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Research Article

GEOGRAPHICAL JUXTA - POSITIONING OF TROPOSPHERIC OZONE THROUGH NITROGEN DIOXIDE AS OZONE PRECURSOR WITH FOCUS ON THE COVID 19 LOCKDOWN PERIOD FOR DELHI- (2019-2021)

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ABSTRACT

Delhi city is not only the country's capital but is also one of the top most polluted cities of the world. In this regard, pollution is discussed as a problem in a number of ways, but the pollutant is not much discussed of. The secondary pollutant of Ozone is also not much observed in literature. Ozone is a naturally occurring gas in the atmosphere but is also formed due to human activities which are generally related to the emission of nitrogen and its compounds. In this regard, the study of human activity becomes very important. The time period offered by COVID 19 provides a significant window to study pollution in ways more than one. The current study observes the relationship between Ozone and Nitrogen dioxide taking Nitrogen Dioxide as an Ozone precursor. Results indicate that Nitrogen Dioxide does not indicate any relationship with Ozone for the city.

KEYWORDS

Delhi, COVID- 19, Lockdown, Ozone, Nitrogen Dioxide.

INTRODUCTION

Described as an 'infectious disease' by the World Health Organisation (WHO 2021), COVID-19 has claimed more than 4 million lives as of Sep. 2021 (Worldometers, 2022). The nature of limitations introduced by it on human life has had serious impacts across the world and the 'recognised' periods named as 'lockdowns' have been historic across the world (Kerimray, et al. 2020; Nakada and Urban 2020). Air

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quality improved in the spatio- temporal context for the city of Delhi too (Sharma, et al. 2020; Mahato, et al. 2020). This has been significant (Kotnala, et al. 2020). The attempt here is extended to examine the relationship between Nitrogen Dioxide as an Ozone causative factor for the urban centre. While other categories of pollutants exhibit linear behavior, the nature of Ozone gas a secondary pollutant is very different in generation and concentration. In this context, it is a significant pollutant at the ground level generating health impacts but is rather an outcome of other pollutants. That is why it is called as a secondary pollutant (Agency,2021). Ozone generated in the presence of other pollutants when they react with sunlight is called 'bad Ozone' and th enaturally occuring one is called good ozone (Agency, 2021). These chemical compounds are called the precursors of Ozone and can be identified as Nitrous Oxides, Methane, Carbon Monoxide, Non Methane Volatile Organic Compounds, Volatile Organic Compounds and other pollutants (Agency, 2021). Ground level Ozone reaches very high levels in urban areas during summers (Society, 2008).

The current study tries to examine the spatial patterning of Ozone gas for the city of Delhi and also observers its behaviour vis a vis the significant Ozone precursor of Nitrogen Dioxide gas. The city of Delhi sadly ranks as the most polluted city in the world (Kotnala, et al. 2020). The COVID19 lockdown periods (Shehzad, et al. 2020) have provided ample evidences to the fact that human induced activities are mainly responsible for pollution in the city (Mahato, et al. 2020; Shehzad, et al. 2020). It is suggested that lower titration levels of Ozone due to restriction on activities is the main reason behind an increased Ozone level in urban areas in many parts of the world (Pierre, et al. 2020).

The periods of 'lockdown' of 2020 and 2021 have provided an extended view to examine the trend of all pollutants for a geographical area. A retrospective study can help in a further comparison. In the current study, such an examination is attempted. The periods of lockdown of 2020 have been taken as the base to retrospectively study Ozone and Nitrogen Dioxide concentration in 2019 and then, currently, for 2021 (which has also experienced lockdown for almost the same period due to COVID19). The findings will give a clear indication as to whether continuation or stoppage of human activities have a role in determining the trend of Ozone gas in the geographical space of the city during. To begin with this examination, it is significant to observe the nature of Ozone gas as a component of the atmosphere.

