Preliminary Assessment of Air During COVID-19 Lockdown: An Unintended Benefit to Environment

Shazia Pervaiz[1*], Kanwal Javid[2], Filza Zafar Khan[3], Younis Zahid[1], and Muhammad Ameer Nawaz Akram[4]

[1]Environmental Protection Agency, Punjab, Pakistan
[2]Department of Geography, University of the Punjab, Lahore, Pakistan
[3]Pakistan Council of Scientific and Industrial Research Laboratories Complex, Lahore, Pakistan
[4]Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, China

ARTICLE INFO

Received: 14 May 2020
Received in revised: 12 Jul 2020
Accepted: 22 Jul 2020
Published online: 11 Aug 2020
DOI: 10.32526/ennrj.18.4.2020.35

Keywords:
Air SDGs/ Coronavirus and air pollution/ COVID-19 and SDGs/ Lahore air quality index

*** Corresponding author:**
E-mail: shaziapervaiz@gmail.com

ABSTRACT

The death rate of people is increasing globally during the current outbreak of coronavirus. To combat with COVID-19 havoc, the world has adopted lockdown policies, including Pakistan. Ironically, the invisible virus is suffocating humans at a fast rate but on the other side, there is a visible monster in the world gobbling up human health, i.e., air pollution. Therefore, the main rationale of the present research is to visualize the air quality during the 'Lockdown' period in Lahore, Pakistan by mapping via online tools and techniques using a geospatial system. According to the present findings, the concentrations of air pollutants, such as particulate matters (PM_{10} and $PM_{2.5}$), nitrogen oxides as NO and NO_2, and sulphur dioxide, are below the maximum permissible levels of the Punjab Environmental Quality standards (PEQs), although ozone exceeds its PEQs. So in light of the results, once this COVID-19 crisis is over, the government should speed up measures to lessen air pollution to achieve targets of sustainable development goals (SDGs). Moreover, the present results of air assessment during COVID-19 would serve as a useful reminder for the government of Punjab to cut down air emission levels after the pandemic.

1. INTRODUCTION

In Pakistan, the first coronavirus case was reported in Lahore on 26th February, 2020 (Badshah et al., 2020) and cases spurted rapidly all over Pakistan within a short span of time (Saqlain et al., 2020). All provinces of Pakistan were affected by COVID-19 (Ahmad et al., 2020) and amongst them Sindh was the most vulnerable province reported with the largest number of coronavirus cases initially (Waris et al., 2020). In the meantime, the wide spread of deadly disease suspended all the religious, academic, social, and administrative activities at international levels (Chauhan and Singh, 2020).

During COVID-19 pandemic, the world faced its highest mortality rate, but on the other side, it proved to be a significant factor in the reduction of air emissions by altering anthropogenic activities. It is the one and only virus that demonstrated a new era to get rid of all the preceding impossible environmental problems in a possible way. As per early published statistics, Pakistan's neighboring country China reported the highest death rate (Saqlain et al., 2020). Meanwhile, a significant reduction in nitrogen dioxide was also reported during COVID-19 in China (Wang et al., 2020). Similarly, a decline in air pollution was also reported in Italy, which is one of the countries in the world most affected by COVID-19 (Gatto et al., 2020).

Hence, air pollution is one of the serious threats (Gupta et al., 2013) to life diversity and is reported as a factor for the high fatality due to COVID-19 in Italy (Ogen, 2020). Its destructive nature has detrimental effects on humans, animals (Camargo and Alonso, 2006) and plants (Najjar, 2011). Ecologically, it damages the quality of water and soil (Mellouki et al., 2016). Further, its toxicology is one of the causes of

Citation: Pervaiz S, Javid K, Khan FZ, Zahid Y, Akram MAN. Preliminary assessment of air during COVID-19 lockdown: An unintended benefit to environment. Environ. Nat. Resour. J. 2020;18(4):363-375. (https://doi.org/10.32526/ennrj.18.4.2020.35)

acid rain and temperature inversion (Singh and Agrawal, 2007). Likewise, the escalating global concern is one of the largest environmental problems in Pakistan (Ali and Athar, 2008; Colbeck et al., 2011). In 2018, Pakistan ranked 169 out of 180 countries in the Environmental Performance Index (EPI) (Pakistan Today, 2020), even though its environmental sector is highly prioritized to achieve SDGs (Elder and Olsen, 2019).

