Stationary Source Emissions and Impact Assessment on Ambient Air Quality: A Case Study of Delhi Region

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Abstract Establishing equilibrium in atoms of various pollutants in atmosphere is the prime objective of environmental policies set by the governing bodies. The industries abide to environmental norms and regulations essential to control air pollution from stationary sources. Among wind, vehicle movement and industry, the latter is a major contributor to air pollution that necessitates regular monitoring. Through this study, we have attempted to analyse the contribution of stationary sources of industries to the air pollution in Delhi. The comparative study before and after nationwide lockdown due to Covid19 pandemic provides an insight into the role of organised and unorganised industry in air pollution emission. This paper portrays the decrease in air pollutants because of temporary shutdown of unorganised industry with stack emissions. However, the organised industries like power generating sector remained functional and continued to add air pollutants. This study on air pollution during lockdown contemplates an urgency to formulate provisions that will force the industries to adhere to air emission monitoring and standards. Due to restrictions of industry, the challenges persist in the detail study of combustion and plume discharge. The future scope of this study is to quantify the contribution of plume discharges from organised and unorganised industries and conduct detailed analysis of stationary sources emissions due to combustion.

Keywords Impact assessment · Air quality · Stationary source emissions · Covid19

1 Introduction

A major part of air pollution results from organised and unorganised industries through stationary source emissions. Emission from the industries is a result of combustion of various sources of fuel that emits greenhouse gases like carbon dioxide, methane, nitrous oxide and also fluorinated gases that trap heat from the sun

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and atmosphere causing global warming [1]. This creates a cycle where air pollution contributes to climate change and climate change creates higher temperatures, in turn, higher temperature intensifies some types of air pollution. The air pollution leads to smog formation because of high heat and increased level of ultraviolet radiation. Smog reduces visibility, irritates the phalanx, irritate the eyes and causes respiratory distress. The conversion of NO–NO_2 is a major factor of smog formation. The power plants and factory emissions are one of major sources of nitrous oxide. The reaction of sunlight with oxides of nitrogen and volatile organic compounds causes the formation of ground level ozone. The deposition of oxides of nitrogen leads to acidified terrestrial and aquatic ecosystem. The consequence of which is loss of plant or fish population and change in biodiversity. The particulate matter in atmosphere causes severe alteration in natural nutrient and chemical balance of soil, air and water. National Ambient Air Quality Standards have specified standard and guidelines for monitoring the industrial emissions. Air being a transboundary element is subjected to permissible limits of being contaminated by industries, and the lack of research in the field of combustion, keep us unaware of the various unknown particles emitted from the stationary source of pollution, i.e. stack, from the industries. The comparative study before and after nationwide lockdown due to Covid19 pandemic provides an insight into the role of organised and unorganised industry in air pollution emission.

2 Study Area

Delhi NCR region is situated along the 28° 24′ 17″ and 28° 53′ 00″ North and longitudes of 76° 50′ 24″ and 77° 20′ 37″ East. The Union Territory shares borders with the States of Uttar Pradesh and Haryana with 51.90 km as maximum length and 48.48 km wide. Through many reports and news article [2, 3], the air pollution level of Delhi has been reported to be much beyond the permissible limit. A study, conducted by IIT Kanpur [4], reported that NO_x emissions are far higher at 312 tonnes per day with industrial stack accounting for 52% (Fig. 1).