About Tropospheric Ozone

A colourless or pale blue gas, is found naturally in the stratosphere in concentration called the Ozone layer (Nahanson, n.d.). While natural Ozone found in the stratosphere is protective in nature (Agency, 2021) at the ground level, Ozone gas is very poisonous and, thus, outside its natural realm it is a concern for air quality and can be irritating even at low amounts (Nathanson, n.d.). Stratospheric Ozone formation takes place upon reaction of molecular Oxygen with sunlight (Agency, 2021). However, Tropospheric Ozone, also called surface Ozone or ground level Ozone forms due to photochemical reactions between pollutants and sunlight and is harmful to health (Agency, 2021). Surface Ozone is an important gas in lower parts of the troposphere and plays a crucial role in a number of atmospheric phenomena (Kotchenruther, et al. 2001). Ozone is, therefore, termed as both, a saviour and a killer (OECD, 2021). Air pollutants are observed in two categories- primary and secondary (OECD, 2021). Ozone gas comes under the

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category of secondary pollutants as it is formed when oxides of nitrogen (NOx) and volatile organic compounds (VOC's), which are mainly generated from vehicles and industries, chemically react in the presence of sunlight (Agency,2021). These chemical compounds are called Ozone precursors. The budget of tropospheric Ozone is dependent on Ozone precursors (Sharma, et al. 2016) and human induced causes play a dominant role in this (Honrath, et. al. 1996).

In the stratosphere, Ozone formation takes place when ultraviolet radiation breaks molecular oxygen into atomic oxygen and destruction of this Ozone is also quick in the presence of sunlight. The process of formation of Ozone at the ground level is also similar in nature with the difference being that here Nitrogen Dioxide (NO_2) provides the main source of Ozone formation and has also been observed to be the prime precursor for Ozone in many instances (John, et al.1998). Vehicular pollution is taken as the main source of Nitrogen Dioxide pollution with negative effects on vegetation, human health and buildings (Nagpure, et al. 2011). The further transport of VOC's and other pollutants at higher altitudes has a capacity to disturb the atmospheric chemistry (Nagpure, et al. 2011). Nitrogen Dioxide splits into nitric oxide and an oxygen atom. This single oxygen atom combines with an oxygen molecule to form Ozone(Agency, 2021).

Also, the knowledge regarding sensitivity of these precursors still needs more research (Xue, et al. 2013) and the vertical interaction of Ozone is different from the ground level Ozone formation (Jonson, et al. 2001). The concentrations of ground-level O_3 currently range from a few parts per billion by volume (ppb) up to 200 ppb (Society, 2008). It can also be produced long after the precursors of its formation have been generated in the atmosphere (Society, 2008). It is also observed that a decline in Nitrogen Dioxide as an Ozone precursor can, in fact, increase the levels of Ozone in the troposphere (Orlando, et al. 2010). Even short lived Ozone precursors can generate significant impacts on the creation of Ozone gas (Derwent et al., 2001). The current examination is that of Nitrogen Dioxide gas as an Ozone precursor from the category of nitrous oxides.

COVID-19 Lockdown periods have provided a crucial window to analyse the behaviour of different pollutants. Ozone generated pollution is a serious matter of concern at the local and larger regional levels (Society, 2008). The relationships between Ozone and its precursors have been observed to be dependent on the nature of the chemical. Further, the sensitivity of Ozone regimes is location specific (Walaszek, et al. 2017)Therefore, the process of Ozone formation is described as a complicated one in itself. Natural precursors determine the pathway of Ozone (Lu, et al. 2019). The amount of Ozone transported from troposphere due to pollutants is generally higher than the Ozone generated in natural form in the stratosphere (Parrish, et al 1993). It has been forwarded that a decline in NOx due to lockdown increased Ozone concentrations at sites because of summers, an increased influence of VOC's and biogenic activities; all of which did not allow degradation of Ozone which takes place otherwise (Sicard, et al. 2020).

Design and Data Source-

To attempt this examination, the following methodology has been followed:

Data for observing the spatial and temporal distribution of Ozone and NO_2 has been taken from Sentinel 5 P, TROPOMI and is derived from the Google Earth Engine Code Editor for the selected time span.