Given above the planetary scenario of air pollution, the highest concentration of atmospheric pollutants (Mansha et al., 2012) were reported at an alarming level in Lahore (Colbeck et al., 2019), namely particulate matter $PM_{2.5}$ (Rasheed et al., 2015) and PM_{10} (Stone et al., 2010). As a result, the consequences of air pollution have led to poor health issues (Ashraf et al., 2019) in the city. Despite the fact that environmental legislations, rules and regulations have been formulated in Punjab, Pakistan to control the air pollution, the environmental development is at a noticeably poor level under EPI.

So with respect to the COVID-19 lockdown plan to overcome the pandemic in the city, the contingency plan altered the existing air quality of Lahore. Considering the above scenario, the aim of the present study is to provide a bird's eye view of air quality during COVID-19 lockdown. So, the objectives of the present study are three fold: (1) to map the air pollution level in Lahore during lockdown of COVID-19; (2) to review the air pollution level in 2019 and compare its concentration with the lockdown period of 2020; (3) to evaluate the key air pollutant concentrations in the lockdown period. Thus, findings of the present study provide updated information of air quality during the COVID-19 lockdown. Further, this information can be used to prepare alternative strategies to mitigate the air pollutants to improve the environment of urban areas.

2. METHODOLOGY

2.1 Site description

Lahore, a well-known historical and cultural city of gardens (Ghaffar, 2015; Pervaiz et al., 2019), was chosen to carry out the present study. Lahore is located in the north-east of Punjab. Neighboring country, India lies on the east of Lahore (Lodhi et al., 2009; Akhtar et al., 2015) and linked with the Indian state of Punjab (Tariq and Ali, 2016). District Sheikhupura is located on the North West of the city, Kasur on the south and River Ravi flows in the north (Riaz, 2010). Geo-spatially, the city is situated between 31°15′-31°45′ North, 74°01′74°39′ East (Colbeck et al., 2011) and consists of 1,172 km^2 land surface area (Figure 1).

