Modelling the Global Air Quality Conditions in Perspective of COVID-19 Stimulated Lockdown Periods Using Remote Sensing Data

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Abstract

COVID-19 outbreak across the world has invited forced lockdown conditions, which causes a huge economic landslide. But it has brought an opportunity for restoring the environment of its own which may cause ecosystem well-being. Focusing on the second issue, the present work has intended to explore the streams of air quality change based on some quality components and develop a multi-date air quality state (AQS) model for the world in consequence of emergency lockdown. It is very clear from the result that amid lockdown aerosol optical depth (AOD), sulfur dioxide (SO_2), ozone, carbon monoxide (CO), particulate matter ($PM_{2.5}$), and black carbon (BC) concentration level have been significantly reduced in fully lockdown countries. AQS is considerably improved amid lockdown. Hotspots of COVID-19 were under unhealthy, very unhealthy air quality class in pre lockdown condition, but amid lockdown, these countries have been shifted to good and moderate healthy air quality classes

Summary

COVID-19 stimulated lockdown improves the air quality index significantly. Several air quality components concentration levels have been significantly reduced in fully lockdown countries.

1. Introduction

On December 31, 2019, World Health Organization (WHO) first informed about the infection of pneumonia-like unknown disease from a seafood market in Wuhan city of Hubei province, China (Neradi et al., 2020). A guideline was issued by WHO for the countries to develop their ability to detect the unknown virus-like to another coronavirus (CoV) like Severe Acute Respiratory Syndrome (SARS) and the provisional name was given like SARS-CoV-2 or novel coronavirus (2019-nCoV) (Ahmed et al., 2020; Bherwani et al., 2020) on 10th of January, 2020. Confirmation of the spreading of novel coronavirus outside China came into the front on 13th January 2020. The 2019-nCoV was then found to be rapidly spreading disease-carrying by man (Hui et al., 2020), and reportedly 1320 of confirmed, 1965 of suspect cases were found till 25th January 2020, out of which 237 were poorly sick and 41 died (World Health Organization, 2020a). A few days later (30th of January, 2020), WHO declared a public health emergency of international concern regarding the outbreak of 2019-nCoV.

This disease was given an official name as 2019- coronavirus disease (COVID-19) on 11th February 2020 (Shereen et al., 2020), without referring to any particular geographical location (World Health Organization, 2020b). Later on, the rapid outbreak of this disease called for the issuance of several health emergency guidelines regarding the mass gathering, carrying of ill travelers, massive preparedness activities, be a ready campaign (Bherwani et al., 2020), and finally on 11th March 2020, WHO characterized COVID-19 as pandemic (World Health Organization, 2020b). Meanwhile, the virus kept spreading and 3,244,586 people got infected and 229,182 people died to date (30th April 2020) with multiple epicenters around the world, such as Italy, Iran, Spain, France, USA, UK, Turkey, Belgium, and Brazil, etc (Gautam and Trivedi, 2020). This explosion of COVID-19 cases around the world led many countries to adopt dramatic measures, like restricting physical human interaction, encouraging social distancing and self-isolation, strict enforcement of quarantine, withdrawal of public transportation and restriction on private roaming, closer of markets/supermarkets, closers of educational institutes, colleges, and other institutions, embargoing on public gathering even at private places, declaration of voluntary curfew, even partial or total lockdown of the entire city, district, state or country (Bera et al., 2020; Bherwani et al., 2020; Lin et al., 2020). China first imposed a partial lockdown on January 23, 2020, and with time several other countries from different parts of the world imposed partial or total countrywide lockdown responding to a severe outbreak of the disease (table 1).

All these aforesaid steps have been taken as preventive measures to withhold the spread of the virus and control the death rate (Saadat et al., 2020; Chinazzi et al., 2020). Such an unusual situation of the past few months has exceptionally changed the world with some unexpected consequences (Harapan et al., 2020). Among them, the lockdown effect has almost stopped all the economic activities, absolutely contributed to improving the environmental quality, which may offset the economic losses to some extent (Chakraborty and Maity, 2020; Muhammad et al., 2020). During the lockdown, the production interregnum of industries, restriction on transportation and public traveling system, and shut down of other business have resulted in a sharp and sudden drop in global carbon emission (Wang and Su, 2020; Chakraborty and Maity, 2020; Saadat et al., 2020). It has also been seen that due to production, manufacturing, and transportation break during the lockdown global demand for oil and coal has declined to its lowest level (Wang and Su, 2020; Muhammad et al., 2020). Therefore, not only the carbon emission, but also the release of some other severely pollutant e.g. Greenhouse Gases (GHG) and substances like Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), Methane (CH_4), and Particulate Matter 2.5 ($PM_{2.5}$) have dramatically decreased (Bera et al., 2020; NASA, 2020). For example, since people were told to stay inside, a 25% reduction in CO_2 is observed in the emission data of China which means about 1million tons reduction in the substantial carbon emission (Wang and Su, 2020).

The emission of NO_2 from the heavy industrial area of North and Northeast China was significantly reduced just after the first week of lockdown (European Space Agency, 2020). Almost 50% drop in air pollution in New York City (USA) was observed at the same time last year after the measures were implemented to control the spread of the virus (Saadat et al., 2020).

The emission of NO_2 has reduced in different countries of Europe, like the UK, Spain, and Italy as captured by satellite images (Ficetola and Rubolini, 2020). A significant reduction in the concentration of $PM_{2.5}$, PM_{10}, CO_2, and NO2 by 43%, 31%, 10%, and 18%, respectively compared to the previous year can be seen in over 22 cities from different parts of India (Sharma et al., 2020).

Several studies have already taken the initiative to show the changes in air quality due to the restriction posed to anthropogenic activities during the COVID-19 lockdown. Gupta et al., (2020) analyzed the impact of air pollution level on the Covid-19 lethality in the nine selected metropolitan cities of Asia pacific region. Muhammad et al. (2020) showed the decrease of mean tropospheric NO_2 density over China and different countries of Europe and the USA after the enforcement of lockdown compiling the environmental data released by National Aeronautics and Space Agency (NASA) and European Space Agency (ESA). Wang and Su (2020) analyzed the air quality index of China using air quality data and extracting the concentration of NO_2, $PM_{2.5}$, and PM_{10} from the earth observation made by NASA and ESA. Tobías et al. (2020) used the recorded atmospheric pollutant data at the traffic air quality monitoring station of urban background to describe changes in pollution levels in Barcelona. The concentration of $PM_{2.5}$, PM_{10}, CO_2, NO_2, ozone (O_3), and SO_2 of

22 Indian cities on mid-March and April 2020 were compared with the same time of 2017 by Sharma et al. (2020) to show the improvement of air quality in different parts of India. After going through all such kinds of literature, some research gaps have been identified. Most of the studies show the changes in air quality and pollution levels by considering one or two indicators like NO_2 or carbon monoxide. Some other studies considered multiple indicators of air quality and pollution, but these are mainly focused on some isolated regions or within the country. Here a need for a comprehensive multi-parametric global scale study arises to evaluate the overall air quality status of the entire world. Though the existing multi-parametric study intensively investigated the component-specific variation of air quality in pre and amid lockdown periods and analyzed the trend, there was a lack of air quality assessment by integrating the criteria of pollution and air quality degradation. In the present study, the lacks are focused with the critical air quality data regarding AOD, $PM_{2.5}$, SO_2, O_3, BC, and CO derived from Modern Era Retrospective-Analysis for Research and Applications, version 2 (MERRA-2) (Song et al., 2018) and Atmospheric Infrared Sounder (AIRS) (Zhang et al., 2020) to explore how far this incident can be able to improve the air quality state (AQS) across the world. It is also investigated in full fledged or partial lockdown can bring any difference in the degree of AQS.