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This is from the Copernicus Sentinel-5 Precursor data from the Google Earth Engine Code editor. It is the first Copernicus mission dedicated to monitoring the atmosphere, launched on 13 October 2017 by the European Space Agency to monitor air pollution. The onboard sensor is frequently referred to as TROPOMI (TROPOspheric Monitoring Instrument). This dataset provides offline high-resolution imagery of total column Ozone concentrations (Engine, 2021). Here, data for Offline Ozone is selected for study.

They enter the atmosphere as a result of anthropogenic activities (notably fossil fuel combustion and biomass burning) and natural processes (wildfires, lightning, and microbiological processes in soils). Here, NO_2 is used to represent concentrations of collective nitrogen oxides because during daytime, i.e. in the presence of sunlight, a photochemical cycle involving Ozone (O_3) converts NO into NO_2 and vice versa on a timescale of minutes. It is further helpful in establishing whether Ozone gas behaves independently of Nitrogen Dioxide gas for its formation or is a major outcome of it. Such an analysis can also help out in bringing the behaviour of the gas with regards to different precursors as well. The examination is carried by deriving satellite images from the Google Code Editor for the said periods and then analysing the trends as exhibited. Besides, to get a better comparative picture, the same period of time has been taken in retrospect for 2019 for comparison. In such a manner, it will become significant to examine the distribution of Ozone with respect to its important precursor of Nitrogen Dioxide gas and how much the lockdown has been 'influential' in reducing/increasing its concentration spatially? This will also help in examining the relationship between the two parameters through correlation. It is also an indirect examination of 'other' factors as operating for specific geographic locations and also location as operating as a significant factor in affecting the trends of distribution of Ozone in the city.

Spatial focus- The city of Delhi, the administrative capital is the study area. The city of Delhi, lies at an altitude range of about 200-300 mts. and is one of the largest urban agglomerations of the country (Sundaram, et al. 2022). The rocky hills of the Aravalli mountains flank the city in west and south while the River Yamuna flows through the city's north south extent in its eastern part. Extending from 28degrees 24 minutes North to 28 degrees 53 minutes North and 76 degrees 50 minutes East to 77 degrees 20 minutes East, it covers an area of about 1,484 sq km. Intense hot summers, dryness and multiple seasons are experienced in the city country (Sundaram, et al. 2022). The summer season begins from mid March to end of June, monsoon from July to September and the dry winter season remains from November to mid March. The city, National Capital, is termed as the pollution capital of the world (Kotnala, et al. 2020). In such a scenario, the study of the nature of various pollutants lends an insight into their behaviour and also for a more informed planning. Ozone pollution is, indeed, a serious concern in urban areas (Council 1991; Agency, 2021).

Temporal focus-The spatial unit for study here is the city of Delhi, the national capital of India. Temporal examination is attempted in a forward and backward way. The aim of examination is to study the behaviour of ground level Ozone and Nitrogen Dioxide gas during the selected time periods and to infer whether a restriction on human activities contributed to variations in Ozone gas quantities geographically across the city of Delhi? It is also cross examined to observe the correlation between both the pollutants vis a vis whether a change in the precursor leads to a change in the pollutant and in what manner. The base

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and division of time period is taken as that of COVID19 Lockdown period in 2020 as declared in India. Keeping it as the benchmark, the analysis is done in the following three ways in which the year 2020 serves as the base year to establish the time period of the study. For the periods of Nation wide Lockdown of 2020 (Hebbar 2020; Singh, 2020); the examination is also done in a retrospective manner taking the same dates for 2019 and for 2021 till 1 Sep.'2021 for a better comparative analysis. The year 2021 faced lockdown situation in Delhi for almost similar time periods as 2020 (www.thehindu.com 2020). On this basis the respective yearly data is analysed using the following time line of study:

a. Pre lockdown period- 1 Jan -24 March for 2019, 2020 and 2021.

b. Lockdown period of 2020- From 25 March' 20- 31 May'20. The Nation wide Lockdown period for 2020 was as under (Correspondent, 2021):

- Phase 1: 25 March' 20 – 14 April' 20 (21 days)
- Phase 2: 15 April' 20 – 3 May' 20 (19 days)
- Phase 3: 4 May' 20 – 17 May' 20 (14 days)
- Phase 4: 18 May' 20 – 31 May' 20 (14 days)

The same time period is considered for 2019 and 2021 for comparative study.