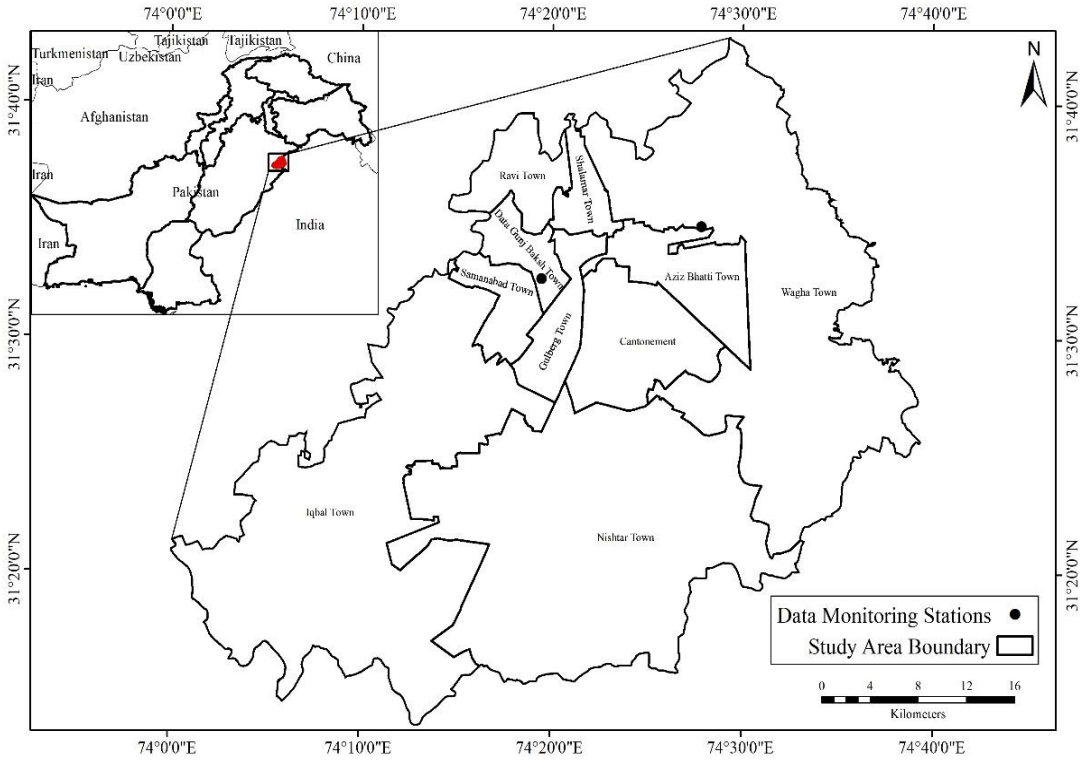

Figure 1. Map of the study area

2.2 Demography

Lahore (Nawaz et al., 2015) is among the mega cities of the world and the second largest metropolis of the country. The population of the city has grown very rapidly during the past decades (Jan and Iqbal, 2008; Aziz et al., 2015) and having 11 million dwellers (Ali et al., 2020) in 2017 (Pakistan Bureau of Statistics, 2017).

2.3 Climate

Lahore has a semi-arid climate (Batool and Ch, 2009; Ali et al., 2020) where extreme and intense weather conditions are observed during different seasons. Lahore experiences summer (April to June with the average temperature above 40°C (Rana and Bhatti, 2018). Whereas, monsoon season (July to September) is associated with heavy rainfalls. December to February is the months of winter with dense fog when temperature falls at low level i.e., 0°C (Alam et al., 2013). Moreover, metrological variables (Kinney, 2008) vary seasonally such as precipitation, temperature, humidity, wind velocity and speed (Sadiq and Qureshi, 2010) which determine the quality of air (Table 1).

Table 1. Metrology of study area in March 2019 and March 2020

March	Wind speed (knot) 300 UTC		Wind speed (knot) 1,200 UTC		Rain (mm)		Min. Temp. (°C)		Max. Temp (°C)		Humidity (%) 300 UTC		Humidity (%) 1,200 UTC	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
20	11	0	7	3	0	0	14	15	29	29	74	78	47	41
21	3	11	8	4	TR	TR	14	16	26	29	74	76	39	54
22	5	0	9	3	0	0	14	14	27	26	71	75	29	42
23	7	0	14	0	0	0	16	15	28	29	55	63	36	25
24	4	0	7	4	TR	TR	14	18	25	31	70	61	59	61
25	5	4	6	3	0	4	14	14	26	22	84	77	38	51
26	5	6	13	4	0	0	13	13	29	26	68	51	27	51
27	0	5	4	12	0	6.4	15	16	29	28	80	95	33	85
28	0	6	5	5	0	14	17	14	31	20	65	89	32	57
29	3	4	4	3	0	0	18	14	32	26	82	81	41	38
30	6	5	12	9	0	0	19	15	33	29	82	60	40	37
31	0	8	10	3	0	0	17	17	32	27	68	63	31	86
Max.	11	11	14	12	-	14	19	18	33	31	84	95	59	86
Min.	0	0	4	0	-	0	13	13	25	20	55	51	27	25
Avg.	4.1	4.1	8.3	4.4	-	2.4	15	15	29	27	73	72	38	52

*TR=0.01 mm

2.4 Environmental overview

Environmentally, the city of gardens 'Lahore' has been converted into the city of concrete in the past three decades. Urban sprawl (Liaqat et al., 2017; Sabir and Anjum, 2017), economic development (Pervaiz et al., 2019), industrial expansion (Raja et al., 2010; Rehman et al., 2019) vehicular emissions (Ilyas, 2007; Shirwani et al., 2019; Ali et al., 2020) and biomass burnings (Sidra et al., 2015; Abas et al., 2019) are the variety of sources deteriorating the natural environment (Pervaiz et al., 2019) of the city. On the top, semi-arid climate of the city strongly supports to accumulate the air pollutants in the atmosphere (Shahid et al., 2013). Thus, the city is vulnerable by having air borne diseases (Aziz and Bajwa, 2007; Raja et al., 2010) caused by the combination of multiple pollutants. Besides, the pernicious air pollution has been also reported to elevate the death rate during the outbreak of COVID-19 (Wang et al., 2020). On the basis of above discussion, Table 2 lists the air pollutants defined in PEQs, their prescribed limit and the impacts on the environment of Lahore.

