Road	190.642	90.3
	Dr.Karni Singh Shooting Range	232.214	102.9
	DTU	198.285	83.7
	Dwarka-Sector 8	242.571	95.8
DELHI	IGI Airport(T3) Airport	166.285	74.3
	IHBAS,Dilshad Garden	184.285	37.5
	ITO	216.428	157.8
	Jahangirpuri	223.857	108.9
	Jawaharlal Nehru Stadium	184.928	78.7
	Lodhi Road	149.714	86.1

	Major Dhyan Chand National Stadium	189.384	79.5
	Mandir Marg	171.785	98
	Mundka	233.714	122.2
	NSIT Dwarka	224	81.9
	Najafgarh	199.071	122.3
	Narela	214	130.2
	Nehru Nagar	221	87.1
	North Campus,DU	167.785	78.9
	Okhla Phase-2	202.428	88
	Patparganj	173.071	77.5
	Punjabi Bagh	201.214	92.4
	R K Puram	166.571	80
	Rohini	239.857	109.3
	Shadipur	160.714	56.5
	Sirifort	224.142	82.2
	Sonia Vihar	194	87.2
	Sri Aurobindo Marg	170.214	79.6
	Vivek Vihar	207	89.4
	Wazirpur	239.428	98.4
	Bandra - MPCB	118.785	63.9
	Borivali East	90.153	65.545
	Chatrapati Shivaji international airport	163.571	62.5
MUMBAI	Colaba- MPCB	164.928	106.7
	Kurla	164.714	92.9
	Powai	109.5	72.9
	Sion- MPCB	186.142	81.4
	Vasai West	124.857	54.5
	Worli	138.285	68
KOLKATA	Ballygunge	207	71.6
	Bidhannagar	167.857	81.7
	Fort william	146.428	80.8
	Jadavpur	147.785	66.3
	Rabindrabharati university	196.642	77.5
	Rabindra sarobar	134.785	70.3
	Victoria memorial	185.5	94.6
	BTM Layout	59.846	53.5
	BWSSB Kadabesanahalli	104.928	48
	Bapuji Nagar	78.571	47
	City Railway Station	118.857	85.9
BENGALURU	Hebbal	83.214	53.3
	Hombegowda Nagar	84.142	63.9
	Jayanagar 5th Block	87.5	44.7
	Peenya	77	56.5
	SaneguravaHalli	71.571	43.8
	Silk Board	91.142	48.6
	Bollaram industrial area, TSPCB	94	60.3
	Central university-TSPCB	85.928	58
HYDERABAD	ICRI SAT, Patancheru	88.142	62.6
	IDA, Pashamylaram	91	64.181
	Sanathnagar	83.357	53.3
	Zoo-Park	115.214	77

CHENNAI	Alandur Bus Depot	68.071	32.7
	Manali - CPCB	103	51.2
	Velachery Res.Area- CPCB	55.142	43.1
CHANDIGARH	Sector-25- CPCC	71.285	39.4

Table 4: Mean value of City specific AQI and ambient air pollutant parameters. (4A to 4D)

4A

VARIABLES	DELHI				MUMBAI			
	Pre lockdown		Post lockdown		Pre lockdown		Post lockdown	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
AQI	6789.571	2528.74	3156	686.843	1257.857	329.746	670.2	110.878
$PM_{2.5}$	6498.714	2635.402	2497.7	609.289	935.357	278.702	485.3	170.982
PM_{10}	5143.929	1577.655	2596.2	600.284	1055.214	211.776	774.3	146.110
NO_2	1925.21	601.041	808.5	128.775	444.5	77.414	214.4	84.244
NH_3	234.643	28.105	182	17.256	39.785	7.007	28.5	15.306
SO_2	489.286	93.197	466.8	71.993	93.714	18.751	122.9	26.455
CO	1678.57	545.605	1199.3	173.463	324.928	69.280	232.2	43.001
OZONE	682.643	306.626	1006.6	283.439	438.142	164.068	290.4	58.680

4B

VARIABLES	KOLKATA				BENGALURU			
	Pre lockdown		Post lockdown		Pre lockdown		Post lockdown	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
AQI	1186	365.260	542.8	180.443	852.5	110.109	545.2	77.516
$PM_{2.5}$	1083.5	404.702	316.9	163.753	541.214	122.415	319.2	69.183
PM_{10}	927.357	251.956	362.4	138.808	607.857	70.179	351.9	71.894
NO_2	494.5	221.955	102.6	28.721	377.071	58.539	152.1	22.961
NH_3	48.214	7.495	27.1	4.458	19.142	1.875	17.9	1.791
SO_2	120.571	34.892	72.6	16.146	83.642	13.112	74.2	5.050
CO	178.071	35.508	137.4	26.692	488.928	32.824	384.4	39.786
OZONE	647.642	172.138	503.7	147.897	257.785	48.508	210.3	38.294

4C

VARIABLES	HYDERABAD				CHENNAI			
	Pre lockdown		Post lockdown		Pre lockdown		Post lockdown	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
AQI	556.642	119.479	374.1	59.120	226.21	43.24	127	22.568
$PM_{2.5}$	451.285	133.985	317.8	75.989	211.857	48.22	87.7	44.444

PM_{10}	454.714	71.382	26	71.493	0	0	0	0
NO_2	247.428	46.699	157.1	31.858	49.214	16.25	30	13.182
NH_3	24.5	12.100	17.6	4.948	10.357	3.002	11.7	1.159
SO_2	46.714	14.274	34.8	8.702	42.857	23.131	18.4	4.993
CO	152.428	28.608	140	26.679	114.074	24.972	98.9	13.008
OZONE	149.071	29.849	156.4	25.426	93.357	20.337	66.1	16.616

4D

VARIABLES	**CHANDIGARH**			
	Pre lockdown		**Post lockdown**	
	MEAN	**SD**	**MEAN**	**SD**
AQI	71.285	18.828	39.4	9.215
$PM_{2.5}$	51.214	22.617	24.2	5.533
PM_{10}	71.285	18.828	38	10.360
NO_2	19.214	7.454	14.2	1.873
NH_3	12.57	6.284	9.4	1.897
SO_2	12.214	2.887	13.8	2.149
CO	25.785	5.451	19.7	4.321
OZONE	21.285	5.483	34.3	11.155

Data Analysis

The study period i.e., overall a tenure of three months was catalogued into two phases viz pre lockdown phase (February-Mid March) and lockdown phase (Late March-April). Due to improper data sampling of the automated air quality monitoring, two spots from Delhi were removed from the analysis due to deficiency in data. The changes in air quality due to lack of vehicular emissions & mass gatherings was evaluated using a descriptive analysis to provide an overview of AQI values & ambient air pollutants among the seven cities of the study.

A linear regression model was constructed to understand the correlation between COVID incidence and AQI values along with all the pollutant parameters considered. In the analysis COVID-19 incidence cases were considered as a dependent variable and AQI values of seven cities along with seven ambient air pollutant parameters were considered as an independent variable. R^2 value for each regression was checked for statistical significance. Pre-lockdown COVID-19 cases were not considered in this regression analysis due to data deficiency. Pre and post-lockdown air quality index parameters were represented through two heat maps respectively.