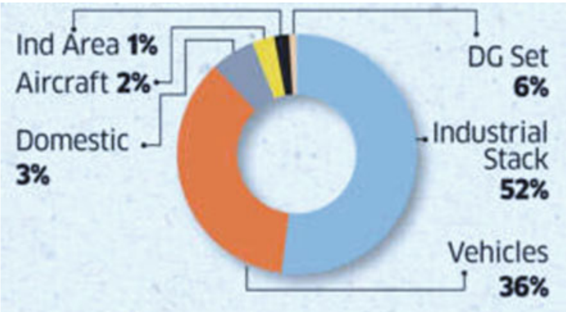

Fig. 1 NO_x emissions in Delhi

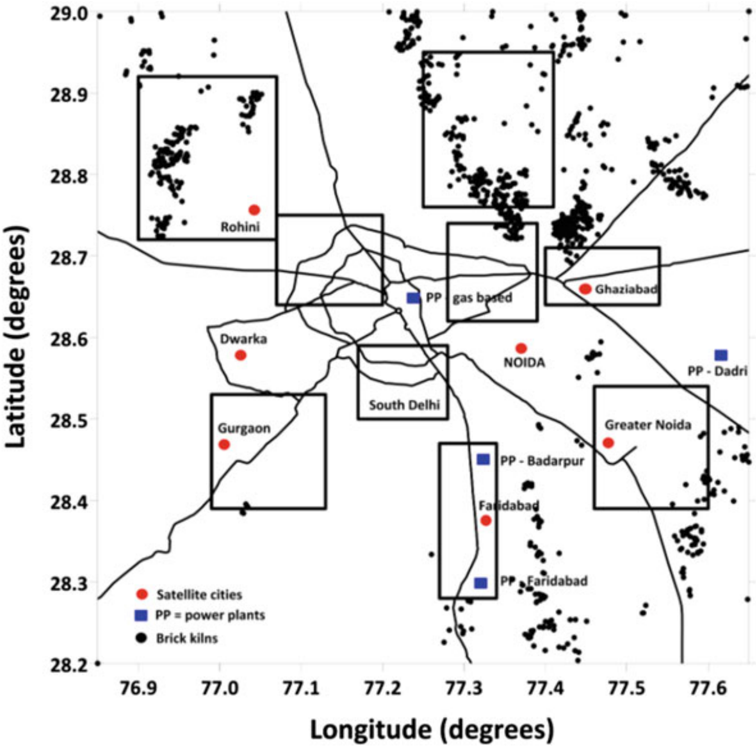

Fig. 2 Delhi and NCR region with kilns and power plants. *Source* urbanemission.info

To understand the air pollution in Delhi region, we have to consider the source of pollutions around and outside the administrative boundary of Delhi [5]. Figure 2, depicts Delhi and satellite cities with road network and location of brick kilns and power plants that are major source of NO_x emissions.

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3 Ambient Air Quality of Stationary Sources

3.1 Plume Chemistry

Sulphur and Nitrogen are being major pollutants from the stationary source of air pollution. Oxidation in atmosphere is the initial reaction of these elements [6, 7]. The rate of oxidation determines the elements they react with and the products formed in gaseous phases and aqueous phase. Power stations use fossils fuels as energy source. Detail reactions study during the combustion of these fossil fuels is a major challenge. However, the major pollutants detection and the effect of photolysis have proven to be of significance in the study of stack emission phenomenon.

Ozone layer depletion is a major cause of NO_x concentration. The water vapour present in atmosphere plays a critical role in heterogeneous oxidation of SO_2 emitted from the plume [8]. The water vapour present in the atmosphere determines the rate of change of SO_2 from one state to another and condensation to form aerosols of sulphate. Acid deposition and environmental acidification are two major contribution of SO_2 oxidation [9].

3.2 *Sulphur Dioxide Chemistry in Atmosphere*

Out of the total sulphur content in coal, 90% is emitted into the atmosphere as sulphur dioxide after combustion process. The reactions of sulphur dioxide in the atmosphere lead to formation of sulphur dioxide and sulphur trioxide. This sulphur dioxide mixes with water vapour and form acid rain, which is the sulphuric acid formation.

