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# Study of air pollutant concentration in four different regions of India during and post the COVID-19 lockdown

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## ABSTRACT

*The SARS-Covid-19 epidemic has caused significant economic losses around the world as well as a serious threat to human health. Like other countries, India has also imposed lockdowns during the first and second waves of COVID-19. The nationwide lockdown to contain the COVID-19 epidemic has given us a unique golden chance to understand the role of human-caused emissions in the overall burden of air pollutants at both global and regional scales. Thus, in the current study, we have used in-situ measurement as part of a network of the Centre Pollution and Control Board (CPCB) to compare the concentration of common ambient air pollutants (i.e., $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$) over Eastern, Western, Southern, and Northern parts of India, during the lockdown of first wave of COVID for the year 2020 with that of non-COVID year 2022. The main findings of the current study show that over Eastern, Western, Southern, and Northern India, the mean mass concentration of all the studied air pollutants- $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$ was significantly lower (4 - 82%) throughout the lockdown periods (25/03/2020 to 31/05/ 2020) when compared with the same period for the year 2022. The unique result of this analysis is that over Southern India, during the lockdown period (25/03/2020 to 31/05/2020), the mean mass concentration of the air pollutant $SO_2$ increased by 54% when compared with the same period in 2022, whereas in Eastern India $PM_{10}$ and CO increased by 12% and 43% respectively. It is anticipated that the pandemic will impact some policy choices on strategies to reduce air pollution. In the future, lockdown situations might be a key component of a potential strategy to reduce air pollution. As a result, this study also raises the possibility of well-planned, short-term lockdowns which could be a useful alternative technique for reducing air pollution during heavy pollution episodes in India.*

***Keywords:*** *Concentration, Covid-19, Lockdown, Particulate matter, Pollutants.*

## 1. INTRODUCTION

In December 2019, Wuhan China became the first city affected by a pandemic caused by SARS-COV-2[1,2]. About 63,072,905 people have been affected worldwide and it has become a global pandemic. In the last few days of November 2020, World Meter reported about 43,546,236 recovered and 1,465,186 total deaths worldwide. The WHO (World Health Organization) declared it a deadly disease worldwide on March 11$^{th}$ 2020 [3]. According to previous observations, a lipid layer that breaks at elevated temperatures prevents the COVID-19 virus from surviving, and a dry and cold environment facilitates the process [4].

The first Covid-19-related case was found on 30th January 2020 in India. Countless cases have since been identified as a result of the epidemic Covid-19, and almost 2000 people were suspected to have positive cases. Later, the cases increased dramatically and a lockdown was implemented in India. As a result of the lockdown, the number of vehicles on the road and the industrial unit activities decreased overall [5] and the transport and industrial sectors emitted less toxic waste. After analysing the various air pollutants which causing the change in the air quality index in a given location, people were wondering if confinement affects the air quality index [6]. Various air pollutants have been studied and analysed including $PM_{10}$, $PM_{2.5}$, $NO_2$, CO, and $O_3$ in different cities and countries around the world. It has been found a decreasing trend in $PM_{10}$, $PM_{2.5}$, $NO_2$, and CO, but an increase in concentration of surface $O_3$ [7–9]. As the confinement period has progressed, air quality has improved over the Indian region [10]. A study by [10] analysed the CPCB actual time atmospheric pollutants data of 34 locations in Delhi and concluded that there was a depletion in concentration of $PM_{10}$, $PM_{2.5}$, $NO_2$, and CO, resulting of 40–50% improvement in the index of air quality. In a study by [11], data were collected from 16th March to 14th April 2020, at 22 locations in India and found a decrease in $PM_{2.5}$, $PM_{10}$, CO, and $NO_2$ by 43%, 31%, 10%, and 18%, respectively. According to [12], the decrease was found less in small cities than in metropolises.

