Impact of COVID-19 on air quality in Rajasthan: A remote sensing-based analysis

Assignment Report

submitted to Blue Sky Analytics

by

Virat Arora

aroravirat@gmail.com

January 2022

Table of contents

1. Introduction 1

1.1 Background 1

1.2 Utilizing remote sensing satellite data for studying air quality 1

2. Aims and objectives 3

3. Study area 3

4. Study time frame 3

5. Material and methods 4

6. Results and discussion 4

6.1 Suratgarh Super Critical Thermal Power Station 6

6.2 Jodhpur city 9

7. Conclusion 9

8. References 10

Annexure-1: Literature relevant to the present study 11

Annexure-2: Google Earth Engine Code Editor Script (JavaScript) 18

List of figures

Figure 1: Map showing pre-lockdown (mean of year 2019) values of tropospheric NO_2 column number density 5

Figure 2: Map showing during-lockdown (mean of April-June 2020) values of tropospheric NO_2 column number density 5

Figure 3: Map showing change in values of tropospheric NO_2 column number density during lockdown period with respect to pre-lockdown period 6

Figure 4: Location map of Suratgarh Super Critical Thermal Power Plant (Source: Google Earth Engine) 7

Figure 5: Ground photograph of Suratgarh Thermal Power Plant (Source: https://zeenews.india.com/) 7

Figure 6: (a) High-resolution satellite image base layer; (b) Mean of 2019 tropospheric NO_2 column number density values; (c) Mean of lockdown period tropospheric NO_2 column number density values; (d) Percentage difference between 2019 vs. lockdown period values (the output displays a maximum of 50% (white) reduction in NO_2 emissions) 8

Figure 7: High values of NO_2 TVCD observed around the industrial area in Jodhpur City 9

List of tables

Table 1: Details of remote sensing instrument and platform with respect to each pollutant of concern 1

Table 2: Literature review focusing on the use of remote sensing data products for studying air quality 2

1. Introduction

1.1 Background

The onset of COVID-19 pandemic led to global lockdowns, which provided a window for scientists world-wide to study the anthropogenic impacts on various environmental factors. On the one side, the reduced traffic volumes during the lockdown period limited the vehicular emissions (Elshorbany, Kapper, Ziemke, & Parr, 2021), while on the other side, industrial emissions were also on the lower side. This overall impacted the air quality positively as evident by the numerous studies (relevant studies are compiled in Annexure-1).

1.2 Utilizing remote sensing satellite data for studying air quality

Remote sensing satellite-based data products have shown huge potential to carry out the global as well as regional scale studies on air quality. Particularly, the remote sensing data products that are widely used for this purpose are listed below (Elshorbany et al., 2021):

- Nitrogen dioxide tropospheric column (NO_2)
- Carbon monoxide atmospheric column (CO)
- Tropospheric ozone column (O_3)
- Aerosol optical depth (AOD)

Interannual variability of each of the above pollutant can be studied. Table 1 lists the remote sensing data products that were used by (Elshorbany et al., 2021). A more detailed literature review analysis is shown in Table 2 that focuses on the use of remote sensing data for analyzing air quality.

Table 1: Details of remote sensing instrument and platform with respect to each pollutant of concern

Parameter	Instrument	Platform	Spatial resolution	Temporal resolution
NO_2	OMI	Aura	0.1°	Daily
CO	MOPITT	Terra	1°	Daily
Ozone	OMPS	MERRA-2	1°	Daily
AOD	MODIS DB land	Terra	1°	Daily

Table 2: Literature review focusing on the use of remote sensing data products for studying air quality

Parameter	Satellite	Sensor	Product	Spatial Resolution	Frequency	Source	Study Area	Effect of COVID-19 lockdown	Reference
NO_2	Aura (NASA) 2004	Ozone Monitoring Instrument (OMI) Hyperspectral imaging spectrometer Visible wavelength range (405-460 nm)	Total column And tropospheric column – Level-3 gridded product	0.25° x 0.25° (around 26x26 km, depends on latitude)	Daily	NASA-GES-DAAC (https://disc.gsfc.nasa.gov/datasets/OMNO2d_003/summary)	India and China	Reduced vehicular movement affect more on NO_X concentration rather than energy and industry sector	(Singh & Kumar, 2018) (Metya, Dagupta, Halder, Chakraborty, & Tiwari, 2020)
NO_2	Sentinel-5 (ESA)	tropospheric monitoring instrument (TROPOMI)	tropospheric vertical column density (TVCD) ($\mu mol/m^2$)	3.5 x 5.5 km Measurements relevant at country-level	Daily	GEE	Global	Decreased about 3.6% from the previous year's mean. Strict lockdowns corresponded with much decreased NO_2 TVCD	(Wang, Tan, & Li, 2021)
SO_2	Aura (NASA) 2004	Ozone Monitoring Instrument (OMI) Hyperspectral imaging spectrometer UV wavelength range (310.5-340 nm)	Boundary layer SO_2	13 x 24 km Measurement relevant from state-level (Metya et al., 2020)	Daily	NASA-GES-DAAC (https://disc.gsfc.nasa.gov/datasets/OMSO2e_003/summary)	India and China	Coal fired power plants were less used during lockdown due to less demands of energy and hence SO_2 emissions were on a lower side	(Metya et al., 2020)
CO	Aqua (NASA) (Since 2002) 16-day repeat cycle	Atmospheric Infrared Sounder (AIRS)	Atmospheric CO – Level-3; version-6 ascending product	1° x 1°	Daily		North-central China	Showed significant reduction	(Metya et al., 2020)

Researchers have found a decrease in the levels of tropospheric vertical column density of nitrogen dioxide (NO_2 TVCD) during the COVID-19 lockdown period, as compared to the 2019 average values (Wang et al., 2021).

2. Aims and objectives

The aim of the present study is to analyze the impact of COVID-19 induced lockdown on the air quality in Rajasthan, the largest State of India. Specifically, the objective of the present study is to prepare a NO_2 vertical column density change detection map for Rajasthan taking benefit of the COVID-19 induced lockdown period.

3. Study area

The study presented here focuses on Rajasthan State in India. Particularly, the effect is studied for Suratgarh Thermal Power Plant (Ganganagar District) and Jodhpur City.