The purpose of this selection is to minimise the observation of other effects assuming 'other things being equal' and see just how human activity, through its absence and presence, is generating variations in the level of the pollutant and in what manner, if any. Further, lockdown period for the city in 2021extended from 15 April- 31 May; for this also the division of time period is taken as the same for 2020 for a convenient analysis.

c. Post Nation Wise Lockdown period analysis- The remaining part of the years 2019 and 2020 are examined along with year 2021 for the same period for the behaviour of tropospheric Ozone and Nitrogen Dioxide. For 2021, the same time period is applied from above is till 1Sep. Although there was a 'strict lockdown' in Delhi in 2021 as well from 19th April'21 – 31' May 21; but for the present study this coincides with 2020 lockdown period which is therefore, taken as the base year for analysis for better comparison.

The examination follows trends of tropospheric Ozone and Nitrogen Dioxide. These are extracted from Sentinel 5P TROPOMI data extracted through the Google Earth Engine Code Editor .

RESULTS AND DISCUSSIONS

The attempt here is primarily geographical in nature with an aim to observe the distribution of Ozone and Nitrogen Dioxide gas in its spatial concentration. For the selected time period, the following observations have been recorded:

a. Pre Lockdown period- 1 Jan- 24 March 2019, 2020 and 2021

b. Lockdown period of 2020 and same time periods for 2019 and 2021* (as applicable till 1 Sep.2021)

This period has been further divided into the mentioned categories as per the above described national lockdown periods. Satellite imagery data is drawn from the Code Editor for these specific time periods, averaging out the trend in the pollutant through the Google Earth Engine Code Editor. These durations are

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presented systematically in the subsequent diagrams for Ozone and Nitrogen Dioxide respectively.

c. **Post Lockdown, 1 Jun- 1Sep., 2 Sep.- 31 Dec, for 2019 and 2020 and 2021* (Till 1Sep. 2021)- For simplifying the extended time span, the period post lockdown has been divided into the mentioned two parts. The following interpretations can be drawn:**

Fig. 1. Delhi- Spatial Analysis of Ozone Gas for 2019-2021 with Base Period of COVID 19 Lockdowns- Offline Ozone; TROPOMI SENTINEL 5P

