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Cover Page Footnote

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RESEARCH ARTICLE

COVID-19: A spectio-temporal analysis of air quality status in coking coalfields of India due to nationwide lockdown in India

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Abstract

A novel infectious corona virus disease (COVID-19) was identified in the month of December 2019. It has now been announced as a worldwide pandemic by the World Health Organization. COVID-19 pandemic has positive impacts on the environmental pollutants. In present work, Coalfield areas of Jharia Coalfields (JCF), India have been taken as a case study to evaluate the effect of the lockdown on air quality at 10 locations. This study had been selected to estimate the reduction in concentration of pollutants like PM_{10}, $PM_{2.5}$, SO_2, and NOx during 3 Seasons (summer, Post-Monsoon and winter season) in the year 2019 in comparison to the concentration during the lockdown period i.e. from April 2020 to June 2020. The study areas selected was as fire affected and non-fire affected areas of Jharia Coalfield to identify the contribution of pollutants in the mining area to establish the baseline concentration of Business as usual (BAU) vs. the lockdown condition.

The average reduction in concentration of PM_{10}, $PM_{2.5}$, SO_2 and NOx was observed as 18%, 14%, 22% and 26% respectively during the lockdown period in comparison with the annual average concentration.

As observed, the AQI value at the selected monitoring sites in JCF was 1.5 times higher in comparison to the lockdown period.

This study will provide the confidence to the regulatory body for strict implementation of the applicable air quality standard/policies in the mining areas. The study will also provide confidence to the regulatory body in making emission control strategies for improvement of environmental conditions and human health.

Keywords: air pollution, Air Quality Index (AQI), coal mining, COVID-19, lockdown

1. Introduction

Due to the spread of a novel contagious infection of the coronavirus (COVID-19) entire world is going through a very stressful situation [1]. World Health Organization (WHO) has declared COVID-19 as a ‘global pandemic’ on 11 March 2020. First case of COVID-19 in India was reported in Kerala on 30th January 2020. As the number of COVID-19 cases increased to 500, Honourable Prime Minister of India asked nationwide Janta (Public) Curfew across India on 22nd March 2020. Followed by this, nationwide lockdown was declared from 25th March 2020 in different phases. The first phase of lockdown was from 25th March to 14th April 2020, second phase was from 15th April 2020 to 3rd May 2020, the 3rd phase was from 4th May to 17th May 2020 and the fourth phase was from 18th May to 31st May 2020.

During the lockdown, social gathering was prohibited. Shopping complexes, school/colleges, educational institutes, restaurants and cinema halls were fully closed. Employees were asked to work from home. Transportation services including Railways, Air and road were suspended except essential services. Hence, the lockdown led to minimum human activities on the road and around the study area. Though, the lockdown has affected economy of the country, but this helped in reduction of air pollution level across the country.

Coal Mining activities are always blamed for degradation of Air Quality Status of its surrounding [2]. COVID-19 has given an opportunity to assess

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pollution load in the mining areas due to mining activities.

This study will provide the baseline condition of the air pollution condition of the coal mining area. This study will provide the confidence to the regulatory body for strict implementation of the applicable air quality standard/policies in the mining areas. The study will also provide confidence to the regulatory body in making emission control strategies for improvement of environmental conditions and human health. The data from study may also be utilized for Validation of Air Quality Models currently being used for Air Quality Impact Prediction (AQIP) in the coalfield areas.

India is falling in the in the list of developing nations of the world. India is the world's largest producer of coal after China. The share of coal has increased in energy mix as well as the power mix in India. Coal provided 44% of the total primary energy supply (TPES) and 74% of electricity generation [21]. India has abundant coal reserve [2]. Coal mining come under essential services, the only measure activity was coal mining in the study area.

This present study had been commenced for assessment the ambient air quality like PM_{10}, $PM_{2.5}$, SO_2 and NOx during three seasons of the previous year i.e. summer, post-monsoon and winter and during the lockdown period i.e. from April 2020 to June 2020.

This study had been undertaken for assessment of ambient air quality among the mine fire-affected and non-mine fire affected coal mining areas of JCF to identify the contribution of pollutants in the mining area for comparison of Business as usual