4. Study time frame

Time period of study depends on time duration of the lockdown and base periods with which comparison is to be made. In India, the country-wide lockdown was imposed from 24 March 2020 onwards and a significant reduction in traffic and industrial activity was observed till the end of June 2020, post which the restrictions were eased in a phased manner. Hence, the quarterly period from April 2020 to June 2020 can be considered to be the most impactful on the air quality.

5. Material and methods

NO_2 tropospheric vertical column density (TVCD) is a parameter that is being measured by the satellite data. The tropospheric monitoring instrument onboard Sentinel-5 is being used for this purpose. The sensor has a resolution of 3.5 x 5.5 km. This data was accessed in the present study using Google Earth Engine (GEE). The pre-lockdown mean was derived using the data from the year 2019. The during-lockdown mean was derived using data from April-June 2020. A difference image was computed using the code shown in Annexure-2.

6. Results and discussion

The resultant maps are shown in Figure 1, Figure 2 and Figure 3. The hotspot areas are labelled as shown in the figures. As evident, mostly, the hotspots are concentrated around thermal power plants, cement plants, industrial areas and cities. A maximum of around 60% reduction is shown in the change map of Figure 3. The distribution observed clearly indicates that the anthropogenic factors that got reduced during the lockdown period were responsible for the increased NO_2 levels.

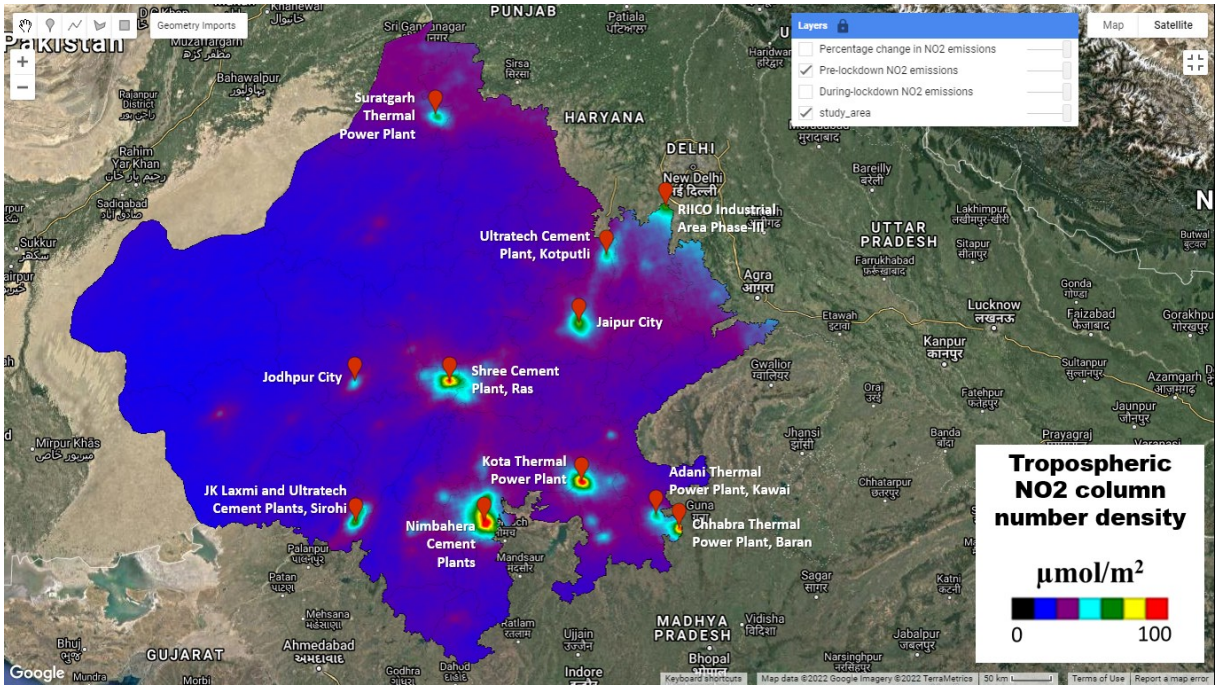


Figure 1: Map showing pre-lockdown (mean of year 2019) values of tropospheric NO_2 column number density