Thus, by analyzing the different studies we found that the studies were mostly local and city level, so we have conducted a study with broad objective and greater region over India. In current study we have analysed the air quality over the Eastern, Western, Southern, and Northern regions of India during March 25th to May 31st of 2020 and 2022 during lockdown and without lockdown days. During lockdown days, a relationship between lockdown and air quality agents like particulate matter ($PM_{10}$, $PM_{2.5}$), sulphur dioxide ($SO_2$), nitrogen dioxide ($NO_2$) and carbon monoxide (CO) can be shown by comparing the concentration in several air pollutant species over a location. A diurnal data analysis during March 25th to May 31st of 2020 and 2022 was done as an empirical specification on the quality of the cities air to quantify the effects of Covid-19 related lockdowns from a global perspective. As a part of the case study, we analysed the daily median concentration for $PM_{10}$, $PM_{2.5}$, CO, $NO_2$, and $SO_2$ across the Eastern, Western, Southern, and Northern regions of India. The environmental effects of lockdowns in the India's Eastern, Western, Southern, and Northern regions, and how these effects vary over different industrial structures and populations region has been studied in the current study. The approach used to analyse the CPCB dataset is described in the Section 2 along with the results that were obtained are presented in Section 3, followed by discussions in Section 4, and finally, the analysis's findings are presented in Section 5 as conclusion.

## 2. DATA AND METHODOLOGY:

During the Covid-19 pandemic, we conducted a study that examined how atmospheric parameters changed during the lockdown period of 2020 (March 25 –May 31) and the post-lockdown period of 2022 (March 25 –May 31) in India. As part of this study, data from 12 different states were analyzed over the Northern, Eastern, Western, and Southern regions of India as shown in Table 1. Our dataset consists of five parameters named $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$ collected from the Central Pollution Control Board (CPCB) site (https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing/data). We have chosen only those states which have the complete datasets for the five pollutant parameters. We have taken the daily dataset (averaged over 24 hours) for the five parameters outlined above during the lockdown 2020 (March 25 –May 31) and post-lockdown period 2022 (March 25 –May 31).

## 3. RESULTS

As a result of India's nationwide lockdown starting on 25th March 2020, the air quality improved significantly. A comparison of air quality data during the lockdown phase 2020 (March 25 –May 31) and post-lockdown phase 2022 (March 25 –May 31) is presented in this section for Eastern, Western, Southern and Northern regions of India.

| Regions | State | Station | Latitude | Longitude |
|---|---|---|---|---|
| **Northern** | Delhi | Ashok Vihar | 28.6910° *N* | 77.1765° *E* |
| | Uttar Pradesh | Indirapuram, Ghaziabad | 28.6460° *N* | 77.3695° *E* |
| | Haryana | Urban Estate-II, Hisar | 29.1406° *N* | 75.7397° *E* |
| **Southern** | Andhra Pradesh | Secretariat, Amaravati | 16.5150° *N* | 80.5181° *E* |
| | Karnataka | Silk Board, Bengaluru | 12.8900° *N* | 77.6230° *E* |
| | Kerala | Vyttila, Kochi | 9.9682° *N* | 76.3182° *E* |
| **Eastern** | West Bengal | Jadavpur, Kolkata | 22.4955° *N* | 88.3709° *E* |
| | Odisha | Talcher Coalfields | 20.9515° *N* | 85.2156° *E* |
| | Bihar | Industrial Area, Hajipur | 25.6928° *N* | 85.2401° *E* |
| **Western** | Gujarat | GIDC, Ankleshwar | 21.6180° *N* | 73.0228° *E* |
| | Maharashtra | Gangapur Road, Nashik | 19.6975° *N* | 75.0105° *E* |
| | Madhya Pradesh | Sector-2, Pithampur | 22.6237° *N* | 75.6557° *E* |