Results

In this study, meticulous information of AQI values & ambient air pollutants among seven metro cities were enlisted in Table 4; (Figure 2). Furthermore, the entire data of COVID-19 incidence during the lockdown period were collected which included confirmed, active and recovered cases (Figure 3). From the column graph (Figure 4) and heat maps (Figure 5) of AQI and other air pollutant parameters, it was observed that in the post-lockdown period, all the values decreased with few exceptions. For all the cities, AQI summed average value was observed to decrease during lockdown, among which Delhi, Mumbai and Kolkata was most significant. Delhi showed significant rise in AQI values 6789.571 ±675.834 & 3156 ±217.198; whereas Chandigarh exhibited lower AQI values 71.825 ±5.032 & 39.4 ±2.914 from pre to post lockdown. Mumbai, Kolkata, Bengaluru, and Hyderabad also showed moderate AQI values but Chennai showed apparently lowest values than these cities respectively. Among all the ambient air pollutants $PM_{2.5}$ & PM_{10} showed a significant decrease along seven cities during the study period and Chennai had no PM_{10} value observed in either of periods. NH_3 was increased marginally (10.3571 ±3.002 & 11.7 ±1.159) in Chennai during post-lockdown. SO2 increased in Mumbai significantly (93.714 ±18.751 & 122.9 ±26.455) and marginally in Chandigarh (12.214 ±2.887 & 13.8 ±2.149). The level of ozone increased during post lockdown phase in Delhi (682.643 ±306.626 & 1006.6 ±283.439), Hyderabad (149.071 ±29.849 & 156.4 ±25.426) and Chandigarh (21.285 ±5.483 & 34.3 ±11.155).

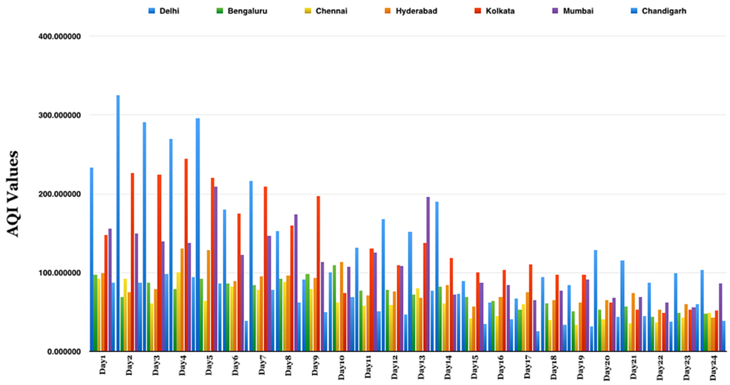


Fig. 2: Comparative total Air Quality Index values for the seven cities day wise (period of study)

Fig. 3: Comparative Representation of the total number of Affected, Recovered and Active cases per city as described in the text for the period of study

The data exhibited variation in relationship between the AQI values & Post lockdown COVID-19 incidences among the enlisted cities. Kolkata & Delhi exhibited moderate significance (R^2=0.64 & 0.51, respectively) at the time of this study, whereas the other cities under consideration displayed weak association in this context (Table 5). Statistically the R^2 value ranging from 0.3-0.5 indicated weaker correlation, from 0.5-0.7 indicated moderate effect and above 0.7 was considered to have a strong correlation between the variables.[32] Observations from this study depicted that AQI along with ambient air pollutants also manifested different effects on COVID-19 incidences. Amidst all air pollutants in Delhi, PM_{10} & Ozone had moderate effect; in Mumbai, PM_{10} & ozone; in Kolkata, SO^2, CO & Ozone; in Bengaluru, NO^2 & CO had higher association with COVID -19 cases, as inferred from the R^2 values tabulated in (Table 5) & graphical representations from (Figure 6).

Discussion

From this study it was noticed that the post lockdown period caused a significant reduction of the AQI values of each city by parallel enhancement of air quality due to scarce level of vehicular and industrial air pollutants.

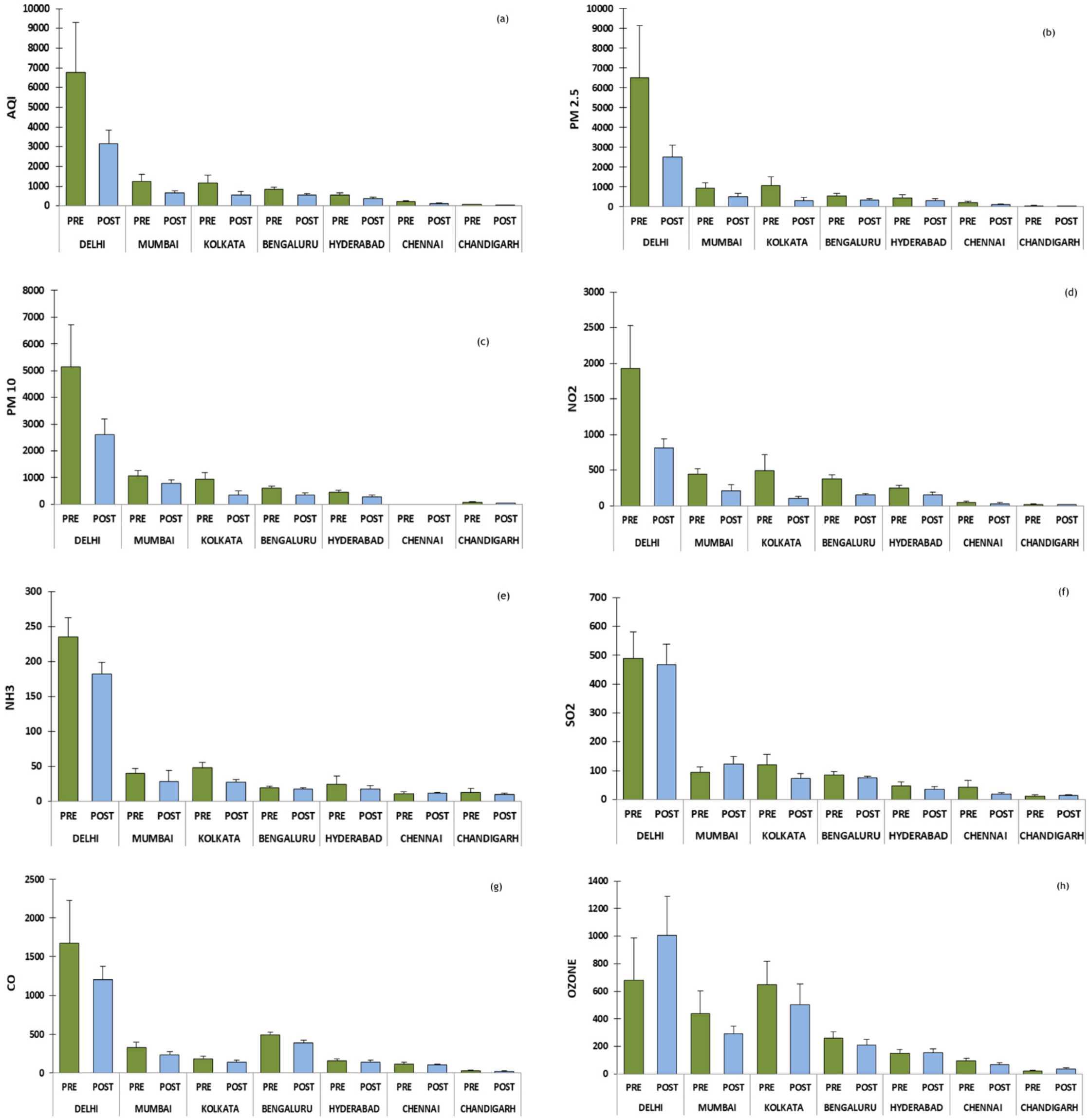
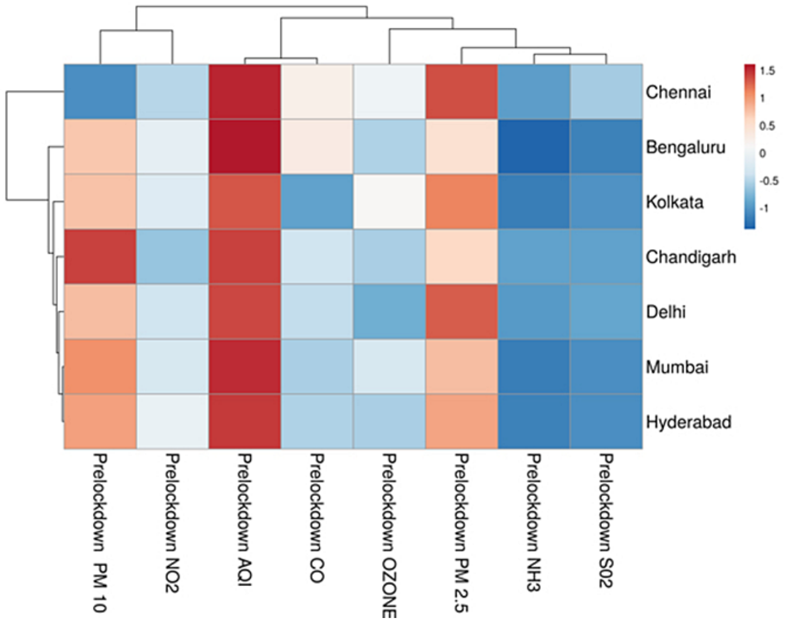