2.5 Data

The present study relied on the data derived from the official website of Environment Protection Department (EPD), Punjab to examine and compare the pollutant concentrations of the study site in March 2019 and during the COVID-19 lockdown (Figure 2 and Figure 3), (EPD, 2020a). Further, the Punjab Environmental Quality Standards (PEQs) for air

(Table 2) were also obtained from the official source of EPD, Punjab (EPD, 2020b).

In addition, considering that meteorological elements are closely associated with air pollution (Yen et al., 2013) the city level data of weather consisting of wind speed (300 and 1,200 Knot), rain (millimeter per hour), temperature (degree Celsius), and humidity (300 UTC and 1,200 UTC) (Bao and Zhang, 2020) was obtained from Pakistan Meteorological Department for the analysis (Table 1).

Table 2. Air pollutants source, environmental effects and PEQs

Sr. No.	Pollutant	Source	Environmental effect	PEQs
1	Particulate matter (PM_{10})	Diesel-powered vehicles; Factories; Power plants; Industries; Incinerators; Construction activities; Windblown dust. (Mabahwi et al., 2014).	Major source of haze; Damages buildings and other materials.	150 µg/m^3
2	Particulate matter ($PM_{2.5}$)	Transportation; Combustion of fossil fuels; Biomass and waste burnings; Construction sites. (Malashock et al., 2018).	Same effects as PM_{10}. (Zha et al., 2013).	35 µg/m^3
3	Nitrogen oxides as (NO)	Motor vehicles; Emissions from the industrial and domestic fossil fuels; (Cheng et al., 2012).	Acid rain; Smog; Damages buildings; Destroys vegetation growth. (Najjar, 2011).	40 µg/m^3
4	Nitrogen oxides as (NO_2)	Fuel combustion (gasoline, coal or oil); Automobile emissions. (Barone-Adesi et al., 2015)	Acid rain; Smog; Deleterious to the cell membrane of plants; Deplete soil fertility. (Chen et al., 2007).	80 µg/m^3
5	Sulphur dioxide (SO_2)	Mining and quarrying; Manufacturing of chemicals; Petroleum refineries; Metal industries; Power generation; Transportation; Community services; Industries;Brick kilns; Combustion of coal and oil. (Haider et al., 2017)	Haze; Formation of acid rain; Damages vegetative growth; Deteriorates surface water and soil by increasing acidification; Corrodes buildings and monuments.	120 µg/m^3
6	Ozone (O_3)	Secondary pollutant formed by chemical reaction of VOCs and NOx in the presence of sunlight. (Guo et al., 2019).	Smog; Damages rubber, fabric and other materials; Reduces plants growth and yield (Munzi et al., 2017).	130 µg/m^3

2.6 Air quality index (AQI)

AQI (Tiwari and Ali, 1987) is based on the concentration values using six key pollutants including Nitrogen Oxides as NO_2 and NO, O_3, $PM_{2.5}$, PM_{10} and SO_2 (Table 2) and calculated according to the following Equation:

$$AQI = NO_2+NO+O_3+PM_{2.5}+PM_{10}+SO_2/6$$

2.7 Data analysis

In order to determine the results, the geospatial technique (Javid et al., 2020) is adopted to analyze and compare the AQI (Chattopadhyay et al., 2010) using six key criteria pollutants. Moreover, the metrological factors were also evaluated by using the minimum, maximum and average criteria.

3. RESULTS AND DISCUSSION

3.1 Air quality index and metrology of Lahore in March 2019 and March 2020

In order to achieve objectives of the study, the AQI was encompassed and classified on six criteria pollutants to analyze the air pollution level during COVID-19 lockdown and compared with the period of March, 2019. Table 2 describes the PEQs level and the Figures 2 and 3 summarizes the results and supports the similar findings which were observed in India (Gautam, 2020). According to Table 2 and Figure 3, the concentration levels of air pollutants in the study area

were below the maximum permissible levels of PEQs in March, 2020, except the northwestern part of Lahore. Moreover, the overall air quality of other towns has also improved significantly during lockdown like other neighboring countries of Pakistan such as India (Mitra et al., 2020) and China (Xu et al., 2020).