Water present in air leads to an aqueous solvent oxidation. With the ionic products of the SO_2, it can dissolve itself in water for establishing equilibrium. Due to this establishment of equilibrium in the aqueous phase, sulphite ions ($SO_2{}^{3-}$), bisulphite ions ($HSO_3{}^-$) hydrated SO_2 ($SO_2 \cdot H_2O$) are found. NO_2 concentration being high in the emission point of stack leads to formation of $O^3(P)$ by photo-dissociation process. This results in higher rate of SO_2 oxidation. But this rate of reaction decreases instantly as the dilution of plume takes place by air flow. Table 1 provides the list of chemical reactions of sulphur dioxide with atmospheric gases and sunlight [9].

Table 1 List plume gas reactions in atmosphere

Reaction	$-\Delta H^{\circ}$ (kJ mol^{-1}) 25 °C	k (cm^3 molec^{-1} s^{-1})
$O_2(^1\Delta_g) + SO_2 \rightarrow SO_4$ (biradical)	105	
$O_2(^1\Delta_g) + SO_2 \rightarrow SO_4$ (cyclic)	~117	3.9×10^{-20}
$O_2(^1\Delta_g) + SO_2 \rightarrow SO_3 + O(^3P)$	−56.5	
$O_2(^1\Delta_g) + SO_2 \rightarrow SO_2(^3\Sigma_g^-) + SO_2$	94	
$O_2(^1\Sigma_g^+) + SO_2 \rightarrow SO_4$ (biradical)	167	
$O_2(^1\Sigma_g^+) + SO_2 \rightarrow SO_4$ (cyclic)	180	6.6×10^{-16}
$O_2(^1\Sigma_g^+) + SO_2 \rightarrow SO_3 + O(^3P)$	6.3	
$O_2(^1\Sigma_g^+) + SO_2 \rightarrow SO_2 + O_2(^1\Delta_g)$	62.8	
$O(^3P) + SO_2(+M) \rightarrow SO_3(+M)$	347	5.7×10^{-14}
$SO_3 + SO_2 \rightarrow O_2 + SO_3$	241	$< 8 \times 10^{-24}$
$NO_2 + SO_2 \rightarrow NO + SO_3$	41.4	8.8×10^{-30}
$NO_3 + SO_2 \rightarrow NO_2 + SO_3$	136	$< 7 \times 10^{-21}$
$ONOO + SO_2 \rightarrow NO_2 + SO_3$	~126	$< 7 \times 10^{-21}$
$N_2O_5 + SO_2 \rightarrow N_2O_4 + SO_3$	100	$< 4 \times 10^{-23}$
$HO_2 + SO_2 \rightarrow HO + SO_3$	69.9	
$HO_2 + SO_2(+M) \rightarrow HO_2SO_2\ (+M)$	29.3	$< 1 \times 10^{-18}$
$CHO_3O_2 + SO_2 \rightarrow CHO_3O + SO_3$	~113	$< 1 \times 10^{-18}$
$CHO_3O_2 + SO_2(+M) \rightarrow CHO_3O_2SO_2(+M)$	~130	$\sim 1.4 \times 10^{-14}$
$(CH_3)_3CO_2 + SO_2 \rightarrow (CH_3)_3CO + SO_3$	~109	
$(CH_3)_3CO_2 + SO_2 \rightarrow (CH_3)_3CO_2SO_2$	~126	$< 7.3 \times 10^{-19}$
$CHO_3COO_2 + SO_2 \rightarrow CH_3CO_2 + SO_3$	~138	
$CHO_3COO_2 + SO_2 \rightarrow CH_3COO_2SO_2$	~155	$< 7 \times 10^{-19}$
$HO + SO_2(+M) \rightarrow HOSO_2\ (+M)$	~155	1.1×10^{-12}
$CHO_3O + SO_2(+M) \rightarrow CH_3OSO_2\ (+M)$	~100	$\sim 5.5 \times 10^{-13}$
$SO_3 + H_2O \rightarrow H_2SO_4$	24.8	9.1×10^{-13}