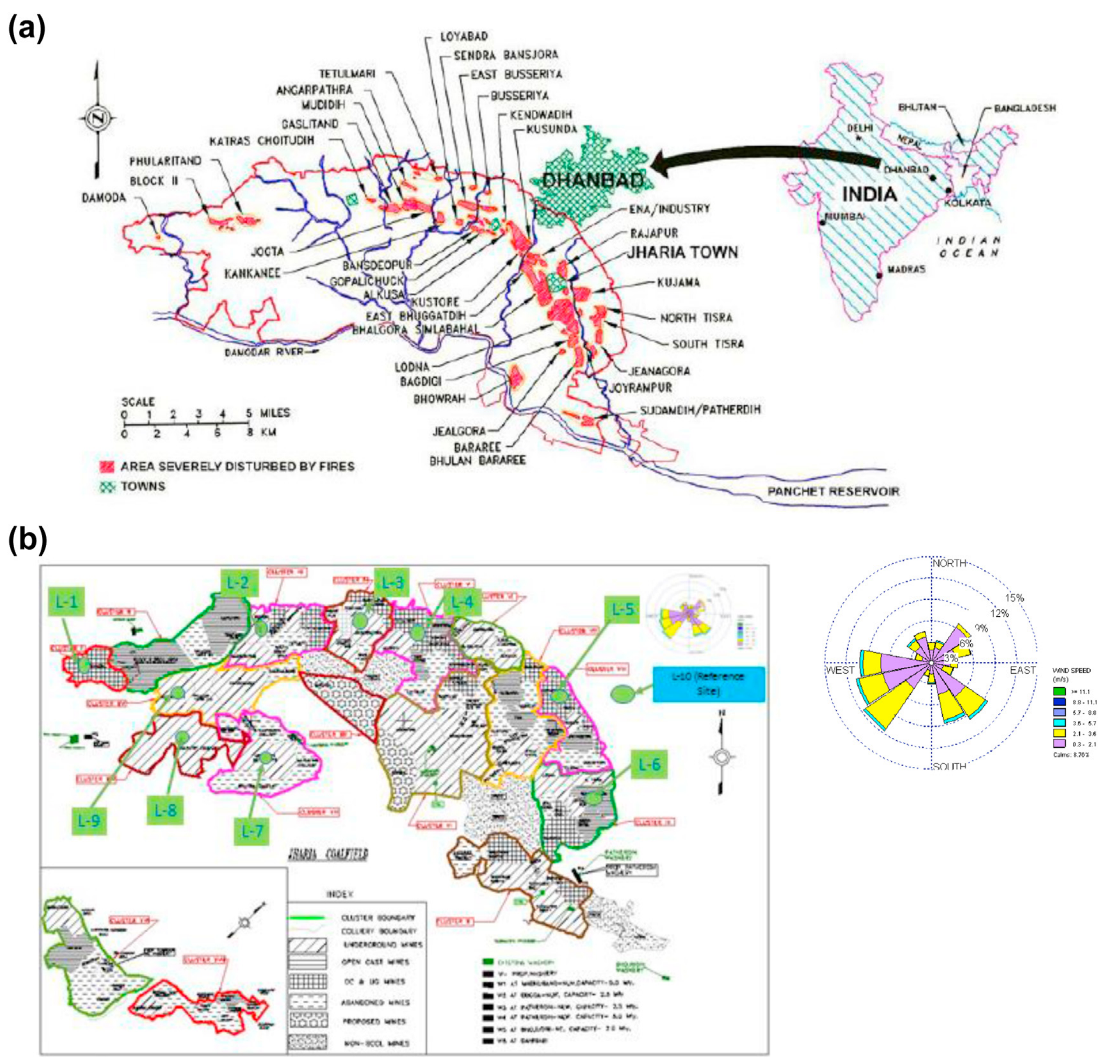

*Fig. 1. **(a)**: Jharia Coalfield (JCF) location shown on the map of India. **(b)**: Monitoring stations shown on the map of Jharia Coalfield (JCF) along with Wind rose diagram.*

(BAU) and during the lockdown period to establish the baseline concentration of BAU vs. the lockdown condition.

This study will be beneficial for the policy maker for reviewing pollution standard in mining areas for implementation of better mitigation measures.

2. Location of the study area

Jharia Coalfield contributes to the Indian economy as it provides metallurgical coal as well as thermal coal to steel and power sectors respectively. It provides infrastructural input to many core industries and powerhouses.

As per the coal mining history of India, it was supposed to be the smartest and profitable area for mining as it has the highest concentration of thick coal seams at relatively shallow depths. In India only JCF is having known reserves of prime coking coal in India and meets a sizeable proportion of coking coal required by the steel industry.

The Jharia coalfield, located in Damodar valley region covering an area of 453 sq. km is sickle-shaped and morph tectonically represents half-graben configuration with its southern boundary marked by basin margin fault [3]. It is bounded by the latitudes 23°36′–23°48′ N and the longitudes 86°07′–87°29′ E. JCF is spread in 38 km (length) and 17 km width (Fig. 1 (a), (b)).

The study area falls under tropical climate and is characterized by very hot summer and cold winters. The months of May and June are very hot. The average temperature of the study area was varying from 20 °C to 40 °C during the study period. The wettest month (with the highest rainfall) was July (342 mm) and driest month (with the lowest rainfall) is December (5 mm). The area receives annual rainfall of about 1140–1700 mm.

Predominant wind direction was from the south-west during the study period. As the wind rose diagram indicates, the percentage of calm condition was 8.76%.

3. Materials and methods

3.1. Study area and its monitoring locations

Air quality monitoring stations were selected at nine locations predominantly affected areas due to mining activities based on coal mine fire and non-fine areas [4,5].

Coal mining in Jharia coalfields is very difficult due to the problem of mine fire and subsidence. In JCF, shallow depth coal seams of good quality were mined out unscientifically. Mining activities were functioned within small leaseholds. In the old days, when the surface was not densely populated, the mine operators used to extract as much coal as possible in the upper coal horizons without stowing or supporting.

The mine fires occurs due to spontaneous heating of the coal through two interconnected processes between oxygen coal contact or oxidation process and the thermal process. The fire spreads and reaches in the strata. About 10% of total national coal resources are in the fire-affected areas [2]. This unscientific mining in the area leads to coal mine fire, caused severe air pollution in the area.

To study background concentration level Monitoring at Koyla Nagar, Dhnabad campus was also done for the same period. The details of monitoring stations along with latitude-longitude and source of air pollution have been presented in the Table 1.

3.2. Monitoring

The monitoring sites (Table 1) had been selected by considering predominant wind direction and area affected by mine fire to give an actual picture. The air quality monitoring had been done in three seasons summer, post-monsoon and winter for the previous year 2019 and again during lockdown period i.e. from April 2020 to June 2020. Monitoring in the selected areas was completed twice in a week (for 24 h) at the uniform intervals (Table 2).

4. Results and discussion

4.1. Particulate matter concentration

Particulate matter and gaseous pollutants like PM_{10}, $PM_{2.5}$, SO_2 and NOx were monitored at nine locations of Jharia Coalfields (JCF) along with one reference site at Koyla Nagar Colony, Dhanbad in the three seasons: summer, post-monsoon and winter. Season wise particulate matter concentration of PM_{10}, $PM_{2.5}$, SO_2 and NOx at ten different monitoring locations are shown in the Fig. 1. A significant variation has been observed in pollutant concentrations in all the monitoring site of the selected mining areas during all the seasons.

The maximum noted PM_{10} concentration (462 μg/m^3) was at AKWMC OC (L-3) during the winter followed by NT/ST Expan. OCP (L-6) (391 μg/m^3), Damoda OC (L-1) (358 μg/m^3), Tetulmari (UG&OC) (L-4) (350 μg/m^3), Bastacolla UG (L-5) (344 μg/m^3), Lohapatty OC (L-8) (336 μg/m^3), Murulidih 20 and 21 pits UG (L-7) (328 μg/m^3), Jogidih Colliery (UG) (L-2) (306 μg/m^3), Madhuband Colliery (L-9) (233 μg/m^3), Koyla Nagar L-10 (120 μg/m^3) Fig. 2.

