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Impacts of COVID-19 lockdown on ambient air quality: Statistical analyses of available data on urban West Bengal (India)

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Abstract. COVID-19 pandemic and consequent unavoidable lockdown left an unprecedented shock on social and economic life. Present study aimed to evaluate the impacts of COVID-19 lockdown on the ambient air quality of urban areas of eastern Indian state West Bengal. During lockdown period, Air Quality Index (AQI) was mostly found in 'Good' or 'Satisfactory' and sometimes, in 'Moderate' categories, and rarely, in 'poor' category. AQI was in 'Good' category for most of the lockdown span at Siliguri (67%) followed by Kolkata (44%), Howrah (38%) and Asansol (25%). Based on average AQI ranges: lockdown period (48.68- 62.12) < same period before 1 year (75.09-89.81) < Period 3 months before lockdown (175-206), it can be stated that AQI category was better during lockdown compared to the other two at all study areas. In Kolkata overall air pollutant levels except ozone (p>0.05) decreased significantly during lockdown. Similarly, $PM_{2.5}$, PM_{10} and NO_2 level reduced in Howrah. Beside, no significant changes observed for NH_3 and SO_2 concentration in Howrah compared to one year before. Apart from $PM_{2.5}$, NO_2, NH_3 and SO_2 level of previous year, mean concentration of PM_{10}, CO, O_3 showed significant drop at Siliguri during lockdown. Ambient air quality parameters except SO_2 showed remarkable decline in Asansol also during lockdown. It can be concluded that COVID-19 lockdown exerted positive effects from environmental health perspective. It improved overall ambient air quality parameters of urban areas of West Bengal. Proper planning and policy making should be given utmost priority to control air pollution in the present 'new normal' COVID-19 scenario.

Keywords: air pollutant; air quality; ambient air pollution; environmental health; COVID-19 lockdown

1. Introduction

Air pollution is a major threat for mankind in the present world (Kim *et al*. 2018). Air quality of the 91% of the world's living places exceeds WHO limit (WHO 2018). 4.2 million premature deaths occur every year on the earth due to ambient air pollution (WHO 2014). Majority of the cases were found in the low-and middle income countries and in WHO South-East Asia and Western pacific regions (WHO 2018). India ranked as 5th most polluted country in the world based on PM $_{2.5}$ level and twenty one Indian cities were within the list of world's top thirty most polluted cities (IQ*Air* 2019 World Air Quality Report). Rapid urbanization and industrialization in Indian

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cities have often failed to keep balance between development and sustainable growth (Das *et al*. 2015). In the developing nations main sources of air pollution are mostly common which include vehicular emissions, huge atmospheric emissions from industries and power plants, municipal solid waste incineration, biomass burning, stubble burning and the dust from construction works etc. (Das *et al*. 2014, Biswas *et al*. 2020). The major anthropogenic air pollutants are suspended particulate matters (SPMs) of variable sizes (PM_{10} and $PM_{2.5}$), volatile organic compounds, carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), lead (Pb), various air toxics, radon (Rn), ozone (O_3), and peroxyacetyl nitrates or PAN (Wright and Boorse 2010, Mukherjee *et al*. 2012). Amongst them PM_{10} and $PM_{2.5}$ are of chief concern due to their dramatic effects on human health. PM_{10} (particles with aerodynamic diameter $\leq$ 10 μm) can enter the trachea and large bronchi while $PM_{2.5}$ (particles with aerodynamic diameter $\leq$ 2.5 μm) may remain deposited within smaller airways and alveoli (Sinha and Ray, 2015). Air pollution may lead to the development of respiratory diseases, including acute respiratory infections, asthma and chronic obstructive pulmonary diseases (COPD). Furthermore, a strong link exists between air pollution exposure and cardiovascular diseases (strokes and ischemic heart diseases) and cancer (WHO 2014). According to WHO (2020) death due to ischemic heart disease, stroke and chronic obstructive pulmonary disease, lower respiratory infections, trachea, bronchus and lung cancers appeared as 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 6^{th} leading causes of death out of top ten in 2019. According to the study of India State-Level Disease Burden Initiative Air Pollution Collaborators (2020) air pollution caused 1·67 million deaths in India in 2019 and it was 17·8% of the country's total death. Mortality caused by household air pollution declined by 64.2% from 1990 to 2019. But ambient particulate matter pollution and ambient ozone pollution recorded increased mortality by 115.3% and 139.2% respectively in India. Of the total deaths due to air pollution in India in 2019, COPD (32·5%), ischemic heart disease (29·2%), stroke (16·2%) and lower respiratory infections (11·2%) are the most notable. The estimated economic loss accounting for lost output from premature deaths and morbidity caused by air pollution was around US$ 36.8 billion, or nearly 1·36% of India's GDP in 2019. Therefore, increased air pollution is a biggest hindrance for India's target of becoming a US$5 trillion economy by 2024.