**Table 1: The selected air quality stations in this study are summarized in the following table.**

### 3.1 STUDY OF AIR QUALITY DURING THE LOCKDOWN PERIOD

The daily average measurement of $PM_{2.5}$, $PM_{10}$, $NO_2$, $SO_2$, and CO concentrations in India's four regions i.e., Eastern, Western, Southern, and Northern during the lockdown and post-lockdown periods of 2020 and 2022 (March 25 – May 31). As shown in Fig. 1(a), during the lockdown, the maximum daily average $PM_{2.5}$ concentration over the Eastern, Western, Southern, and Northern parts of India were 65.86 μg/m$^3$, 59.58 μg/m$^3$, 31.21 μg/m$^3$, and 100.11 μg/m$^3$, respectively. Fig. 1(b) show that the daily maximum average $PM_{10}$ concentration for Eastern, Western, Southern, and Northern regions was 206.53 μg/m$^3$, 141.48 μg/m$^3$, 76.06 μg/m$^3$, and 221.46 μg/m$^3$ respectively, while the daily maximum average $NO_2$ concentration was 16.39 μg/m$^3$, 14.22 μg/m$^3$, 14.52 μg/m$^3$, and 54.01 μg/m$^3$ for the same regions shown in Fig. 1(c). As shown in Fig. 1(d), the maximum daily average $SO_2$ concentrations were 30.38 μg/m$^3$, 11.97 μg/m$^3$, 16.83 μg/m$^3$, and 34.42 μg/m$^3$ in India's four regions - Eastern, Western, Southern, and Northern respectively. During the lockdown, the maximum daily average CO concentration in India's Eastern, Western, Southern, and Northern regions was 1.46 μg/m$^3$, 1.02 μg/m$^3$, and 1.13 μg/m$^3$, and 1.10 μg/m$^3$ respectively (see Fig. 1(e)). The blue bars present in Figs. 3(a), 3(b), 3(c), and 3(d)display variation in mean concentrations of $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$ measured in the Eastern, Western, Northern, and Southern regions of India. From Fig. 3(a) it is observed that the mean concentrations of $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$ were 26.04 μg/m$^3$, 86.03 μg/m$^3$, 1.01 μg/m$^3$, 10.66 μg/m$^3$, and 10.06 μg/m$^3$ respectively over the Eastern region of India during Lockdown whereas the mean concentrations of $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$ were 29.22 μg/m$^3$, 82.46 μg/m$^3$, 0.68 μg/m$^3$, 11.11 μg/m$^3$, and 6.82 μg/m$^3$ respectively within the Western region of India during Lockdown as shown in Fig. 3(b). During lockdown, the mean concentrations of $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$ were 20.10 μg/m$^3$, 45.40 μg/m$^3$, 0.75 μg/m$^3$, 7.59 μg/m$^3$, and 10.33 μg/m$^3$ respectively over the Southern region as displayed in Fig. 3(c). In the case of the Northern region of India, the mean concentrations of $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$ were 47.29 μg/m$^3$,111.60 μg/m$^3$, 0.63 μg/m$^3$, 20.66 μg/m$^3$, and 15.90 μg/m$^3$ respectively during the lockdown as shown in Fig.3(d). Fig. 4 displays the percentage changes in concentration