Table1: list of the countries with complete, partial or no lockdown

Complete lockdown				Partial lockdown				No lockdown	
S. No	Country	Starting date	No of Weeks	S. No.	Country	Starting date	No of Weeks	S. No	Country
1	South Africa	26-Mar	3	1	China	23-Jan	Up to 20-Mar	1	USA
2	New Zealand	25-Mar	4	2	Saudi Arabia	25-Mar	-	2	Brazil
3	India	25-Mar	3	3	Columbia	24-Mar	-	3	Sweden
4	United Kingdom	23-Mar	-	4	Australia	23-Mar	-	4	Pakistan
5	Jordan	25-Mar	-	5	Israel	19-Mar	-	5	Canada
6	Argentina	21-Mar	3	6	European Union	16-Mar	-	6	North Korea
7	Belgium	17-Mar	4	7	Czech Republic	16-Mar	-	7	Ukraine
8	Germany	20-Mar	4	8	Morocco	15-Mar	-	8	Indonesia
9	Malaysia	16-Mar	4	9	Kenya	15-Mar	-	9	Croatia
10	France	16-Mar	4	10	Poland	13-Mar	-	10	Turkmenistan
11	Spain	14-Mar	-	11	Qatar	26-Mar	-	-	-
12	Kuwait	13-Mar	2	12	UAE	31-Mar			
13	Ireland	27-Mar	2	13	Panama	25-Mar			
13	Norway	12-Mar	4	14	Peru	16-Mar			
15	Denmark	11-Mar	4	15	Russia	30-Mar			
16	Italy	10-Mar	-	16	Serbia	15-Mar			
17	Iran	28-Mar	-	17	Uzbekistan	24-Mar			
18	Dubai	4-Apr	2	18	Kazakhstan	18-Mar			
19	El Salvador	22-Mar	4	19	Chile	23-Mar			
20	Rwanda	21-Mar	4	-	-	-			
21	Portugal	20-Mar	4						
22	Austria	16-Mar	4						
23	The Netherlands	22-Mar	6						
25	Slovenia	20-Mar	-						

26	Sudan	2-Apr	4
27	Singapore	3-Apr	4
28	Mexico	2-Apr	4

2. Materials And Methodology

2.1 Materials

2.1.1 MERRA-2 data

The MERRA-2 is a NASA atmospheric reanalysis data that was launched in 1980 replacing original MERRA (Rienecker et al., 2011), and uses the data assimilation system of upgraded version of Goddard Earth-observing System Model, Version-5 (GEOS-5) (Randles et al., 2017). GEOS-5 is a weather and climate capable model that is composed of oceanic and land components and circulation of the atmosphere (Song et al., 2018). While assimilating atmospheric data GEOS-5 uses grid-points based interpolation of GIS algorithms which can combine both in-situ and remote sensing data (Buchard et al., 2016). This study particularly employed MERRA-2 reanalyzed AOD, $PM_{2.5}$, SO_2, O_3, black carbon. MERRA-2 is the first one multi-temporal reanalysis system, which contained the meteorological aerosol observations assimilated with the global assimilation system (Randles et al., 2017). GEOS-5 is radiatively combined with Goddard Chemistry, Aerosol, Radiation, and Transport (GOCART) provided aerosol module to produce companion gridded dataset of aerosol. Aerosol species are considered to be non-interactive with each other. Emissions of both dust and sea salt are dependent on the speed of surface wind whereas the sulfate and carbonaceous are principally emitted from the combustion of fossil fuel and burning of biomass, additionally standard inventories are prescribed as the sources of black carbon (Randles et al., 2017). The Emission Database for Global Atmospheric Research 4.1 (EDGAR) inventory is attached for prescribing SO_2 emission from anthropogenic sources (Buchard et al., 2014). The corresponding resolution of MERRA-2 and its outputs are on regular $0.62\hat{5}$ x $0.\hat{5}$ longitude by latitude grid with 72 vertical layers extended up to 80 km from the ground.

2.1.2 AIRS data

The AIRS was launched in 2002 is a high-spectral-resolution infrared sounder onboard aqua satellite consisting of a total of 2378 channels which cover 3.7-15.4 μm wavelength with the spectral resolution of that provides global observation of a 40 km vertical atmospheric profile (Zhang et al., 2020). AIRS measures CO concentration with a 45 km spatial resolution at nadir and 1650 km of the cross-track swath (Chahine et al., 2006). Due to having the advantage long term high spatial coverage AIRS have been used by several researchers in previous years (Fisher et al., 2010; Xiong et al., 2013; Xiong et al., 2014; Field et al., 2016; Wu et al., 2017). Over the last few years the retrieval algorithm for extracting data from the AIRS has been developed (Suskind et al., 2014) and the CO data has achieved researcher confidence for studying tropospheric CO (McMillan et al., 2005; McMillan et al., 2011; Warner et al., 2010; Warner et al., 2014). Unlike other satellite data regarding CO, AIRS has the cloud cleaning capacity that provides up to 80% cloud-free data with daily 70% of global coverage (Han et al., 2018). Besides, the long historical records are the reason behind the use of ARIS CO data in this study.

2.2 Method for preparation of air quality state (AQS)

A global AQS model has been developed to assess the status of overall air quality. The air quality is assessed based on the concentration level of the pollutants which may harm human life due to high toxicity (Olvera-Garcia et al., 2016). For fulfilling the present purpose six major air quality indicators, as well as pollutants, have been considered namely AOD, $PM_{2.5}$, SO_2, O_3, black carbon and CO. Concentration of all these pollutants has been investigated based on their toxic capacity and negative impact to the good air quality. Integrated AQS maps have been classified into six classes denoting very good to hazardous following World Air Quality Project (WAQP) (https://waqi.info/).

2.2.1 Fuzzy logic and its application

A fuzzy set is a semi-quantitative method based on the training and membership weighting technique which was developed by Zadeh (1996) for the modeling of an uncertain and nonlinear complex system (Sowlat et al., 2011). In the present context, a fuzzy logic system was used to integrate causative air pollutants. As this approach works based on training and membership weighting techniques, here membership value indicates the intensity of the effect of the quantity (Agarwal et al., 2017). In such a semi-quantitative approach, the fuzzy membership value ranges from 0 to 1 where values trending toward 0 indicate a lesser degree of fuzzy relation and trending toward 1 indicate a greater degree of fuzzy relation (Saha and Pal, 2019). This approach is not bound to any universal approach of weight determination for the fuzzy membership (Li and Ma, 2007). Therefore, any suitable and best fitting approach may produce an accurate result. For AQS assessment several researchers have used different knowledge-based approaches to assign fuzzy membership value (Sowlat et al., 2011; Agarwal et al., 2017; Carbajal-Hernández et al., 2012; Olvera-Garcia et al., 2016). This membership system allows us to signify a high concentration of pollutants and determine the successive degree of AQS. Following this rule, the membership values of the pollutants *(x)* and were assigned from 0 to 1 and with varying degree of confidence *(f(x))* and the fuzzy set can be formulated as (eq. 1)-

$$A = \left\{ x, f_A(x) \right\}, x_{\in} R \qquad (1)$$

where *A* represents the fuzzy set, *x* is the element of universal set *R*, and *f(x)* signifies the membership function of fuzzy.

2.3 Time progressive change of air quality state

To evaluate the change of AQS in comparison to the previous date of lockdown enforcement and its change during lockdown implementation time progress change rate of AQS has been calculated. In this computation, the AQS of December is considered a pre-lockdown enforcement reference date, and the change rate is calculated for January, February, and March (Alemayendu, 2016). The following equation (Eq. 2) shows the mathematical formulation of this change estimation.

$$C_{AQS}\frac{Pv_{AQS}-Pr_{AQS}}{Pv_{AQS}}\times 100 \qquad (2)$$

where C_{AQS} is the calculated Time progressive change of AQS; Pv_{AQS} and Pr_{AQS} are the AQS of respectively in pre and during lockdown implementation. The result will lie between 0 to ±100 where negative and positive values show respectively degradation and improvement of AQS and 0 indicates no change.