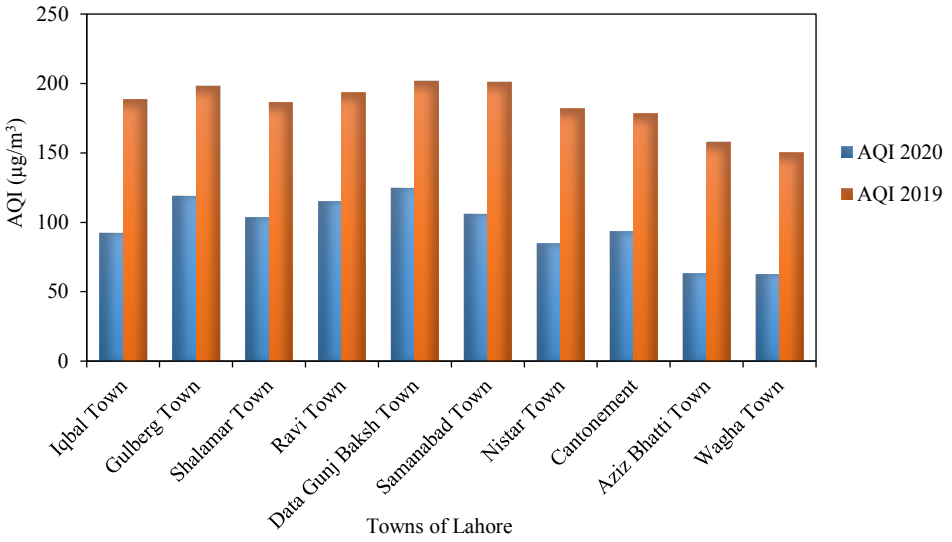

Figure 2. Air quality index level of Lahore in March 2019 and March 2020

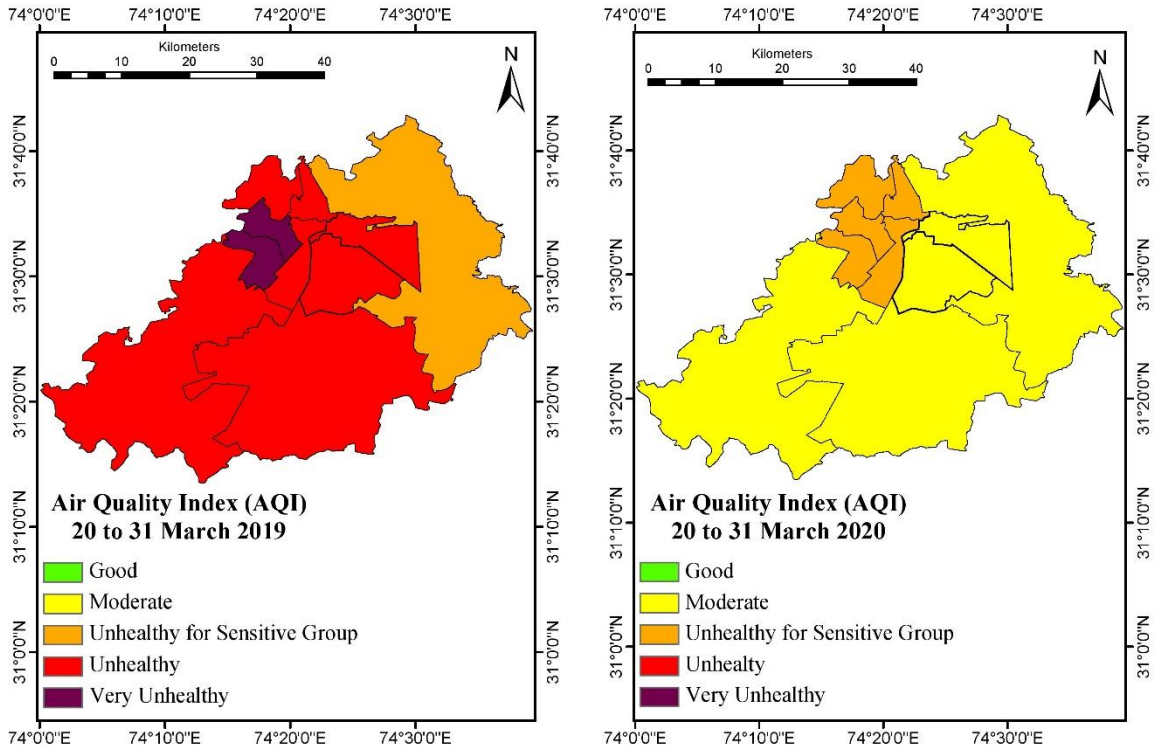

Figure 3. Air quality index of Lahore in March 2019 and March 2020
(The studies conducted by Kambalagere (2020), Ramasamy (2020), Isaifan (2020), Zambrano-Monserrate et al. (2020) supported the above results globally during COVID-19.)

On the other hand, rain showers reduced the concentration of air pollutants during the lockdown. So, the recorded 22ºC average temperature (Bao and Zhang, 2020) and the average rainfall (2.4 mm) had a strong influence on the state of air in March 2020 (Table 1).

Furthermore, analyzing the results (Figure 3), it is recorded that the air quality index has dropped from

188 to 92 in Iqbal Town (IT), 198 to 118 in Gulberg Town (GT), 186 to 103 in Shalamar Town (ST), 193 to 114 in Ravi Town (RT), 201 to 124 in Data Gunj Baksh Town (GBT), 200 to 105 in Samanabad Town (SBT), 181 to 84 in Nishtar Town (NT), 157 to 63 in Aziz Bhatti Town (ABT) and 194 to 62 in Wagha Town (WT) and 178.25 to 93.50 in Cantonment (Cantt) area. In contrast, the ground based measurements of air pollutants exhibited on the south-eastern and north-western side of Lahore experienced the highest concentrations of air pollution and did not meet PEQs in March 2019. Extraordinarily high concentrations of air pollution in these parts of Lahore are mainly due to the industrial estates, small and medium industrial units, vehicular fumes and burning trash.

3.2 NO_2 assessment in March 2019 and March 2020