COVID-19 is caused by SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) which can trigger infection in the respiratory system (Yuki *et al*. 2020). The highly infectious COVID-19 was first reported in Wuhan, China in December 2019. Later the disease has spread across 212 countries around the world and put the lives of millions at risk (Ghosh *et al*. 2020). In India it was first detected in Kerala on January 30, 2020 (PIB 2020). WHO (2020) declared novel coronavirus (COVID-19) outbreak a 'global pandemic' on 11^{th} March, 2020. No specific treatment or vaccine was available for COVID-19 till then. Lockdown and social distancing appeared as two cost-effective tools to prevent outbreak of COVID-19. In India Central Government imposed country-wide lockdown in different phases: Phase 1.0 (25 March 2020 to 14 April 2020), Phase 2.0: (15 April 2020 to 3 May 2020), Phase 3.0: (4 May 2020 to 17 May 2020) and Phase 4.0: (18 May 2020 to 31 May 2020) (Kumar *et al*. 2020). Prolonged country-wide lockdown rendered an unprecedented shock to the social and economic life.

However, study of environment during COVID-19 lockdown with reduced anthropogenic activities has been the centre of attention of many researches. Wu *et al*. (2020) reported that prolonged air pollution can aggravate the risk of death rate due to COVID-19 infection. Air quality in a city is influenced by complex interaction between natural and anthropogenic environmental conditions (Mouli *et al*. 2004). Several researchers worked on the effects of the COVID-19 lockdown on ambient air qualities of Indian cities. Kumar *et al*. (2020) observed significant