3.3 Oxides of Nitrogen Chemistry in Atmosphere

The production of oxides of nitrogen ($NO + NO_2 \rightarrow NO_x$) is about 21–25 Tg NO_x every year. NO and NO_2 are emitted due to combustion process in power plants. The percentage of NO emitted during the high temperature combustion is 95% and NO_2 is 5%. During low atmospheric temperature, in places with high pollution concentration rapid oxidation of NO and NO_2 occur due to simultaneous reaction with atmospheric Oxygen. This occurs when the oxidants such as O_3, HO_2, OH and RO_2 are produced by photochemical reaction. This leads to the smog formation in the atmosphere at lower level. Acid deposition, acid rain and ozone formation in troposphere layer of the atmosphere are the significant hazards to human health and environment due to presence oxide of nitrogen. Nitric acid remains suspended in gas phase due to its volatile nature. The ammonium nitrate forms aerosol droplets at moderate humidity.

4 Air Quality Comparison Before and After Lockdown in Delhi Region

Through this study, we have attempted to analyse the contribution of stationary sources of industries to the air pollution in Delhi. The comparative study before and after nationwide lockdown due to Covid19 pandemic provides an insight into the role of organised and unorganised industry in air pollution emission.

The observation of one-month period from 16 March to 15 April 2020 as published by CPCB was used for the analysis [10]. The lockdown in our country was declared on 21 March 2020 and the period before this was taken as pre-lockdown and period after this date was considered as lockdown period. Several parameters were monitored in order to study the air quality of the capital city Delhi. Monitoring stations recorded a drastic change in the major pollutants of the atmosphere covering the city.

$PM_{2.5}$, PM_{10} and Nitrogen oxides were monitored and studies about to know the reduction of its level. The decrease in $PM_{2.5}$ is observed to be 46%, while PM_{10} is recorded to reduce its concentration by 50% due to this immediate pause of all outdoor activities in the city. The CO level is observed to be reduced by 37% during lockdown compared to the percentage observed pre lockdown. A considerable reduction of 56% was observed in NO_2 level. The NO_2% decrease in the atmosphere with in the first 20 days lockdown is recorded to reduce by 75% with 24-h observation by standards set for monitoring of air quality. However, the SO_2 level drop is comparatively less as power plant industries continued operation due to the necessity is recorded to 19% in reduction. This drop in the SO_2 emission is also due to the adaptation of less polluting industry fuels such as biogas. The benzene reduction is observed to reduce by 47%. The lowest pollutant emission parameters recorded on 24-h basis are 39 $\mu g/m^3$ of PM_{10}, 24 $\mu g/m^3$ of $PM_{2.5}$ 15 $\mu g/m^3$ of NO_2 and 10 $\mu g/m^3$ of SO_2. Figure 3 presents the comparison of various pollution parameters for pre and post lock down period in Delhi region.

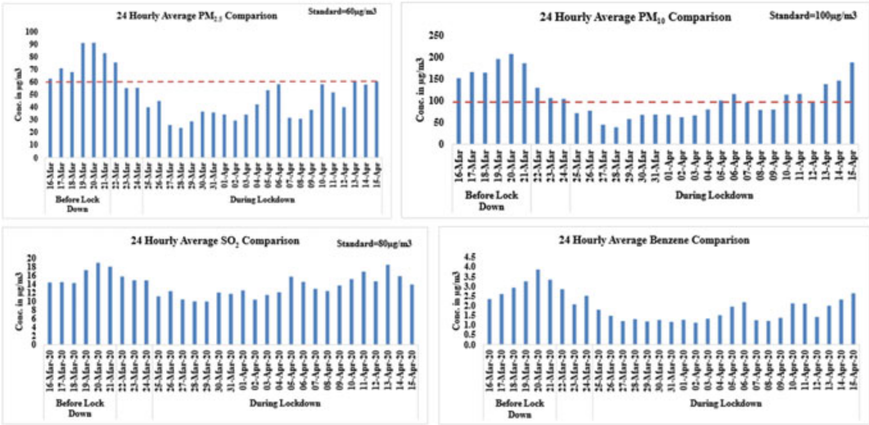

Fig. 3 24-hourly average comparison of air pollution parameters ($PM_{2.5}$, PM_{10}, SO_2, Benzene) for one month (16 March to 15 April 2020) in Delhi region

Because of close down of unorganised industrial activities like brick kilns along with vehicle movement led to a significant improvement in air quality.