Based upon the results of NO_2 level in March 2019 and 2020 (Figure 4) it was reflected that the highest trends of air pollutant in terms of NO_2 were found in Ravi Town (RT), Shalamar Town (ST), Data Gunj Baksh Town (DGBT) and Samanabad Town (SBT). This is attributed to the industrial and population density in all towns that have increased the levels of toxic air pollution. On the other side, during lockdown a huge demand of home delivery has suddenly increased for groceries, food, household and medical items which accelerates the NO_2 values. Furthermore, in crowded areas stay-at-home policy was not followed strictly. So, the high concentration of NO_2 can be attributed due to the non-seriousness of the people towards social distancing which is also reported in the study of Dantas et al. (2020). Similarly, another reason is the operational movement of heavy duty vehicles (HDV) used to transport food in the market during lockdown. Additionally, the combustion of fuels in industries may also have increased the trend of NO_2 as the towns of Lahore have big industrial network and diesel based vehicles are common in the city. Apart from that, the nitrogen in the air compresses at high temperature and reacts with oxygen in the combustion chambers of gasoline and diesel driven vehicles and emits NOx. That is why no significant drop in NO_2 emissions has been recorded and supports the similar results of a previous study (Goyal et al., 2006). Moreover, the previous study of Jafary and Faridi (2006) has also reported the highest concentration of NO_2 in one of the crowded towns of Lahore i.e., Samanabad. Moreover, the similar result of the present study is also reported during the lockdown period in the capital city of Iran (Bauwens et al., 2020). Additionally, considering the results of other towns the NO_2 values has declined during lockdown and presents the improvement in air quality. Therefore, in support of this result, several studies have been reported globally (Aloi et al., 2020; Bao and Zhang, 2020; Bashir et al., 2020; Kerimray et al., 2020; Kaplan and Avdan, 2020; İban, 2020).

