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

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ARTICLE DETAILS

Article History:
Received 02 December 2020
Accepted 05 January 2021
Available Online 12 January 2021

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\textsubscript{2.5}, PM\textsubscript{10}, SO\textsubscript{2}, CO, O\textsubscript{3}, AQI and NO\textsubscript{2} 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, SO\textsubscript{2}, NO\textsubscript{2}, O\textsubscript{3}, PM\textsubscript{2.5}, and PM\textsubscript{10} in Pre COVID-19 times, but under the lockdown continuously decrease in NO\textsubscript{2} from 54 mg/cm\textsuperscript{2} to 26 mg/cm\textsuperscript{2}, SO\textsubscript{2} from 0.5 mg/cm\textsuperscript{2} to 7.77 mg/cm\textsuperscript{2}, PM\textsubscript{2.5} (49.22 mg/cm\textsuperscript{2}) to 44.34 mg/cm\textsuperscript{2}), PM\textsubscript{10} concentrations (80.83 mg/cm\textsuperscript{2} to 57.04 mg/cm\textsuperscript{2}) and AQI (72.95 mg/cm\textsuperscript{2} to 49.64 mg/cm\textsuperscript{2}) 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; Xia 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.,...
2020. However, after a few weeks, this infectious disease has started spreading quickly, not only in Wuhan but also in other regions of China (Anderson et al., 2020; Duthel et al., 2020). Typical symptoms for this disease were reported as fever, dry cough, myalgia, pneumonia, and failure of the respiratory system may result in death (Huang et al., 2020). In the late January 2020, the Chinese government claimed that this infectious disease is a new type of coronavirus which is named as novel coronavirus 2019 (nCoV-2019), later on named as COVID-19 by WHO on 11 February 2020 (Li et al., 2020; Chan et al., 2020; WHO, 2020). Chinese government has adopted hard and fast measures to minimize the prevalence of the infection, especially in Wuhan (Hubei) based on past experiences from earlier viral attack of SARS in 2003 and MERS in 2012 (Simmons et al., 2004; Groot et al., 2015).

Chinese authorities closure the Wuhan and cut down its link from other states of China by transportation (Wilder-Smith and Freedman, 2020). Wuhan becomes the first city under quarantine, and subsequently other regions of the country also went under forced confinement to prevent further spread of COVID-19 from 23 January 2020 (Huang et al., 2020). The Chinese government close down public transport, parks, educational centers, business centers, and other social places to restrict the infection rate. The government also established numerous quarantines centers for the infectious persons (Wilder-Smith and Freedman, 2020). Moreover, the pandemic downfall the economic and social activities (Wang et al., 2020).

China enacted health emergency, and bounded people to stay at home instead of going outside to save the life of population at the beginning of January 2020, till 25th March and Wuhan was unlocked on 8th April 2020 with social distancing and safety measures (http://www.mot.gov.cn/, last access: 10 September 2020) (Wang et al., 2020; Tian et al., 2020).

Unhealthy emissions of gases and particulates were reduced as because of strict order by government of China on human activities, industrial production, constructions, restaurants and even reduction in number of Vehicle Kilometers Travelled (VKT) (Zhang et al., 2019). Air quality has improved at reasonably healthy level due to safety precautions and stoppage of various anthropogenic actions (Hua and Ping, 2018; Tobias et al., 2020). COV19-19 modified the quality of air not only in China, in fact all over the countries of the world (Arshad et al., 2020). The National Aeronautics and Space Administration (NASA) has published satellite imageries with reduction in NO2 over China and all over the world due to slowdown of economic and human activities (NASA, 2020). The subsequent shortfall in human actions have decreased the anthropogenic emissions and healthy air in urban centers (NASA, 2020). The pandemic corona virus has reduced the growing infectious particulate in air due to less emission from transports and industries (NASA, 2020). For instance, after two weeks of lockdown, concentrations of air pollutants in Barcelona urban area markedly decreased by 28%–51% (Tobias et al., 2020).

Similarly, concentrations decreased by 18%–43% during the lockdown period compared to previous years in India (Hua and Ping, 2018). NASA scientists have discovered the fade out of NO2 pollutant near Wuhan then spread across the rest of the country, and eventually worldwide due to the restriction measures (Huang et al., 2020; NASA, 2020). In Central China, NO2 emissions were decreased up to 30% (NASA, 2020). CO2 emissions is another common tracer of air pollution, decreased 25% in China and 6% worldwide (Hanaoka and Masui, 2020; Leh et al., 2014). The NASA earth observatory satellite founded 10%~30% less nitrogen dioxide (NO2) in eastern and central China from 2019 to early 2020 (NASA, 2020). The European Environment Agency (EEA) acquired a similar large gap in the pollutants of atmosphere across European cities during 16-22 March 2020 (Berman and Ebisu, 2020). It was reported that Bergamo in Italy and Barcelona in Spain showed rapid decline in NO2 of 47%–55% during lockdown from 2019. Moreover, remote sensing provided a valuable estimate of air pollution for broad exposures and there is an inherent value for corroboration of pollution trends in-situ measurements (Bechle et al., 2013).