3. Results And Discussion

3.1 Change in pollution parameters

Country-wise spatiotemporal distribution of the major pollution indicating parameters have been illustrated in figure 1(a-h)-3(a-h). The monthly average state of the parameters since the beginning of the outbreak of COVID-19 in China to present has been depicted in the maps. From the time series maps, it is quite clear that before the outbreak of these fatal diseases and imposing partial and fully fledged lockdown across the world pollution level was high in most parts of the world which are highly affected by the COVID-19. But just after initiation of lockdown at different dates of the respective nations the pollution level is reduced significantly and it continued with the continuation of lockdown. At the very initial stage, a lockdown was announced in parts of China (23 January 2020) and it led to improvement in air pollution level (AOD was 1.72 in January and reduced to 1.21 in February and 0.65 in March) (Fig. 1c, d), but in other parts of the world, the situation was as usual in the case of January and February months of 2020 (Fig. 1b, c). After announcing lockdown in European countries like Italy, France, Germany, Spain, the UK in March 2020, and onward, the situation of pollution level has been qualitatively upgraded. For instance, CO was 123-205 ppb, and it is reduced to 59-101 PPV in European countries (Fig. 2e-h). In the case of ozone, countries like the USA, Canada, West European countries and parts of Russia had recorded 312-405db in December 2019 (Fig. 2a) and it is reduced 306-347db in March 2020 (Fig. 2d). Figure 3a has reported that India, China, Arabian Peninsula countries, West African Countries like Senegal, Mali were registered at a high rate of $PM_{2.5}$ in December 2019 and it is significantly reduced in February and March 2020 (Fig. 3c-d). In African countries, a higher rate of $PM_{2.5}$ is observed in March 2020. The South and South East Asian countries like India, Bangladesh, Pakistan, Myanmar, Thailand, and Indonesia have experienced a huge reduction of black carbon between the periods of December 2019 to March 2020 (Fig. 3e-h). The rate of decline was faster immediately after experiencing lockdown and it has been decelerated over the progress of the lockdown period. The countries that used to witness high pollution levels triggered by a very high energy footprint have undergone a massive decrease in pollution level. Some city level studies in India, China, and USA also have identified similar results (Mahato et al., 2020; Muhammad et al., 2020).

3.2 Changing air quality state (AQS)

Integrated air quality parameters in the name of AQS in four months across the world are portrayed in figure 4 (a-d). The qualitative pollution state has been categorized into six classes following the World Air Quality

Project (WAQP) (https://waqi.info/). These classes have indicated the possible exposure level. In the month of December 2019 and January 2020, the overall pollution level is found to be high in all the highly urbanized and industrialized nations like India, China, Bangladesh, West African countries, South American Countries, and some of the western European countries. Earlier pollution reports and studies have exhibited the same situation (Tilt, 2019; North et al., 2019; Li et al., 2019). But after implementation of lockdown in different countries to stop COVID 19, the different parts of the world have experienced an improvement in air quality (Dutheil et al., 2020; Mahato et al., 2020; Muhammad et al., 2020). As all the nations have not announced a lockdown on the same date and the nature of lockdown is either partial or full-fledged, all countries have not experienced a uniform improvement in air quality from a specific date and the degree of improvement is also not uniform. For example, in China, as the lockdown was announced at the earliest (23 January 2020). AQS was found good in late January, February, and March. AQS had started to deteriorate in successive periods (fig. 4). The hotspot of COVID-19 has then shifted to some European nations like Italy, Spain, France, UK, Germany, etc. To prevent the situation, they have imposed lockdown March onward and improvement in AQS was observed in successive periods. The rate of improvement was found high within one to two weeks after commencing lockdown. AQS in a regulated situation has come under the ambient air quality category. If this state is judged in reference to WAQP forwarded exposure level scale, then it can be stated that China, India, Bangladesh, West African countries, some parts of USA, Argentina, Brazil, Thailand, Malaysia, etc. countries were under hazardous to unhealthy AQS category in the pre-lockdown period, and all these countries have shifted to good to very good AQS category during lockdown (February-March, 2020). With the continuation of the lockdown, the gradual improvement of AQS is noticed in all the respective countries (Table 2). In the countries, where lockdown was partial, the degree of quality improvement of air is relatively less than the countries have undergone into full fledged lockdown. Tobias et al (2020), Muhammad et al. (2020) have also found a declining trend of pollution level in Barcelona (Spain) and some other major cities of Italy, China, and the USA.

3.3 Rate of change in AQS with the continuation of lockdown condition

Figure 5(a-c) shows the percentage of change of AQS from December month of 2020 to successive other months. In China, AQS is improved by 10% between December 2020 to February 2020. This rate is found high (>20%) in European countries like Italy, Spain, France, Germany, Denmark, UK in between December 2020 to March 2020 (Table 2). Extension of the hotspot to the USA with the casualty of about 54000 deaths and lockdown situations has shown quality improvement of air in the USA. Russia, Latin American countries, and counties of the Middle East are also identified under this category. Over the progress of time more, a number of countries have included ambient AQS (Fig. 5a-c). The rate of change is recorded higher in the countries which have experienced full-fledge lockdown than countries with partial lockdown with almost the same tenure of lockdown. A wider part of the developing and underdeveloped countries has recorded qualitative degradation as an annual cycle of pollution level where lockdown has not been implemented. In some countries where lockdown is applied in some specific cities or regions, the average AQS of the entire country does not provide any significant change. But this effect is clear in those areas where it is implemented.

Table 2 Worldwide air quality state change rate between 1st month (December) to third month (February), 1st month to 4th month (March) and analyze based on the date of lockdown

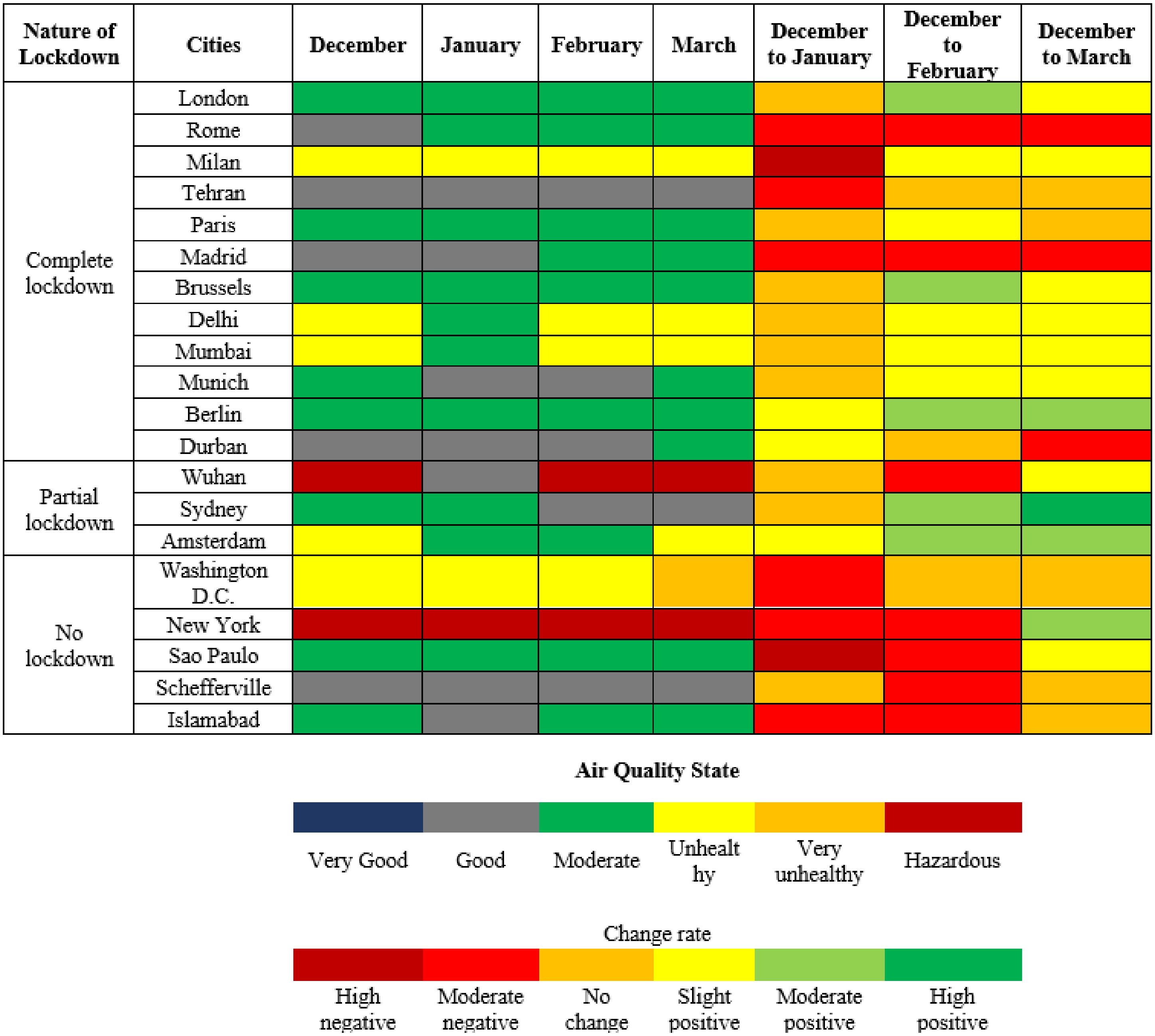
Change	Lockdown Status	1st to 3rd month	1st to 4th month
Slight Positive change (<20%)	Partial lockdown	Finland (7.83%), Brazil (15.37%), United Kingdom (14.19%), Ireland (8.16%), New Zealand (17.77%), Zimbabwe (14.70%), Nepal (9.61%), Sweden (1.83%), Japan (2.72%)	Sweden (2.35%)
	Full lockdown	Bangladesh (2.80%), Bhutan (3.77%), India (5.30%), Thailand (2.94%), Vietnam (2.75%), Germany (5.19%),	Finland (8.99%), United Kingdom (13.05%), Ireland (4.99%), Nepal (12.76%), India (10.03%), Germany (9.54%), Australia (7.50%), Japan (8.56%), Bangladesh (3.68%), Bhutan (1.36%), Thailand (5.49%), Vietnam (4.85%), France (-4.23%), Spain (-2.23%)
Moderate positive change (20-40%)	Partial lockdown		
	Full lockdown	Madagascar (27.89%), Bolivia (28.82%), Paraguay (20.09%), Netherland (42.50%)	Paraguay (36.85%), New Zealand (36.11%)
High positive change (40-60%)	Partial lockdown		
	Full lockdown	Senegal (51.86%), Mali (43.41%),	Mali (53.31%), Zimbabwe (45.28%), Netherland (55.91%), Brazil (42.92%),
Very high positive change (>60%)	Partial lockdown		
	Full lockdown		Senegal (89.31%), Madagascar (61.22%), Bolivia (64.39%)