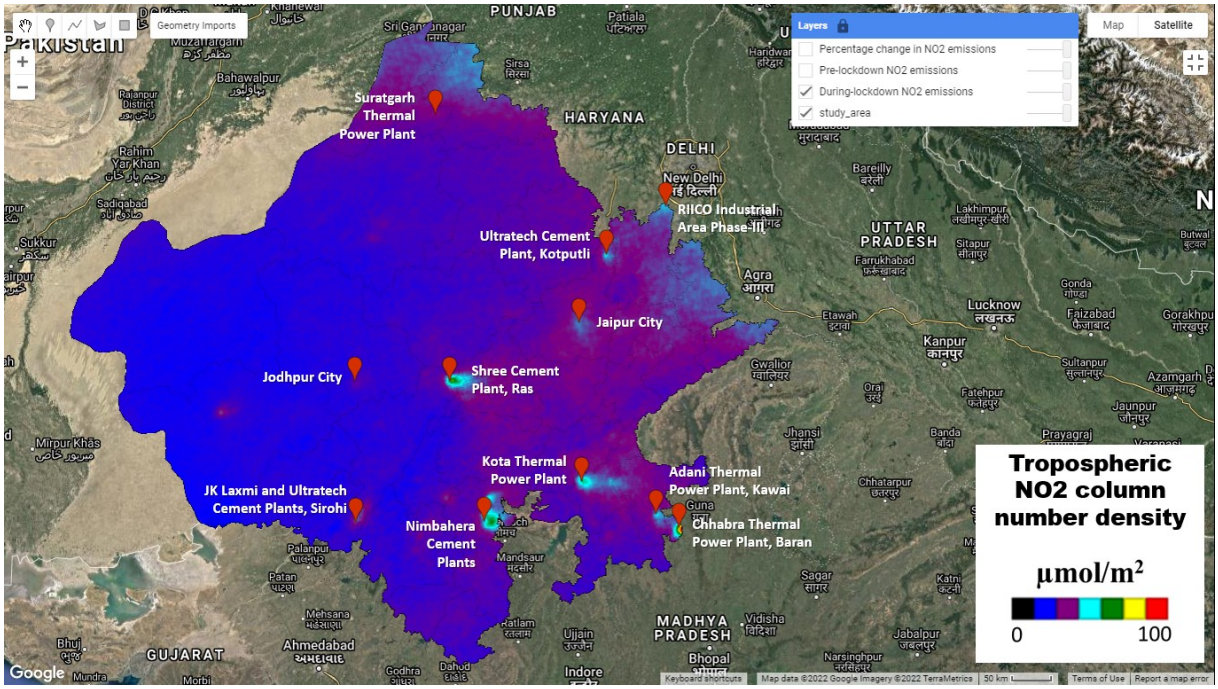


Figure 2: Map showing during-lockdown (mean of April-June 2020) values of tropospheric NO_2 column number density

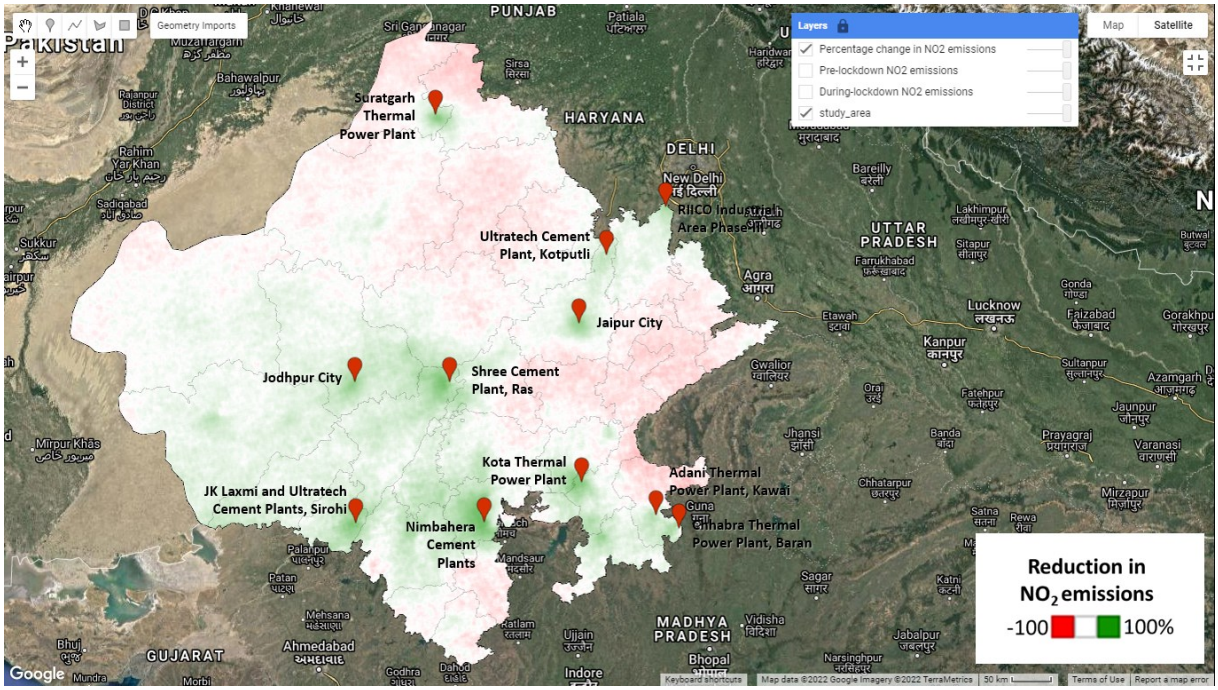


Figure 3: Map showing change in values of tropospheric NO_2 column number density during lockdown period with respect to pre-lockdown period

6.1 Suratgarh Super Critical Thermal Power Station

It is located in Ganganagar District of Rajasthan (Figure 4). It is operational since May, 1998. The power plant has an operational thermal capacity of 1500 MW (6 units of 250 MW each). The results shown in Figure 6 corresponds with the real situation on ground as mentioned in the news article (https://www.business-standard.com/article/economy-policy/lockdown-impact-dip-in-electricity-demand-hits-coal-fired-power-generation-120050501137_1.html). The article mentioned that the power plants were operating on half of their operational capacity. The results correspond that the benefit of about 50% is observed as evident from Figure 6d. Since the area lies significantly away from urban centers, there is negligible contribution from vehicular emissions in this case.

