

RESEARCH ARTICLE

THE IMPACT OF THE LOCKDOWN ON AIR QUALITY IN RESULT OF COVID-19 PANDEMIC OVER HUBEI PROVINCE, CHINA

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ABSTRACT

The novel coronavirus (COVID-19) infectious respiratory disease becomes a global pandemic in few weeks from its start in December 2019 to early 2020. Various countries across the world including China went to lockdown and several caution were implemented to reduce the further spread of this infectious disease. Wuhan (China) was the first city to impose the lockdown for controlling the impact of COVID-19. The lockdown unexpectedly gives the scientific community a chance to investigate the influence of the human activity on air pollution in real world scenario. The present study attempted to investigate the impact of lockdown during the ongoing viral disease on the changes of fine particulate matters and some unhealthy gases i.e. PM_{2.5}, PM₁₀, SO₂, CO, O₃, AQI and NO₂ over Hubei province of China, by using ground station data and TROPOMI satellite data. The air pollutants were compared as, (i) pre COVID-19 period (i.e. October-December 2019), (ii) throughout the lockdown in Hubei province (i.e. January 2020-March 2020) and Post lockdown duration (i.e. April 2020-June 2020). Results clearly showed that air quality was not secured due to high emission of CO, SO₂, NO₂, O₃, PM_{2.5}, and PM₁₀ on Pre COVID-19 times, but under the lockdown continuously decrease in NO₂ from (54 mg/cm³ to 26 mg/cm³), SO₂ (10.5 mg/cm³ to 7.77 mg/cm³) PM_{2.5} (49.22 mg/cm³ to 44.34 mg/cm³), PM₁₀ concentrations (80.83 mg/cm³ to 57.04 mg/cm³) and AQI (72.95 mg/cm³ to 49.64 mg/cm³) has been observed. Because lockdown shuts all anthropogenic activities like industrial work, traffic vehicles and various socio-economic activities, which developed a healthy change on air quality. Emission of unhealthy gases and particulates were quite clear during the lockdown but again increase after finishing the lockdown period. However, we don't support the lockdown as a measure for the betterment of air quality as this has severely posed negative impacts on the socio-economic processes and progress, but changes in human behavior of using industries and vehicles can help us to improve the air quality.

KEYWORDS

COVID-19, Lockdown, Hubei, TROPOMI, Air quality, Fine Particles.

1. INTRODUCTION

China as a largest developed country has achieved enormous economic development since 1980s, to become the second-largest economy in the world, after the USA (Luhang, 2020). The fastest growing economy, urbanization, socio-economic development, and progress in advanced technical motor vehicles have a huge impact on the Air Quality (AQ), especially in southeastern China (Fan et al., 2020). Enormous measures were taken to reduce air pollution during different events, as the 2008 Olympic games in Beijing, the 2010 Guangzhou Asian Games, the 2014 Youth Olympic Games in Nanjing, the 2014 Asian Pacific Economic Cooperation Conference (APEC), and the 2015 China Victory Day parade (Okuda et al., 2011; Xua et al., Ding et al., 2015; Chen et al., 2015; Zhao et

al., 2017). Air quality was substantially improved during these events and the results were used in scientific studies as emission control strategies at local level, however, activities in rest of the country continue as usual. Therefore, these events developed changes at small scale, whereas the transport and meteorological factors continue to influence the concentrations at long range (Fan et al., 2020).

In 2013, the Ministry of Ecology and Environment (MEE) of the People's Republic of China has established a ground-based AQ monitoring network with in situ measurements at more than 1000 sites, and this data were publicly available (Section 3.1). At the end of end of 2019 first case of COVID-19 was reported in Wuhan (Capital of Hubei Province, China) (Huang et al., 2020). At that time, its etiology was unknown (Sohrabi et al.,

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The operational validation results are reported every three months at the S5P-MOC-VDAF website (<http://mpc-vdaf.TROPOMI.eu/>, last access: 28 July 2020). The TROPOMI/S5P tropospheric NO₂ column has operationally validated by the S5P-MPC-VDAF (S5P-Mission Performance Centre – Validation Data Analysis Facility) using the Pandora NO₂ total columns from the Pandora Global Network (PGN). The comparison shows a negative bias of roughly 30%. The TROPOMI/S5P SO₂ column data are found in generally good agreement with ground-based measurements and with other satellite observations. The bias and dispersion with respect to validation of data are smaller than 0.2 DU. The TROPOMI/S5P total CO column data is in good agreement with correlative measurements from the NDACC and TCCON FTIR monitoring networks, with a positive bias of approximately 10% (NRTI, before July 2019) or 6% (OFFL) on average.