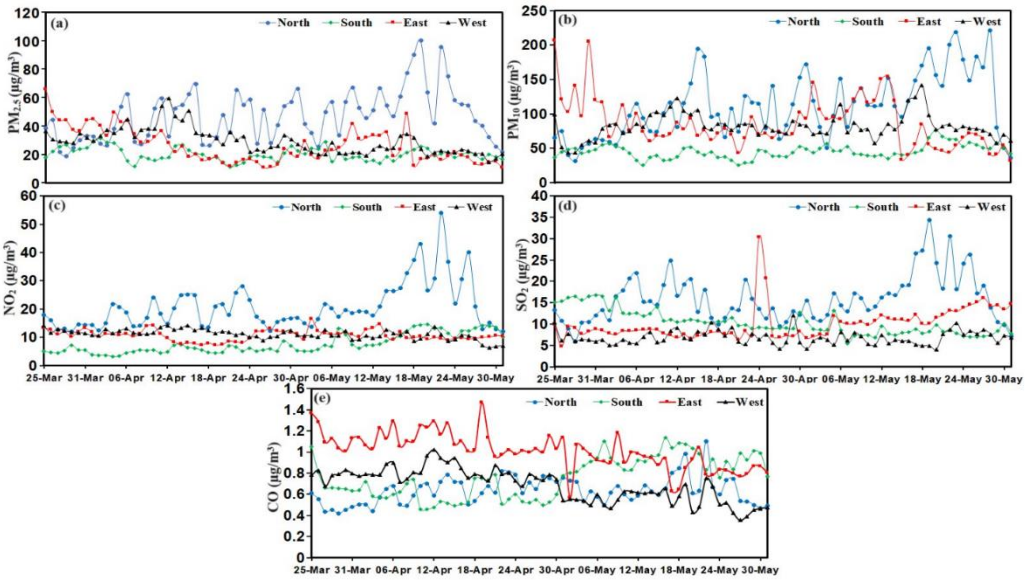


**Fig. 1: Variations of measured daily average concentration (a) $PM_{2.5}$ (b) $PM_{10}$ (c) $NO_2$ (d) $SO_2$ (e) CO over four Indian regions Eastern, Western, Southern, and Northern during 2020 (March 25 – May 31).**

of $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$ during the lockdown phase. It is observed during lockdown that $PM_{2.5}$ is found to be decreased by 34.10%, 38.32%, 47.68%, and 39.56% over the Eastern, Western, Northern, and Southern regions of India, respectively, whereas $NO_2$ is found to decrease by 30.60%, 49.18%, 81.79%, and 34.95% across the same regions of India respectively. Over Western, Southern, and Northern regions, $PM_{10}$ is found to be decreased by 22.44%, 35.44%, and 54.03%, respectively, whereas in Eastern regions, it is increased by 11.55% during the lockdown. During the Lockdown, CO is increased by 43.35% in India's Eastern region, whereas $SO_2$ is increased by 54.17% in India's Southern region. Meanwhile, CO is decreased by 38.37%, 3.46%, and 48.74% in Western, Southern, and Northern regions, respectively. Over Eastern, Western, and Northern regions of India, $SO_2$ is observed to be decreased by 9.15%, 49.05%, and 15.38%, respectively. As illustrated in Fig.2(d), the daily maximum $SO_2$ concentration was 26.45 μg/m$^3$, 35.17 μg/m$^3$, 13.35 μg/m$^3$, and 37.5 μg/m$^3$ in Eastern, Western, Southern, and Northern parts of India, respectively. India's Eastern, Western, Southern, and Northern areas showed maximum daily average CO concentrations of 1.45 μg/m$^3$, 3.35 μg/m$^3$, 1.98 μg/m$^3$, and 2.16 μg/m$^3$ after the lockdown, as shown in Fig. 2(e). In Figures 3(a), 3(b), 3(c), and 3(d), orange bars indicate variation in mean concentrations of $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$ measured in India's four regions - Eastern, Western, Northern, and Southern. As shown in Fig. 3(a), the mean concentrations of $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$ were 39.53 μg/m$^3$, 77.12 μg/m$^3$, 0.70 μg/m$^3$, 15.37 μg/m$^3$, and 11.07 μg/m$^3$, correspondingly, over the Eastern region post lockdown however, the mean concentrations of $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$ were 47.38 μg/m$^3$, 106.32 μg/m$^3$, 1.11 μg/m$^3$, 21.86 μg/m$^3$, and 13.38 μg/m$^3$correspondingly within the Western region of India after the lockdown as illustrated in Fig. 3(b). According to Fig.3(c), the mean concentrations of $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$ in

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Southern region were 38.43 μg/$m^3$, 70.33 μg/$m^3$, 0.78 μg/$m^3$, 41.68 μg/$m^3$, and 6.70 μg/$m^3$correspondingly, post lockdown. Fig.3(d) shows that the mean concentrations of $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$ in Northern region of India were 78.26 μg/$m^3$, 242.80 μg/$m^3$, 1.23 μg/$m^3$, 31.77 μg/$m^3$, and 18.79 μg/$m^3$ correspondingly, after the lockdown.