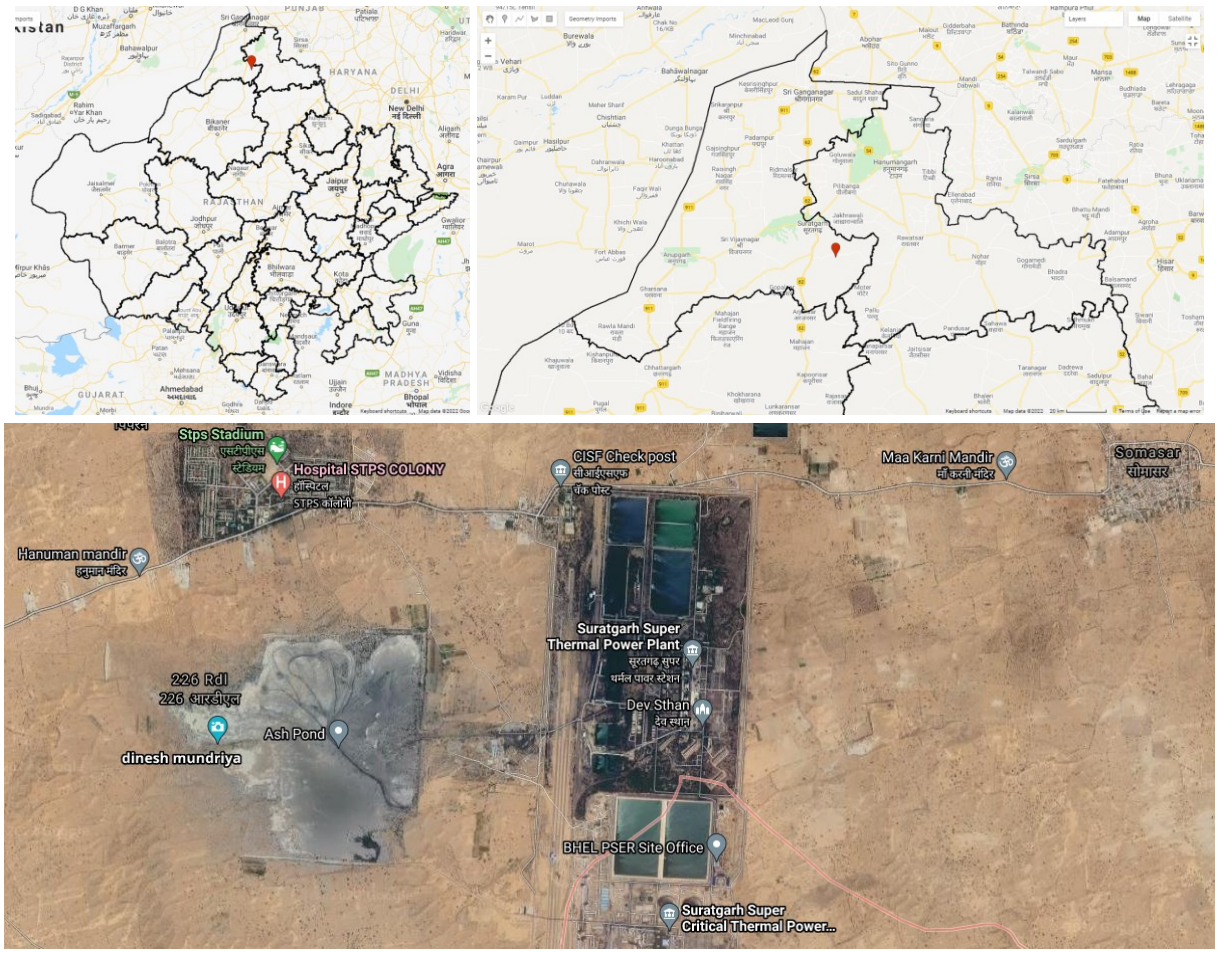
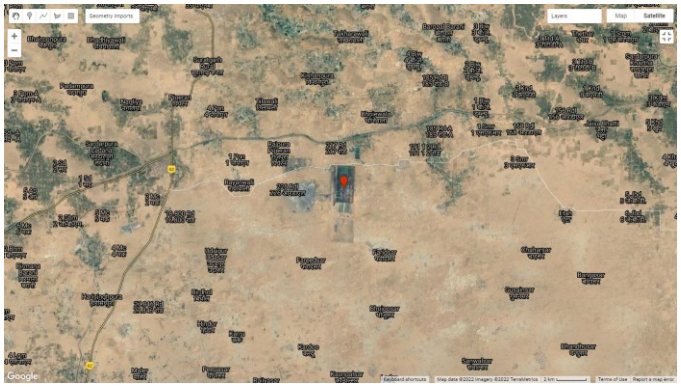


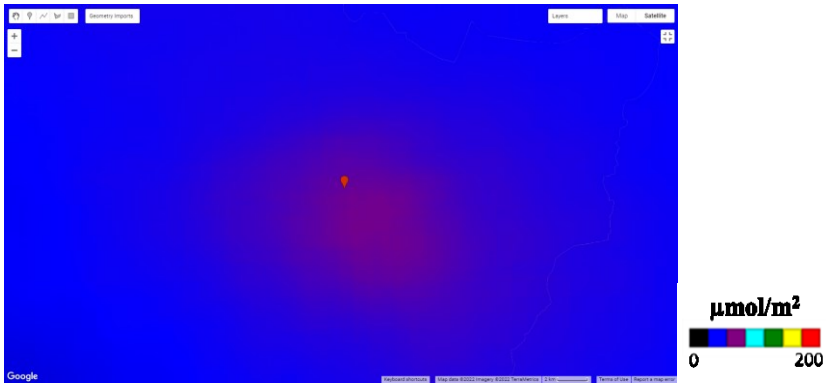
Figure 4: Location map of Suratgarh Super Critical Thermal Power Plant (Source: Google Earth Engine)

Figure 5: Ground photograph of Suratgarh Thermal Power Plant (Source: https://zeenews.india.com/)

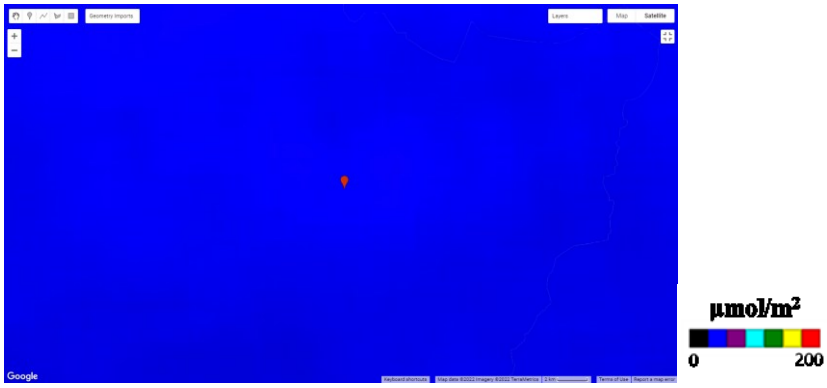
a)



b)



c)



d)

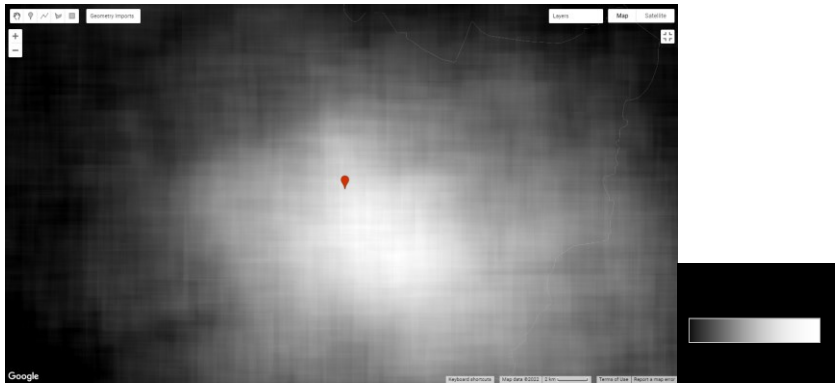


Figure 6: (a) High-resolution satellite image base layer; (b) Mean of 2019 tropospheric NO_2 column number density values; (c) Mean of lockdown period tropospheric NO_2 column number density values; (d) Percentage difference between 2019 vs. lockdown period values (the output displays a maximum of 50% (white) reduction in NO_2 emissions)