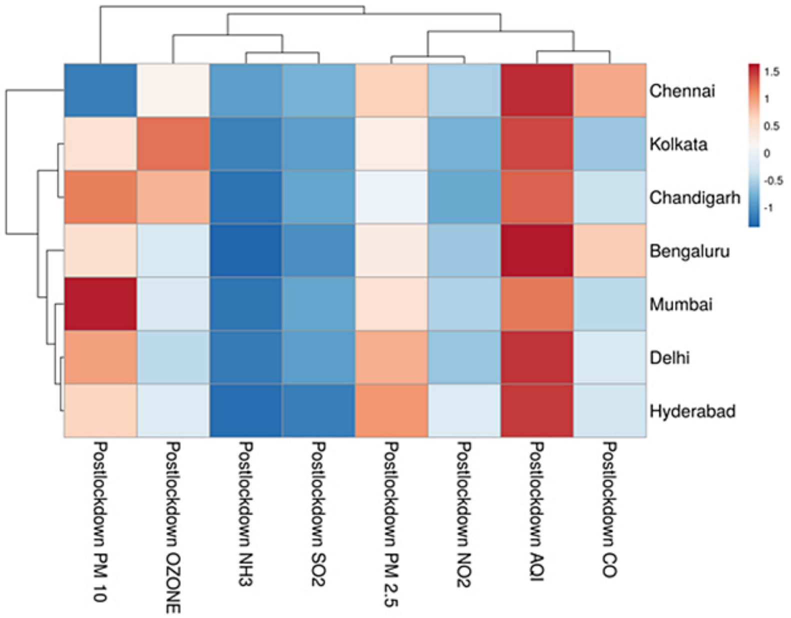
Fig. 4: Mean values of AQI (a), $PM_{2.5}$ (b), PM_{10} (c), NO_2 (d), NH_3 (e), SO_2 (f), CO (g) and Ozone (h). Green and Blue column representing pre and lockdown phase respectively

From the heat map, it was observed Chandigarh was independent and out of the cluster of other cities, in the pre lockdown phase. Having only one AQI measuring station, Chandigarh had the least value of all air pollutants except NH_3 (Figure 4). Vehicular and industrial pollution emit PM, SO_2, NO_2 and CO but not NH_3, which projected that Chandigarh has different pollution status than the other cities considered in this study. Chandigarh has lesser number of industries (mostly packaging or paper making industries) that emit lesser pollutants which probably contribute towards its position in the heat map.

In the post lockdown phase Delhi, Mumbai, Bengaluru and Hyderabad were in a single cluster as they probably have a similar emission status. This can be justified from the similar industrial and vehicular pollution standard near the air quality measuring stations. Column graphs depicted that Delhi, Mumbai and Bengaluru have significantly higher SO_2 and CO level compared to other cities in either of the phase due to the presence of higher number of industries in them (Figure 4). SO_2 and CO were the primary gas emitted from the industries and NO_2, PM_{10} and $PM_{2.5}$ were principal emission of automobiles (Table 1), which probably ascertain a constant level of air pollutants in the cities clustered together. As Kolkata, Chennai and Chandigarh have very less industries located in the city and lockdown norms restricted the automobile emissions, these cities were clustered separately in the heat map.



(a)



(b)

Fig. 5: Heat map representation of AQI and ambient air quality parameters during (a) prelockdown and (b) postlockdown (during lockdown phase) respectively

Table 5: R2 values obtained from the regression analysis of COVID incidence with AQI and other ambient air pollutants

PARAMETERS	R^2 VALUE						
	Delhi	Mumbai	Kolkata	Bengaluru	Hyderabad	Chennai	Chandigarh
AQI	0.518	0.1981	0.6436	0.0156	0.1207	0.0211	0.1101
$PM_{2.5}$	0.189	0.4626	0.5647	0.001	0.1169	0.0185	0.0005
PM_{10}	0.501	0.9989	0.5936	0.7064	0.0092	0	0.1404
NO_2	0.009	0.6867	0.4198	0.8821	0.0957	0.1351	0.063
NH_3	0.011	0.0176	0.6447	0.1143	0.1608	0.0121	0.2161
SO_2	0.295	0.0453	0.9996	0.0018	0.1286	0	0.7662
CO	0.01	0.3164	1	0.9996	0.1523	0.0042	0.1375
OZONE	0.688	0.9998	1	0.1609	0.4707	0.084	0.0103

There has been previous reports of corelation between air pollution and virus mediated respiratory disorder.[33] A study also highlighted considerable potency in enhancement of virulence and infection rate of influenza with the effect of air quality parameters.[34] Air pollutants such as $PM_{2.5}$ and PM_{10}, carbon monoxide, sulphur dioxide, ozone and nitrogen dioxide cause severe respiratory tract infection by enhancing susceptibility.[35] Higher percentage of air pollutant may promote greater persistence of air borne virus particles.[36] It has the potential to favour a passive diffusion of SARS-CoV-2, in addition to the direct diffusion of the viral particles from individual to individual.[37] People living in zones with high concentrations of air pollutants are more susceptible to respiratory diseases.[38] In this study, only Kolkata and Delhi showed significant relationship of AQI with COVID-19 incidence with a statistically significant R^2 value. Moreover, these two cities also have a significantly higher level of pollution in both the period. Observation are in concurrence to previous studies that enhanced air pollutants in the air might have been a reason for the higher confirmed cases of the viral infection. Chennai and Chandigarh are showing lowest AQI in either of the period which justifies its significantly low confirmed cases of infection as compared to the other cities.