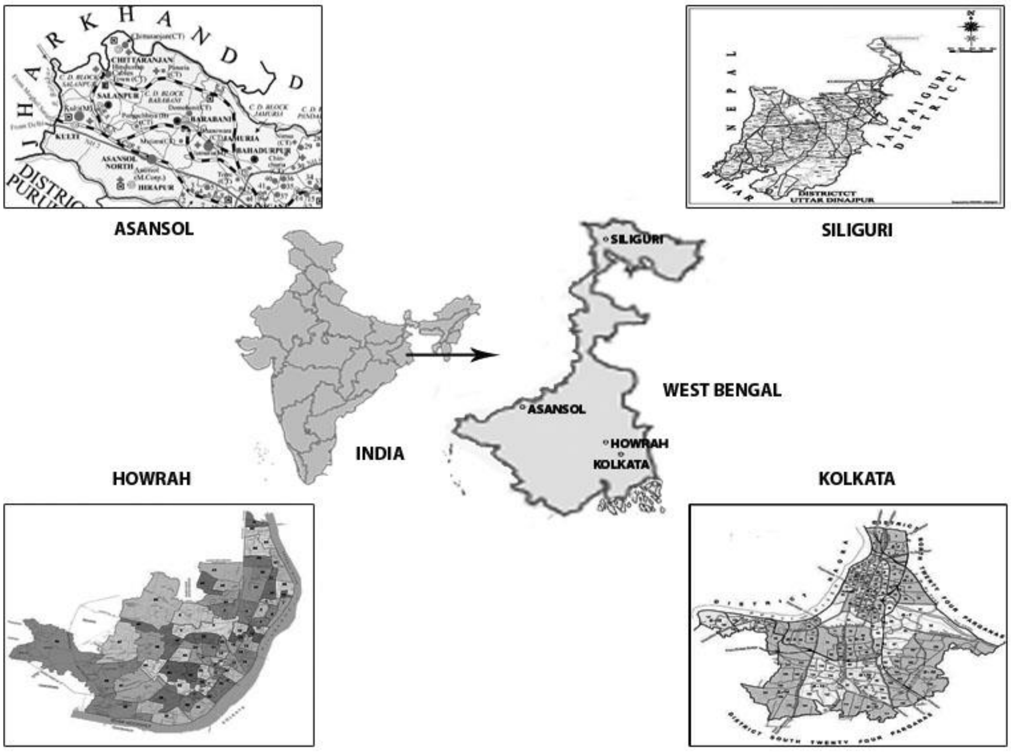

Fig. 1 Location map of study areas

decrease in $PM_{2.5}$ concentration during COVID-19 lockdown in Delhi (41–53%), Chennai (19 to 43%), Hyderabad (26–54%), Kolkata (24–36%) and Mumbai (10–39%). Lokhandwala and Gautam (2020) also showed sharp decrease in $PM_{2.5}$ (85.1%), PM_{10} (50.8%), NO_2 (48.7%) and SO_2 (16.3%) concentration in Ghaziabad, one of the most polluted Indian city. Tropospheric NO_2 concentration showed 12.1% drop over India after lockdown (Biswal *et al*. (2020). Rise in ground level ozone at Delhi, Kolkata and Chennai was reported by Bedi *et al*. (2020). Decrease in aerosol loading was reported by Kumar *et al*. (2020) during lockdown. But very limited studies could be found regarding the impacts of the COVID-19 persuaded lockdown on air quality of urban area of West Bengal. Present study is an effort to trace the effects of the COVID-19 lockdown on the alteration of the ambient air quality in four selected cities of West Bengal namely Kolkata, Howrah, Siliguri and Asansol.

2. Areas under analyses

Kolkata, Howrah, Siliguri, and Asansol are the four metro cities of West Bengal, an eastern Indian state. Reasons behind their inclusion in the present study as study areas were their unique location, rapid urbanization and importance in the economy of the state (Fig. 1). Population density of the Kolkata is the highest in the state: 24306/km^2 (Census of India 2011). Kolkata

(22°34′11″N, 88°22′11″E) is situated on the east bank of river Hooghly. Kolkata is the state capital and known as commercial hub of eastern India (Chowdhuri *et al*. 2020). Apart from two thermal power plants, a few large and medium scale industries are operating within Kolkata Municipal Corporation (KMC) area. Furthermore, large numbers of small scale industries including small rubber industries, dyeing and bleaching units, small fertilizer plants, secondary lead smelting units, anodizing and galvanizing units, cast iron foundries, hot rolling mills, gold smelting industries etc. are also operating in the city. Howrah (22° 35′ 44.77″ N, 88° 15′ 49.11″ E) is another important metropolitan city of West Bengal and situated on west bank of the Hooghly River. A huge conglomeration of several small and medium scale industries such as cast iron foundries, hot rolling mills, galvanizing units, cement unit, non-ferrous metal smelting units, jute mills, brick kilns etc. occur in and around Howrah mainly. Siliguri (26° 42′ 36″ N, 88° 25′ 48″ E) is situated in the northern part of the state. It lies on the bank of Mahananda River and at the foothills of Himalayas. It serves as 'gateway' of North-Eastern India and popular center for trade & commerce, tourism and employment. All these cause rapid population growth in Siliguri. Asansol (23° 40′ 48″ N, 86° 59′ 24″ E), an industrial city of West Bengal well-known for its rich coal mines. It is geographically part of Chotanagpur plateau and located on the bank of river Damodar. Development of Integrated iron and steel units, open cast mines, cement units, thermal power plants, Ferro Alloy units, Sponge iron units, Carbon black unit, Chlor-alkali unit, locomotive works etc. make Raniganj-Asansol area as one of the important economic hub of West Bengal. All of the four cities have been suffering the problems of urbanization, pollution and traffic congestion.

3. Materials and methods

Air Quality index (AQI) is mainly used to report the state of air quality and its effects on human health (Lokhandwala and Gautam, 2020). It is an overall scheme which transforms the weighted values of seven air pollutants ($PM_{2.5}$, PM_{10}, CO, NH_3, NO_2, SO_2 and Ozone) into a single number. Increase in AQI value indicates increase in air pollution and related health impacts (Mukherjee *et al*. 2012). An AQI between 0-50 is considered as 'Good', 51-100 as satisfactory, 101-200 as moderate, 201-300 as Poor, 301-400 as very Poor and 401-500 as severe. 24-h daily air quality data on Air Quality Index (AQI) and seven pollutants ($PM_{2.5}$, PM_{10}, NO_2, NH_3, SO_2, CO, and O3) were collected from the websites of Central Pollution Control Board (CPCB), NAQI-CPCB (National Air Quality Index-Central Pollution Control Board), Government of India for fixed-site monitoring stations of four selected cities of West Bengal. In West Bengal, March to May fall within pre-monsoon while December to February fall under winter season (Mukherjee *et al*. 2012). Three period: 1. Lockdown period: 25th March, 2020-31st May, 2020; 2. Pre-lockdown period: 24th December, 2020- 24th March, 2020 i.e., 3 months before and 3. 'Same window period' of previous year: 25th March, 2019-31st May, 2019 were considered for data collection and comparison. Period 1 and 3 both represent pre-monsoon while period 2 falls in winter. One way ANOVA analysis followed by least significant difference (LSD) tests were carried out to analyze significance of differences at 5% level of probability in ambient air quality parameters of COVID-19 lockdown, pre-lockdown (before 3 months) and same period of previous year at all four study areas (Gomez and Gomez 1984). Analyses on variation of different ambient air quality parameters throughout the different phases of lockdown were made.