2.2.2 Ground Based Observations

The ground-based used data were downloaded from <http://www.pm25.in/> (last access: 13 July 2020), from the national real-time air quality publishing platform public website of air quality monitoring data. The China National Environmental Monitoring Center (CNEMC) of the Ministry of Ecology and Environment of China maintained this data (MEE, see <http://www.mee.gov.cn/>, last access: 13 July 2020). Hourly and 24 hour moving averages of each site were gathered of PM_{2.5}, PM₁₀, SO₂, NO₂, O₃, and CO. Various measurement techniques, reliability of the data and quality control were briefly described and see also (Ministry of Environmental Protection of the People’s Republic of China, 2012) at the stations (Silver et al., 2018; Zhai et al., 2019; Xue et al., 2020). The data from these websites were provided by local governments and used in several studies related to air pollution, air quality, and other aspects in China (<http://www.pm25.in/sharer>, last access: 13 July 2020) (Fan et al., 2020; Krotkoy et al., 2016). For the current study, we collected hourly base data of PM_{2.5}, PM₁₀, SO₂, NO₂, O₃, and CO of Hubei Province with the main focus on Wuhan, as indicated in Section 3 and Figure 6. The data were collected with the interval of three months for pre-COVID-19 (October- December 2019), during pandemic outbreak (January 01-March 30, 2020) and after COVID-19 lockdown (April 01-June 30, 2020). Keep in view that COVID-19 virus was discovered in Wuhan on 30 December 2019, spread within the 30-day period (Fan et al., 2020). In the current study, acquired data of various sites within the city were averaged to get spatially representative number for the whole city based on daily (24 h).

TNO₂_ave reduction and recover quickly about 70~80%, during the lockdown.

Nevertheless, after lockdown due to starting back toward businesses and human activities, the concentrations of NO₂ is increasing again (figure 2c). The data in Figure 2b showed that the TNO₂_ave column densities was overall substantially lower than in three months earlier to pre-COVID-19 duration (Figure 2a) and difference is so large. In the period of lockdown under COVID-19, the atmosphere over Hubei was effectively cleaned from NO₂ as the map in Figure 3b shows. The tropospheric VCDs dropped from 6-10*10¹⁵ molec.cm⁻², and locally 18*10¹⁵ molec. ·cm⁻² to about 4~6*10¹⁵ molec. Cm⁻², with the highest values of about 10 *10¹⁵ molec. ·cm⁻². In other words, the VCDs were overall a factor of 1.5~2 lower during the lockdown under COVID-19. Quantitatively, the ratio of the TNO₂_ave column densities under the lockdown (January-March 2020) decreased 80~90% (Figure 2b) as compare to the normal days before the COVID-19 epidemic (figure 2a), because of reduction in social and human activities.

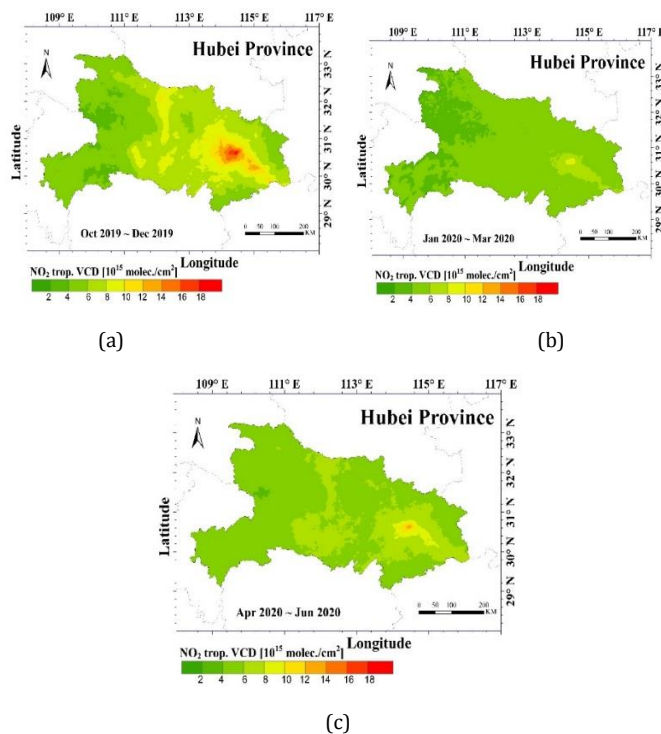


Figure 2: The spatial distribution of the TNO₂_ave (a) three month before COVID-19 outbreak (Oct-Dec 2019); (b) During the COVID-19 Outbreak and lockdown; (c) after releasing the lockdown