6.2 Jodhpur city

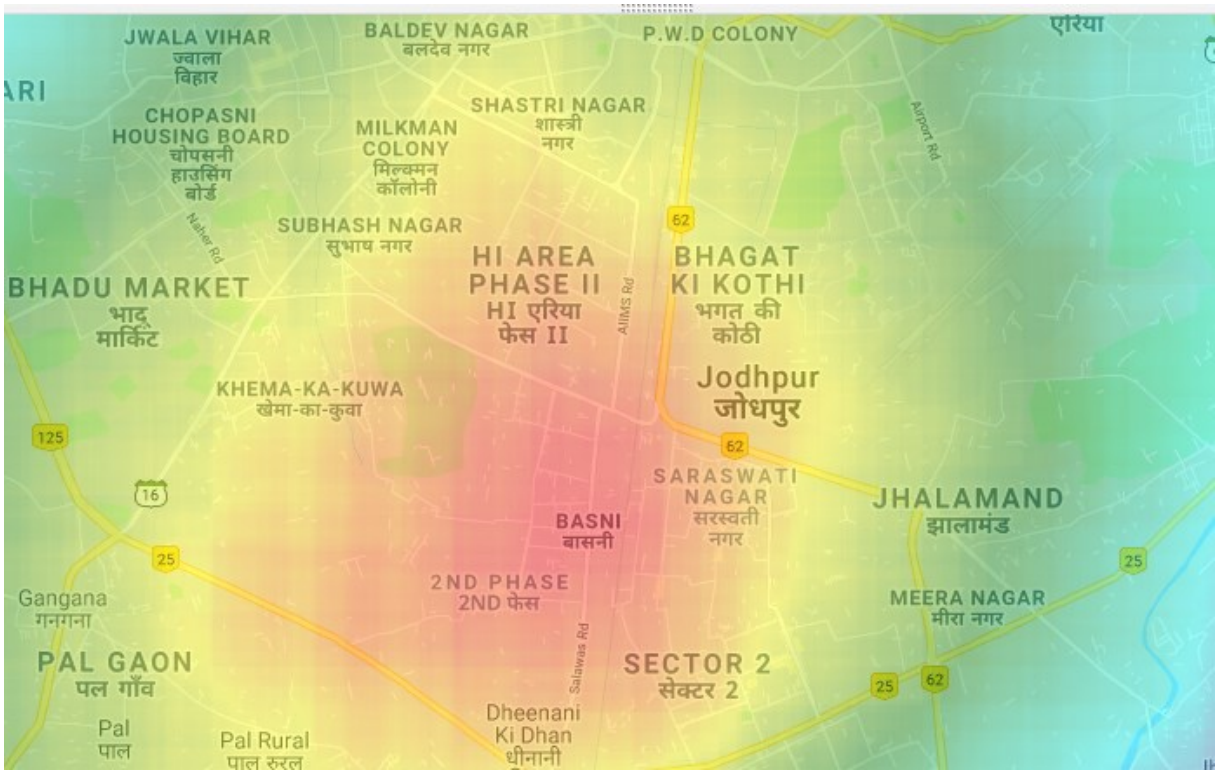


Figure 7: High values of NO_2 TVCD observed around the industrial area in Jodhpur City

7. Conclusion

The effect of reduced anthropogenic activities is important to study towards reaching the bigger goal of reducing carbon emissions, and COVID-19 pandemic offered the ideal time period to study this. The study presented here outlined the lockdown-induced changes that occurred in NO_2 concentrations in air within the State of Rajasthan. Overall, it was found that about a maximum of 60% reductions in NO_2 concentrations happened that may be attributed to the reduced anthropogenic activities such as reduced mobility in vehicles and reduced industrial activity. The study may be utilized towards making evidence-based policies for climate mitigation.

8. References

Elshorbany, Y. F., Kapper, H. C., Ziemke, J. R., & Parr, S. A. (2021). The status of air quality in the united states during the covid-19 pandemic: A remote sensing perspective. *Remote Sensing*, *13*(3), 1–23. https://doi.org/10.3390/rs13030369

Metya, A., Dagupta, P., Halder, S., Chakraborty, S., & Tiwari, Y. K. (2020). COVID-19 lockdowns improve air quality in the South-East Asian regions, as seen by the remote sensing satellites. *Aerosol and Air Quality Research*, *20*(8), 1772–1782. https://doi.org/10.4209/aaqr.2020.05.0240

Wang, H., Tan, J., & Li, X. (2021). Global NO2Dynamics during the COVID-19 Pandemic: A Comparison between Two Waves of the Coronavirus. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *14*(2), 4310–4320. https://doi.org/10.1109/JSTARS.2021.3073156