3.4 AQS of selected cities based on lockdown implementation

As few cities were already identified as a hotspot of COVID-19 as per the records of very high death counts and count of infected people, this section has inspected the AQS condition with special emphasis with some less or non-affected cities. In Wuhan, the first hotspot of this virus, AQS was improved substantially just after starting lockdown. New York, Barcelona, Venice, London, Paris, Brussels, Berlin, Sydney, Amsterdam, Sao Paulo, and other cities of European and American countries have also witnessed a remarkable improvement in

AQS as the regions have implemented full-fledge lockdown (Table 3). Wuhan, Sydney, and Amsterdam cities have implemented partial lockdown and consequently, the air quality improvement rate is not detected so high (Table 3). New York, Washington DC and Islamabad cities have not experienced any such discernible change in AQS as these areas have not experienced lockdown. In lockdown conditions as most of the sources of air pollution like industries, transport, agriculture farms have been regulated, the pollution level is consequently reduced. The finding of the study is not any discrete event. A few studies have already been done in environmental perspective (Saadat et al, 2020; Sharma et al, 2020; Wang and Su, 2020; Wang et al, 2020; Tobias et al, 2020) also have reported a similar result. Tobias et al (2020) have reported that lockdown in Spain on 15th March 2020 has reduced NO_2 level by 51%, PM10 by 31%, O3 level has increased by 33-57% in Barcelona city and adjacent areas. Muhammud et al, (2020) have documented that pollution level in some epicenters of COVID- 19 across Italy, Spain, the USA has reduced by 30%. Shereen et al (2020) have found a strong association between a change of air quality and climate indicators stating the fact that lockdown has also impacted the climate indicators like air temperature, land surface temperature, wind movement, etc. Previous studies by Anderson and Nässén (2016), Jerez et al (2018), Manabe (2019) have also reported that a high concentration of greenhouse gases may enhance the temperature and related other climatic components like fog, dew, and precipitation, etc. Similarly, Aydın et al., (2020) noted that the ozone level has increased significantly during the Covid-19 lockdown than pre-lockdown period which has increased the sunlight penetration. They also pointed that the increase in ozone is associated with the decline in $PM_{2.5}$ concentration. Thus it can be concluded that the drastic changes in atmospheric elements and pollutants have been observed due to the Covid-19 lockdown and each of the atmospheric changes are associated with each other.

Table 3 Analyzing the AQS of selected cities based on lockdown implementation



4. Conclusion

The present study has clearly explored that around the world the AQS has improved in COVID -19 persuaded lockdown period. The degree of improvement is regulated by the nature of lockdown policies. The full-fledge lockdown has exerted a greater impact on the degree of AQS improvement than partial and no lockdown state. The present study is confined up to March 2020 but the threat of COVID-19 has been accelerating over time in different countries of the world. So, lengthening of lockdown is expected to further improve the environmental quality. Certainly, this incident has brought colossal economic failure, millions of people are facing even food scarcity and more people may face severe starvation in the coming days in consequence of this but from an environmental and ecosystem point of view, this incident has extended an opportunity to restore the decaying quality of nature. The result has clearly noted that within a very short period nature has started to restore herself. It is really good for not only environmental health but also the health and well-being of the human being. The increase of ozone will obviously provide better security to the entire ecosystem. Pollution free-breathing not only refreshes our mind and body but also gives temporary relief to the millions of people who are suffering from air pollution-related diseases. However, amid curse, some blessing is there with this lockdown compulsion. When the entire world is worried about how to control pollution and paying huge amounts of money to abate this problem, this unfortunate incident has vividly pointed out that the temporary lockdown would be a good alternative to minimize pollution levels and its consequences.

Declarations

Conflict of Interest

The authors declare that they have no conflict of interest on any issue.

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References

Aggarwal, A., Choudhary T. and Kumar, P., 2017. "A fuzzy interface system for determining air quality index," In Proceedings of the 2017 International Conference on Infocom Technologies and Unmanned Systems, Dubai, UAE, 18–20 December 2017; pp. 786–790.

Ahmed, W., Angel, N., Edson, J. et al., 2020. First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: A proof of concept for the wastewater surveillance of COVID-19 in the community. *Science of The Total Environment*. https://doi.org/10.1016/j.scitotenv.2020.138764

Aydın, S., Nakiyingi,, B.A., Esmen, C., Güneysu, S. and Ejjada, M., 2020. Environmental impact of coronavirus (COVID-19) from Turkish perceptive. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-020-00933-5

Alemayehu, F., 2016. Land use and land cover change in the coastal area of WatamuMida Creek, Kenya. *Open Journal of Forestry*, *6*(4), 230-242.

Andersson, D., and Nässén, J., 2016. Should environmentalists be concerned about materialism? An analysis of attitudes, behaviors, and greenhouse gas emissions. *Journal of Environmental Psychology*, *48*, 1-11.

Bera, B., Bhattacharjee, S., Shit, P.K., Sengupta, N. and Saha, S., 2020. Significant impacts of COVID-19 lockdown on urban air pollution in Kolkata (India) and amelioration of environmental health. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-020-00898-5

Bherwani, H., Anjum, S., Kumar, S., Gautam, S., Gupta, A., Kumbhare, H., Anshul, A. and Kumar, R., 2020. Understanding COVID-19 transmission through Bayesian probabilistic modeling and GIS-based Voronoi approach: a policy perspective. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-020-00849-0

Buchard, V., Da Silva, A.M., Calarco, P., Krotkov, N., Dickerson, R.R., Stehr, J.W., Mount, G., Spenei, E., Arkinson, H.L. and He, H., 2014. Evaluation of GEOS-5 Sulfur Dioxide Simulations during the Frostburg, MD 2010 Field Campaign. *Atmospheric Chemistry and Physics*, 14, 1929–1941.

Buchard, V., da Silva, A.M., Randles, C.A., Colarco, P., Ferrare, R., Hair, J., Hostetler, C., Tackett, J., Winker, D., 2016. Evaluation of the surface PM2.5 in version 1 of the NASA MERRA aerosol reanalysis over the United States. *Atmospheric Environment*, 125, 100–111.