Table 1: Study period for 2019–2020				
Study Region	Year	Before COVID-19 Epidemic	During Lockdown	After lockdown
Hubei	2019-	Oct 01 – Dec	Jan 01- Mar 30,	Apr 01-June
China	2020	30, 2019	2020	30, 2020

3. RESULTS

3.1 Satellite Data

3.1.1 NO₂

Maps of the spatial distribution of tropospheric NO₂ Vertical Column Densities (VCDs) were averaged over three months (TNO₂_ave) before, during and after the lockdown under COVID-19 pandemic all over Hubei, China in Figure 2. The spatial distribution of the TNO₂_ave for 2019 represents the condition of three months’ pre COVID-19 pandemic (Figure 2a) that there were several regional hotspots with high concentrations of tropospheric NO₂ on the order of 27*10¹⁵ molec.cm⁻², especially over the Wuhan city (capital of Hubei province). Throughout the lockdown period during the COVID-19 pandemic (January-March, 2020) concentration of NO₂ get substantially lower in result of reducing human activities, shutdown all kind of factories, business and traffic. To identify the differences and their spatial variation, different maps were produced showing the pixel-by-pixel ratio of the TNO₂_ave for different intervals showing pre, under and post lockdown scenarios with three month’s interval (Figure 2a, b, c). The map in Figure 2b confirms that the largest

3.1.2 SO₂

The three months averages of the TROPOMI-retrieved SO₂ VCDs for 2019 and 2020 before, during and after the lockdown under COVID-19 (Figure 3a, b, c) showed that the substantial reduction of the SO₂ VCDs. Like NO₂, the highest values of SO₂ VCDs were detected before the COVID-19 pandemic but during the lockdown the values of SO₂ VCDs decreased (figure 3b, 3c). The averages of three months of the TROPOMI-retrieved SO₂ VCDs for 2019 and 2020 before, during and after the lockdown in Hubei (Figure 2) showed that the substantial changes in the SO₂ VCDs. Like NO₂, the highest SO₂ VCDs were seen before the COVID-19 outbreak but during lockdown (October-December 2019) decrease over the western part of Hubei province. After the lock down it has observed that the SO₂ values again increasing as the startup of essential industries and power generation elements. In surrounding areas, the SO₂ VCDs were reduced to 10 x 10¹⁵ molec.cm⁻² or less (Zhao et al., 2012; Monks et al., 2015). Before the COVID-19 outbreak showed that the concentrations of SO₂ VCD were overall higher particularly in the north western part of Hubei, China. However, after the lockdown and minimization of social and human activities, the concentrations were substantially lower with large spatial differences.