Fig.1.1.- Pre Lockdown 1 Jan -24 March

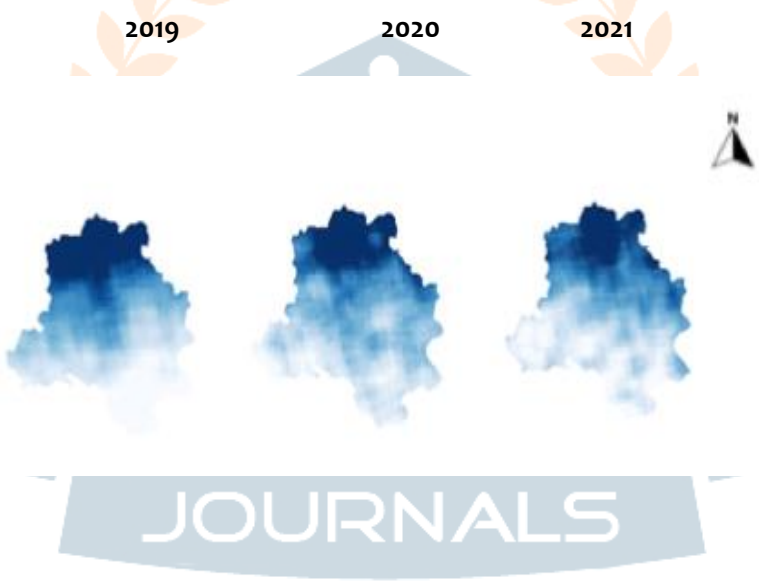

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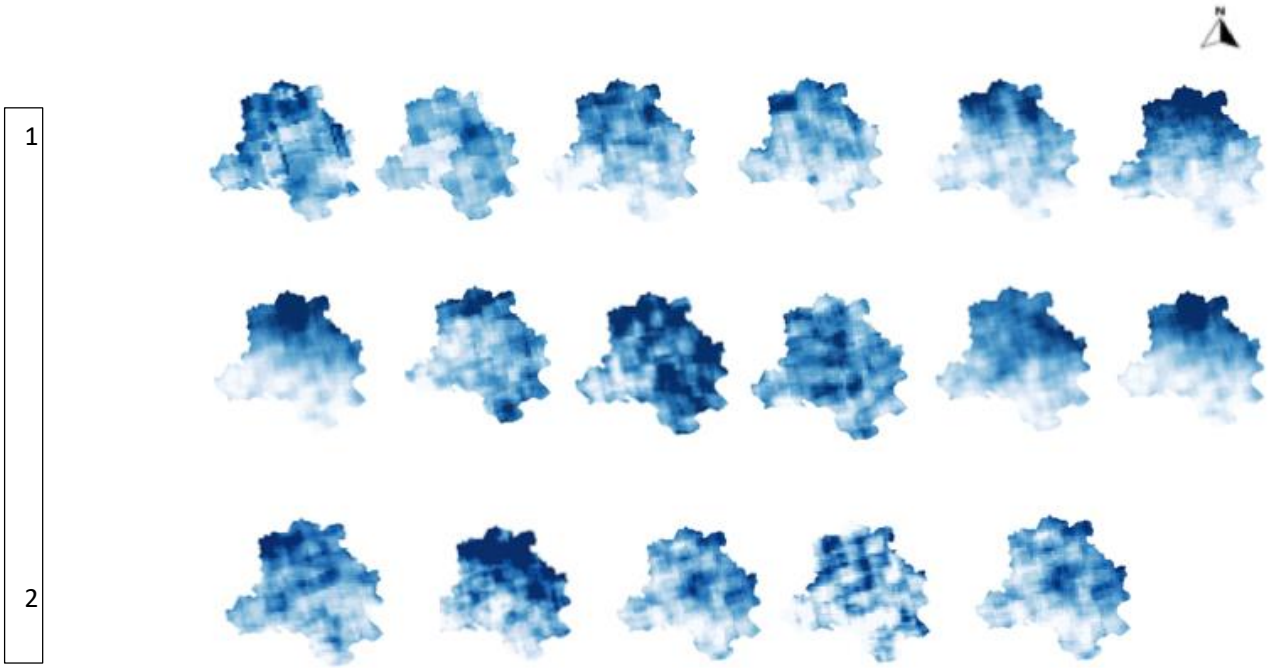
Fig. 1.2. Trends in Ozone- 25 March- 2019- 1 Sep. 2021



Source- Author, 2021 (derived from Google Earth Engine Code Editor), processed in QGIS 3.16

- **Row1 -2019 (25 March -14 April , 15 April – 3 May, 4 – 17 May, 18– 31 May, 1 June- 1Sep., 2 Sep.- 31 Dec.)**
- **Row2- 2020 (25 March -14 April , 15 April – 3 May, 4 – 17 May, 18– 31 May, 1 June- 1Sep., 2 Sep.- 31 Dec.)**
- **Row 3- 2021 (25 March- 14 April , 15 April – 3 May, 4 – 17 May, 18– 31 May, 1 June- 1Sep.)**

The above derivations indicate that tropospheric Ozone during the above period exhibits a distinct pattern of concentration over the extreme Northern part of the city. Measured in mol/sq.mt. in the range of 0.025-0.3048, the trend of distribution from an increased to decreased concentration is mostly north-south as Ozone gas levels fall from the northern part of the city to the south; particularly in the winter season in the city. It can be hypothesised that during winters the nature of activities in the extreme northern part of the city lead to a concentration of Ozone gas while declining towards the southern part. Also, there are variations observed even within this trend towards the southern part of the city. This geographic concentration clearly highlights that there are certain specific processes which are spatially operating to generate this trend. There is a similarity of this trend from 2019-2021. However, in 2021, this concentration was less pronounced in the northern part of the city. Such observations are not due to a single causative factor as it has been observed that Ozone concentrations do exhibit an increase even when precursors show a decreased value (Cho, et al. 2006). Comparing the 2020 actual lockdown period trend beginning from 25 March with the same period in 2019 brings out certain notable facts about tropospheric Ozone for the city.