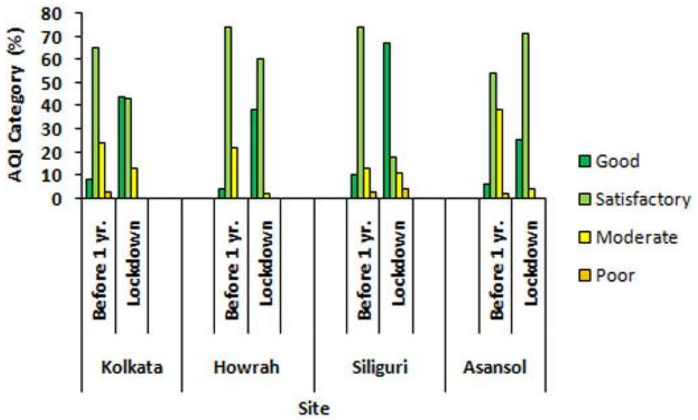

Fig. 2 Comparison of AQI category sharing (%) between COVID-19 lockdown period with 'Same period' of previous year (before 1 year) at study area

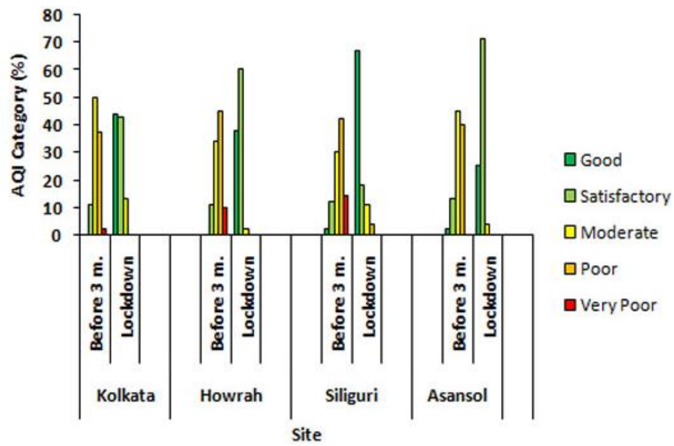

Fig. 3 Comparison of AQI category sharing (%) between COVID-19 lockdown period and Pre-lockdown period (before 3 months) at study area

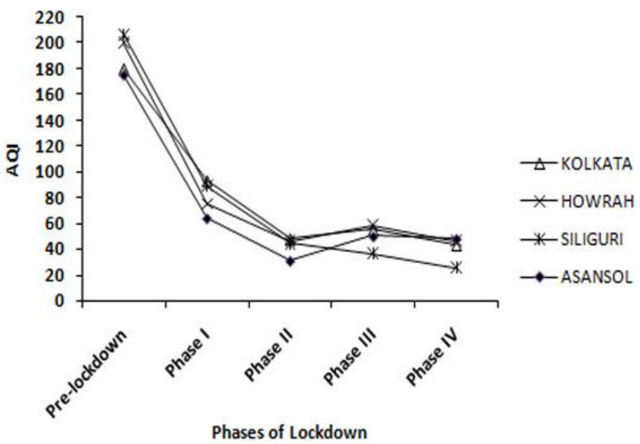

Fig. 4 Changes in AQI trend throughout the lockdown period in Kolkata, Howrah, Asansol and Siliguri, West Bengal, India

Table 1 Spatio-temporal variations of Air Quality Index (AQI) in different cities of West Bengal before and during lockdown

City	Average (Mean ± SD) Air Quality Index (AQI)			% change during Lockdown	
	Lockdown Period	Before three months	Before one year	Compared to three months before	Compared to one year before
Kolkata	62.12±26.84	180.00±59.61	86.74±37.65	65.49*	28.38*
Howrah	57.26±18.86	199.91±73.16	88.13±25.75	71.36*	35.03*
Siliguri	57.44±45.35	206.82±83.99	75.09±45.83	72.23*	23.51
Asansol	48.68±35.67	175.37±70.17	89.81±37.42	72.24*	45.80*

*Statistical Significance ($p < 0.05$)

4. Results and discussion

Two comparisons were made: one in Fig. 2 between COVID-19 lockdown period and same period of previous year and another one in Fig. 3 between COVID-19 lockdown period and pre-lockdown period i.e., 3 months before lockdown based on AQI category (%). Beside, changes in AQI trend throughout the lockdown period and spatio-temporal variations of AQI in different study areas of West Bengal, India were given in Fig. 4 and Table 1.