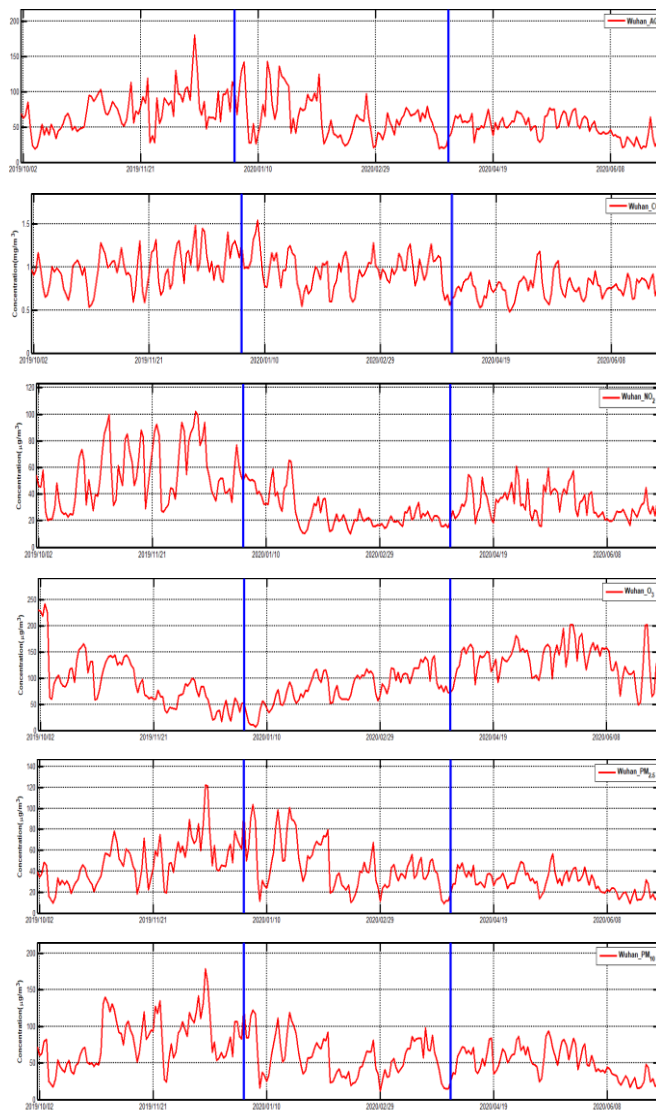
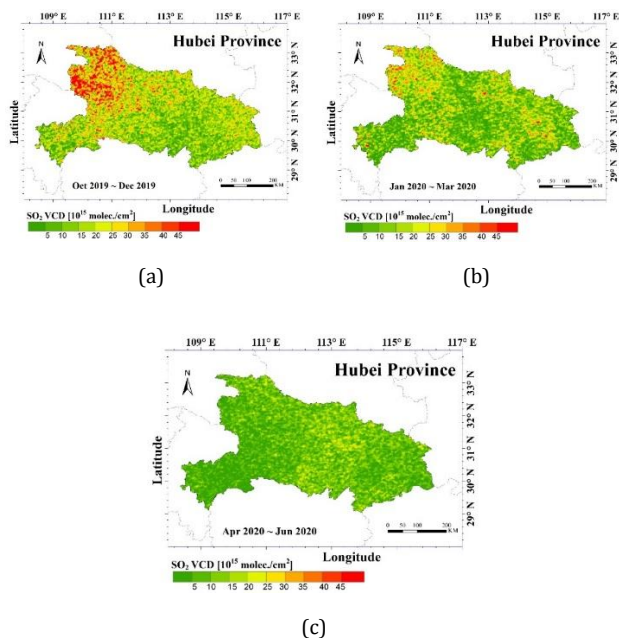


Figure 3: The spatial distribution of the SO₂ VCD (a) three month before COVID-19 Outbreak; (b) During the COVID-19 Outbreak and lockdown; (c) after releasing the lockdown

3.2 Ground-Based Observations

Satellite observations showed that lockdown has decreased the concentrations of NO₂ and SO₂ in all areas of Hubei especially Eastern and North West parts. For further observation ground-based data was inter compared. The satellite data shows such fluctuations, but for column-integrated quantities instead of the ground level and for monthly averages rather than daily. In 2020, strict control measures were enforced in Wuhan after the COVID-19 outbreak, leading to a complete lock-down in the Wuhan and Hubei province, while severe measures were also taken to avoid spreading of the COVID-19 virus in rest of the China. Therefore, the main focus of the ground-based AQ data analysis was Wuhan, for detailed overview of the data described in section 3.2.1 based on both monthly and daily averages. Air quality has controlled on account for tendencies, i.e. the decreased in concentrations of unhealthy emissions due to control policy. However, in many cases, this appeared not possible due to meteorological and other local influences.

3.2.1 Wuhan

Daily averages representative for the whole city of the concentrations of four trace gases (NO₂, SO₂, CO, and O₃), and two particulates PM_{2.5}, and PM₁₀ shows in figure 4. For each of the study period, the data was averaged over a period of three months before, during and after the COVID-19 pandemic. The mean concentrations are presented in figure 4 and figure 5 together with the standard deviations.