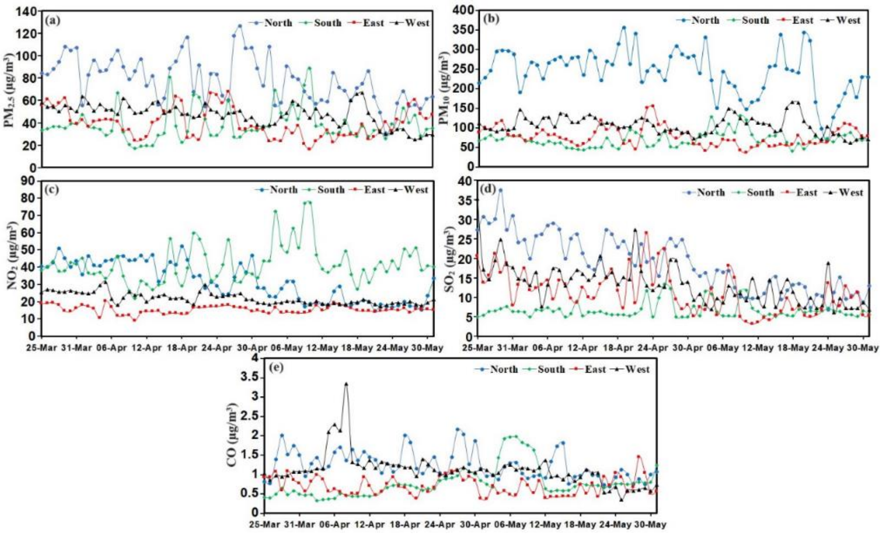


**Fig. 2: Variations of measured daily average concentration (a) $PM_{2.5}$ (b) $PM_{10}$ (c) $NO_2$ (d) $SO_2$ (e) CO over four Indian regions Eastern, Western, Southern, and Northern during 2022 (March 25 – May 31).**

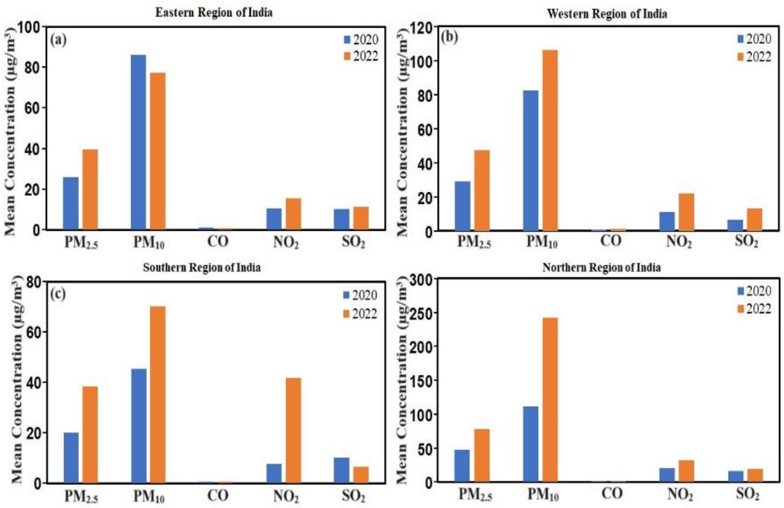


**Fig. 3: Comparison of mean concentrations of $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$ over four Indian regions (a) Eastern, (b) Western, (c) Southern, and (d) Northern.**