During COVID-19 lockdown period AQI category (%) was mostly in the ‘Good’, ‘Satisfactory’ and fewer ‘Moderate’ categories, with rare instances of ‘poor’ category (only in Siliguri) as shown in Figs. 2 and 3. AQI was in ‘Good’ category for maximum lockdown span at Siliguri (67%) followed by Kolkata (44%), Howrah (38%) and Asansol (25%). Average AQI ranges in between 48.68- 62.12 during the lockdown period (Table 1). Out of 4 cities during lockdown average AQI at Kolkata, Howrah and Siliguri were in ‘Satisfactory’ category and remaining one i.e., Asansol was in ‘Good’ category. In comparison to same period of previous year, significant improvements in average AQI were also noted in all the cities except Siliguri ($p >$ 0.05) during lockdown. Then average AQI ranges in between 75.09-89.81 and was in ‘Satisfactory category’ at all study areas. Table 1 showed 28.38% (Kolkata), 35.02 % (Howrah) and 45.80% (Asansol) decrease in average AQI during lockdown period compared to same period of previous year. In contrast, comparatively much higher average AQI values were recorded during pre-lockdown period (3 months before the lockdown): Kolkata (180), Howrah (199), Siliguri (206) and Asansol (175) due to vehicular emissions, road dust resuspensions and construction activities. Highest AQI recorded for Siliguri, Howrah, Kolkata and Asansol was 355, 340, 326 and 296 respectively during this period of winter season. Pollutant concentrations have a strong negative correlation with temperature, wind speed and relative humidity. So, particulate concentration become more in winter season – December to January (Mukherjee *et al*. 2012). ‘Moderate’ and ‘Poor’ AQI categories shared majority span of pre-lockdown period (Fig. 3). In Kolkata, average AQI has improved from 180 (moderate) to 93, 48, 55 and 43 (good); for Howrah, average AQI has recovered from 199 (Moderate) to 75, 46, 58, and 46 (good); In Siliguri, average AQI has improved from 207 (Poor) to 89, 44, 36 and 25 (good) and also for Asansol, average AQI has recovered also from 175 (Moderate) to 64, 31, 50 and 48 (good) during Lockdown in phase I-IV (Fig. 4). So, there is a positive trend in AQI shift with the progress of lockdown and appearance of good and satisfactory AQI category became more frequent.

Table 2 Spatio-temporal variations of ambient air quality parameters in Kolkata before and during lockdown

Air Pollutant	Average (Mean ± SD) pollutant concentration Location: KOLKATA			% change during Lockdown	
	Lockdown Period	Before three months	Before one year	Compared to three months before	Compared to one year before
$PM_{2.5}$ (μg/m^3)	38.84±23.15	164.95±79.78	79.86±42.08	76.45*	51.36*
PM_{10} (μg/m^3)	45.35±18.10	138.10±53.85	84.32±33.82	67.16*	46.22*
NO_2 (μg/m^3)	12.03±4.66	62.52±28.02	35.0±25.32	80.76*	65.63*
NH_3 (μg/m^3)	3.16±1.15	6.87±3.42	4.16±2.67	54.01*	24.04*
SO_2 (μg/m^3)	8.97±2.84	17.06±9.26	6.27±5.36	47.42*	- 43.06*
CO (mg/m^3)	18.97±7.08	32.48±20.30	24.92±10.64	41.59*	23.88*
O_3 (μg/m^3)	35.09±13.76	80.04±56.03	31.87±16.84	56.16*	- 10.10

*Statistical Significance ($p < 0.05$). N.B.: - sign indicates increase and + sign indicates decrease

Table 3 Spatio-temporal variations of ambient air quality parameters in Howrah before and during lockdown

Air Pollutant	Average (Mean ± SD) pollutant concentration Location: HOWRAH			% change during Lockdown	
	Lockdown Period	Before three months	Before one year	Compared to three months before	Compared to one year before
$PM_{2.5}$ (μg/m^3)	37.43±20.17	192.29±95.54	69.14±26.97	80.54*	45.86*
PM_{10} (μg/m^3)	51.20±28.24	165.18±77.83	83.95±23.84	69.00*	39.01*
NO_2 (μg/m^3)	18.32±6.51	71.82±25.27	32.49±17.88	74.49*	43.61*
NH_3 (μg/m^3)	2.15±0.97	6.76±2.25	2.33±1.64	68.20*	7.73
SO_2 (μg/m^3)	12.67±4.01	27.05±16.99	13.26±13.10	53.16*	4.45
CO (mg/m^3)	17.80±6.11	28.02±13.16	26.19±6.41	36.47	32.04*
O_3 (μg/m^3)	47.41±19.51	58.04±33.55	37.20±15.81	18.31*	- 27.45*