Table 1. Details of monitoring stations along with latitude-longitude and air pollution sources.

Location	Details	Monitoring Location	Latitude -Longitude	Source of Air Pollution
L-1	Mine fire area	Damoda OC	23.763° N 86.178°E	The Sampling location is present nearby Damoda Opencast (OC), which is adjacent to the ongoing Mining activities like coal transportation, vehicular movement etc. The surrounding of the site is also densely populated area.
L-2	Non fire area	Jogidih Colliery (UG)	23.799°N 86.255°E	Underground (UG) Mining activities and coal transportation, vehicular movement etc.
L-3	Mine fire area	AKWMC OC	23.806°N 86.336°E	The Sampling location is present nearby AKWMC Opencast (OC).Apart from the mining activity there is coal fire in coal seam and on the Over Burden (OB) dumps.
L-4	Mine fire area	Tetulmari (UG&OC)	23.808°N 86.336°E	Monitoring site is nearby the ongoing mining activities and active mine fire in the coal seam.
L-5	Non fire area	Bastacolla UG	23.768°N 86.411°E	Underground (UG) mining activities and coal transportation, vehicular movement etc.
L-6	Mine fire area	NT/ST Expan. OCP	23.727°N 86.434°E	The sampling location is present nearby NT/ST Expn. Open cast (OC). Apart from the mining activity there are coal fire in coal seam and on the Over Burden (OB) dumps.
L-7	Non fire area	Murulidih 20 and 21 pits UG	23.732°N 86.282°E	Underground (UG) mining activities and coal transportation, vehicular movement etc.
L-8	Non fire area	Lohapatty OC	23.741°N 86.214°E	Underground (UG) mining activities and coal transportation, vehicular movement etc.
L-9	Non fire area	Madhuband Colliery	23.780°N 86.252°E	Underground (UG) mining activities and coal transportation, vehicular movement etc. and surrounded by densely populated area.
L-10	Reference Site-Non Mining area	Koyla Nagar	23.801°N 86.463°E	Used as a reference monitoring site. Its residential area and isolated from any mining activities.

The PM_{10} Concentration of the ten selected monitoring sites varied between 65 and 462 μg/m^3 being minimum and maximum at AKWMC OC (L-3) and Koyla Nagar Colony respectively.

Average annual concentrations of PM_{10} were observed maximum in the ambient air of NT/ST Expan. OCP (L-6) (326 μg/m^3) during the whole period of monitoring, followed by AKWMC OC (L-3) (325 μg/m^3), Bastacolla UG (L-5) (237 μg/m^3), Damoda OC (L-1) (254 μg/m^3), Lohapatty OC (L-8) (232 μg/m^3), Murulidih 20 and 21 pits UG (L-7) (233 μg/m^3), Jogidih Colliery (UG) (L-2) (228 μg/m^3), Tetulmari (UG&OC) (L-4) (208 μg/m^3), Madhuband Colliery (L-9) (175 μg/m^3), Koyla Nagar L-10 (87 μg/m^3).

The sampling location at AKWMC OC (L3) is at a distance of 3 km from opencast mine, the highest noted concentration was noted in all three seasons (345 ± 39 μg/m^3) in summer, 262 ± 42 μg/m^3 in post-monsoon and 369 ± 61 μg/m^3 in winter season. At concentration level of particulate matter at Damoda OC (L-1), NT/ST Expan. OCP (L-6), Lohapatty OC (L-8) was noted higher due to the observed active mine fire along with other mining activities. In these areas due to spontaneous combustion and unscientific coal mining and other factors caused self-ignition of coal, leads to active coal mine fire in the coal seams [6,7].

The observed $PM_{2.5}$ values of the monitoring sites were found in the range of 40 μg/m^3 to 235 μg/m^3 during winter. The average $PM_{2.5}$ concentrations (156 μg/m^3) were noted at NT/ST Expan. OCP (L-6) during the winter followed by AKWMC OC (L-3) (151 μg/m^3), Murulidih 20 and 21 pits UG (L-7)

Table 2. Sampling methods along with the instruments used.

Particular	Instruments	Analysis Method	Limit of Detection
Particulate matter PM_{10}	Respirable dust sampler (RDS) (Make: Envirotech APM 460)	Gravimetric method IS 5182 (Part -23):2006 [17]	3.5 μg/m^3 to 1000 μg/m^3
Particulate matter $PM_{2.5}$	Fine particulate sampler (Make: Envirotech APM550 ELM)	Gravimetric method IS 5182 (Part -24):2006 [17]	2 μg/m^3 to 200 μg/m3
Sulphur dioxide SO_2	Respirable dust sampler (RDS) along with gaseous sampler (Make: Envirotech APM 411 TE)	Improved West and Gaeke method (CPCB, 2012) [5].	10 μg/m^3 to 200 μg/m^3
Oxides of nitrogen NOx	RDS along with gaseous sampler (Make: Envirotech APM 411 TE)	Jacob and Hochheiser modified method: IS 5182 (Part − 6): 2006 [17]	6 μg/m^3 to 750 μg/m^3