Carbajal-Hernández, J.J., Sánchez-Fernández, L.P., Carrasco-Ochoa, J.A. and Martínez-Trinidad, J.F., 2012. Assessment and prediction of air quality using fuzzy logic and autoregressive models. *Atmospheric Environment*, *60*, 37-50.

Chahine, M.T., Pagano, T.S., Aumann, H.H., et al. 2006. "AIRS: Improving weather forecasting and providing new data on greenhouse gases." *Bulletin of the American Meteorological Society,* 87(7), 911-926.

Chinazzi, M., Davis, J.T., Ajelli, M., Gioannini, C., Litvinova, M., Merler, S., y Piontti, A.P., Mu, K., Rossi, L., Sun, K. and Viboud, C., 2020. The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak. *Science*, 368(6489), 395-400.

Chakraborty, I. and Maity, P., 2020. COVID-19 outbreak: Migration, effects on society, global environment and prevention. *Science of The Total Environment*, 728, 138882. https://doi.org/10.1016/j.scitotenv.2020.138882

Dutheil, F., Baker, J.S. and Navel, V., 2020. COVID-19 as a factor influencing air pollution? *Environmental Pollution,* 263, 114466. https://doi.org/10.1016/j.envpol.2020.114466

European Space Agency. 2020. COVID-19: nitrogen dioxide over China. https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5 P/COVID 19_nitrogen_dioxide_over_China.

Ficetola, G.F. and Rubolini, D., 2020. Climate affects global patterns of COVID-19 early outbreak dynamics. *medRxiv*. https://doi.org/10.1101/2020.03.23.20040501

Field, R.D., Van Der Werf, G.R., Fanin, T., Fetzer, E.J., Fuller, R., Jethva, H., Levy, R., Livesey, N.J., Luo, M., Torres, O. and Worden, H.M., 2016. Indonesian fire activity and smoke pollution in 2015 show persistent nonlinear sensitivity to El Niño-induced drought. *Proceedings of the National Academy of Sciences*, *113*(33), 9204-9209.

Fisher, J.A., Jacob, D.J., Purdy, M.T. et al., 2010. Source attribution and interannual variability of Arctic pollution in spring constrained by aircraft (ARCTAS, ARCPAC) and satellite (AIRS) observations of carbon monoxide. *Atmospheric Chemistry and Physics*, 10, 977–996.

Gautam, S. and Trivedi, U., 2020. Global implications of bio-aerosol in pandemic. Environment, Development and Sustainability, 22, 3861–3865.

Gupta, A., Bherwani, H., Gautam, S., Anjum, S., Musugu, K., Kumar, N., Anshul, S. and Kumar, R., 2020. Air pollution aggravating COVID-19 lethality? Exploration in Asian cities using statistical models. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-020-00878-9

Han, H., Liu, J., Yuan, H., Jiang, F., Zhu, Y., Wu, Y., Wang, T. and Zhuang, B., 2018. Impacts of synoptic weather patterns and their persistence on free tropospheric carbon monoxide concentrations and outflow in eastern China. *Journal of Geophysical Research: Atmospheres*, *123*(13), 7024-7046.

Harapan, H., Itoh, N., Yufika, A., Winardi, W. et al., 2020. Coronavirus disease 2019 (COVID-19): A literature review. *Journal of Infection and Public Health*. https://doi.org/10.1016/j.jiph.2020.03.019

Hui, D.S., Azhar, E.I., Madani, T.A., Ntoumi, F. et al., 2020. The continuing 2019-nCoV epidemic threat of novel coronaviruses to global health — The latest 2019 novel coronavirus outbreak in Wuhan, China. *International Journal of Infectious Diseases*, 91, 264–266.

Jerez, S., López-Romero, J.M., Turco, M., Jiménez-Guerrero, P., Vautard, R. and Montávez, J.P., 2018. Impact of evolving greenhouse gas forcing on the warming signal in regional climate model experiments. *Nature communications*, *9*(1), 1-7.

Li, X., Jin, L. and Kan, H., 2019. Air pollution: a global problem needs local fixes. *Nature*, 570, 437-439.

Li T. and Ma J., 2007. Fuzzy Approximation Operators Based on Coverings. In: An A., Stefanowski J., Ramanna S., Butz C.J., Pedrycz W., Wang G. (eds) Rough Sets, Fuzzy Sets, Data Mining and Granular Computing. RSFDGrC 2007. Lecture Notes in Computer Science, vol 4482. Springer, Berlin, Heidelberg.

Lin, Q., Zhao, S., Gao, D. et al., 2020. A conceptual model for the coronavirus disease 2019 (COVID-19) outbreak in Wuhan, China with individual reaction and governmental action. *International Journal of Infectious Diseases*, 93, 211-216.

Mahato, S., Pal, S. and Ghosh, K.G., 2020. Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. Science of The Total Environment. https://doi.org/10.1016/j.scitotenv.2020.139086

Manabe, S., 2019. Role of greenhouse gas in climate change. *Tellus A: Dynamic Meteorology and Oceanography*, *71*(1), 1-13.

McMillan, W.W., Barnet, C., Strow, L., Chahine, M.T., McCourt, M.L., Warner, J.X., Novelli, P.C., Korontzi, S., Maddy, E.S. and Datta, S., 2005. Daily global maps of carbon monoxide from NASA's Atmospheric Infrared Sounder. *Geophysical Research Letters*, *32*(11), L11801.

McMillan, W.W., Evans, K.D., Barnet, C.D., Maddy, E.S., Sachse, G.W. and Diskin, G.S., 2011. Validating the AIRS Version 5 CO retrieval with DACOM in situ measurements during INTEX-A and-B. *IEEE transactions on geoscience and remote sensing*, *49*(7), 2802-2813.

Muhammad, S., Long, X. and Salman, M., 2020. COVID-19 pandemic and environmental pollution: A blessing in disguise? *Science of The Total Environment*, 728, 138820. https://doi.org/10.1016/j.scitotenv.2020.138820

NASA. 2020. Airborne Nitrogen Dioxide Plummets Over China. https://earthobservatory.nasa.gov/images/146362/airborne- nitrogen-dioxide-plummets-over-china. (Accessed on 28 April 2020).

Neradi, D., Hooda, A., Shetty, A., Kumar, D., Salaria, A.K. and Goni, V., 2020. Management of Orthopaedic Patients During COVID-19 Pandemic in India: A Guide. Indian Journal of Orthopaedics. https://doi.org/10.1007/s43465-020-00122-6

North, C.M., Rice, M.B., Ferkol, T., Gozal, D., Hui, C., Jung, S.H., Kuribayashi, K., McCormack, M.C., Mishima, M., Morimoto, Y. and Song, Y., 2019. Air pollution in the Asia-Pacific region. A joint Asian Pacific Society of Respirology/American Thoracic Society perspective. *American journal of respiratory and critical care medicine*, 199(6), 693-700.

Olvera-García, M.Á., Carbajal-Hernández, J.J., Sánchez-Fernández, L.P. and Hernández-Bautista, I., 2016. Air quality assessment using a weighted Fuzzy Inference System. *Ecological informatics*, *33*, 57-74.

Randles, C.A., da Silva, A.M., Buchard, V., Colarco, P.R., Darmenov, A., Govindaraju, R., Smirnov, A., Holben, B., Ferrare, R., Hair, J., Shinozuka, Y., Flynn, C.J., 2018. The merra-2 aerosol reanalysis, 1980 onward. part I: system description and data assimilation evaluation. Journal of Climate, 30, 6823–6850.

Rienecker, M.M., Suarez, M.J., Gelaro, R. et al., 2011. MERRA - NASA's Modern-Era Retrospective Analysis for Research and Applications. J*ournal of Climate,* 24, 3624-3648.

Saadat, S., Rawtani, D. and Hussain, C.M., 2020. The environmental perspective of COVID-19. *Science of The Total Environment*, 728, 138870. https://doi.org/10.1016/j.scitotenv.2020.138870

Saha, T.K. and Pal, S., 2019. Exploring the physical wetland vulnerability of the Atreyee river basin in India and Bangladesh using logistic regression and fuzzy logic approaches. *Ecological indicators*, *98*, 251-265.