## 4. DISCUSSION

During the lockdown period, a significant decrease in the daily average level of $PM_{2.5}$, $PM_{10}$, $NO_2$, $SO_2$, and CO can be observed in India's Western and Northern regions but a significant decrease in the daily average level of $PM_{2.5}$, $NO_2$, and CO can be noticed in India's Southern and Eastern regions whereas, in the same region, daily average values of $PM_{10}$ and $SO_2$ are found to be increased during lockdown period in comparison with a non-lockdown period as shown in Fig.1 and 2. This occurs as a result of the fact that in India, there are regional disparities in the reduction of air pollutants during lockdown phase, as well as regional differences in the types of industries, weather patterns, and local sources of pollution [12–14]. The Western and Northern regions have a higher concentration of industries and manufacturing facilities, making them generally more industrialized. It has been noticed that the noteworthy decrease of $PM_{2.5}$, $PM_{10}$, $NO_2$, $SO_2$, and CO during the lockdown period could be due to the restriction of industrial activity due to the drop in emissions from these sources [15,16]. With substantial agriculture and crop burning, India's Southern and Eastern regions have a stronger agricultural basis. The burning of crop leftovers is one agricultural practice that can greatly increase the amount of $SO_2$ and $PM_{10}$ pollutants in the air [17–19]. There is a chance that the lockdown mechanisms failed to stop these actions in a timely manner, which would have increased the concentration of these contaminants. The earlier research [12,16–18] likewise came to similar conclusions. Also, it has been observed that the reduction in daily average values of $PM_{2.5}$, $PM_{10}$, $NO_2$, and $SO_2$ is low across the Northern region than that of India's Eastern, Western, and Southern regions during the lockdown phase, whereas the reduction in daily average values of $SO_2$ and CO during lockdown period is high over Northern region than that of the remaining three regions of India (see Fig. 1 and 2). This is the unique result of the analysis over the Northern region of India. This unusual outcome is because, although pollution sources are present in the Eastern, Western, and Southern regions as well, they may not be as intense as they are in the Northern region [20]. Therefore, the decrease in human activity during the lockdown would have a bigger influence on lowering pollution levels in these areas [17,21,22]. From Fig. 3 the $PM_{2.5}$, $NO_2$, and CO mean concentrations are smaller during the lockdown period than that of the non-lockdown period over all four regions of India. This finding is quite reliable with the findings of [12]. This is due to a major decrease in commercial and industrial activity, as well as transit and vehicle traffic, due to the lockdown measures adopted during the COVID-19 epidemic [14,23]. Emissions of $PM_{2.5}$, $NO_2$, and CO are mostly produced by these industries. Lower amounts of pollutants were observed as a result of companies closing and a reduction in the number of automobiles on the roadways [6,24]. $PM_{2.5}$ and other pollutants are produced by construction operations. Construction activities were stopped or drastically scaled back during the lockdown, which led to a decrease in the amount of $PM_{2.5}$ in the air [3,14,25]. Mean concentrations of $PM_{10}$ and $SO_2$ in India's Northern and Western regions are also observed to be smaller during the lockdown phase whereas mean concentrations of $PM_{10}$ and $SO_2$are also observed to be larger over India's Southern and Eastern regions. The mean concentrations high value of $PM_{10}$ and $SO_2$ over the Southern and Eastern regions of India during the lockdown period signifies a unique result of the analysis. This result is in best agreement with the results obtained by the previous researchers [5,13,16,18]. This outcome results from decreased industrial emissions, increased burning of biomass, decreased emissions from vehicles, favourable air conditions, and limited maintenance of pollution control equipment [26]. During lockdown the percentage reduction in concentration of $PM_{2.5}$ is found to be high over the Southern region whereas the percentage reduction in concentration of $PM_{10}$ is found to be high over the Northern region of India as shown in Fig. 4. The percentage reduction in concentrations of CO, $NO_2$, and $SO_2$ are observed to be high