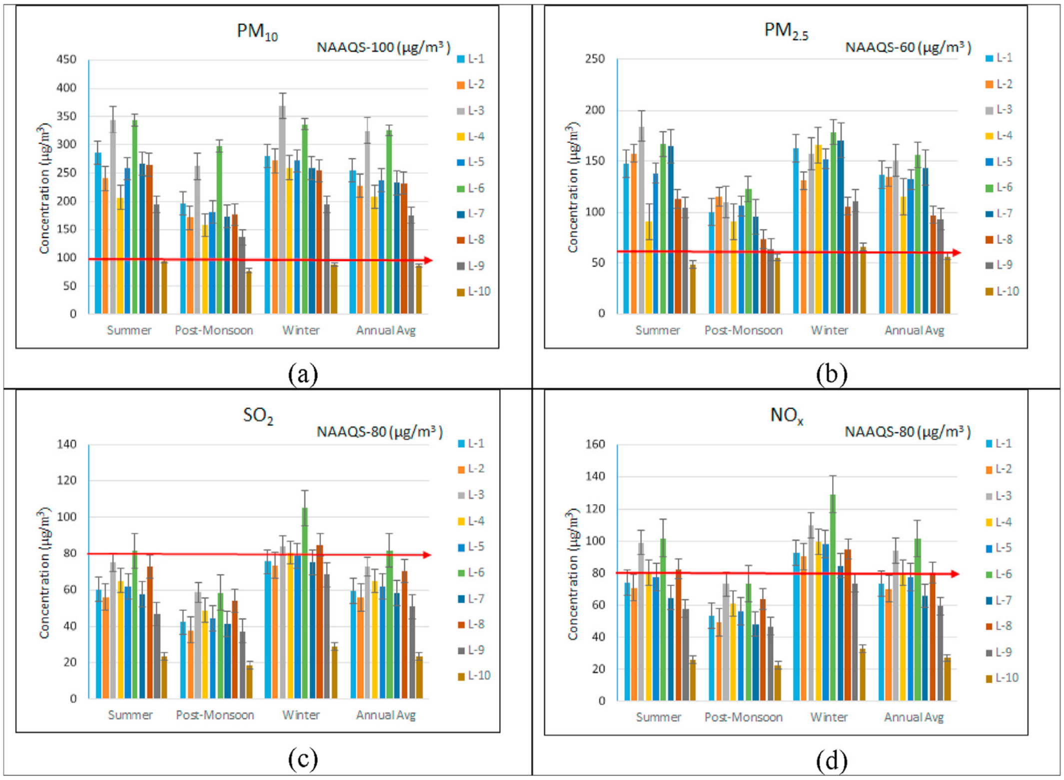

Fig. 2. Seasonal variation in Concentration (μg/m³) of (a) PM_{10}, (b) $PM_{2.5}$, (c) SO_2 and (d) NOx at ten monitoring sites before lockdown i.e. Business as usual (BAU) at JCF.

(144 μg/m³), Bastacolla UG (L-5) (132 μg/m³), Damoda OC (L-1) (137 μg/m³), Jogidih Colliery (UG) (L-2) (135 μg/m³), Tetulmari (UG&OC) (L-4) (116 μg/m³), Lohapatty OC (L-8) (97 μg/m³), Madhuband Colliery (L-9) (93 μg/m³) and at Koyla Nagar L-10 (57 μg/m³).

At NT/ST Expan. OCP (L-6) and Koyla Nagar (L-10) the concentration was shown highest and lowest concentration of $PM_{2.5}$ during the period of monitoring.

The concentrations levels of $PM_{2.5}$ in the ambient air ranging between 49 and 185 μg/m³ during winter, 56 and 110 μg/m³ during summer and 66 and 179 μg/m³ during post-monsoon.

The concentration levels of particulate matter at Jogidih Colliery (UG) (L-2), Tetulmari (UG&OC) (L-4), Murulidih 20 and 21 pits, Lohapatty OC (L-8) and Madhuband Colliery (L-9) which are coal mining areas of Jharia Coalfield (JCF) but not affected by coal mine fire were observed lower than areas suffering from mine fire. The concentration of $PM_{2.5}$ was found in higher side compared with the permissible limits as per by the National Ambient Air Quality Standards [8].

At all the sites except Koyla Nagar (L10) (reference site) exceeded the limit value of NAAQS, 2009 for particulate matter by a factor of 2.54 (L-1), 2.28 (L-2), 3.25 (L-3), 2.08 (L-4), 2.37 (L-5), 3.26 (L-6), 2.33 (L-7), 2.32 (L-8), and 1.75 (L-9) respectively for PM_{10} and by a factor of 2.28 (L-1), 2.24 (L-2), 2.51 (L-3), 1.93 (L-4), 2.20 (L-5), 2.60 (L-6), 2.39 (L-7), 1.62 (L-8), and 1.55 (L-9) respectively for $PM_{2.5}$.

The particulate matter concentration is affected by the mechanism of dispersion of pollutant, topography of the monitoring areas along with meteorological parameters [9]. The particulate matter in the winter season near the pollution sources remains concentrated. Due to lower temperatures and wind speed, the particulate matter does not disperse to a greater distance. In the summer season, due to higher wind speed and dispersion of particulate matter lower atmospheric pollutants were observed. During post-monsoon season, the lower pollution level was observed due to higher relative humidity. In this season, the particulate matter washed out by precipitation, causing the lowest concentration level.

Spatial distribution of particulate pollutants concentration observed at different monitoring stations have been drawn. There were significant variations in the concentration level at all the monitoring sites selected among JCF.

Air quality of reference site, Koyla Nagar colony (L-10) was observed as a satisfactory level because it was far away from mining and its allied activities.