Annexure-1: Literature relevant to the present study

S. No.	Authors	Title	Publication	Volume	Number	Pages	Year	Publisher
1.	Elshorbany, Yasin F; Kapper, Hannah C; Ziemke, Jerald R; Parr, Scott A;	The status of air quality in the united states during the COVID-19 pandemic: A remote sensing perspective	Remote Sensing	13	3	369	2021	Multidisciplinary Digital Publishing Institute
2.	Metya, Abirlal; Dagupta, Panini; Halder, Santanu; Chakraborty, Supriyo; Tiwari, Yogesh K;	COVID-19 lockdowns improve air quality in the South-East Asian regions, as seen by the remote sensing satellites	Aerosol and Air Quality Research	20	8	1772-1782	2020	Taiwan Association for Aerosol Research
3.	Wang, Yan; Peng, Dailiang; Yu, Le; Zhang, Yaqiong; Yin, Jie; Zhou, Leilei; Zheng, Shijun; Wang, Fumin; Li, Cunjun;	Monitoring crop growth during the period of the rapid spread of COVID-19 in China by remote sensing	IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing	13		6195-6205	2020	IEEE
4.	van Zyl, Terence L; Celik, Turgay;	Did we produce more waste during the covid-19 lockdowns? a remote sensing approach to landfill change analysis	IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing	14		7349-7358	2021	IEEE
5.	Chen, Yulu; Qin, Rongjun; Zhang, Guixiang; Albanwan, Hessah;	Spatial temporal analysis of traffic patterns during the COVID-19 epidemic by vehicle detection using planet remote-sensing satellite images	Remote Sensing	13	2	208	2021	Multidisciplinary Digital Publishing Institute
6.	Ghasempour, Fatemeh; Sekertekin, Aliihsan; Kutoglu, Senol Hakan;	Google Earth Engine based spatio-temporal analysis of air pollutants before and during the first wave COVID-19 outbreak over Turkey via remote sensing	Journal of Cleaner Production	319		128599	2021	Elsevier
7.	Sun, Kang; Li, Lingbo; Jagini, Shruti; Li, Dan;	A satellite-data-driven framework to rapidly quantify air-basin-scale NO x emissions and its application to the Po Valley	Atmospheric Chemistry and Physics	21	17	13311-13332	2021	Copernicus GmbH

		during the COVID-19 pandemic						
8.	Avtar, Ram; Kumar, Pankaj; Supe, Hitesh; Jie, Dou; Sahu, Netranada; Mishra, Binaya Kumar; Yunus, Ali P;	Did the COVID-19 lockdown-induced hydrological residence time intensify the primary productivity in lakes? Observational results based on satellite remote sensing	Water	12	9	2573	2020	Multidisciplinary Digital Publishing Institute
9.	Xu, Hanqiu; Xu, Guangzhi; Wen, Xiaole; Hu, Xiujuan; Wang, Yifan;	Lockdown effects on total suspended solids concentrations in the Lower Min River (China) during COVID-19 using time-series remote sensing images	International Journal of Applied Earth Observation and Geoinformation	98		102301	2021	Elsevier
10.	Singh, Manmeet; Singh, Bhupendra Bahadur; Singh, Raunaq; Upendra, Badimela; Kaur, Rupinder; Gill, Sukhpal Singh; Biswas, Mriganka Sekhar;	Quantifying COVID-19 enforced global changes in atmospheric pollutants using cloud computing based remote sensing	Remote Sensing Applications: Society and Environment	22		100489	2021	Elsevier
11.	Garg, Vaibhav; Aggarwal, Shiv Prasad; Chauhan, Prakash;	Changes in turbidity along Ganga River using Sentinel-2 satellite data during lockdown associated with COVID-19	Geomatics, Natural Hazards and Risk	11	1	1175-1195	2020	Taylor & Francis
12.	Pathakoti, Mahesh; Muppalla, Aarathi; Hazra, Sayan; Dangeti, Mahalakshmi; Shekhar, Raja; Jella, Srinivasulu; Mullapudi, Sesha Sai; Andugulapati, Prasad; Vijayasundaram, Uma;	An assessment of the impact of a nation-wide lockdown on air pollution–a remote sensing perspective over India	Atmospheric Chemistry and Physics Discussions			16-Jan	2020	Copernicus GmbH
13.	Soni, Manish; Verma, Sunita; Jethava, Hiren; Payra, Swagata; Lamsal, Lok; Gupta, Priyanshu; Singh, Janhavi;	Impact of COVID-19 on the Air Quality over China and India Using Long-term (2009-2020) Multi-Satellite Data	Aerosol and Air Quality Research	21			2021	Taiwan Association for Aerosol Research
14.	Mazhar, Usman; Jin, Shuanggen; Bilal, Muhammad; Ali, Md Arfan; Khan, Rehana;	Reduction of surface radiative forcing observed from remote sensing data during	Atmospheric Research			105729	2021	Elsevier

		global COVID-19 lockdown						
15.	Franch-Pardo, Ivan; Desjardins, Michael R; Barea-Navarro, Isabel; Cerdà, Artemi;	A review of GIS methodologies to analyze the dynamics of COVID-19 in the second half of 2020	Transactions in GIS	25	5	2191-2239	2021	Wiley Online Library
16.	KAPLAN, Gordana; AVDAN, Zehra YİĞİT;	COVID-19: Spaceborne nitrogen dioxide over Turkey	Eskişehir Technical University Journal of Science and Technology A-Applied Sciences and Engineering	21	2	251-255	2020	
17.	Stavrakou, Trissevgeni; Müller, Jean-François; Bauwens, Maite; Doumbia, Thierno; Elguindi, Nellie; Darras, Sabine; Granier, Claire; Smedt, Isabelle De; Lerot, Christophe; Van Roozendael, Michel;	Atmospheric impacts of COVID-19 on NOx and VOC levels over China based on TROPOMI and IASI satellite data and modeling	Atmosphere	12	8	946	2021	Multidisciplinary Digital Publishing Institute
18.	Jawak, Shridhar D; Andersen, Bo N; Pohjola, Veijo; Godøy, Øystein; Hübner, Christiane; Jennings, Inger; Ignatiuk, Dariusz; Holmén, Kim; Sivertsen, Agnar; Hann, Richard;	SIOS's Earth Observation (EO), Remote Sensing (RS), and operational activities in response to COVID-19	Remote Sensing	13	4	712	2021	Multidisciplinary Digital Publishing Institute
19.	Mallik, Santanu; Soni, Shivam; Podder, Krishanu; Mishra, Umesh; Ahamed, Maqusood;	Prediction and assessment of change in PM2. 5 during COVID-19 lockdown using remote sensing and deep learning approach: A case study of Kanpur city					2020	
20.	Chen, Jiandong; Gao, Ming; Huang, Shasha; Hou, Wenxuan;	Application of remote sensing satellite data for carbon emissions reduction	Journal of Chinese Economic and Business Studies	19	2	109-117	2021	Taylor & Francis
21.	Roman-Gonzalez, Avid; Navarro-Raymundo, Angel F; Vargas-Cuentas, Natalia I;	Air Pollution Monitoring in Peru Using Satellite Data During the Quarantine Due to COVID-19	IEEE Aerospace and Electronic Systems Magazine	35	12	73-79	2020	IEEE
22.	Avtar, Ram; Komolafe, Akinola Adesuji; Kouser, Asma; Singh, Deepak; Yunus, Ali P; Dou, Jie; Kumar, Pankaj; Gupta, Rajarshi Das; Johnson, Brian	Assessing sustainable development prospects through remote sensing: A review	Remote Sensing Applications: Society and Environment			100402	2020	Elsevier