The graph in Fig. 4 depicts the hourly concentration of $PM_{2.5}$ and PM_{10} for prelockdown phase 16 March 2020 to 21 March 2020 and the lockdown phase from 25 March 2020 to 15 April 2020.

A major observation recorded with respect to the PM_{10} is that the maximum concentration amount pre-lockdown days were 244 $\mu g/m^3$ at 22:00 h which declined to 127 $\mu g/m^3$ and the minimum concentration amount pre-lock down was calculated to be 118 $\mu g/m^3$ at 17:00 h which declined to 63 $\mu g/m^3$ during the lockdown phase. For $PM_{2.5}$, maximum concentration pre-lockdown phase was 114 $\mu g/m^3$ at 08:00 h, which was recorded to drop to 21 $\mu g/m^3$ at 17:00 h during the lockdown phase. Due to restriction over the industrial activities, the maximum concentration of benzene was reduced to 49% and the minimum value was recorded to reduce by 50%. However, the SO_2 concentration was recorded to have the least reduction rate of 14% as the power plants were operational.

5 Impact Assessment

Urbanisation has accelerated the rise of industries with increase in air pollution, water pollution and fresh water scarcity and solid waste generation. The industries and vehicular movement is a major contributor of air pollution. More than 50% of SO_2 and NO_x emissions in Delhi are attributed by stationary source emissions of organised and unorganised industries. Air pollutants are majorly causing acid rain, toxic cloud formation, reduction in visibility, entrapment of heat which is further leading to the alteration of biodiversity, degradation in quality of plants, and materials. The

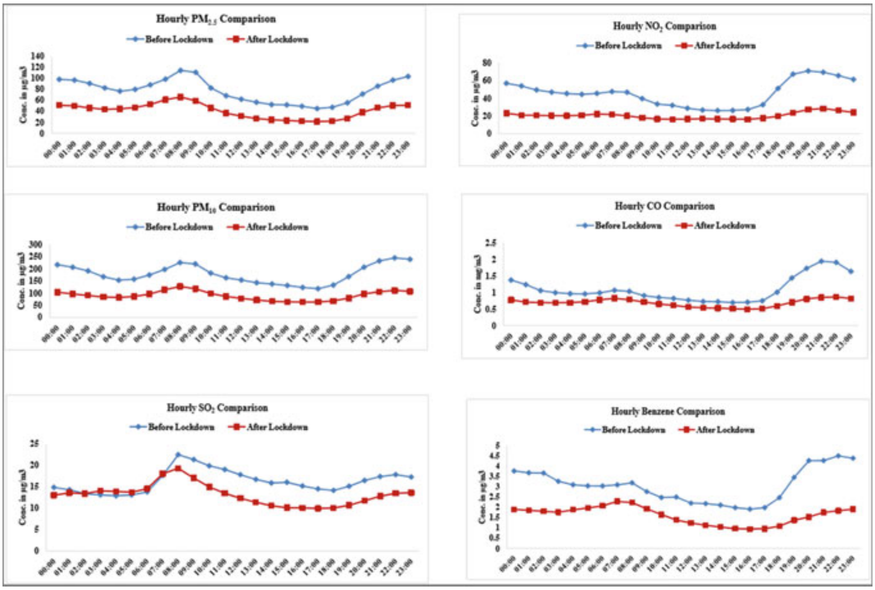

Fig. 4 Hourly comparison of air pollution parameters ($PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, Benzene) for during lockdown and before lockdown in Delhi region