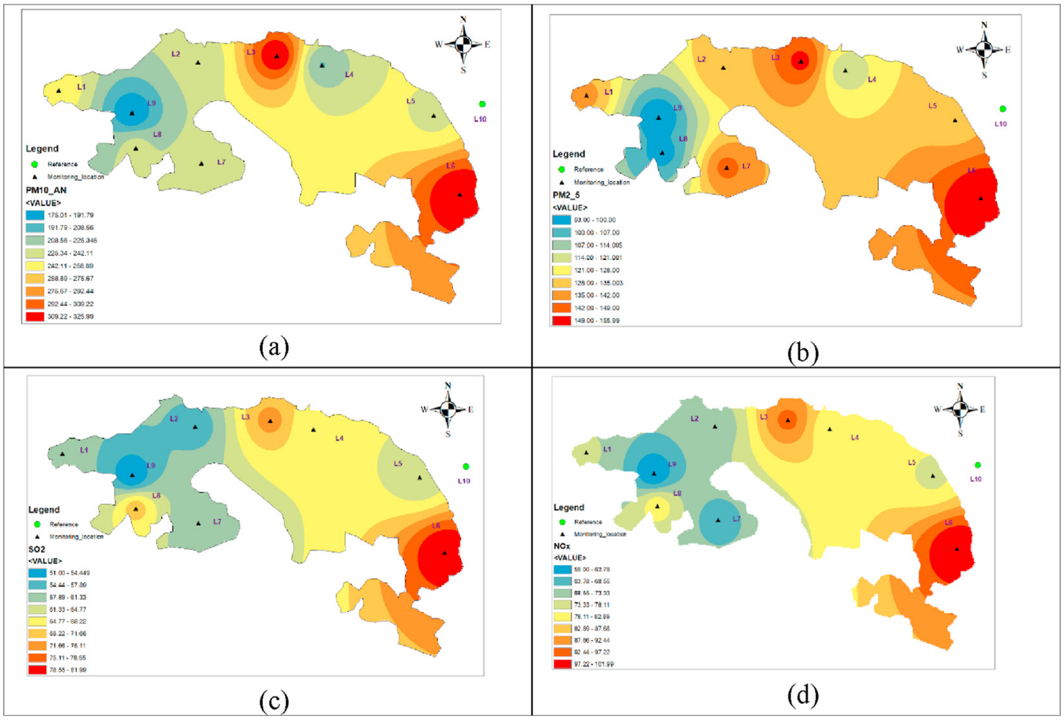

Fig. 3. Spatial distribution of 3(a) PM_{10}, 3(b) $PM_{2.5}$, 3(c) SO_2 and 3(d) NOx at different monitoring sites ***before the lockdown i.e. Business as usual (BAU).***

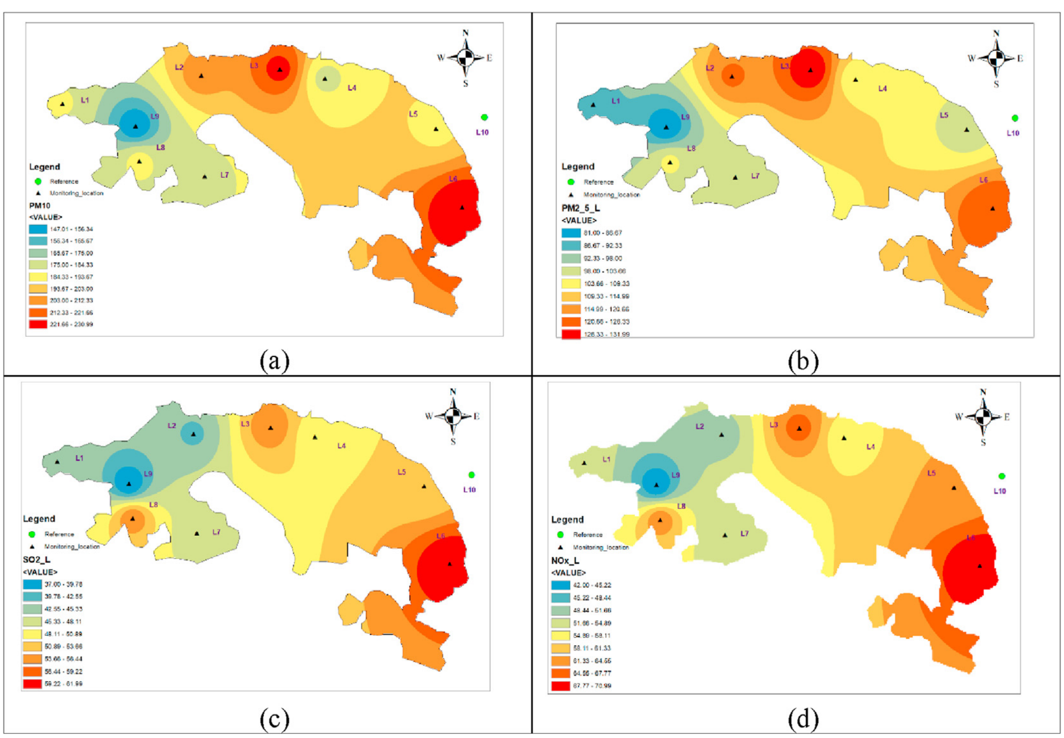

Fig. 4. Spatial distribution of 4 (a) PM_{10}, 4 (b) $PM_{2.5}$, 4 (c) SO_2 and 4 (d) NOx at different monitoring sites ***during the lockdown.***

Koyla Nagar colony is surrounded by Green Belt and is free from any polluting sources. Hence, the pollutants levels observed were minimum in all three seasons. All sites except the at Koyla Nagar (L-10) (reference site) indicated a much higher concentration of gaseous pollutants than the NAQQS (2009) permissible limit in the pre-lockdown situation.

Average SO_2 concentration levels were observed highest during the monitoring period at NT/ST Expan. OCP (L-6) (82 μg/m^3), followed by AKWMC OC (L-3) (73 μg/m^3), Lohapatty OC (L-8) (70 μg/m^3), Tetulmari (UG&OC) (L-4) (65 μg/m^3), Bastacolla UG (L-5) (62 μg/m^3), Damoda OC (L-1) (59 μg/m^3), Murulidih 20 and 21 pits UG (L-7) (58 μg/m^3), Jogidih Colliery (UG) (L-2) (56 μg/m^3), Madhuband Colliery (L-9) (51 μg/m^3) and Koyla Nagar L-10 (24 μg/m^3).

The average concentration levels of NO_x in ambient air were seen highest at NT/ST Expan. OCP (L-6) (102 μg/m^3), followed by AKWMC OC (L-3) (94 μg/m^3), Lohapatty OC (L-8) (81 μg/m^3), Tetulmari (UG&OC) (L-4) (80 μg/m^3), Bastacolla UG (L-5) (77 μg/m^3), Damoda OC (L-1) (74 μg/m^3), Jogidih Colliery (UG) (L-2) (70 μg/m^3), Murulidih 20 and 21 pits UG (L-7) (66 μg/m^3), Madhuband Colliery (L-9) (59 μg/m^3) and Koyla Nagar L-10 (27 μg/m^3).