Particulate matters are known for its suspension form in the air and invasion of the respiratory barriers to penetrate the pulmonary tract mucosal layers and directly get in contact with respiratory surfactant causing health hazards. $PM_{2.5}$ and PM_{10} particles are having less than 2.5 and 10 micrometres of diameter respectively. $PM_{2.5}$ and PM_{10} are the most important air pollutants in correlation to viral particle transmission. Northern Regions of Italy, which were most affected by COVID-19, had significantly higher PM_{10} and $PM_{2.5}$ level.[37] Study also showed that the viral infection has increased in the presence of abundant particulate matter such as PM_{10} in air.[39] In our study, Delhi, Mumbai, Kolkata and Bengaluru have significantly higher values of $PM_{2.5}$ and PM_{10} and also the R^2 values suggesting a strong relationship with confirmed COVID cases. This supports the justification that higher particulate matter in air in the locations mentioned has contributed towards higher viral transmission. Moreover, this condition is significantly lesser adverse in other cities due to relatively lesser $PM_{2.5}$ than PM_{10}.

Increased O_3 level has been correlated with reduction of NO_2 emissions.[40] These results are coherently supported by the recent findings for Milan in Italy[41] and for Wuhan area in China.[42-44] Experiment showed that the drastic reductions in NO_2 and other air pollutants during Milan's COVID-19 lockdown led to substantial increase in ground level Ozone (O_3).[41] As a result, atmospheric oxidizing potential was elevated which escalated formation of secondary aerosols having negative impact on human respiratory tract along with an increase in COVID-19 confirmed cases.[41] This trend was also observed in case of Indian metropolitans where NO_2 and SO_2 levels have decreased in most of the cities with a few insignificant exceptions along with the significant rise in ground level of Ozone after lock-down.[23,45-46] In Delhi this observation led to a noticeable impact in the confirmed COVID cases throughout the post-lockdown phase.

In conclusion, lockdown provided a significantly good impact on the improvement of overall air quality of the cities. On the other hand, it was found that the increase of particular pollutants had an impact on the spread of viral infection. Higher confirmed cases in major cities like Delhi and Mumbai could have been due to higher air pollutants present in the air and in the cities like Chandigarh and Chennai, comparatively lower pollutant levels justified the lower rate of confirmed cases of infection.

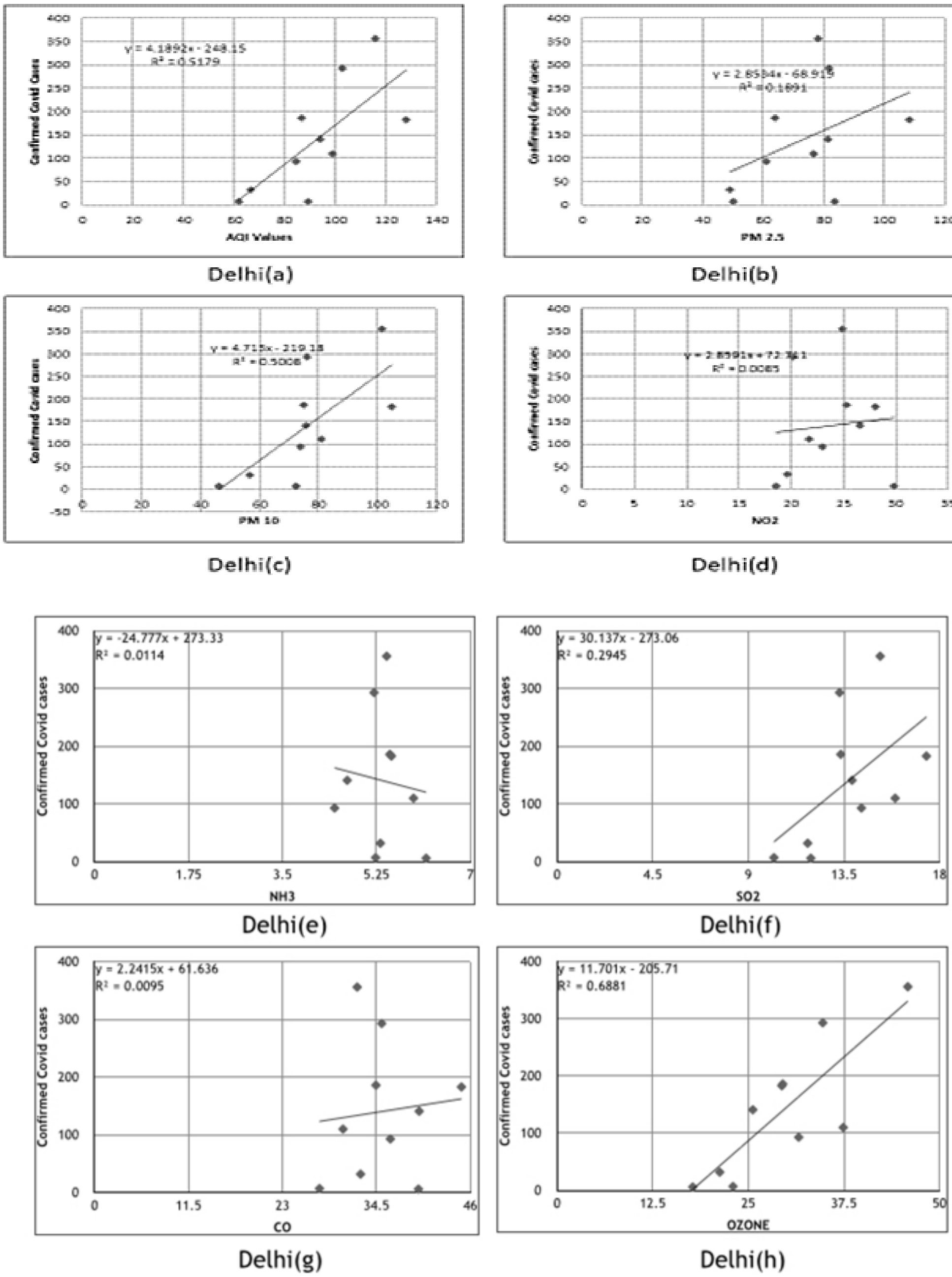


Fig. 6.A:

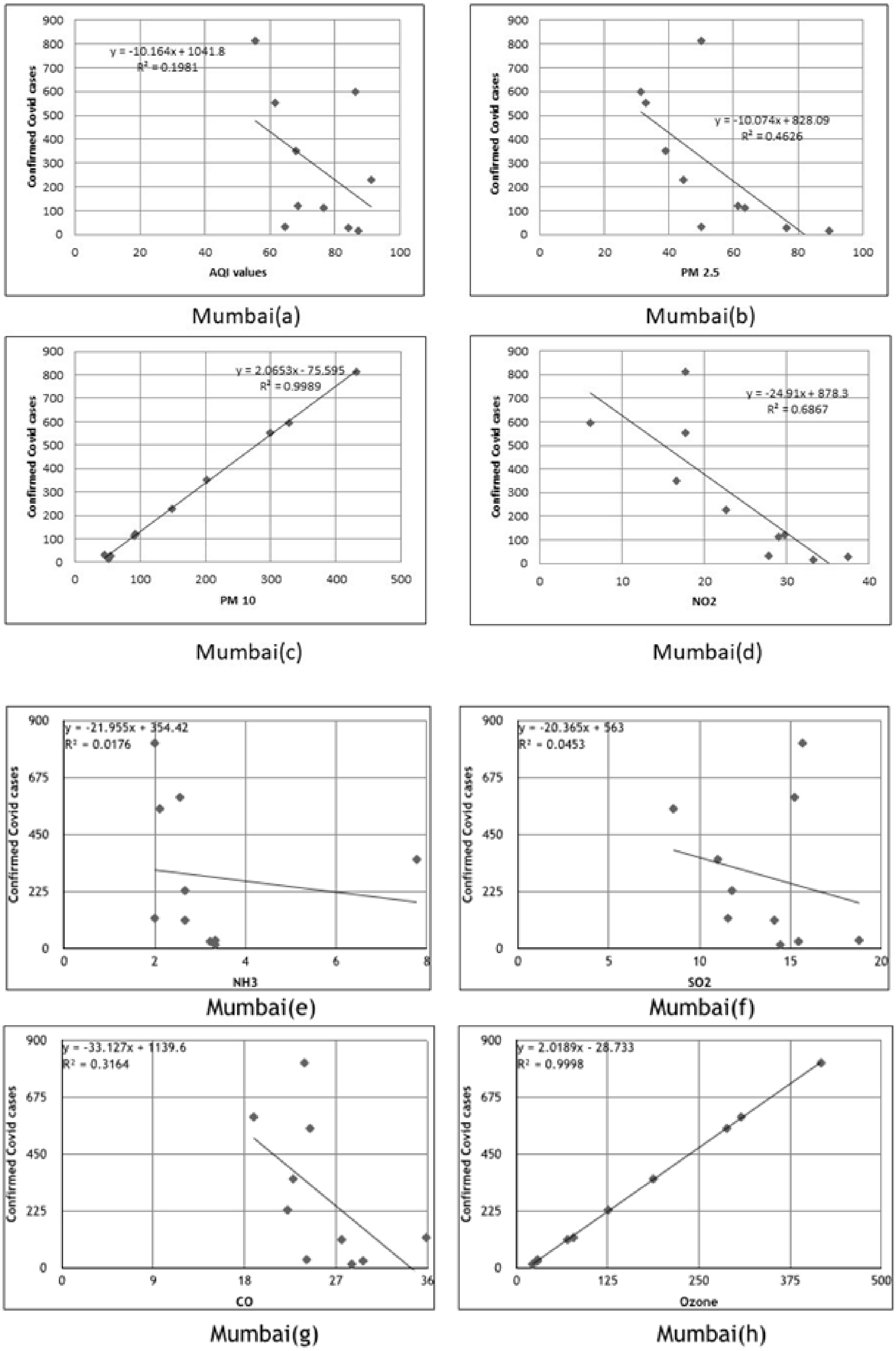

y = -10.164x + 1041.8
R² = 0.1981
Confirmed Covid cases
AQI values
Mumbai(a)
y = -10.074x + 828.09
R² = 0.4626
Confirmed Covid cases
PM 2.5
Mumbai(b)
y = 2.0653x - 75.595
R² = 0.9989
Confirmed Covid cases
PM 10
Mumbai(c)
y = -24.91x + 878.3
R² = 0.6867
Confirmed Covid cases
NO2
Mumbai(d)
y = -21.955x + 354.42
R² = 0.0176
Confirmed Covid cases
NH3
Mumbai(e)
y = -20.365x + 563
R² = 0.0453
Confirmed Covid cases
SO2
Mumbai(f)
y = -33.127x + 1139.6
R² = 0.3164
Confirmed Covid cases
CO
Mumbai(g)
y = 2.0189x - 28.733
R² = 0.9998
Confirmed Covid cases
Ozone
Mumbai(h)

Fig. 6.B:

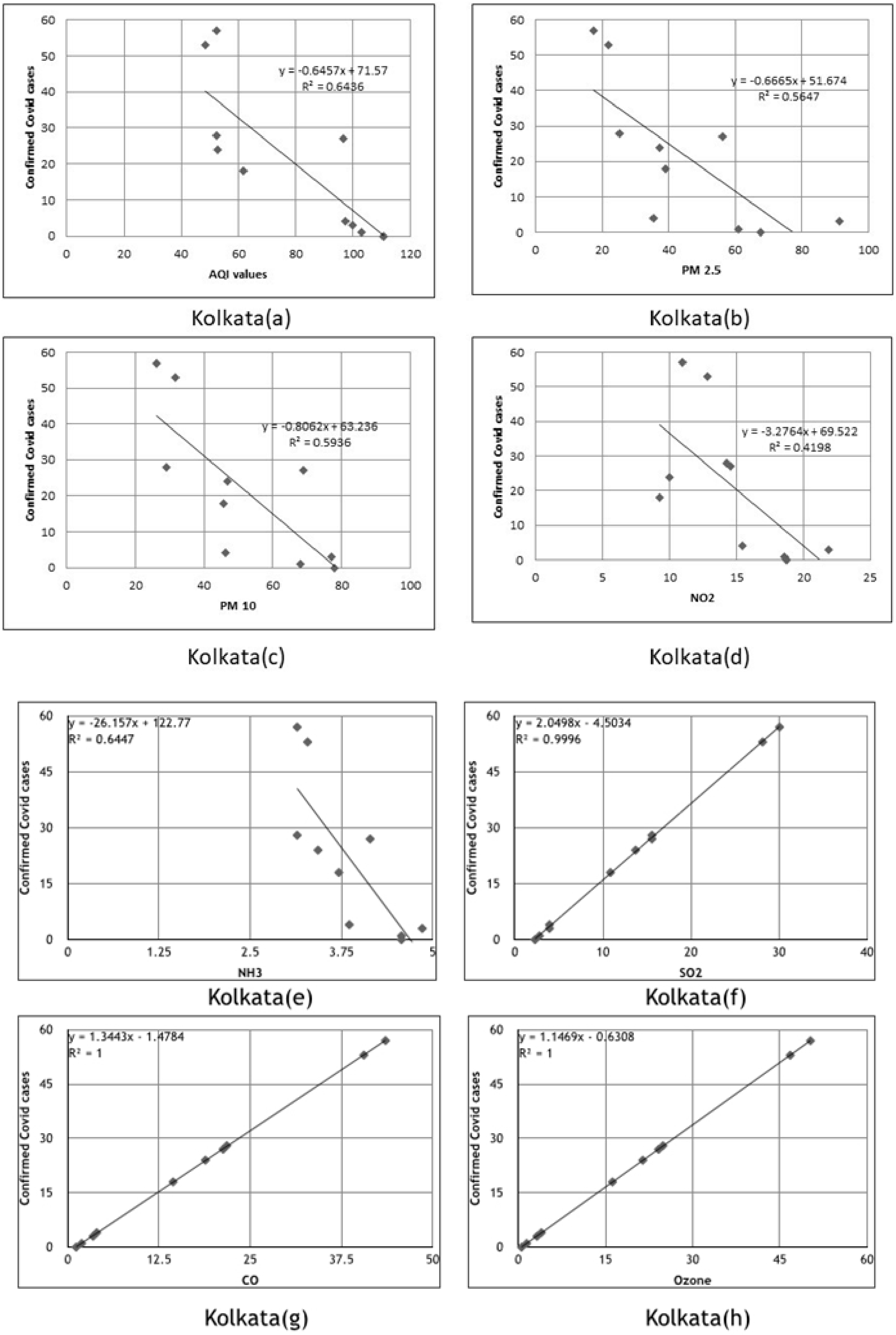
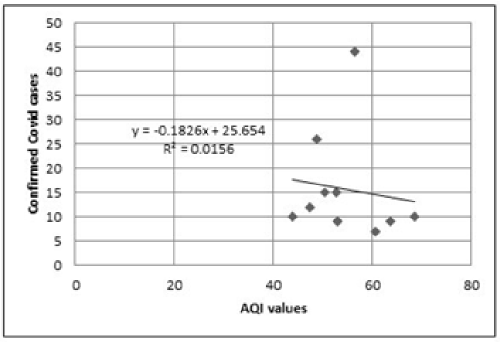
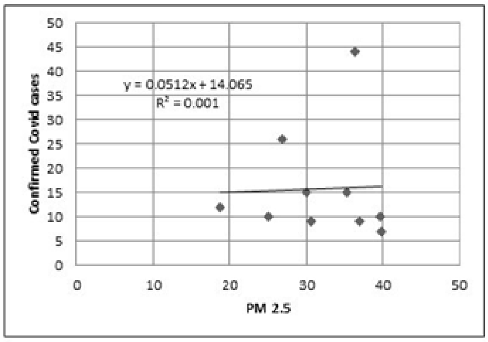

y = -0.6457x + 71.57
R² = 0.6436
Confirmed Covid cases
AQI values
Kolkata(a)
y = -0.6665x + 51.674
R² = 0.5647
Confirmed Covid cases
PM 2.5
Kolkata(b)
y = -0.8062x + 63.236
R² = 0.5936
Confirmed Covid cases
PM 10
Kolkata(c)
y = -3.2764x + 69.522
R² = 0.4198
Confirmed Covid cases
NO2
Kolkata(d)
y = -26.157x + 122.77
R² = 0.6447
Confirmed Covid cases
NH3
Kolkata(e)
y = 2.0498x - 4.5034
R² = 0.9996
Confirmed Covid cases
SO2
Kolkata(f)
y = 1.3443x - 1.4784
R² = 1
Confirmed Covid cases
CO
Kolkata(g)
y = 1.1469x - 0.6308
R² = 1
Confirmed Covid cases
Ozone
Kolkata(h)

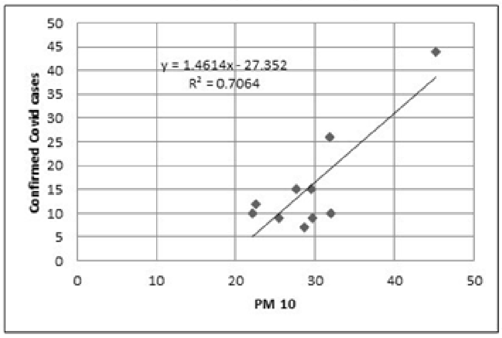
Fig. 6.C:



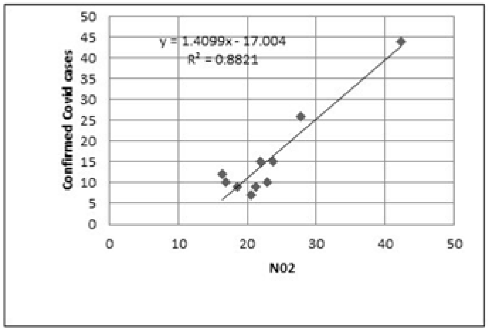
Bengaluru(a)



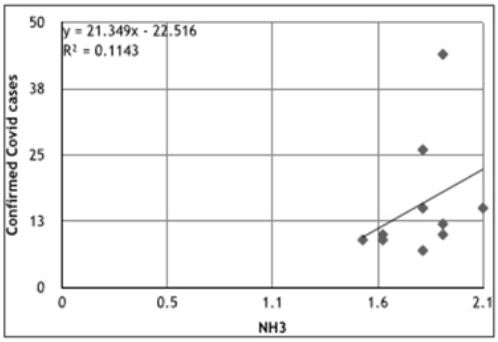
Bengaluru(b)



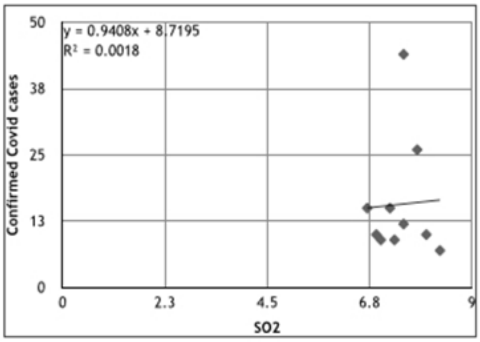
Bengaluru(c)



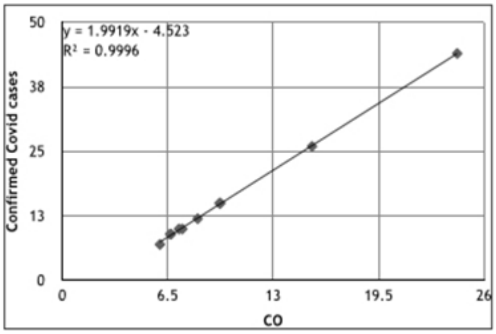
Bengaluru(d)



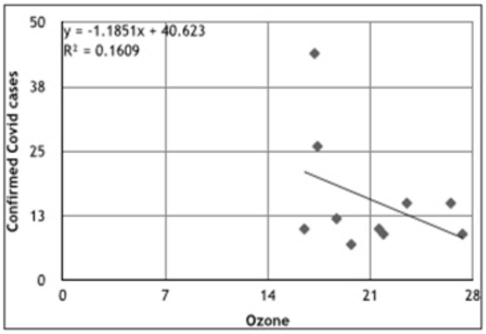
Bengaluru(e)