Ground based measurements represented gold standards in the concentration of pollutants and the tool for regulatory compliance. Measured concentrations should be used to evaluate air pollution changes, particularly where robust monitoring networks exist. In this study, we aimed to assess the effects of lockdown on air quality by comparing the pre-covid-19, through the covid-19 duration and post covid-19 in Hubei province, China. Data has been gathered from TROPOMI satellite observations and ground-based measurements. The spatial temporal distributions of the aerosols and trace gases were compared to develop an understanding about the change in air quality. It will provide important clues regarding control of air pollution emissions for policy makers in future to control the air quality.

2. MATERIAL AND METHOD

2.1 Study Area

In this study we have conducted research over Hubei province of China (Figure 1), located between 30.7378° N, 112.2384° E and having 59.02 million population in 2017 (hubeigov.cn). Wuhan city covered 8569 km2 area and a population of about 11 million (Wuhan Bureau of Statistics, 2016). As at the end of 2019, first case of COVID-19 was reported in Wuhan (Capital of Hubei Province, China) (Huang et al., 2020).

2.2 Data

This study was designed to analyze the changes in air particulates and gases to see the impact of lockdown on the atmospheric chemical components i.e. PM10, and PM2.5 are particulate matters and NOx, SOx, O3 and CO are unhealthy gases. Online datasets of ground data and satellite data have been utilized with three-month intervals i.e., pre-covid-19 outbreak (October 2019-December 2019), lockdown period (January 2020-March 2020), and subsequently after lockdown (April 2020-June 2020). Satellite data has obtained from the Tropospheric Monitoring Instrument (TROPOMI) for NOx and SO2 products (section 2.2.1), and inter compared with ground station data from China National Environmental Monitoring Center (CNEMC) of the Ministry of Ecology and Environment (MEE) of China (http://www.mee.gov.cn/ (section 2.2.2). Satellite data were processed using the Google Earth Engine (GEE), cloud computing platform and the ArcGIS platform (Gorelick, 2017; Kneissl et al., 2011).

2.2.1 TROPOMI Data

TROPOMI a passive hyperspectral nadir-viewing imager aboard the Sentinel-5 Precursor satellite (also known as Sentinel-5P) has launched on 13 October 2017 (Veekind et al., 2012). Sentinel-5P is a near-polar orbiting sun-synchronous satellite flying at an altitude of 817 km in an ascending node with an equator crossing time at 13:30 LT and a repeat cycle of 17 days (Silver et al., 2018). The swath width is approximately 2600 km, resulting in daily global coverage, with an along-track resolution of 1 km (Zhai et al., 2019). For this research, TROPOMI products have used L3 off-line (OFFL) version products (see http://www.TROPOMI.eu/data-products/ for more detail): tropospheric NOx column density data, SO2 total vertical column data, and the vertical integrated column density of CO for the period around the 2019 and 2020. The spatial resolution at nadir for most products has used 1 x 1 km2.
The operational validation results are reported every three months at the SSP-MOC-VDAF website (http://moc-vdaf.TRIPOMI.eu/, last access: 28 July 2020). The TROPOMI/SSP tropospheric NO\textsubscript{2} column has operationally validated by the SSP-MPC-VDAF (SSP-Mission Performance Centre – Validation Data Analysis Facility) using the Pandora NO\textsubscript{2} total columns from the Pandonia Global Network (PGN). The comparison shows a negative bias of roughly 30\%. The TROPOMI/SSP SO\textsubscript{2} 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/SSP 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 (CNEC) 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 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; Krotkov et al., 2016). For the current study, we collected hourly base data of PM\textsubscript{10}, PM\textsubscript{2.5}, SO\textsubscript{2}, NO\textsubscript{2}, O\textsubscript{3}, 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).