Among the selected monitoring stations, concentration at NT/ST Expan. OCP was found the highest concentration of gaseous pollutants (SO_2 and NO_x) during the entire monitoring period [10]. It was because of the existence of coal mines nearby the site which were highly affected by coal mine fire. Sites like AKWMC OC (L-3) (73 μg/m^3), Lohapatty OC (L-8) (70 μg/m^3), Tetulmari (UG&OC) (L-4) (65 μg/m^3), Bastacolla UG (L-5) (62 μg/m^3), were present nearby to mines fire affected area. These sites showed higher level of gaseous pollutants (SO_2 and NO_x) which badly polluted the ambient air quality. In monitored coal mines, sulphur rich coal discharges sulphur dioxide after the combustion. The coke-oven plants also discharge incompletely oxidized nitrogen dioxide. Due to this monitoring stations like, Lohapatty OC, Tetulmari, Bastacolla, Damoda, Murulidih 20 and 21 pits and Jogidih Colliery showed higher concentration. Hence, the production of higher levels of SO_2 and NOx was a sign of the greater level of pollution in the areas under coal mine fire [16]. The concentration levels of gaseous pollutants were higher at all monitoring sites in winter in comparison with the seasons like summer and post-monsoon. It was due to the lower atmospheric dispersion of pollutants concentrations during the winter seasons [11,12].

The Jharia Coalfields falling under a tropical climatic pattern with temperature lower along with lower sunlight and lower wind speed (on an average 2 km/h) during winter season. This causes very poor dispersion of pollutants in the areas. Hence concentration level of NOx was highest in winter in comparison with seasons like summer and post-monsoon. Raised levels of NO_x in six monitoring sites may also be endorsed due to the incident like active coal mine fire, vehicular movement and other mining and allied activities [13,14]. Spatial distribution of the average concentration levels of pollutants like PM_{10}, $PM_{2.5}$, SO_2 and NOx are depicted in Fig. 3 [2,15].

5. Pollutant concentration levels during the lockdown period

During lock down period the average PM_{10} concentrations were found maximum in the ambient air of NT/ST Expan. OCP (L-6) (231 μg/m^3) followed by AKWMC OC (L-3) (226 μg/m^3), Jogidih Colliery (UG) (L-2) (208 μg/m^3), Bastacolla UG (L-5) (191 μg/m^3), Lohapatty OC (L-8) (188 μg/m^3), Damoda OC (L-1) (185 μg/m^3), Tetulmari (UG&OC) (L 4) (181 μg/m^3), Murulidih 20 and 21 pits UG (L-7) (181 μg/m^3), Madhuband Colliery (L-9) (147 μg/m^3), and Koyla Nagar L-10 (95 μg/m^3).

Spatial distribution of PM_{10}, $PM_{2.5}$, SO_2 and NOx average concentration levels have at different monitoring sites **during the lockdown period** have been shown in the Fig. 4.

During lock down the average concentrations of $PM_{2.5}$ were found maximum at AKWMC OC (L-3) (132 μg/m^3), followed by NT/ST Expan. OCP (L-6) (126 μg/m^3), Jogidih Colliery (UG) (L-2) (122 μg/m^3), Tetulmari (UG&OC) (L-4) (105 μg/m^3), Lohapatty OC (L-8) (105 μg/m^3), Bastacolla UG (L-5) (100 μg/m^3), Damoda OC (L-1) (90 μg/m^3), Murulidih 20 and 21 pits UG (L-7) (98 μg/m^3), Madhuband Colliery (L-9) (81 μg/m^3) and Koyla Nagar L-10 (58 μg/m^3).

It was observed that there was a significant reduction of pollutant levels at all the monitoring stations in comparison with the Annual Average (BAU), Summer-2019 and during Lock-down period at ten monitoring sites of JCF. This reduction was due to the decreased human activities in the area other than mining activities.

Comparative Concentration level of PM_{10}, $PM_{2.5}$, SO_2 and NOx between annual Average (BAU), Summer-2019 and during the lockdown period at ten monitoring sites of JCF has been shown in the Fig. 5.

Comparative reduction of concentration levels (%) w.r.t. annual average (BAU) vs. annual average at all the monitoring sites have been executed, the same has been shown in the table no. 3. It has been

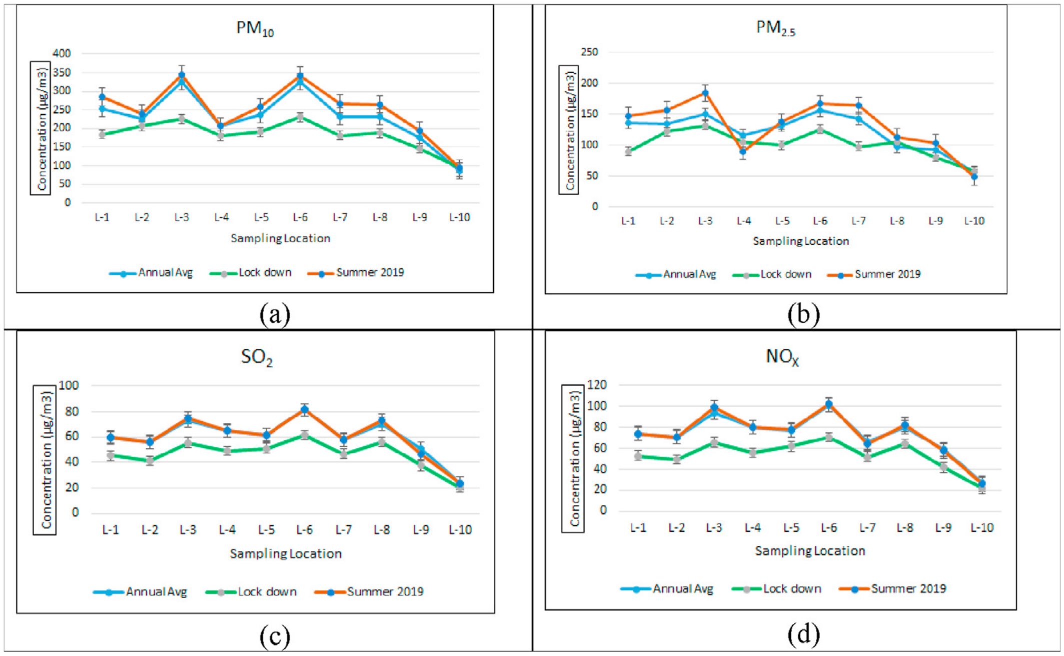

Fig. 5. Comparative Concentration (µg/m³) level of 5 (a)PM_{10}, 5 (b) $PM_{2.5}$, 5 (c) SO_2 and 5 (d) NOx between Annual Average (BAU), Summer-2019 and during the lockdown period at ten monitoring sites of JCF.