Sharma, S., Zhang, M., Gao, J., Zhang, H. and Kota, S.H., 2020. Effect of restricted emissions during COVID-19 on air quality in India. *Science of The Total Environment*, *728*, 138878. https://doi.org/10.1016/j.scitotenv.2020.138878

Shereen, M.A., Khan, S., Kazmi, A., Bashir, N. and Siddiqui, R., 2020. COVID-19 infection: Origintransmission, and characteristics of human coronaviruses. *Journal of Advanced Research*, 24, 91-98.

Song, Z., Fu, D., Zhang, X., Wu, Y., Xia, X., He, J., Han, X., Zhang, R. and Che, H., 2018. Diurnal and seasonal variability of PM2. 5 and AOD in North China plain: Comparison of MERRA-2 products and ground measurements. *Atmospheric Environment*, *191*, 70-78.

Sowlat, M.H., Gharibi, H., Yunesian, M., Mahmoudi, M.T. and Lotfi, S., 2011. A novel, fuzzy-based air quality index (FAQI) for air quality assessment. *Atmospheric Environment*, *45*(12), 2050-2059.

Susskind, J., Blaisdell, J.M. and Iredell, L., 2014. Improved methodology for surface and atmospheric soundings, error estimates, and quality control procedures: the atmospheric infrared sounder science team version-6 retrieval algorithm. *Journal of Applied Remote Sensing*, *8*(1), 084994.

Tilt, B., 2019. China's air pollution crisis: Science and policy perspectives. *Environmental science & policy*, *92*, 275-280.

Tobías, A., Carnerero, C., Reche, C., Massagué, J., Via, M., Minguillón, M.C., Alastuey, A. and Querol, X., 2020. Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic. *Science of The Total Environment*, 726, 138540. https://doi.org/10.1016/j.scitotenv.2020.1385400

Wang, P., Chen, K., Zhu, S., Wang, P. and Zhang, H., 2020. Severe air pollution events not avoided by reduced anthropogenic activities during the COVID-19 outbreak. *Resources, Conservation and Recycling*, *158*, 104814. https://doi.org/10.1016/j.resconrec.2020.104814

Wang, Q. and Su, M., 2020. A preliminary assessment of the impact of COVID-19 on the environment–A case study of China. *Science of The Total Environment*, 728, 138915. https://doi.org/10.1016/j.scitotenv.2020.138915

Warner, J.X., Wei, Z., Strow, L.L., Barnet, C.D., Sparling, L.C., Diskin, G. and Sachse, G., 2010. Improved agreement of AIRS tropospheric carbon monoxide products with other EOS sensors using optimal estimation retrievals. *Atmospheric Chemistry and Physics, 10, 9521–9533.*

Warner, J.X., Yang, R., Wei, Z., Carminati, F., Tangborn, A., Sun, Z., Lahoz, W.A., Attié, J.L., El Amraoui, L. and Duncan, B.N., 2014. Global carbon monoxide products from combined AIRS, TES and MLS measurements on A-train satellites. *Atmospheric Chemistry and Physics,* 14, 103–114.

World Health Organization, 2020a. Novel Coronavirus (2019-nCoV) Situation Report – 5, 25 January 2020. https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200125-sitrep-5-2019-ncov.pdf?sfvrsn=429b143d_8. (Accessed 30 April 2020).

World Health Organization, 2020b. Rolling updates on coronavirus disease (COVID-19) Updated 28 April 2020. https://www.who.int/emergencies/diseases/novel-coronavirus-2019/events-as-they-happen (Accesses 30 April 2020).

Wu, Y., Han, Y., Voulgarakis, A., Wang, T., Li, M., Wang, Y., Xie, M., Zhuang, B. and Li, S., 2017. An agricultural biomass burning episode in eastern China: Transport, optical properties, and impacts on regional air quality. *Journal of Geophysical Research: Atmospheres*, *122*(4), 2304-2324.

Xiong, X., Barnet, C., Maddy, E., Wofsy, S.C., Chen, L., Karion, A. and Sweeney, C., 2013. Detection of methane depletion associated with stratospheric intrusion by atmospheric infrared sounder (AIRS). *Geophysical Research Letters*, *40*(10), 2455-2459.

Xiong, X., Maddy, E.S., Barnet, C., Gambacorta, A., Patra, P.K., Sun, F. and Goldberg, M., 2014. Retrieval of nitrous oxide from Atmospheric Infrared Sounder: Characterization and validation. *Journal of Geophysical Research: Atmospheres*, *119*(14), 9107-9122.

Zadeh, L.A., 1965. Fuzzy sets. *Information and control*, *8*(3), 338-353.

Zhang, X., Wang, H., Che, H.Z., Tan, S.C., Shi, G.Y. and Yao, X.P., 2020. The impact of aerosol on MODIS cloud detection and property retrieval in seriously polluted East China. *Science of The Total Environment*, *711*, 134634. https://doi.org/10.1016/j.scitotenv.2019.134634

Figures

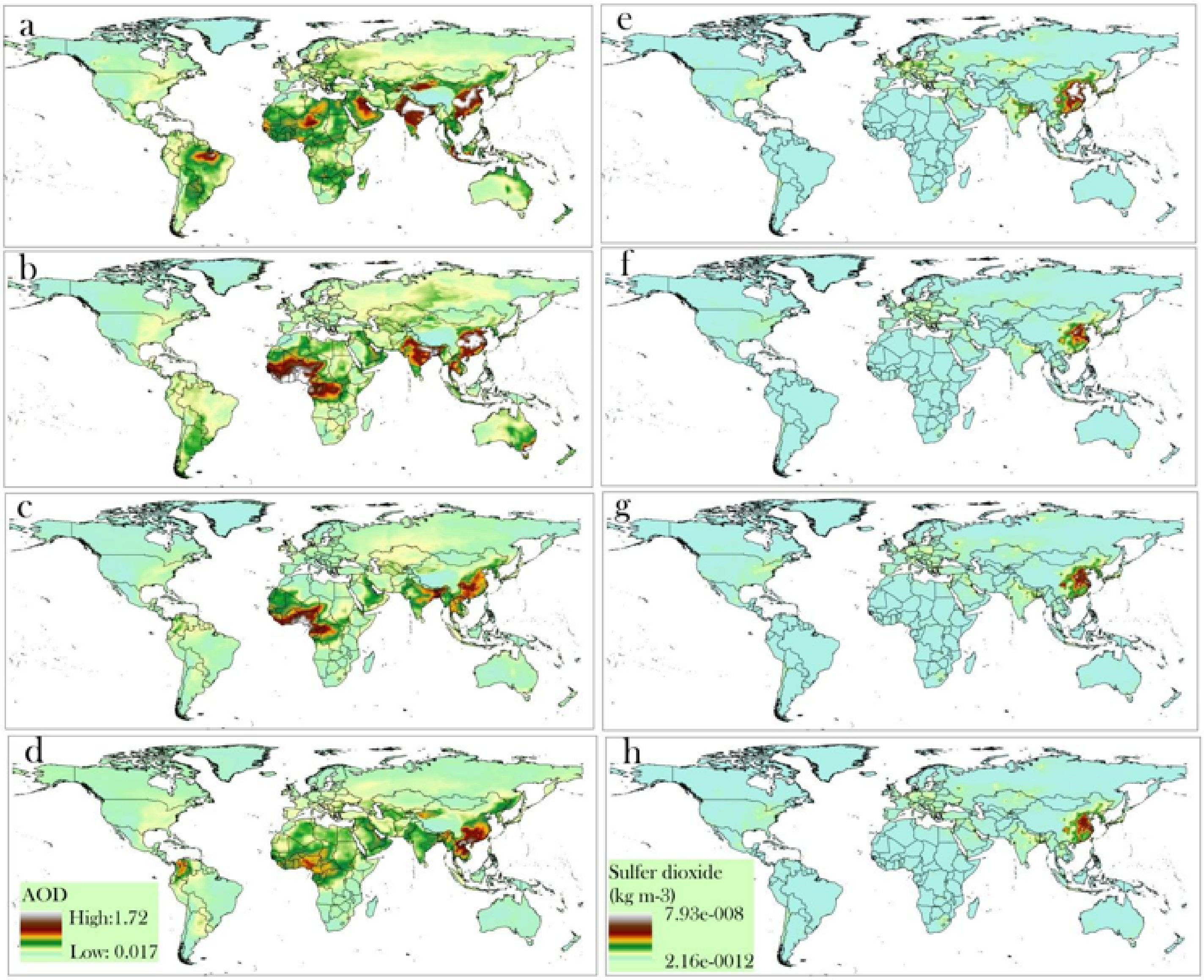

Figure 1

Spatio-temporal mapping of monthly averaged aerosol optical depth and sulfur dioxide for (a), (e) December of 2019; (b), (f) January of 2020; (c), (g) February of 2020; and (d) , (h) March of 2020. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