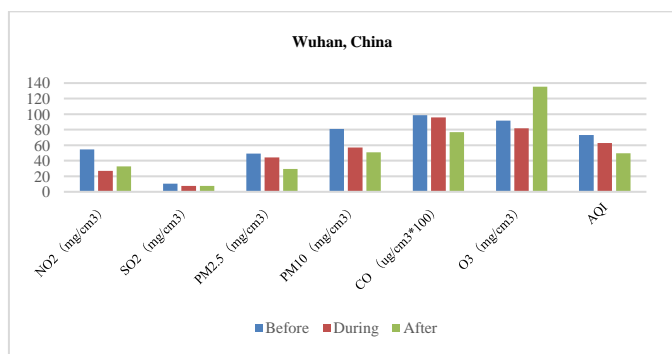


Figure 4: Mean and standard deviation for three month duration before, during and post COVID-19 period for NO₂, SO₂, PM_{2.5}, PM₁₀, CO, and O₃ in Wuhan, China.

Figure 5: Time series of ground-based concentration of AQI, CO, NO₂, O₃, PM_{2.5} and PM₁₀ measured in Wuhan during October 2019- July 2020, from three months before, during and after the lockdown

The data show that for all emissions except O₃ and NO₂, the concentrations is going toward decrease, especially during and after the lockdown. For NO₂, the concentrations decrease during the lockdown as compare to the prevailing condition before lockdown. This is an indication of the effect of COVID-19 measures. However, after lockdown and the reopening of city, the value of NO₂ is started increasing again. Concentrations of SO₂ in Wuhan were low as observe by satellite data. Major reduction in SO₂ is also observed during and after the lockdown in 2020. For the other concentrations i.e. PM_{2.5}, PM₁₀, CO and AQI have also decreased as the restricted measures and less socio-economic activities are adopted during and somehow after the lockdown period.

The daily mean concentrations of the various species contributing to the air quality in Wuhan are Plotted in figure 5 during the temporal durations of study from October 2019 to June 2020, Including pre-COVID-19 outbreak (October-December 2019), on lock down (January 2020- March 2020) and post lockdown (April to June 2020). The density of NO₂ describe large variations due to gap in socio-economic activities and major dense clouds of NO₂ likely began to decrease throughout and afterward COVID-19. Clear deviation as compared to previous years were detected in Wuhan from January to March due to the minimization of human socio-economic activities. China was relaxed the lockdown on around 25th March after opening city roads and although Wuhan was reopened on 8th April 2020 with certain restrictions of social distancing. Shortly figure 5 indicates continuously decrease in NO₂ concentrations due to strict measures adopt throughout the lockdown from 54 mg/cm³ to 26 mg/cm³ but after lockdown concentration again increase to 32 mg/cm³.

A notable reduction in tropospheric VCDs were dropped from $6\text{--}10 \times 10^{15}$ molec. $\cdot\text{cm}^{-2}$, and locally 18×10^{15} molec. $\cdot\text{cm}^{-2}$ to about $4\text{--}6 \times 10^{15}$ molec. $\cdot\text{cm}^{-2}$, with the highest values of about 10×10^{15} molec. $\cdot\text{cm}^{-2}$. In other words, the VCDs were lower with a factor of 1.5–2 during the lockdown under COVID-19. In a similar way, SO_2 concentration was 10.5 mg/cm^3 in the normal time period before COVID-19 outbreak (October–December 2019), and decreased to 7.77 mg/cm^3 during the lockdown period and after releasing the lockdown its value reached up to 7.67 mg/cm^3 . Observations were also affected under various weather conditions despite of lockdown and strict measures. On the other hand, SO_2 concentrations were substantially lower as in previous years. There were various sources contributed to aerosol formation and direct emissions of $\text{PM}_{2.5}$ and PM_{10} concentrations. Therefore, the variation of the PM_x (where x stands for either 2.5 or 10) concentrations may sometimes vary in a similar way as that of NO_2 or SO_2 , with coincident peak values, but they behave in different manner as to trace gases. Concentrations of PM_x also behaved similarly to NO_2 , with strong variations and change as $\text{PM}_{2.5}$, were on 49.22 mg/cm^3 to 44.34 mg/cm^3 and PM_{10} concentrations 80.83 mg/cm^3 to 57.04 mg/cm^3 due to an effect of lockdown. After the lockdown $\text{PM}_{2.5}$ concentrations were more dropped to 29.50 mg/cm^3 and same trend of decreasing noted for PM_{10} as 50.90 mg/cm^3 . Trend for AQI were also observed in decreasing manner from 72.95 mg/cm^3 to 49.64 mg/cm^3 . But the situation was detected opposite for O_3 , as compared to other traces gases NO_2 , SO_2 , and particulates (PM_x).