observed that there was a significant reduction in all the four parameters like PM_{10}, $PM_{2.5}$, SO_2 and NOx.

The average reduction in concentration of PM_{10}, $PM_{2.5}$, SO_2 and NOx was observed as 18%, 14%, 22% and 26% respectively during the lockdown period in comparison with the annual average concentration (see Table 3).

The graphical representation of the % reduction has been shown in the Fig. 6.

6. Air quality index

Data generated after monitoring at different monitoring stations does not represent air quality status to the common public, scientific community and policy makers. Hence to represent the air quality in a single number (AQI index value), air quality index (AQI) is a very important tool.

To compare air quality status of the study area in the pre-lockdown (BAU) and lockdown period AQI for all the monitoring stations have been calculated and represented in the Table 4. AQI of the monitoring stations have calculated by using National Air Quality Index guidelines provided by Central Pollution Control Board (CPCB), Government of India [8].

AQI converts complex air quality data of the pollutants into a single number (index value) and a specific color code gives information on air quality and its connected health impacts, which can be understood by a common people. The pollutant concentration (Ip) values were calculated and the

Table 3. Reduction in Concentration Levels (%) w.r.t. Annual Average (BAU) vs. Annual Average.

Location	% Reduction PM_{10}	% Reduction $PM_{2.5}$	% Reduction SO_2	% Reduction NOx
L-1	27	34	24	28
L-2	9	9	26	30
L-3	31	12	23	30
L-4	13	9	24	31
L-5	20	24	17	20
L-6	29	19	25	31
L-7	22	32	19	21
L-8	19	−8	20	20
L-9	16	13	27	30
L-10	−10	−2	15	21

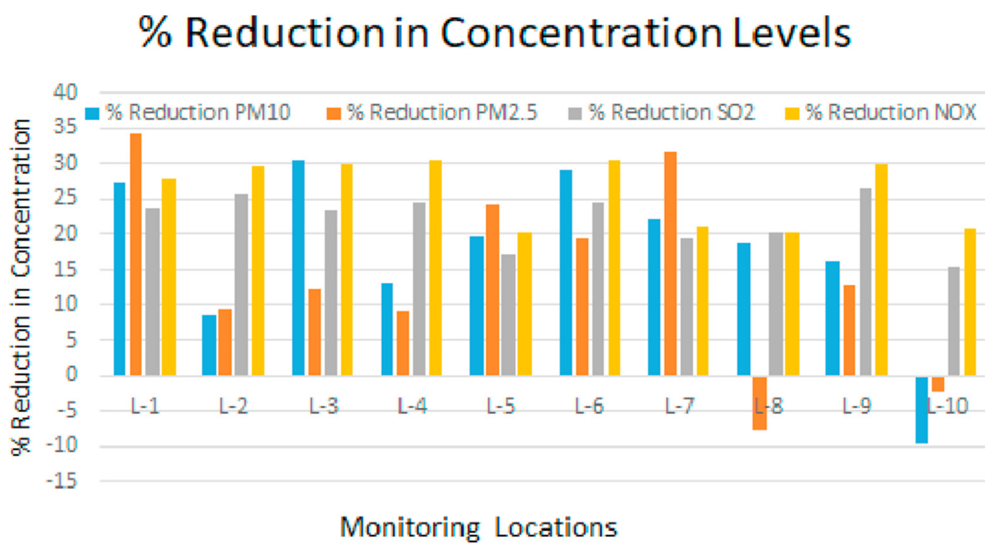

Fig. 6. Percentage Reduction in concentration of PM_{10}, $PM_{2.5}$, SO_2 and NOx during the lockdown period w.r.t. Annual Average (BAU) concentration.

Table 4. Air Quality Index (AQI) of different monitoring sites BAU vs the lockdown period at different sampling locations of study area.

	Pre Lock-down Period(BAU)		**Lock-down Period**	
ID no. of Monitoring Location	**AQI Value**	**AQI Category**	**AQI Value**	**AQI Category**
L-1	313	Very Poor	200	Moderate
L-2	311	Very Poor	302	Very Poor
L-3	324	Very Poor	309	Very Poor
L-4	285	Poor	250	Poor
L-5	309	Very Poor	233	Poor
L-6	328	Very Poor	305	Very Poor
L-7	318	Very Poor	250	Poor
L-8	225	Poor	250	Poor
L-9	210	Poor	170	Moderate
L-10	95	Satisfactory	97	Satisfactory

maximum Ip values were taken as the AQI of the site monitored according to the formula:

$$I_P = [\{(I_{HI}\text{-}I_{LO})/(B_{HI}\text{-}B_{LO})\}X(C_P\text{-}B_{LO})] + I_{LO} \qquad (1)$$

where I_P is the sub-index, B_{HI} is the breakpoint concentration greater than or equal to the concentration given, B_{LO} is the breakpoint concentration less than or equal to the concentration given, I_{HI} is