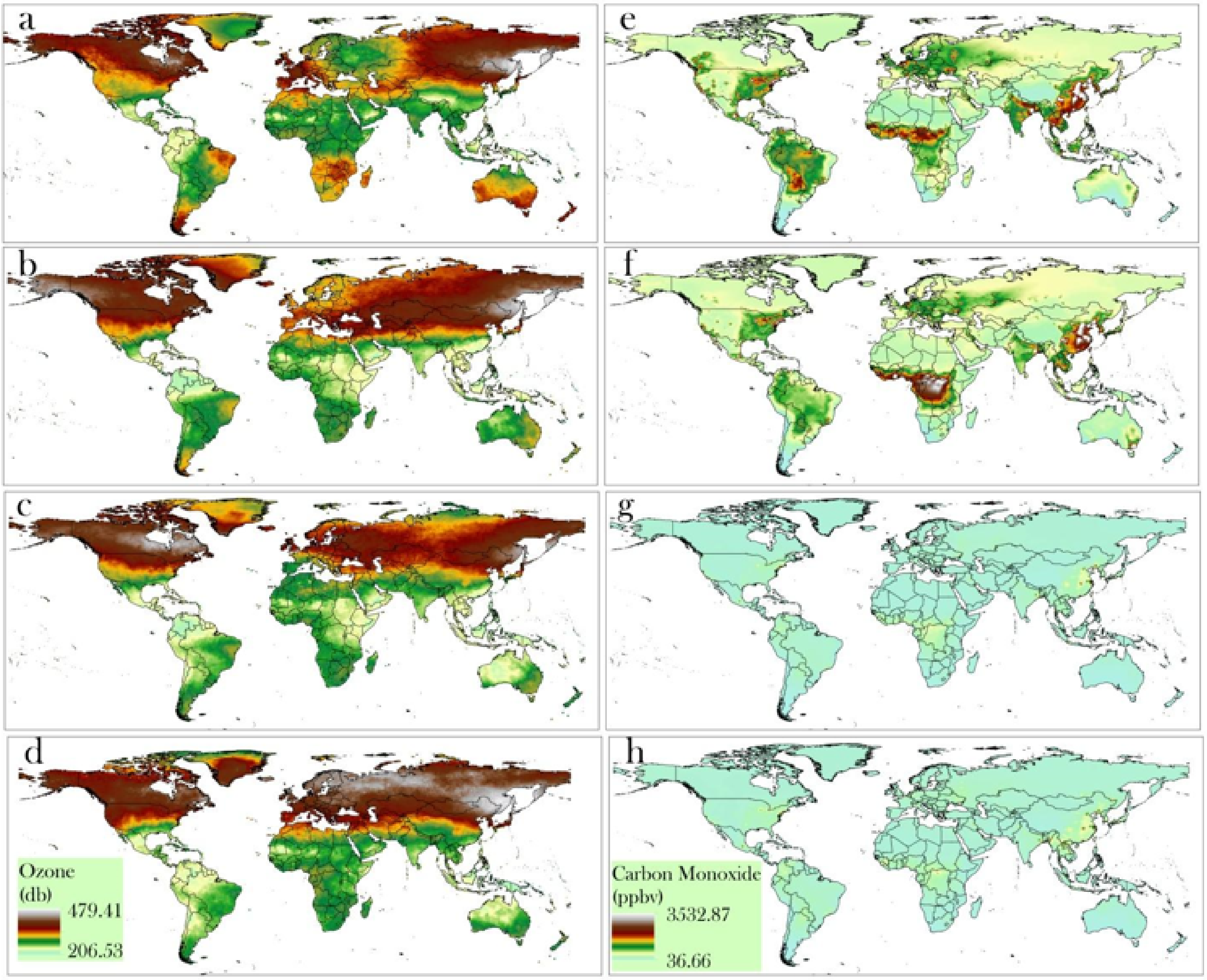

Figure 2

Spatio-temporal mapping of monthly averaged ozone and carbon dioxide for (a), (e) December of 2019; (b), (f) January of 2020; (c), (g) February of 2020; and (d), (h) March of 2020. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

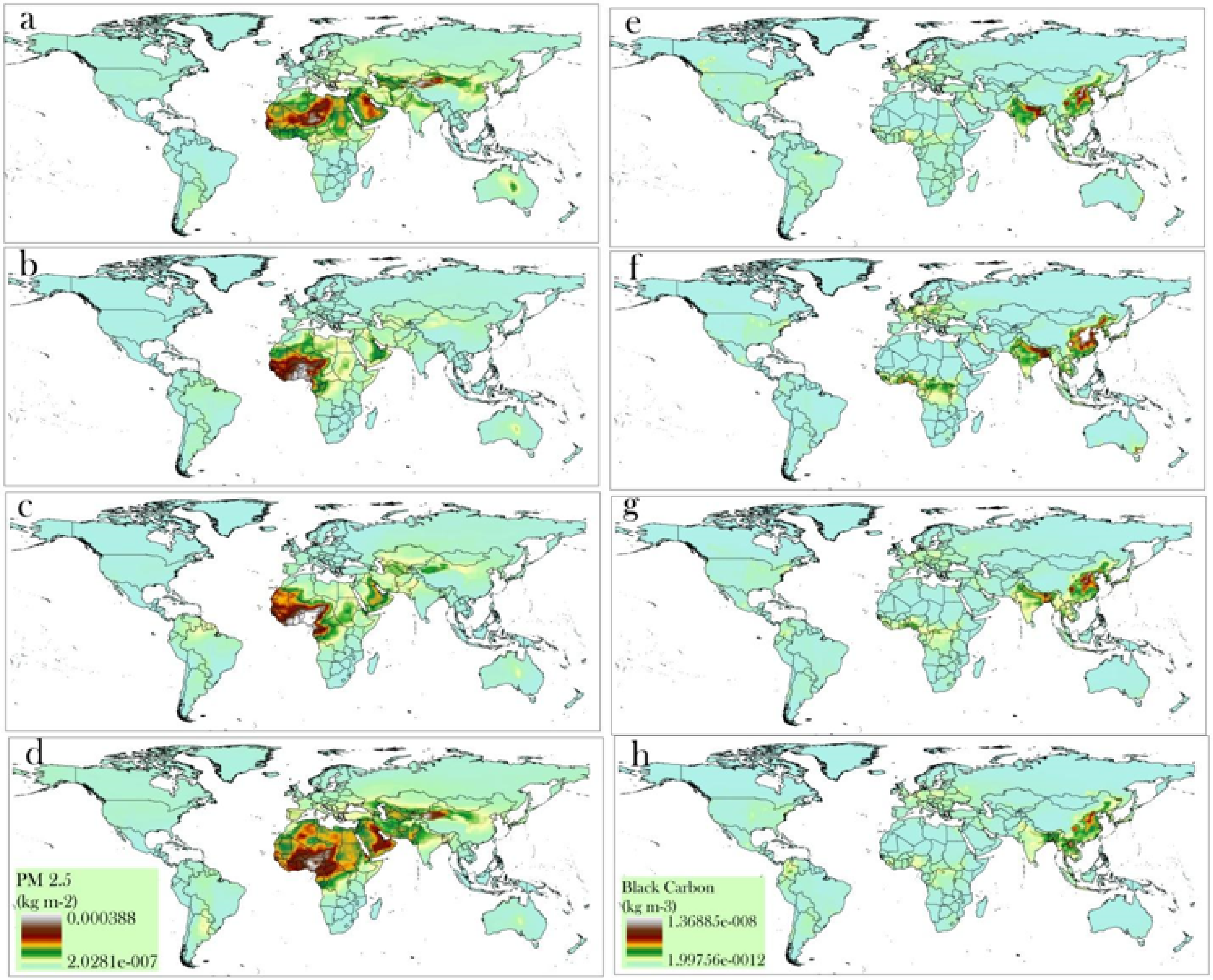

Figure 3

Spatio-temporal mapping of monthly averaged PM2.5 and black carbon for (a), (e) December of 2019; (b), (f) January of 2020; (c), (g) February of 2020; and (d), (h) March of 2020. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