Density of O_3 was 91.72 mg/cm^3 before the COVID-19 outbreak, decrease to 81.64 mg/cm^3 during the lockdown but its value has been increased to 135.32 mg/cm^3 after releasing the lockdown and opening back to all the activities in the whole province, especially in Wuhan. The O_3 is the important aspect for the quality of air as O_3 behave in different manner than others trace gases and particulates. Comparison with NO_2 showed similar fluctuations due to meteorological influences but at the same time, O_3 is removed by NO_x titration, i.e., a reduction in NO_x (NO) can contribute to an increase in O_3 (Cai et al., 2017). Although in previous years this effect is not easy to see, but the O_3 concentrations are very high after day-zero in 2020.

4. DISCUSSION

Observation of decrease in the concentrations of aerosols and trace gases have based on satellite observations and spatial temporal series in Hubei. Although satellite observation and ground-based instruments provide information in the same manner, so multiple techniques and measures were used in different properties. Taking them into observation for the required detail is beyond the scope of the current study and the following discussion is qualitative. Satellite observations have provided the spatial variations in trace gases and particulates of different periods. Ratio plots were presented the spatial variations and spatial temporal decrease in the density of trace gases and particulates because of less activities and social distance measures adopted during lockdown (COVID-19). Therefore, three months duration were used to obtain a representative estimates because some regions may under the metrological influences such as formation of haze while some may influenced by clear air (Zhong et al., 2018; Petersen et al., 2019).

Results were also varied due to metrological variations. An alternative way to avoid such uncertain sources; chemical transport model was used. However, CTM were introduced other uncertainties in the research (Gu et al., 2017). Effects of meteorological variations were clearly represented the variations of the ground-based concentrations in figure 6 and 7. For instance, the co-variation of NO_2 , SO_2 and to some extent $\text{PM}_{2.5}$ reflect the broad influence of climate with deviations of $\text{PM}_{2.5}$ such as effects of hygroscopic growth due to variations in Relative Humidity (RH) variations or the formation of new particles. Satellite has observed the decline in the concentration in the last decade. All uncertainties have been related with satellite observation of 2020. Seasonal variations as well as temporal variations were identified the consistent decline in NO_2 and for the concentration of ground-based differences in the TROPOMI tropospheric NO_2 VCDs were clearly examined (Zheng et al., 2019; ESA, 2020). The tropospheric NO_2 over the United Kingdom (UK) and Germany was

approximately $8\text{--}9 \times 10^{15}$ molecules/ cm^2 in 2020 before the lockdown, and it was relatively close to the baseline average while after the lockdown (especially from Apr–May) its values has reduced to $<5 \times 10^{15}$ molecules/ cm^2 .

Recent imageries published by ESA (European Space Agency) also reported that tropospheric NO_2 during Mar–Apr 2020 had dropped about 54% over France, 48% over Spain, and 49% over Italy compared to the mean of 2019 (Lal et al., 2020). The dramatic drop in NO_2 across Europe coincided with the substantial shift in human activities during the lockdown periods (Sharma et al., 2020). The recent decline in tropospheric NO_2 is associated with less consumption of fossil fuels, due to the shift in mobility patterns and sharp reduction in industrial activities, which ultimately lead to a reduction of the pollutants released towards the atmosphere (Wang and Su, 2020; Mahato et al., 2020; Ruixiong et al., 2020; Li et al., 2017). A significant reduction in air pollution have been found globally over the major metropolitan and industrialized regions (Li et al., 2017). However, variability in NO_2 vertical profiles in the troposphere between different locations in China were commonly observed (Zheng et al., 2019). Ground based instrument and satellite measurement for particulates of aerosols were even more complicated and varied due to difference changes in physical and chemical properties of aerosol in different meteorological environment (Zheng and Li, 2015).

The in-situ measurement relevant for AQ applications is the mass of particulate matter, $\text{PM}_{2.5}$, which is measured by sampling particles with in situ aerodynamic diameters of $2.5 \mu\text{m}$ (i.e., in equilibrium with ambient RH), which then is brought into a low RH environment in which aerosol water evaporates before the mass is determined. Satellites measure the AOD, which is the column-integrated aerosol extinction, i.e., an optical property of aerosol particles, which depends on the aerosol composition and size distribution, which in turn changes with ambient RH. The AOD/ $\text{PM}_{2.5}$ relationship can be evaluated using statistical or physical methods or using a variety of CTMs (Zhai et al., 2019; Zhang et al., 2019; Xin et al., 2016; Theys et al., 2017). It is noted that the AOD/ $\text{PM}_{2.5}$ relation varies across China (Theys et al., 2017).