*Statistical Significance ($p < 0.05$). N.B.: - sign indicates increase and + sign indicates decrease

Table 4 Spatio-temporal variations of ambient air quality parameters in Siliguri before and during lockdown

Air Pollutant	Average (Mean ± SD) pollutant concentration at SILIGURI			% change during Lockdown	
	Lockdown Period	Before three months	Before one year	Compared to three months before	Compared to one year before
$PM_{2.5}$ (μg/m^3)	57.09±14.46	203.77±89.07	71.21±45.47	71.98*	19.83
PM_{10} (μg/m^3)	50.55±30.10	148.62±50.03	74.10±38.65	65.99*	31.78*
NO_2 (μg/m^3)	32.60±9.08	63.07±20.24	37.17±12.04	48.31*	12.29
NH_3 (μg/m^3)	6.33±1.72	8.24±1.80	5.88±2.17	23.18*	- 7.65
SO_2 (μg/m^3)	5.04±1.62	6.50±1.33	5.52±2.20	22.46*	8.70
CO (mg/m^3)	21.88±3.20	27.10±5.21	51.63±8.33	19.26*	57.62*
O_3 (μg/m^3)	29.56±8.70	37.07±7.27	57.78±17.19	20.26*	48.84*

*Statistical Significance ($p < 0.05$). N.B.: - sign indicates increase and + sign indicates decrease

Table 5 Spatio-temporal variations of ambient air quality parameters in Asansol before and during lockdown

Air Pollutant	Average (Mean ± SD) pollutant concentration at ASANSOL			% change during Lockdown	
	Lockdown Period	Before three months	Before one year	Compared to three months before	Compared to one year before
$PM_{2.5}$ (μg/m³)	52.33±14.46	171.52±74.08	91.72±33.83	69.49*	42.95*
PM_{10} (μg/m³)	68.80±19.14	133.99±37.13	88.48±27.42	48.65*	22.24*
NO_2 (μg/m³)	15.98±7.04	50.63±26.94	28.73±9.30	68.44*	44.38*
NH_3 (μg/m³)	3.04±1.49	8.13±5.23	7.12±2.68	62.61	57.30*
SO_2 (μg/m³)	11.57±6.17	20.60±7.75	5.23±5.23	43.83*	- 121.22*
CO (mg/m³)	24.58±10.02	32.32±12.23	19.00±7.29	23.95*	- 29.37*
O_3 (μg/m³)	20.94±7.29	41.08±14.08	54.49±29.37	49.03*	61.64*

*Statistical Significance ($p < 0.05$). N.B.: - sign indicates increase and + sign indicates decrease

Spatio-temporal variations of ambient air quality parameters in different cities of West Bengal found during lockdown, pre-lockdown (3 months before lockdown) and same period of previous year (before 1 year) are summarized in Tables 2-5 showing mean concentration and percent difference.

In Kolkata 76.45%, 51.36% reduction in $PM_{2.5}$; 67.16%, 46.22% reduction in PM_{10}, 80.76%,65.63% reduction in NO_2; 54.01%, 24.04% reduction in NH_3; 41.59%, 23.88% reduction in CO occured during lockdown compared to pre-lockdown and 'same period' of previous year respectively (Table 2). In comparison to pre-lockdown, 47.42% and 56.16% reduction in SO_2 and O_3 level noted during lockdown. But SO_2 level during lockdown was 43.06% higher than the 'same period' of previous year. However, there was no change in O_3 concentration during lockdown as compared to identical period of previous year.

Similarly 80.54%, 45.86% reduction in $PM_{2.5}$; 69%, 39.01% reduction in PM_{10}, 74.49%, 43.61% reduction in NO_2 occurred during lockdown in Howrah while comparing to pre-lockdown period and 'same period' of previous year respectively (Table 3). Beside 68.20%, 53.16% and 18.31% decrease in NH_3, SO_2, O_3 level found during lockdown as compared to pre-lockdown. Carbon monoxide level remained unchanged. On the other hand, NH_3 and SO_2 level during lockdown remain same as that of previous year. 32.04% reduction in CO and 27.45% increase in O_3 level observed during lockdown in comparison to previous year. Rise in O_3 level may be due to lesser emissions of O_3 degrading compounds like NO_x during lockdown.