### Table 1: Study period for 2019-2020

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

3. RESULTS

3.1 Satellite Data

3.1.1 NO\textsubscript{2}

Maps of the spatial distribution of tropospheric NO\textsubscript{2} Vertical Column Densities (VCDs) were averaged over three months (TNO2\textsubscript{ave} before, during and after the lockdown under COVID-19, all over Hubei, China in Figure 2). The spatial distribution of the TNO2\textsubscript{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 NO\textsubscript{2} on the order of 2*10\textsuperscript{15} molec cm\textsuperscript{-2}, especially over the Wuhan city (capital of Hubei province). Throughout the lockdown period during the COVID-19 pandemic (January-March, 2020) concentration of NO\textsubscript{2} 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\textsubscript{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 TNO2\textsubscript{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 NO\textsubscript{2} is increasing again (Figure 2c). The data in Figure 2b showed that the TNO2\textsubscript{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 NO\textsubscript{2} as the map in Figure 2b shows. The tropospheric VCDs dropped from 6-10*10\textsuperscript{15} molec cm\textsuperscript{-2}, and locally 10*10\textsuperscript{15} molec cm\textsuperscript{-2} to about 4-6*10\textsuperscript{15} molec cm\textsuperscript{-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\textsubscript{ave} column densities under the lockdown (January-March 2020) decreased 80-90\% (Figure 2b) as compared to the normal days before the COVID-19 epidemic (figure 2a), because of reduction in social and human activities.

![Image](https://example.com/image.jpg)

**Figure 2**: The spatial distribution of the TNO2\textsubscript{ave} (a) three month before COVID-19 outbreak (Oct-Dec 2019); (b) During the COVID-19 Outbreak and lockdown; (c) after releasing the lockdown

3.1.2 SO\textsubscript{2}

The three months averages of the TROPOMI-retrieved SO\textsubscript{2} 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 SO\textsubscript{2} VCDs. Like NO\textsubscript{2}, the highest values of SO\textsubscript{2} VCDs were detected before the COVID-19 pandemic but during the lockdown the values of SO\textsubscript{2} VCDs decreased (Figure 3b, 3c). The averages of three months of the TROPOMI-retrieved SO\textsubscript{2} VCDs for 2019 and 2020 before, during and after the lockdown in Hubei (Figure 2) showed that the substantial changes in the SO\textsubscript{2} VCDs. Like NO\textsubscript{2}, the highest SO\textsubscript{2} 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 SO\textsubscript{2} values again increasing as the startup of essential industries and power generation elements. In surrounding areas, the SO\textsubscript{2} VCDs were reduced to 10 x 10\textsuperscript{15} molec cm\textsuperscript{-2} or less (Zhao et al., 2012; Monks et al., 2015). Before the COVID-19 outbreak showed that the concentrations of SO\textsubscript{2} 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.

Cite the Article: Faisal Mumtaz, Yu Tao, Barjeeshe Bashir, Hamid Faiz, Mariam Kareem, Adeeel Ahmad, Hammad Ul Hassan (2021). The Impact of The Lockdown on Air Quality in Result of Covid-19 Pandemic Over Hubei Province, China. Environment & Ecosystem Science, 5(1): 15-22.
Satellite observations showed that lockdown has decreased the concentrations of NO\textsubscript{2} and SO\textsubscript{2} 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 Ground-Based Observations

Daily averages representative for the whole city of the concentrations of four trace gases (NO\textsubscript{2}, SO\textsubscript{2}, CO, and O\textsubscript{3}), and two particulates PM\textsubscript{2.5} and PM\textsubscript{10} show 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.

#### 3.2.1 Wuhan

Daily averages representative for the whole city of the concentrations of four trace gases (NO\textsubscript{2}, SO\textsubscript{2}, CO, and O\textsubscript{3}), and two particulates PM\textsubscript{2.5} and PM\textsubscript{10} show 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.

The data show that for all emissions except O\textsubscript{3} and NO\textsubscript{2}, the concentrations is going toward decrease, especially during and after the lockdown. For NO\textsubscript{2}, 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 NO\textsubscript{2} is started increasing again. Concentrations of SO\textsubscript{2} in Wuhan were low as observe by satellite data. Major reduction in SO\textsubscript{2} is also observed during and after the lockdown in 2020. For the other concentrations i.e. PM\textsubscript{2.5}, PM\textsubscript{10}, 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 lockdown (January 2020- March 2020) and post lockdown (April to June 2020). The density of NO\textsubscript{2} describe large variations due to gap in socio-economic activities and major dense clouds of NO\textsubscript{2} 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 25\textsuperscript{th} March after opening city roads and although Wuhan was reopened on 8\textsuperscript{th} April 2020 with certain restrictions of social distancing. Shortly figure 5 indicates continuously decrease in NO\textsubscript{2} concentrations due to strict measures adopt throughout the lockdown from 54 mg/cm\textsuperscript{2} to 26 mg/cm\textsuperscript{2} but after lockdown concentration again increase to 32 mg/cm\textsuperscript{2}.