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The North South spatial variation in the pollutant (as observed as a trend during winters) is gradually replaced with a different trend from end March onwards. The subsequent periods from March to May, wherein the season turns from winters to summers, exhibits that the whole city is engulfed with an increased concentration of Ozone gas at the tropospheric level; thereby highlighting that temperature is an important factor coming into play. However, the lockdown period of 2020 shows that tropospheric Ozone concentration further increased to its maximum from 4-17 May during 2020 as compared to the same period in 2019.

This is an important finding as generally pollutants declined for the city during the lockdown period (Kotnala, et al. 2020; Mahato, et al. 2020; Shrangi and Pillai 2020). But Ozone showed a peculiar behaviour whereby its concentration increased for the city in general during lockdown periods. The above diagrams do highlight that there does not exist any specific trend in the concentration of Ozone across the city. Further, fluctuations occur in its distribution spatially and seasonally but the trend is not specific in nature.

These observations bring to an important examination regarding the nature of the gas with regards to its precursors. So, if precursors have a role in the generation of Ozone in a positive manner, then it is apparent that as Ozone concentrations have increased in the city during the lockdown period, the precursor, in the current case of Nitrogen Dioxide gas should also show an increased concentration in space in the said time spans. But is this so? For carrying forward this study, Nitrogen Dioxide gas is next examined for its spatial and temporal trends for similar time periods.

Fig.2. Delhi- Spatial Analysis of NO_2 Gas for 2019- 2021 with Base Period of COVID 19 Lockdowns through Tropospheric NO_2 column number density (tropospheric vertical column of NO_2); TROPOMI SENTINEL 5P data

Fig.2.1.

a. 1 Jan -24 March

2019 2020 2021

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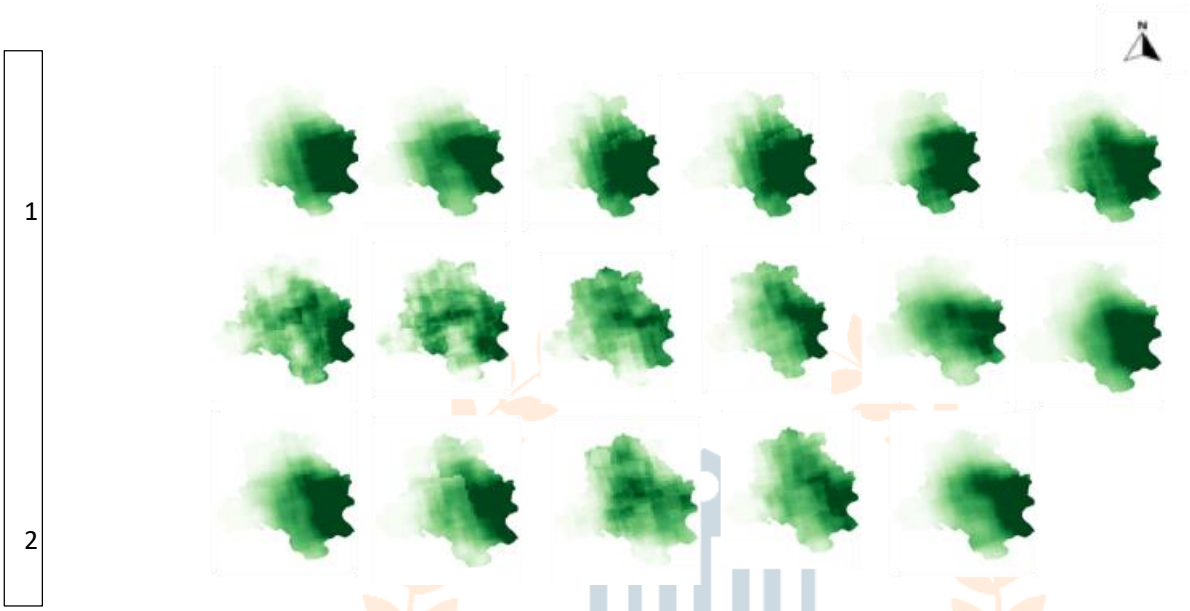
Fig. 2.2.