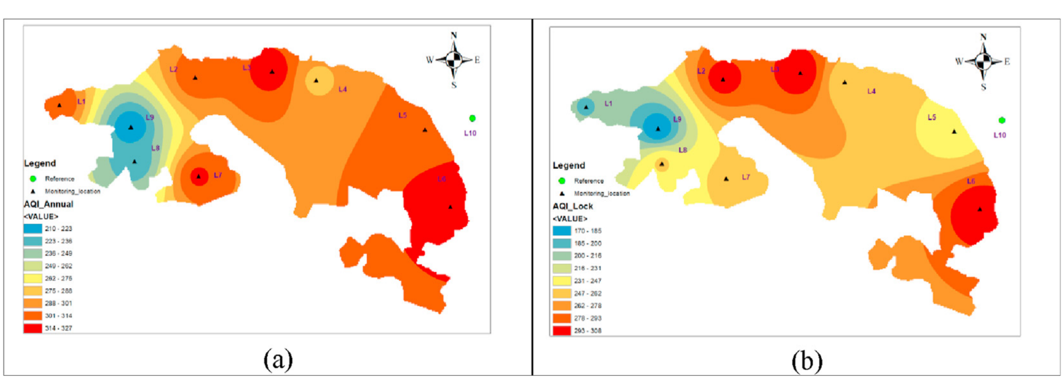

Fig. 7. Spatial distribution of Air Quality Index (AQI) of different monitoring sites (a) BAU vs (b) the lockdown period.

the AQI value corresponding to B_{HI}, I_{LO} is the AQI value corresponding to B_{LO} and C_P is the concentration of pollutants. Finally,

$$AQI = \max(I_P) \quad (2)$$

where $P = 1, 2, \ldots, n$ denotes n pollutants.

AQI were calculated by using the formula prescribed by CPCB (2014) for all the ten selected monitoring stations (Fig. 7). AQI values in the prelockdown varies from minimum 95 to maximum 328 and during the lockdown it was varying from minimum 97 to maximum 309. As shown in the table no. 3 the AQI values in the monitoring location falling in the mine fire affected area was observed in the very poor category. However, it has been noted that during the lockdown period the AQI value observed was in the poor category. Further, it is observed that in the reference site (L-10), AQI value was in the satisfactory category in both the period of monitoring i.e. in BAU vs. the lockdown period.

The reason of monitoring areas falling in the category very poor, it was due to burning of coal, road transportation of the coal and insufficient burning of coal in the exposed coal seams and over burden (OB) of the mining areas.

As observed, the air quality of the monitoring station at Koyla Nagar (L-10) comes under satisfactory level, as this location does not attract any mining and its allied activities.

As observed (Fig. 7) the AQI of the monitoring area shows the overall image of the Jharia Coalfields with pollution load in the coal capital of India.

7. Conclusions

COVID-19 has created a severe threat to the population on the earth. It has affected the world economy. However, the COVID-19 has some positive impact on air pollution reduction of the glove due to the implementation of national lockdown since 25th March 2020 [18–20]. The present study has shown the comparative status of the pollutants in the selected study area in the pre-lockdown situation (BAU) and during the lockdown. It was observed that there was a significant reduction of pollutant levels at all the monitoring stations in comparison with the Annual Average (BAU), Summer-2019 and during the lockdown period at ten monitoring sites of JCF. The average reduction in concentration of PM_{10}, $PM_{2.5}$, SO_2 and NOx was observed as 18%, 14%, 22% and 26% respectively during the lockdown period in comparison with the annual average concentration.

This reduction was due to the decreased human activities in the area other than mining activities. As observed, the AQI value at the selected monitoring sites in JCF was 1.5 times higher than the in comparison to the lockdown period. This study will provide the baseline condition of the air pollution condition of the coal mining area. This study will provide the confidence to the regulatory body for strict implementation of the applicable air quality standards/policies in the mining areas. The study will also provide confidence to the regulatory body in making emission control strategies for the improvement of environmental conditions and human health. The data from study may also be utilized for Validation of Air quality Models currently being used for Air quality Impact Prediction (AQIP) in the coalfield areas.

Ethical statement

The authors state that the research was conducted according to ethical standards.

Funding body

None.

Conflicts of interest

None declared.

Appendix A. Supplementary Data.

Table 1. Location wise Annual Average PM10 Concentration (2019 and during lockdown)

Location	Annual Average PM_{10}		Lockdown PM_{10}	
	Annual Avg	SD	Lockdown	SD
L-1	254	53	185	23
L-2	228	53	208	26
L-3	325	64	226	24
L-4	208	60	181	30
L-5	237	53	191	25
L-6	326	39	231	18
L-7	233	52	181	20
L-8	232	49	188	17
L-9	175	32	147	14
L-10	87	14	95	14

Table 2. Location wise Annual Average PM2.5 Concentration (2019 and during lockdown)

Location	Annual Avg $PM_{2.5}$		Lockdown $PM_{2.5}$	
	AM	SD	AM	SD
L-1	137	31	90	5
L-2	135	23	122	14
L-3	151	36	132	14

(continued on next page)

Table 2. (continued)

Location	Annual Avg $PM_{2.5}$		Lockdown $PM_{2.5}$	
	AM	SD	AM	SD
L-4	116	41	105	19
L-5	132	26	100	10
L-6	156	32	126	9
L-7	144	40	98	9
L-8	97	23	105	10
L-9	93	24	81	9
L-10	57	9	58	13

Table 3. Location wise Annual Average SO2 Concentration (2019 and during lockdown)

Location	Annual Avg SO_2		Lockdown SO_2	
	AM	SD	AM	SD
L-1	59	15	45	4
L-2	56	17	42	5
L-3	73	18	56	5
L-4	65	15	49	6
L-5	62	16	51	9
L-6	82	21	62	6
L-7	58	16	47	5
L-8	70	15	56	6
L-9	51	18	37	4
L-10	24	6	20	3

Table 4. Location wise Annual Average NO_X Concentration (2019 and during lockdown)

Location	Annual Avg NO_X		Lockdown NO_X	
	AM	SD	AM	SD
L-1	74	18	53	8
L-2	70	20	50	6
L-3	94	21	66	6
L-4	80	18	56	8
L-5	77	20	62	11
L-6	102	25	71	11
L-7	66	17	52	8
L-8	81	15	64	8
L-9	59	16	42	7
L-10	27	6	22	2

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