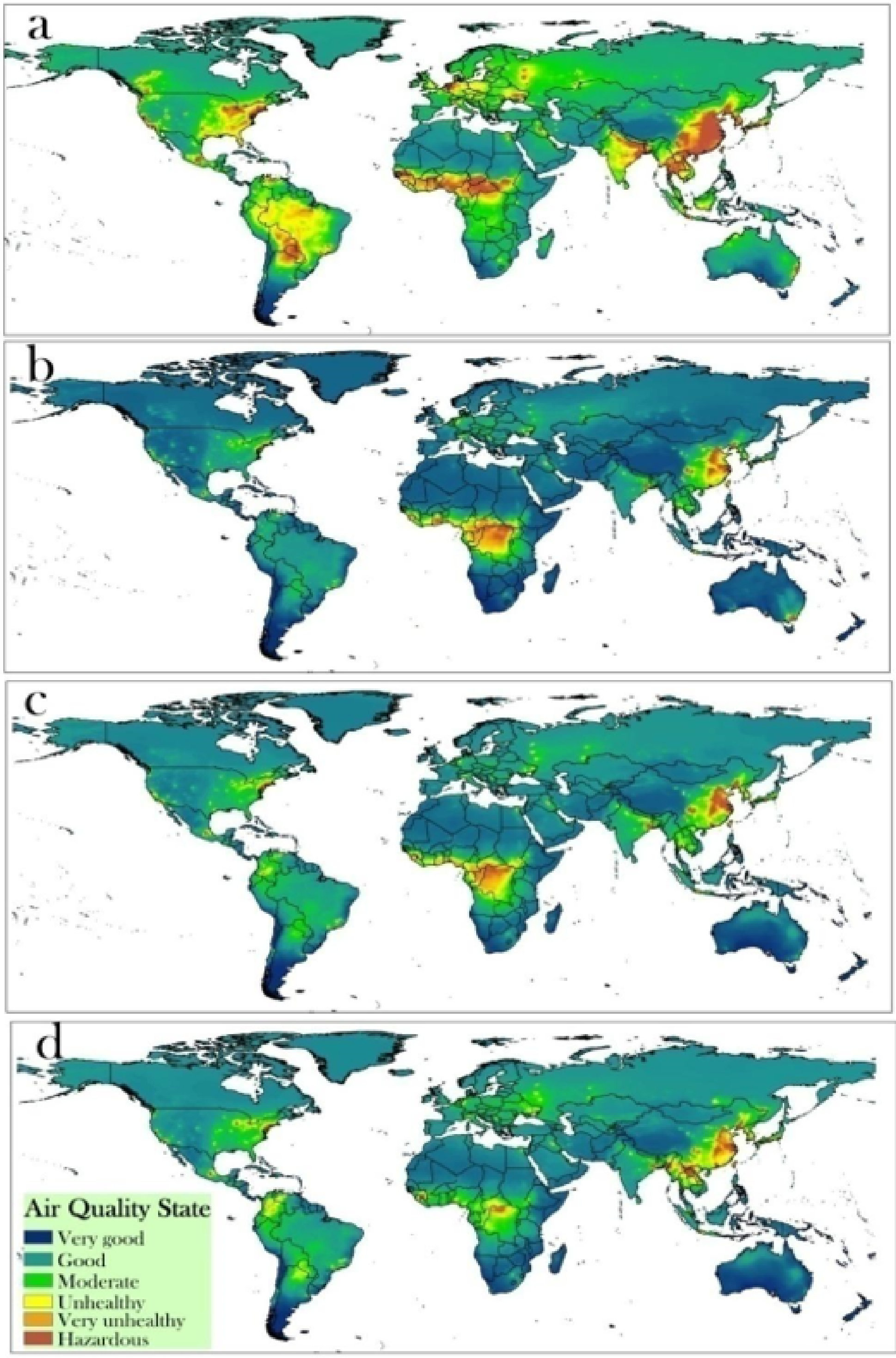

Figure 4

Air quality state modeling for (a) December of 2019, (b) January of 2020, (c) February of 2020, and (d) March of 2020. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

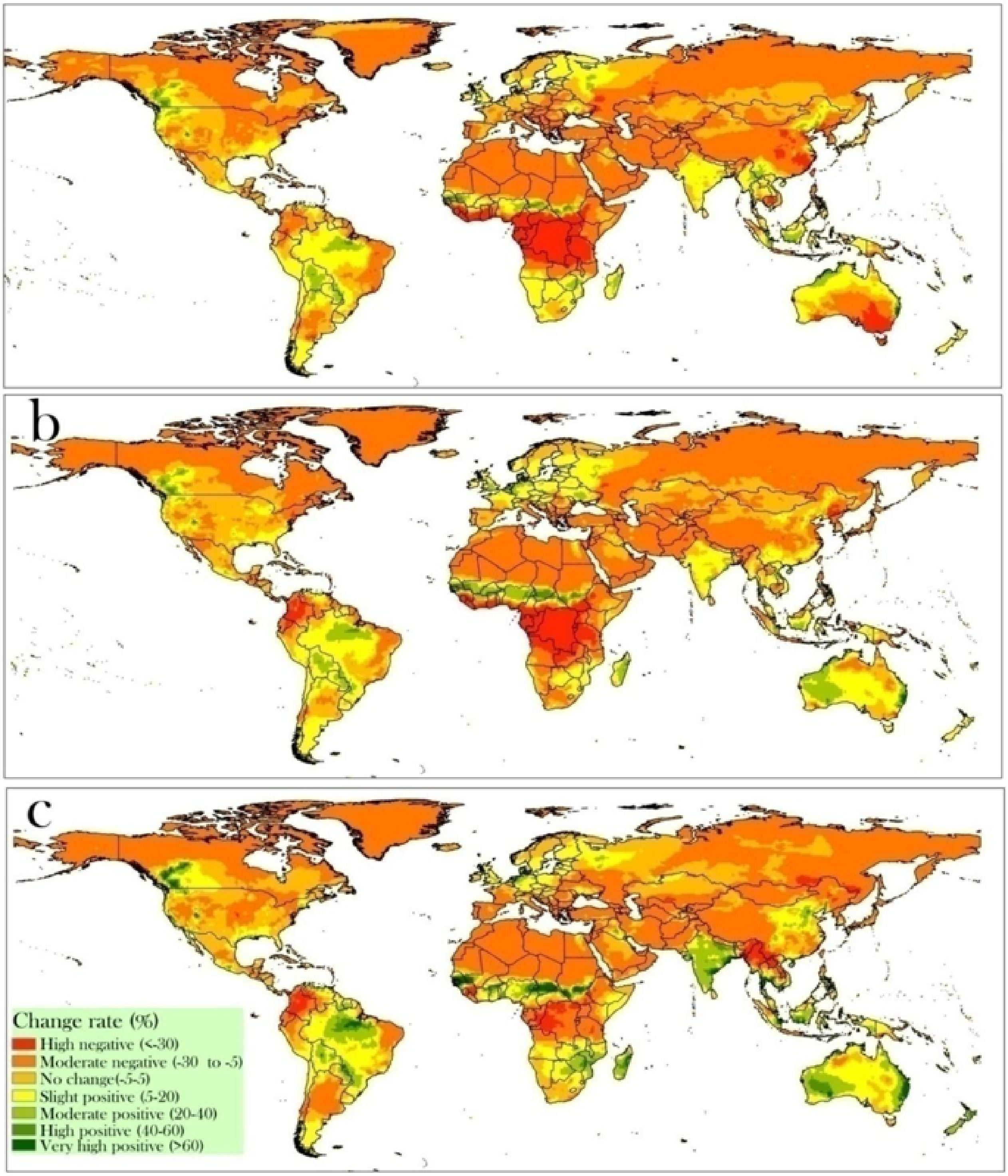

Figure 5

Change rate of air quality state between (a) December of 2019 and January of 2020, (b) December of 2019 and February of 2020, (c) December of 2019 and March of 2020. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.