b. Lockdown period of 2020- 25 March -14 April, 15 April – 3 May, 4 – 17 May, 18– 31 May, 1 June-1 Sep, 2 Sep.- 31 Dec.



Source- Author, 2021 (derived from Google Earth Engine Code Editor), processed in Q GIS 3.16

- **Row1 -2019 (25 March -14 April , 15 April – 3 May, 4 – 17 May, 18– 31 May, 1 June- 1Sep., 2 Sep.- 31 Dec)**
- **Row2- 2020 (25 March -14 April , 15 April – 3 May, 4 – 17 May, 18– 31 May, 1 June- 1Sep., 2 Sep.- 31 Dec)**
- **Row 3- 2021 (25 March- 14 April , 15 April – 3 May, 4 – 17 May, 18– 31 May, 1 June- 1 Sep.'2021)**

Measured as mol/sq.mt, the range for NO_2 is -0.00051-0.0192. Row 1 which exhibits data for 2019 is clearly indicative of the fact that there is a distinct geographical concentration of NO_2 in the city in its eastern part. The concentrations decline gradually from east to west. A strong decline is geographically observed in 2020 as well for Nitrogen dioxide in the city. This is a clear indicator of the effect of lockdown due to which a clear stoppage was there anthropogenic activities which were large generators of NO_2. However, wherever, high concentrations were observed were located near to the industrial areas outside the city viz. Faridabad, Ghaziabad and Noida in the eastern part; all ranking high in pollution otherwise.

As the lockdown ceases, NO_2 concentrations return back to their pattern. However, 2021 data in Row 3 indicates that since the lockdown was in Delhi applied late as compared to 2020, the patterning is showing alteration.wThe next aspect of study in this paper is that of observing NO_2 as an Ozone precursor and studying the strength of this relationship. As observed above, during the lockdown period, NO_2 showed a consistent decline in value but Ozone levels showed a higher value. This primarily gives an idea that Ozone is also affected by other factors for its formation.

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CONCLUSION

For 2020, till the period of established lockdown till 31 May, there is a constant fall in the concentration of NO_2 across the city. But as soon as the lockdown period is over, NO_2 concentrations not only show an increased concentration but also show the same geographic patterning of high concentration zones. This is a very important observation for NO_2 as a pollutant. Slowly and gradually as the influence of lockdown period wades, NO_2 levels keep coming back to the same geographic patterning as is observable in Row 2 and 3 which shows data from 25 March- 1 Sep. 2021. Thus, from the above it can be clearly said that despite being a significant NMVOC's (Non Methane Volatile Organic Compounds) precursor, NO_2 does not show any clear or direct relationship in determining Ozone levels in the city.

The other most important observation is that Nitrogen Dioxide has a distinct geographical patterning with regards to its distribution and lockdowns have had a significant impact in causing a decline in the pollutant. It is observed to be heavily influenced by industrial activity in and around the city. Similar observation cannot be forwarded for Ozone.

On the whole, for the city, it can be clearly said that NO_2 only does not act as the precursor of the formation of the secondary pollutant of Ozone. Therefore, while for NO_2, the pre, lockdown and post lockdown periods did exhibit strong declining trends in absence of human activity; for Ozone as a pollutant this operated in reverse in many cases and there is no clear cut influence of restricting human activities in generating a trend of spatial distribution of Ozone as observed in the city through Nitrogen Dioxide as a precursor. This is an indicator of factors other than Nitrogen Dioxide for determining the spatial and temporal distribution of Ozone as a pollutant for the city of Delhi which can range from meteorological to anthropogenic as discussed earlier.

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