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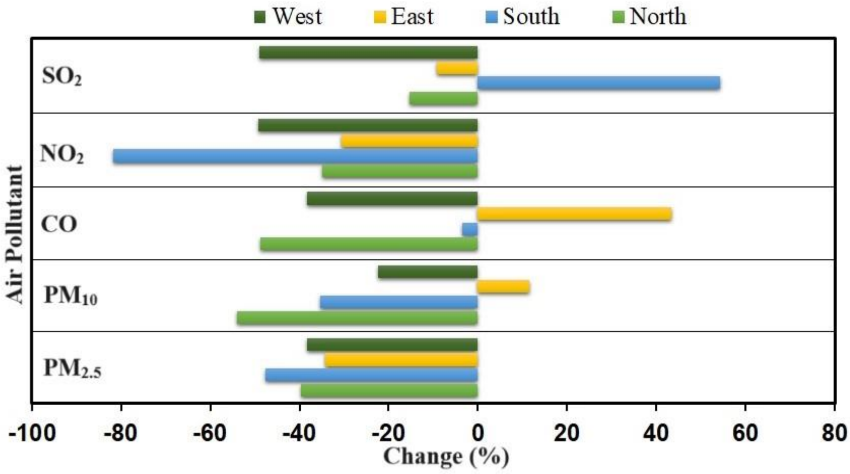


**Fig. 4: Total percentage change of total concentration of $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$ over four Indian regions Eastern, Western, Southern, and Northern.**

during lockdown over India's Northern, Southern, and Western regions respectively. A similar finding was also obtained by the previous researchers [17,19]. The percentage change in concentrations of $PM_{10}$ and CO is found to be increased over the Eastern region whereas the percentage change in concentration of $SO_2$ is found to be increased over the India's Southern region throughout the lockdown phase. During the lockdown period, the increase in percentage change in concentrations of $PM_{10}$, CO, and $SO_2$ over Eastern and Southern regions of India represents a unique result of an analysis of the number of air pollutants in four regions of India during and after the lockdown. The main source of CO emissions in Northern India is automobile traffic, particularly in densely populated, industrialized places like Delhi and its environs. The number of vehicles on the road during the lockdown was drastically decreased due to stringent limits on mobility and limited transit, which resulted in a large reduction in CO emissions [5,14]. A decline in industrial activity is to blame for the fall in $NO_2$ concentrations in India's southern region. Numerous industrial hubs, power plants, and manufacturing facilities may be found in this area. The lockdown measures enforced limitations on industrial activities, which led to a decrease in $NO_2$ emissions from industrial sources [25,26]. The industrial and manufacturing operations in the Western region of India, particularly in Gujarat and Maharashtra, are well-known [15]. Large amounts of sulphur dioxide ($SO_2$) are released by businesses like refineries, petrochemical factories, and thermal power plants. Reduced energy production and industrial output as a result of the lockdown limitations led to lower $SO_2$ emissions [26,27].

## 5. CONCLUSION

As part of our study, we examined concentrations of common ambient air pollutants in 12 different states across the country during and post the lockdown period imposed following the COVID-19 outbreak, categorized according to four different regions: eastern, western, southern, and northern. A comparison between during and post the lockdown period values shows decreasing behaviour of $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, and $SO_2$. Also, throughout the lockdown phase (25th March-31st May 2020), air pollutants showed a declining trend compared to (25th March-31st May 2022) values for these parameters. It has been shown that some regions exhibit contradictory trends when it comes to $PM_{10}$, CO, and $SO_2$. As well, $PM_{10}$ and CO levels in Eastern regions increased. There are many causes of this dissimilarity, such as cooking activities, migration of low-income groups, reactions with hydrogen-containing carbons produced by agricultural waste burning, and the burning of relic fuels. [28]. The southern region, which is rich in coal power plants, coal mining, etc., showed an increase in $SO_2$ values due to these industries operating at low levels. [29].

Considering this comparison, it may be possible to draw some conclusions about how environmental regulations can be created during the recovery process. It enabled us to compare results across countries and taught policymakers that the fundamental rule for determining how to combat air pollution in the post-pandemic phase should be to take actions appropriate to local conditions. By estimating the expected health benefits associated with apparent improvements in air quality, our study has added to the body of knowledge regarding health costs caused by variations in air pollution concentrations. The current study and preliminary analysis of data on the quality of the air is suggesting that the Covid-19 epidemic might be a 'blessed in disguise', as the environment improves and the earth is reviving. Several health problems can be noticeably reduced, including respiratory illness, cardiovascular disease, asthma, and premature death due to controlled emission of major pollutants of air. In order to improve air quality and control emissions, strict policies and strategies must be implemented, the government and authorities can be confident that air pollution will be greatly reduced and human health will be significantly improved.