In Siliguri 71.98%, 48.31%, 23.18%, 22.46% reduction occurred in $PM_{2.5}$, NO_2, NH_3, SO_2 during lockdown compared to pre-lockdown period but no significant changes were found in comparison to 'same period' of previous year. Beside 65.99%, 31.78% reduction in PM_{10}; 19.26%, 57.62% reduction in CO and 20.26%, 48.84% reduction in O_3 during lockdown in Siliguri as compared to pre-lockdown period and 'same period' of previous year respectively (Table 4).

During lockdown, 69.49%, 48.65%, 68.44%, 43.83%, 23.95% and 49.03% decrease in $PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, O_3 occurred in Asansol compared to pre-lockdown period. But no significant change was found in NH_3 level. In comparison to 'same period' of previous year 42.95%, 22.24%, 44.38%, 57.30%, 61.64% reduction in $PM_{2.5}$, PM_{10}, NO_2, NH_3, O_3 level occurred during lockdown. Beside 121.22% and 29.37% increase in SO_2 and CO occurred respectively during

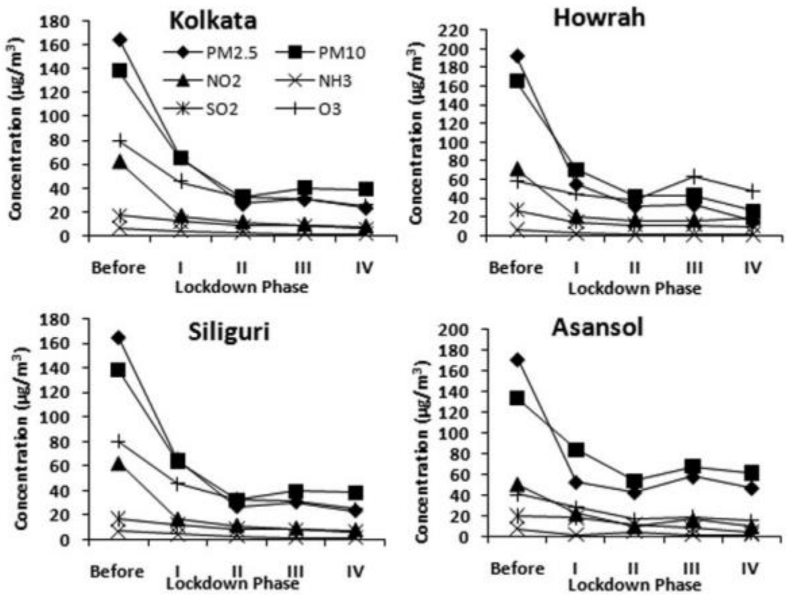

Fig. 5 Spatio-temporal variations of ambient air quality parameters in different cities of West Bengal during lockdown (Phase I – IV).

lockdown for the same (Table 5). Rise in CO may have correlation with lower precipitation and high temperature during lockdown.

Ambient air quality parameters in all of the areas of present study showed sharp decline in Phase-1.0 of lockdown due to sudden implementation of restrictions on anthropogenic activities (Fig. 5). Decline trend remained unaltered in phase-2.0 also. There was no significant changes ($p > 0.05$) in CO and O_3 level in Howrah compared to Phase 2.0. However, further reductions in Phase-3.0 were noted for NO_2 and NH_3 level in Kolkata; NH_3 and O_3 in Siliguri; NH_3 and SO_2 in Kolkata. In contrast, rising level of $PM_{2.5}$ and PM_{10} in Kolkata; O_3 level in Howrah; $PM_{2.5}$, PM_{10}, NO_2 and CO levels in Asansol were also noted in Phase-3.0. Again, NH_3 and SO_2 level in Kolkata; $PM_{2.5}$, PM_{10}, O_3 level in Howrah; CO and O_3 level in Siliguri; NO_2 and SO_2 level in Asansol decreased in Phase-4.0 of lockdown. Level of NH_3 increased. Others remained same as that of Phase-3.0 of lockdown.

Findings of the present study are in close agreement with several other researchers. In comparison to previous year, Garg *et al*. (2020) reported due to lockdown 62%, 52% and 69% reduction in the concentration of $PM_{2.5}$, PM_{10}, and NO_2 respectively within India while SO_2 and O_3 remained unchanged. Kulshrestha (2020) also observed drop in air pollutants level in the major mega-cities of India during nationwide lockdown since 24 March 2020. Again, Bedi *et al*. documented 53.6%, 34.2%, 31.5%, 22.8%, 28.5% and 6.3% decrease in $PM_{2.5}$, PM_{10}, NH_3, SO_2, CO and O_3 respectively in Kolkata during lockdown. Major contributors of air pollution in Kolkata are emissions from motor vehicles (51.4%) followed by industry (24.5%) and dust particles (21.1%) (WBPCB 2005). Since 2009 to 2017, there was 144.61% increase in the number of registered motor vehicles in West Bengal while Kolkata experienced 37.69 % increase in its registered motor vehicle population (Government of India, 2011, 2019). In Kolkata, around 65% of the total vehicles and 99% of commercial vehicular population are running on diesel (CSE