A further uncertainty in the estimates on the concentrations of NO_2 and SO_2 may be sensitive for TROPOMI instrument. TROPOMI has limited sensitivity to SO_2 as discussed in detail by [57], which may explain in the Figure 3 of SO_2 VCD (van der A et al., 2017). As regards NO_2 , comparison with ground-based reference data shows that TROPOMI tropospheric VCD has a negative bias of 30% (<http://mpcvdaf.TROPOMI.eu/>, last access: 6 June 2020), which implies in an absolute sense where high NO_2 VCDs were underestimated than for low NO_2 VCDs. The trace gas and aerosol concentrations observed a steady decline in satellite observations over China (Sogacheva et al., 2018; Wang et al., 2017). Locally in situ observations, all species do not show such behavior. It is noted here that the local representation for ground-based measurements cannot be directly compared with satellite-derived trends and estimation from columns at provincial scale and larger areas where the contributions from various sources were dispersed (Sogacheva et al., 2018; Wang et al., 2017). Ground-based observations in Wuhan were discussed in detail in Section 3.2.1, where the lockdown has a clear effect in reducing the dense clustered of NO_2 , SO_2 , PM_{10} , and $\text{PM}_{2.5}$ over Hubei especially Wuhan but not on O_3 . On the other side concentrations of O_3 (O_3) has actually increased. Similarly monthly averaged observations were depicted strong decline from January to February 2014 for NO_2 , SO_2 , PM_{10} , $\text{PM}_{2.5}$, and also CO (Ma et al., 2019). Consistence decline process were actually progressed till March 2013 to July but afterward their concentration increased in December during winter. Hence, an increase in the concentrations of these components would not be expected during 2017–19.

However due to lockdown in 2020, various cities of china as well as in Wuhan all concentrations were remained low. But later on an initial increase is evident in reflection of pollution from transport toward desert dust (Ma et al., 2019; Muhammad et al., 2020). COVID-19 forced confinement has dramatically reduced the anthropogenic activities, for example, transport and industrial activities, which eventually resulted in

a decline in the energy consumption and lowered the oil demands. These changes have significant impacts on the environmental quality, particularly over the air quality of metropolitan urban communities. During the epidemic lockdown, forced confinements were adopted, especially in metropolitan cities, which consequently resulted in a significant reduction of NO₂ pollution due to controlled energy consumptions and anthropogenic emissions (Muhammad et al., 2020).

5. CONCLUSION

This research has concluded that the measures to interrupt the prevalence of COVID-19 provide a positive and healthy effect in air pollution levels due to shortfall in human socio-economic activities. COVID-19 virus in China has great influence in changing the concentrations of trace gases (NO₂, SO₂, CO, and O₃) and aerosols (PM_{2.5} and PM₁₀). The satellite-based estimates are based on data averaged over 3 months. Under COVID-19 all human and social activities in Hubei province has developed better atmospheric conditions and reduced air pollution. The results displayed huge reduction up to 80% in NO₂ during the COVID period in eastern part of Hubei. Measures for SO₂ are difficult to make due to the confined sensitivity of TROPOMI to SO₂, has also reflected the possible minimization in the cluster of SO₂ over China since 2007. Accurate estimates of the diminishing aerosols, PM_{2.5} and PM₁₀, or CO were difficult due to the lifetime atmospheric CO and the composite behavior of aerosols. Ground-based in situ data in Wuhan showed the decline concentrations of NO₂, SO₂, CO, PM_{2.5}, and PM₁₀ during the lockdown period and again increase after releasing the lockdown. However, various cities faced the increasing of concentration rapidly after lockdown. Initially pollution from transport caused in north and south of Wuhan. In terms of air quality, the reduction of NO₂, SO₂, and PM_{2.5} concentrations was favorable facts in atmospheric changes probably as a result of the lower NO_x concentrations. This study has also attempted to estimate the recovery of aerosols and trace emissions after COVID-19 and scenario develop due to beginning of social and human activities again in Hubei province.

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