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## REFERENCES

[1] G Pant, Alka, D Garlapati, A Gaur, K Hossain, S V Singh, and A K Gupta *Environ. Sci. Pollut. Res.* **27** 44629 (2020).

[2] Q Bukhari and Y Jameel *SSRN Electron. J.* (2020).

[3] S Kumar *Sci. Total Environ.* **745** 141021 (2020).

[4] D Schoeman and B C Fielding *Virol. J.* **16** 1 (2019).

[5] K Patel and A K Singh *Indian J. Phys.* **97** 319 (2023).

[6] Y Wang, X Duan, T Liang, L Wang, and L Wang *Chemosphere* **291** 132799 (2022).

[7] L Y K Nakada and R C Urban *Sci. Total Environ.* **730** 139087 (2020).

[8] P Krecl, A C Targino, G Y Oukawa, and R P Cassino Junior *Environ. Pollut.* **265** 19 (2020).

[9] G Dantas, B Siciliano, B B França, C M da Silva, and G Arbilla *Sci. Total Environ.* **729** 139085 (2020).

[10] S Mahato, S Pal, and K G Ghosh *Sci. Total Environ.* **730** 139086 (2020).

[11] S Sharma, M Zhang, J Gao, H Zhang, and S Harsha *Sci. Total Environ.* **728** 138878 (2020).

[12] P Kumari and D Toshniwal *Int. J. Environ. Health Res.* **32** 503 (2022).

[13] N Singh, Y Tang, Z Zhang, and C Zheng *Resour. Conserv. Recycl.* **163** (2020).

[14] M Abu Talib, M Abdallah, A Abdeljaber, and O Abu Waraga *Eng. Appl. Artif. Intell.* **117** 105617 (2023).

[15] S Selvam, P Muthukumar, S Venkatramanan, P D Roy, K M Bharath, and K Jesuraja *Sci. Total Environ.* **737** 140391 (2020).

[16] A Saxena and S Raj *Urban Clim.* **35** 100754 (2021).

[17] B P Singh and P Kumar *Urban Clim.* **40** 101013 (2021).

[18] D Roy, S Tripathy, S K Kar, N Sharma, S K Verma, and V Kaushal *Asian J. Psychiatr.* **51** 102083 (2020).

[19] S Arora, K Deoli, and P Kumar *Sci. Total Environ.* **742** 140573 (2020).

[20] N Sharma, K Patel, and S Kumar *J. Environ. Impact Manag. Policy* 1 (2023).

[21] J Hahn, Y Lee, N Kim, C Hahn, and S Lee *Environ. Geol.* **33** 43 (1997).

[22] P J Tsai, H Y Shieh, W J Lee, and S O Lai *Sci. Total Environ.* **278** 137 (2001).

[23] L Yumin, L Shiyuan, H Ling, L Ziyi, Z Yonghui, L Li, W Yangjun, and L Kangjuan *Environ. Pollut.* **290** (2021).

[24] T Li and X Cheng *Appl. Earth Obs Geoinf.* **101** 102356 (2021).

[25] R Yadav, N Korhale, V Anand, A Rathod, S Bano, R Shinde, R Latha, S K Sahu, B S Murthy, and G Beig *Urban Clim.* **34** 100729 (2020).

[26] F Liu, M Wang, and M Zheng *Sci. Total Environ.* **755** 142533 (2021).

[27] H Kan, R Chen, and S Tong *Environ. Int.* **42** 10 (2012).

[28] W S Daniels (2021).

[29] S K Guttikunda, K A Nishadh, and P Jawahar **27** 124 (2019).