	Alan; Minh, Huynh Vuong Thu;							
23.	Amoroso, Nicola; Cilli, Roberto; Maggipinto, Tommaso; Monaco, Alfonso; Tangaro, Sabina; Bellotti, Roberto;	Satellite data and machine learning reveal a significant correlation between NO2 and COVID-19 mortality	Environmental Research	204		111970	2022	Elsevier
24.	Pérez-Martínez, Pedro José; Magalhães, Tiago; Maciel, Isabela; de Miranda, Regina M; Kumar, Prashant;	Effects of the COVID-19 Pandemic on the Air Quality of the Metropolitan Region of São Paulo: Analysis Based on Satellite Data, Monitoring Stations and Records of Annual Average Daily Traffic Volumes on the Main Access Roads to the City	Atmosphere	13	1	52	2022	Multidisciplinary Digital Publishing Institute
25.	Chen, Xu; Chen, Wei; Bai, Yanbing; Wen, Xiaole;	Changes in turbidity and human activities along Haihe River Basin during lockdown of COVID-19 using satellite data	Environmental Science and Pollution Research			16-Jan	2021	Springer
26.	Prakash, Satya; Goswami, Mrinalini; Khan, YD Imran; Nautiyal, Sunil;	Environmental impact of COVID-19 led lockdown: A satellite data-based assessment of air quality in Indian megacities	Urban Climate	38		100900	2021	Elsevier
27.	Wu, Chen; Zhu, Sihan; Yang, Jiaqi; Hu, Meiqi; Du, Bo; Zhang, Liangpei; Zhang, Lefei; Han, Chengxi; Lan, Meng;	Traffic Density Reduction Caused by City Lockdowns Across the World During the COVID-19 Epidemic: From the View of High-Resolution Remote Sensing Imagery	IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing	14		5180-5193	2021	IEEE
28.	Saxena, Shalini; Rabha, Amit; Tahlani, Preeti; Ray, Shibendu S;	Crop situation in India, before, during and after COVID-19 lockdown, as seen from the satellite data of resourcesat-2 AWiFS	Journal of the Indian Society of Remote Sensing	49	2	365-376	2021	Springer

29.	Wagh, Poonam; Sojan, Jency M; Babu, Sriram J; Valsala, Renu; Bhatia, Suman; Srivastav, Roshan;	Indicative Lake Water Quality Assessment Using Remote Sensing Images-Effect of COVID-19 Lockdown	Water	13	1	73	2021	Multidisciplinary Digital Publishing Institute
30.	Sari, Nurwita Mustika; Kuncoro, Muhammad Nur Sidiq;	Monitoring Of Co, No2 And So2 Levels During The Covid-19 Pandemic In Iran Using Remote Sensing Imagery	Geography, Environment, Sustainability				2021	
31.	Scheibenreif, Linus; Mommert, Michael; Borth, Damian;	A Novel Dataset and Benchmark for Surface NO2 Prediction from Remote Sensing Data Including COVID Lockdown Measures	2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS			8364-8367	2021	IEEE
32.	Represa, Natacha S; Della Ceca, Lara S; Abril, Gabriela; Ferreyra, María F García; Scavuzzo, Carlos M;	Atmospheric Pollutants Assessment during the COVID-19 Lockdown Using Remote Sensing and Ground-based Measurements in Buenos Aires, Argentina	Aerosol and Air Quality Research	21			2021	Taiwan Association for Aerosol Research
33.	Sun, Kang; Li, Lingbo; Jagini, Shruti; Li, Dan;	A Satellite Data-Driven Framework to Rapidly Quantify Air Basin-Scale NO x Emission and Its Application to the Po Valley during the COVID-19 Pandemic	Atmospheric Chemistry and Physics Discussions			29-Jan	2021	Copernicus GmbH
34.	Tehrani, Nadia Abbaszadeh; Mollalo, Abolfazl; Farhanj, Farinaz; Pahlevanzadeh, Nooshin; Janalipour, Milad;	Time-Series Analysis of COVID-19 in Iran: A Remote Sensing Perspective	COVID-19 Pandemic, Geospatial Information, and Community Resilience			277-290	2021	CRC Press
35.	Magidi, James; Nhamo, Luxon; Mpandeli, Sylvester; Mabhaudhi, Tafadzwanashe;	Application of the Random Forest Classifier to Map Irrigated Areas Using Google Earth Engine	Remote Sensing	13	5	876	2021	Multidisciplinary Digital Publishing Institute
36.	Rodríguez-Benito, Cristina; Caballero, Isabel; Nieto, Karen; Navarro, Gabriel;	Observation of Maritime Traffic Interruption in Patagonia during the	Remote Sensing	13	6	1119	2021	Multidisciplinary Digital Publishing Institute