Bengaluru(f)



Bengaluru(g)



Bengaluru(h)

Fig. 6.D:

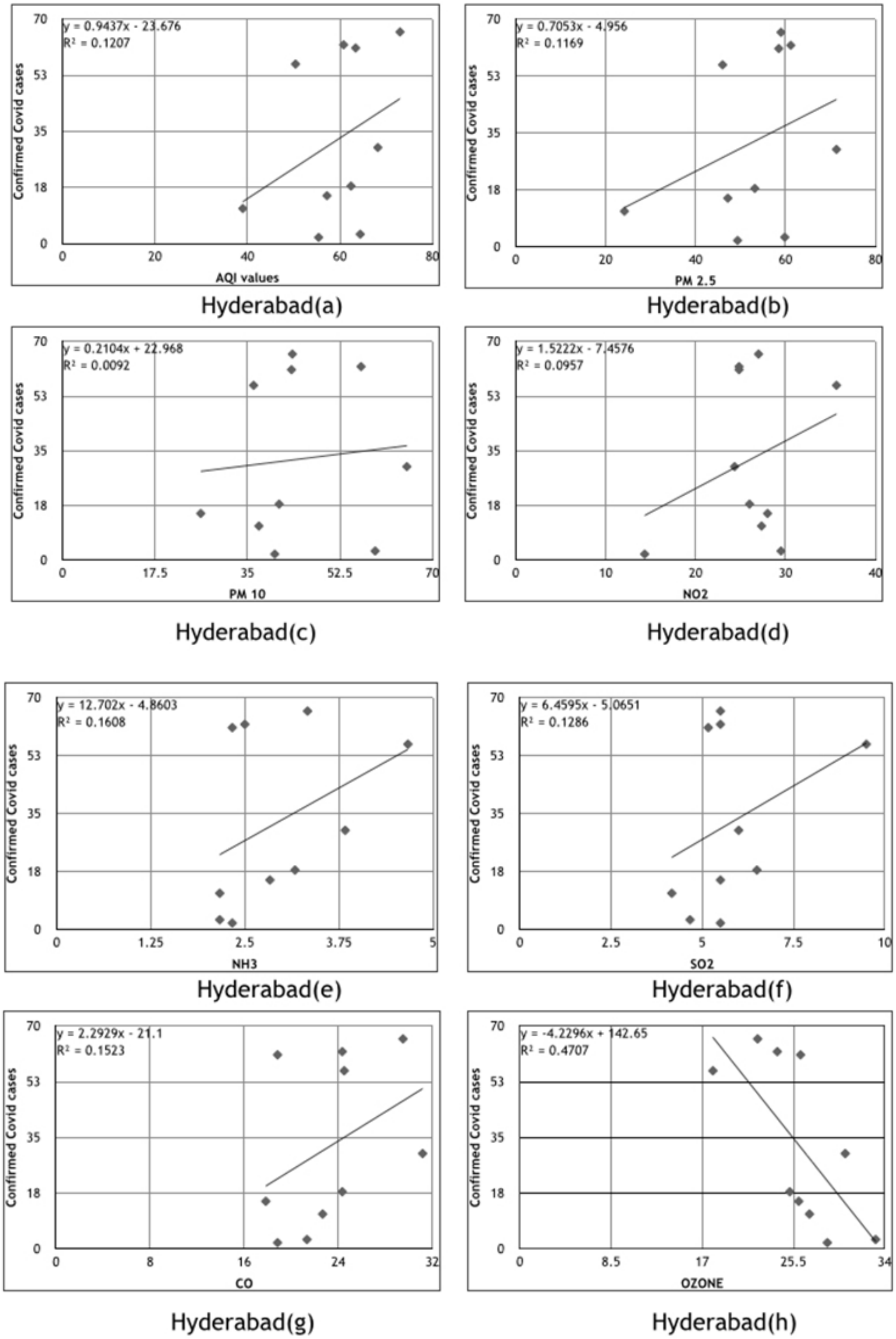

y = 0.9437x - 23.676
R² = 0.1207
Confirmed Covid cases
AQI values
Hyderabad(a)
y = 0.7053x - 4.956
R² = 0.1169
Confirmed Covid cases
PM 2.5
Hyderabad(b)
y = 0.2104x + 22.968
R² = 0.0092
Confirmed Covid cases
PM 10
Hyderabad(c)
y = 1.5222x - 7.4576
R² = 0.0957
Confirmed Covid cases
NO2
Hyderabad(d)
y = 12.702x - 4.8603
R² = 0.1608
Confirmed Covid cases
NH3
Hyderabad(e)
y = 6.4595x - 5.0651
R² = 0.1286
Confirmed Covid cases
SO2
Hyderabad(f)
y = 2.2929x - 21.1
R² = 0.1523
Confirmed Covid cases
CO
Hyderabad(g)
y = -4.2296x + 142.65
R² = 0.4707
Confirmed Covid cases
OZONE
Hyderabad(h)

Fig. 6.E:

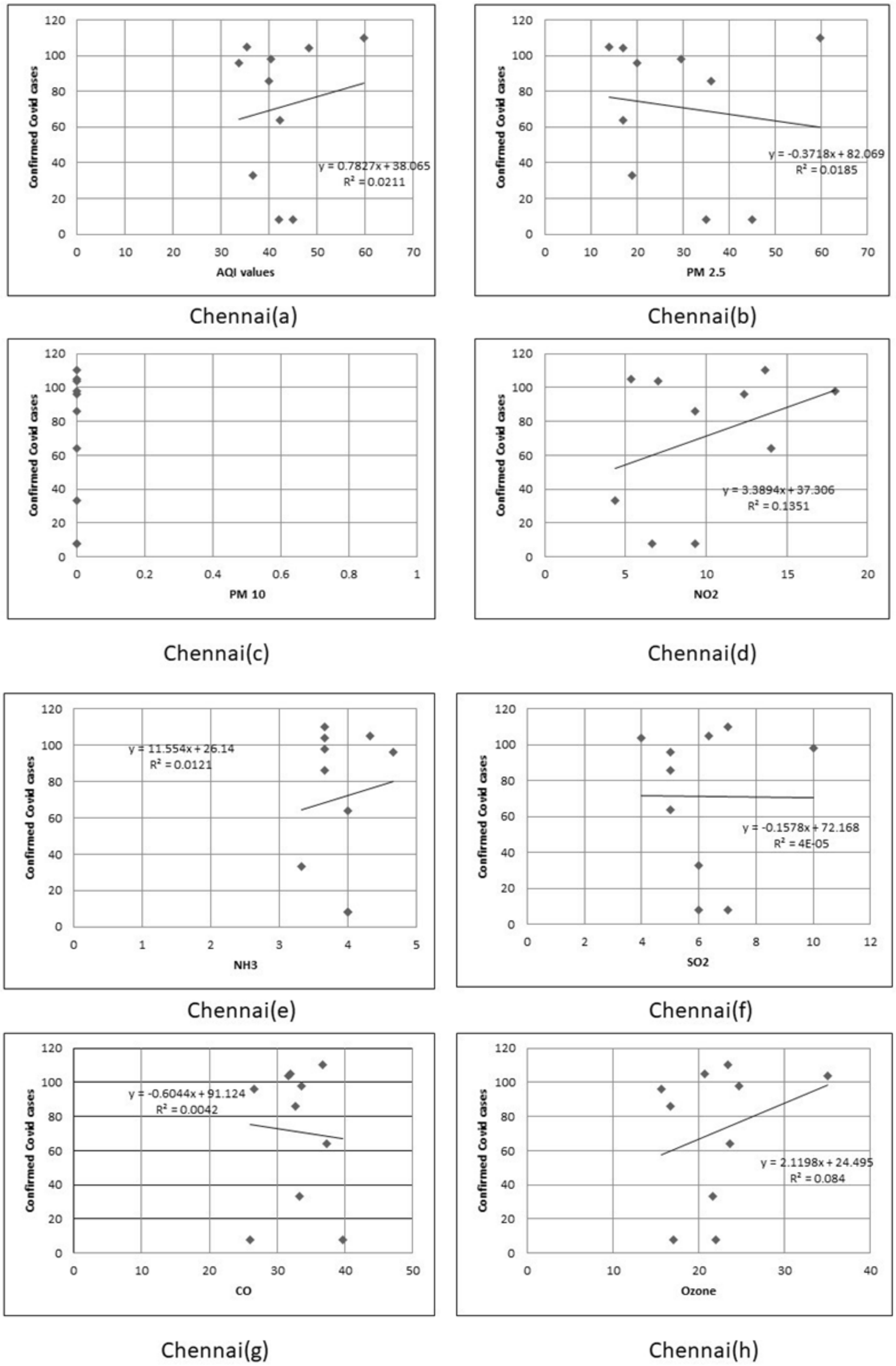

Confirmed Covid cases
AQI values
y = 0.7827x + 38.065
R^2 = 0.0211
Chennai(a)
Confirmed Covid cases
PM 2.5
y = -0.3718x + 82.069
R^2 = 0.0185
Chennai(b)
Confirmed Covid cases
PM 10
Chennai(c)
Confirmed Covid cases
NO2
y = 3.3894x + 37.306
R^2 = 0.1351
Chennai(d)
Confirmed Covid cases
NH3
y = 11.554x + 26.14
R^2 = 0.0121
Chennai(e)
Confirmed Covid cases
SO2
y = -0.1578x + 72.168
R^2 = 4E-05
Chennai(f)
Confirmed Covid cases
CO
y = -0.6044x + 91.124
R^2 = 0.0042
Chennai(g)
Confirmed Covid cases
Ozone
y = 2.1198x + 24.495
R^2 = 0.084
Chennai(h)

Fig. 6.F:

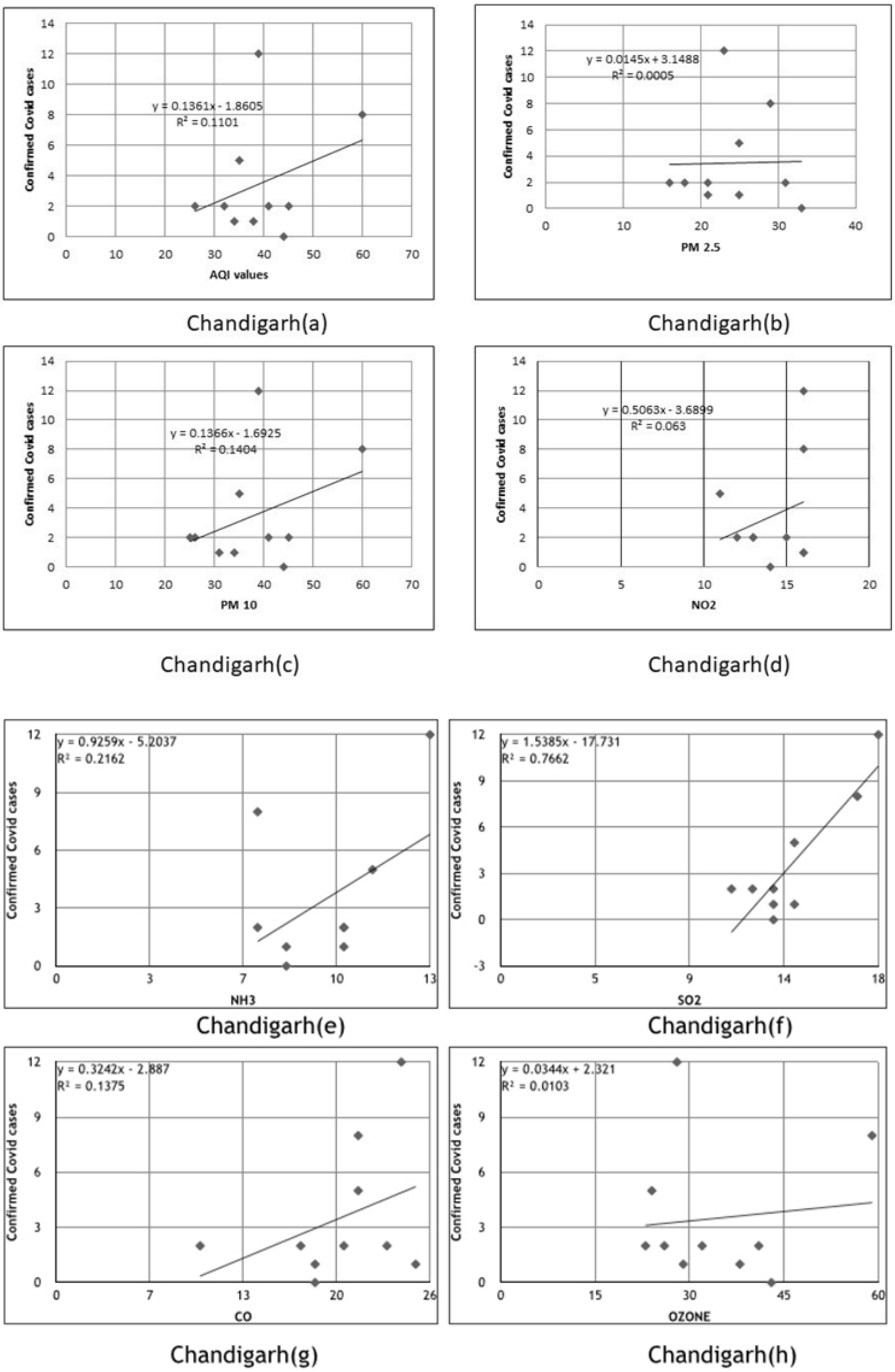


Fig. 6.G:

Fig. 6: Graphical representation of regression analysis performed between COVID incidence and air quality parameters of seven cities. (Fig. 6.A: Delhi; Fig. 6.B: Mumbai; Fig. 6.C: Kolkata; Fig. 6.D: Bengaluru; Fig. 6.E: Hyderabad; Fig. 6.F: Chennai; Fig. 6.G: Chandigarh)

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Conflict of Interest

The authors confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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