2011). Remaining vehicles run on petrol. Excessive use of cars and motor cycles further aggravate vehicular pollution load contributing nitrogen oxides (NO_x), hydrocarbon, particulate matter and carbon monoxide in ambient level (Mukherjee *et al*. 2012). Calcutta High Court issued an order on July 18, 2008 to ban commercial vehicles older than 15 years or more and all two-stroke auto-rickshaws have to convert to new four stroke liquefied petroleum gas (LPG) or compressed natural gas (CNG) autos by March 31, 2009 in Kolkata Metropolitan area (Mukherjee *et al*. 2012). Illegal uses of adulterated fuel called 'Katatel' in autos instead of LPG deteriorate air quality of the city. Another potent source of city's air pollution is fossil fuel based power plants in and around the city. Furthermore, huge number of roadside eateries using coal, kerosene oil etc. while cooking foods are also responsible to cause air pollution. All these factors render detrimental effects on ambient air quality index (AQI) of the city. Air quality deteriorates more in winter than summer. Due to strictness of lockdown in the form of shut down in industrial sector, construction works, transports and strict restrictions on human movement etc. air pollutants level goes down. However, air quality in different urban areas may differ with regards to their geographical position, sources of pollution, development status and meteorological conditions (Marlier *et al*. 2016).

The National Ambient Air Quality Standards (NAAQS, 2009) for 24 h average samples in industrial, residential, rural and other area is 60 $\mu g/m^3$ for $PM_{2.5}$, 100 $\mu g/m^3$ for PM_{10}, 80 $\mu g/m^3$ for Nitrogen Dioxide (NO_2) and Sulphur Dioxide (SO_2), 400 $\mu g/m^3$ for Ammonia (NH_3), 4mg/m^3 for Carbon Monoxide (CO) and 180 $\mu g/m^3$ for Ozone (O_3) of 1 h average samples according to notification of Central Pollution Control Board, India. Except carbon monoxide, all other six ambient air quality parameters ($PM_{2.5}$, PM_{10}, NO_2, NH_3, SO_2 and O_3) were well within permissible limit of NAAQS (2009) at all study areas during COVID-19 lockdown. Furthermore, the levels of NO_2, SO_2, O_3 in all four cities during lockdown were found within WHO air quality guideline values (2018). But the daily mean concentration of $PM_{2.5}$ was found to be two times higher than the WHO daily reference value of 25$\mu g/m^3$ for all the cities. Kumar *et al*. (2020) pointed out variation in reduction level of $PM_{2.5}$ in different cities of the world during lockdown. Lockdown strictness, local meteorological conditions, anthropogenic pollution sources and their switch off period may remain behind such variation. Furthermore, household biomass burning, municipal solid waste incineration, thermal power plants, local transport etc may contribute $PM_{2.5}$ during lockdown. Apart from Kolkata, daily average PM_{10} level at other three cities exceeded WHO limits (50$\mu g/m^3$). Vehicular emissions, coal and wood combustion, road dust, dust from construction works, secondary aerosols etc. are the major sources of $PM_{2.5}$ and PM_{10} in Kolkata and Howrah. $PM_{2.5}$, PM_{10} level and $PM_{2.5}$ / PM_{10} ratio in the study areas draw utmost attention to curb the particulate matter.

5. Conclusions

It may be concluded from the present statistical analyses that the recent COVID-19 lockdown appeared to be quite positive in West Bengal, India from environmental health perspective. Air quality especially in cities showed remarkable improvement during lockdown compared to pre-lockdown and 'same period' of previous year due to restricted anthropogenic activities. COVID-19 lockdown not only restricted spread of novel corona virus but also benefited mother earth by giving the scope of healing and rejuvenation. But costs of enforcing lockdown are massive and it should never be the option- rather alternative ways should be invented to mitigate air pollution. Undoubtedly, there is urgent need of peoples' consciousness about environment. Judicious exploitation of mother nature and keeping environmental health at optimized level should become the goal of every nation by making pollution level down. We should avoid unnecessary use of cars with gas oil and should insist to run with bio-fuel/ hydrogen fuel with zero/clean emission. Industries should be operated with controlled emissions. Proper planning and policy making should be needed to control air pollution in the present ‘new normal’ COVID-19 scenario.

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