		COVID-19 Lockdown Using Copernicus Sentinel-1 Data and Google Earth Engine						
37.	Faisal, Moh; Prakoso, Kukuh Adi; Sanjaya, Hartanto; Darminto, Mohammad Rohmaneo;	Spatio-Temporal Analysis of Air Pollutants Changes During The COVID-19 Using Sentinel-5P in Google Earth Engine (Case Study: Java Island)	2021 IEEE Asia-Pacific Conference on Geoscience, Electronics and Remote Sensing Technology (AGERS)			102-108	2021	IEEE
38.	Gulácsi, András; Kovács, Ferenc;	Sentinel-1-imagery-based high-resolution water cover detection on wetlands, Aided by Google Earth Engine	Remote Sensing	12	10	1614	2020	Multidisciplinary Digital Publishing Institute
39.	Khan, Rabia Munsaf; Salehi, Bahram; Mahdianpari, Masoud; Mohammadimanesh, Fariba;	Water quality monitoring over finger lakes region using sentinel-2 imagery on google earth engine cloud computing platform	ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences	3		279-283	2021	Copernicus GmbH
40.	Shami, Siavash; Ranjgar, Babak; Azar, Mahdi Khoshlahjeh; Moghimi, Armin; Sabetghadam, Samaneh; Amani, Meisam;	Trends of CO and NO2 Pollutants Change in Iran during Covid-19 Pandemic using Time-Series Sentinel-5 Images in Google Earth Engine					2021	
41.	Ang, Michelle Li Ern; Arts, Dirk; Crawford, Danielle; Labatos Jr, Bonifacio V; Ngo, Khanh Duc; Owen, John R; Gibbins, Chris; Lechner, Alex M;	Socio-environmental land cover time-series analysis of mining landscapes using Google Earth Engine and web-based mapping	Remote Sensing Applications: Society and Environment	21		100458	2021	Elsevier
42.	Jangid, Amita; Gupta, Mukesh Kumar;	Investigating the Effect of Lockdown During COVID-19 on Land Surface Temperature Using Machine Learning Technique by Google Earth Engine: Analysis of Rajasthan, India	Communication and Intelligent Systems			355-364	2021	Springer

43.	Oo, Tin Ko; Arunrat, Noppol; Kongsurakan, Praeploy; Sereenonchai, Sukanya; Wang, Can;	Nitrogen Dioxide (NO2) level changes during the control of COVID-19 pandemic in Thailand	Aerosol and Air Quality Research	21		1-0	2021	Taiwan Association for Aerosol Research
44.	Naik, Rajashree; Sharma, LK;	Migratory Birds Monitoring of India's Largest Shallow Saline Ramsar Site with Big Geospatial Data Using Google Earth Engine for Restoration					2021	Preprints
45.	Tan, Zhenyu; Li, Xinghua; Gao, Meiling; Jiang, Liangcun;	The Environmental Story During the COVID-19 Lockdown: How Human Activities Affect PM2. 5 Concentration in China?	IEEE Geoscience and Remote Sensing Letters				2020	IEEE
46.	Verma, Nidhi; Kumar, Nilesh; Mishra, Pooja; Purohit, Neetesh;	Profound implications of COVID-19 pandemic lockdown on the Earth's ecosystem: a case study using remote sensing data	Current Science	121	1	115	2021	INDIAN ACAD SCIENCES CV RAMAN AVENUE, SADASHIVANAGAR, PB# 8005, BANGALORE …
47.	Fardani, Irland; Aji, Riswandha Risang;	Analysis of Changes in Air Quality in Major Cities Indonesia During COVID 19 Using Remote Sensing Data	IOP Conference Series: Earth and Environmental Science	830	1	12085	2021	IOP Publishing
48.	Raji, Saheed Adekunle; Odeja, Olubunmi;	Monitoring the Impact of COVID-19 Lockdown and Correlates on Nigeria's Air Quality Using TROPOMI Data					2021	
49.	Oo, Tin Ko; Arunrat, Noppol; Kongsurakan, Praeploy; Sereenonchai, Sukanya; Wang, Can;	Nitrogen dioxide (NO_2) level changes during the control of COVID-19 2 pandemic in Thailand						
50.	Wang, Haibo; Tan, Junlei; Li, Xin;	Global NO 2 Dynamics During the COVID-19 Pandemic: A Comparison Between Two Waves of the Coronavirus	IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing	14		4310-4320	2021	IEEE

Annexure-2: Google Earth Engine Code Editor Script (JavaScript)

```
var study_area =
ee.FeatureCollection("users/aroravirat/rj_districts"),
    geometry = /* color: #d63000 */ee.Geometry.MultiPoint(
        [[74.01950546405902, 29.180208881717107],
         [75.79967245817184, 26.89910921928759],
         [74.19017538785934, 26.255549449488587],
         [73.02013144254684, 26.25062291125165],
         [73.02562460660934, 24.678529866179897],
         [74.62413534879684, 24.683521210539688],
         [75.82713827848434, 25.13192026193509],
         [76.13578543424606, 27.656162934708533],
         [77.03563437223434, 24.61362421796779],
         [76.8659407899955, 28.177136064670623],
         [76.75546282723562, 24.767995143642626]]),
    imageVisParam =
{"opacity":1,"bands":["tropospheric_NO2_column_number_density"],"m
in":-100,"max":100,"palette":["ff0000","ffffff","109300"]},
    imageVisParam2 = {"opacity":1,"bands":["NDVI"],"min":-
100,"max":100,"palette":["119d00","ffffff","ff0000"]};

//////// STUDY AREA //////////////

Map.centerObject(study_area);
var styling = {color: 'black', width: 1, fillColor: '00000000'};
Map.addLayer(study_area.style(styling), {}, 'study_area');



/////// SENTINEL-5P - TROPOMI - NO2 DATA - PRE-LOCKDOWN AND
DURING-LOCKDOWN //////////////

var collection = ee.ImageCollection('COPERNICUS/S5P/NRTI/L3_NO2')
  .select('tropospheric_NO2_column_number_density');

var pre_ld = collection.filterDate('2019-01-01', '2019-12-
31').mean().clip(study_area);
var dur_ld = collection.filterDate('2020-04-01', '2020-06-
30').mean().clip(study_area);

var band_viz = {
  min: 0,
```

```
  max: 0.0001,
  palette: ['black', 'blue', 'purple', 'cyan', 'green', 'yellow',
'red']
};

Map.addLayer(dur_ld, band_viz, 'During-lockdown NO2 emissions');
Map.addLayer(pre_ld, band_viz, 'Pre-lockdown NO2 emissions');



///////// SPATIAL DIFFERENCING OF PRE-LOCKDOWN AND DURING-LOCKDOWN
IMAGES ////////////////

var dif = (pre_ld.subtract(dur_ld)).divide(pre_ld).multiply(100);
Map.addLayer(dif, imageVisParam, 'Percentage change in NO2
emissions');
```