![Figure 3: The spatial distribution of the SO\textsubscript{2} VCD (a) three month before COVID-19 Outbreak; (b) During the COVID-19 Outbreak and lockdown; (c) after releasing the lockdown](image)

![Figure 4: Mean and standard deviation for three month duration before, during and post COVID-19 period for NO\textsubscript{2}, SO\textsubscript{2}, PM\textsubscript{2.5}, PM\textsubscript{10}, CO, and O\textsubscript{3} in Wuhan, China.](image)

![Figure 5: Time series of ground-based concentration of AQI, CO, NO\textsubscript{2}, O\textsubscript{3}, PM\textsubscript{2.5} and PM\textsubscript{10} measured in Wuhan during October 2019-July 2020, from three months before, during and after the lockdown.](image)
A notable reduction in tropospheric VCDs were dropped from 6 × 10^{15} molec.·cm^{-2} and locally 18 × 10^{15} molec.·cm^{-2} to about 4.6 × 10^{15} molec.·cm^{-2}, with the highest values of about 10 × 10^{15} molec.·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, SO2 concentration was 10.5 mg/cm² in the normal time period before COVID-19 outbreak (October–December 2019), and decreased to 7.77 mg/cm² during the lockdown period and after releasing the lockdown it’s value reached up to 7.67 mg/cm². Observations were also affected under various weather conditions despite of lockdown and strict measures. On the other hand, SO2 concentrations were substantially lower as in previous years. There were various sources contributed to aerosol formation and emissions of PM2.5 and PM10 concentrations. Therefore, the variation of the PMx (where x stands for either 2.5 or 10) concentrations may sometimes vary in a similar way as that of NO2 or SO2, with coincident peak values, but they behave in different manner as to trace gases. Concentrations of PMx also behaved similarly to NO2, with strong variations and change as PM2.5 were on 49.22 mg/cm² to 44.34 mg/cm² and PM10 concentrations 80.83 mg/cm² to 57.04 mg/cm² due to an effect of lockdown. After the lockdown PM2.5 concentrations were more dropped to 29.50 mg/cm² and same trend of decreasing noted for PM10 as 50.90 mg/cm². Trend for AOD were also observed in decreasing manner from 72.95 mg/cm² to 49.64 mg/cm². But the situation was detected opposite for O3 as compared to other trace gases NO2, SO2 and particulates (PMx).

Density of O3 was 91.72 mg/cm² before the COVID-19 outbreak, decrease to 81.64 mg/cm² during the lockdown but its value has been increased to 135.32 mg/cm² after releasing the lockdown and opening back to all the activities in the whole province, especially in Wuhan. The O3 is the important aspect for the quality of air as O3 behave in different manner than others trace gases and particulates. Comparison with NO2 showed similar fluctuations due to meteorological influences but at the same time, O3 is removed by NOx titration, i.e., a reaction with NOx (NO) can contribute to an increase in O3 (Ca et al., 2017). Although in previous years this effect is not easy to see, but the O3 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 meteorological influences such as formation of haze while some may remain clear by air (Zheng et al., 2018; Petersen et al., 2019).

Results were also varied due to meteorological 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 NO2, SO2 and to some extent PM2.5 reflect the broad influence of climate with deviations of PM2.5 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 NO2 and for the concentration of ground-based differences in the TROPOMI tropospheric NO2; VCDs were clearly examined (Zheng et al., 2019; ESA, 2020). The tropospheric NO2 over the United Kingdom (UK) and Germany was approximately 8–9 × 10^{15} molecules/cm² 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 × 10^{15} molecules/cm².

Recent imageries published by ESA (European Space Agency) also reported that tropospheric NO2 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 NO2 across Europe coincided with the substantial shift in human activities during the lockdown periods (Sharma et al., 2020). The recent decline in tropospheric NO2 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 Xu, 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 NO2 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 (Zhang and Li, 2015).

The in-situ measurement relevant for AQ applications is the mass of particulate matter, PMx, which is measured by sampling particles with in situ aerodynamic diameters of 2.5 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. TROPOMI AOD/PMx relations 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/PM2.5 relation varies across China (Theys et al., 2017).

A further uncertainty in the estimates on the concentrations of NO2 and SO2 may be sensitive for TROPOMI instrument. TROPOMI has limited sensitivity to SO2 as discussed in detail by [57], which may explain in the Figure 3 of SO2 VCD (van der A et al., 2017). As regards NO2 comparison with ground-based reference data shows that TROPOMI tropospheric VCD has a negative bias of 30% (http://mpc.dlr.de/TROPOMI.eu/, last access: 6 June 2020), which implies in an absolute sense where high NO2 VCDs were underestimated than for low NO2 VCDs. The trace gas and aerosols 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 NO2, SO2, PM10, and PM2.5 over Hubei especially Wuhan but not on O3. On the other side concentrations of O3 (Ozone) has actually increased. Similarly monthly averaged observations were depicted strong decline from January to February 2014 for NO2, SO2, PM10, PM2.5, and also CO (Ma et al, 2019). Concentrion 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

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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 (PM2.5 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, PM2.5 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, PM2.5, 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 PM2.5 concentrations was favorable facts in atmospheric changes probably as a result of the lower NOX 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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