particulate matters referred as $PM_{2.5}$ are recorded to be 114 $\mu g/m^3$ during normal working days and 21 $\mu g/m^3$ during the lockdown phase. The PM_{10} is recorded to hold a maximum hourly value of 244 $\mu g/m^3$ during normal working days and was observed to reduce to a concentration of 127 $\mu g/m^3$ during the lock down phase. The hourly concentration of SO_2 on normal working days were observed to be 25 $\mu g/m^3$ and during the lock down, the value reduced to 19 $\mu g/m^3$. For NO_2 on normal working days, the value was observed to be 80 $\mu g/m^3$ and during the lockdown, it was recorded to reduce to 18 $\mu g/m^3$. These observations are conducted by the monitoring stations of the CPCB, Ministry of Environment and Forest and Climate Change. It is interesting to note that the SO_2 emissions have gone down by 24% which is mainly attributed to the closure of unorganised industries like brick kilns thus restricting the stack emissions. However, it is evident that the stationary source emissions from organised industries of power plants are major source of SO_2. It is the reason that the change in SO_2 level is small as compared to particulate matters. Further, it may also be noted that the level of NO_2 and CO has also decreased in atmosphere and it can also directly correlate to closure of industries contributing to air pollution through stack emissions. A major amount of the air pollution is toxic in nature. Mercury, lead, benzene and dioxins are released during gas or coal combustion of the fuel used in organised and unorganised industries, waste incineration or burning of gasoline.

6 Conclusion

This study portrays the decrease in air pollutants because of temporary shutdown of unorganised industry with stack emissions. However, the organised industries like power generating sector remained functional and continued to add air pollutants. The power generating plants are considered as red category industries as the total Greenhouse gas emission generated from these industries are 635 MTCO2e approximately. This study on air pollution during lockdown contemplates an urgency to formulate provisions that will force the industries to adhere to air emission monitoring and standards [11]. Due to restrictions of industry, the challenges persist in the detail study of combustion and plume discharge. The future scope of this study is to quantify the contribution of plume discharges from organised and unorganised industries and conduct detailed analysis of stationary sources emissions due to combustion.

References

1. Martins A (2010) Industrial air emissions in Portugal: 2008 Report. WIT Trans. Ecol. Environ. 201–210. https://doi.org/10.2495/AIR100181
2. Sindhwani R, Goyal P (2014) Assessment of traffic-generated gaseous and particulate matter emissions and trends over Delhi (2000–2010). Atmosp Pollut Res 5:438–446. https://doi.org/10.5094/APR.2014.051
3. Economic survey of Delhi report 2014—2015, https://delhiplanning.nic.in
4. Sharma M, Dikshit O Comprehensive study on air pollution and green house gases (GHGs) in Delhi
5. Hopke PK (2016) Review of receptor modeling methods for source apportionment. J Air Waste Manag Assoc 66:237–259. https://doi.org/10.1080/10962247.2016.1140693
6. Wang LK, Pereira NC, Hung Y Handbook on environmental engineering. Air Pollut Control Eng
7. Corio LA, Sherwell J (2000) In-stack condensible particulate matter measurements and issues. J Air Waste Manag Assoc 50:207–218. https://doi.org/10.1080/10473289.2000.10464002
8. Xu S (2020) Analysis of the influencing factors of industrial air pollution in Shenzhen. IOP Conf Series Earth Environ Sci 450:012094. https://doi.org/10.1088/1755-1315/450/1/012094
9. Hewitt CN (2001) The atmospheric chemistry of sulphur and nitrogen in power station plumes. Atmos Environ 35:1155–1170. https://doi.org/10.1016/S1352-2310(00)00463-5
10. Central Pollution Control Board, https://cpcb.nic.in
11. Henneman LRF, Liu C, Mulholland JA, Russell AG (2017) Evaluating the effectiveness of air quality regulations: A review of accountability studies and frameworks. J Air Waste Manag Assoc 67:144–172. https://doi.org/10.1080/10962247.2016.1242518