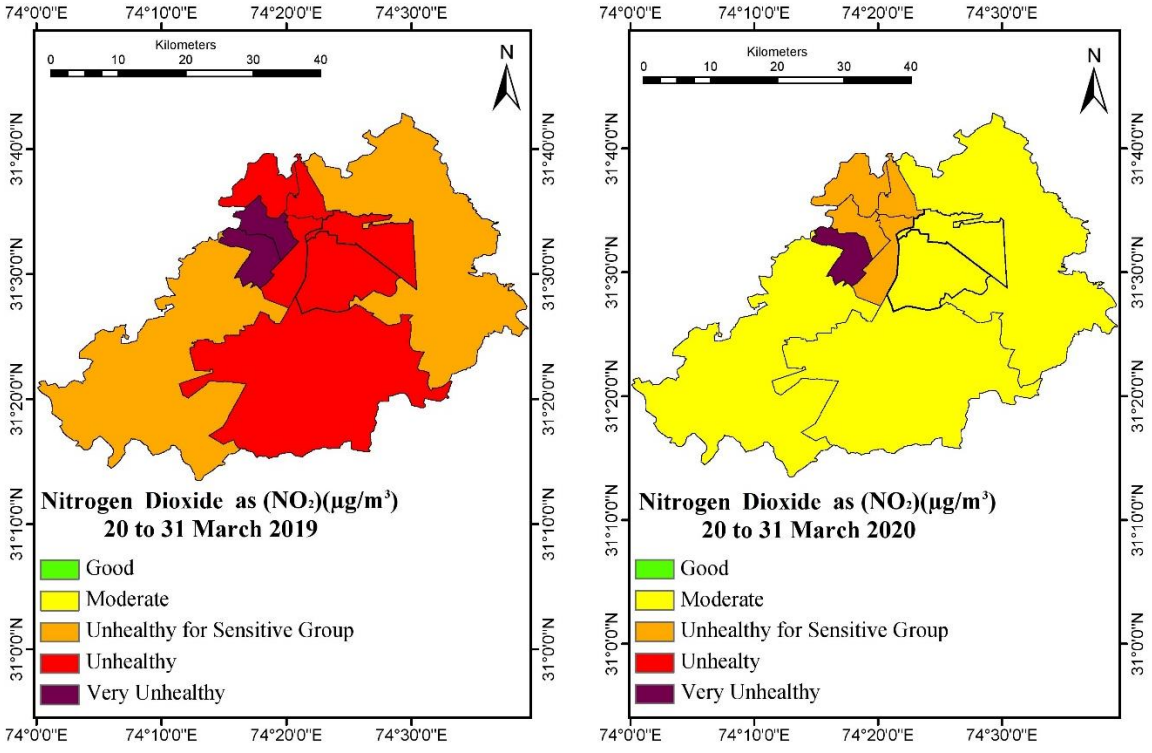

Figure 4. NO_2 level of Lahore in March 2019 and March 2020

3.3 NO assessment in March 2019 and March 2020

According to Figure 5, the air quality index classes have shown reduction in the NO level during March 2020 when the lockdown came into effect. Based on the results of Figure 5, the urban air quality of Lahore has exhibited good air quality index level in Nishtar Town (NT), Iqbal Town (IT), Samanabad Town (SBT). While in Wagha Town (WT), air quality index was recorded as moderate under and displayed similar trends as in 2019. Moreover, Gulberg Town (GT) showed an unhealthy air quality index which is one of the largest hubs of industrial estates of Lahore and located in the north-western part of the city. Further, the highest values of air quality index (hazardous) have been recorded in the Ravi and Data Gunj buksh Towns. Basically, the hazardous level of air quality index is associated with the burning of substandard fuel commercially. In addition, the Lahore's air pollutants are the compound results of industrial and vehicular emissions with the inclusion of metrological elements (Table 2). So, the concentration level of NO is relatively unhealthy for sensitive group in 2019 and supports the similar findings of earlier study (Gorai et al., 2015). However, the overall results indicate that air quality index has improved in few towns of Lahore due to the closure of anthropogenic activities.

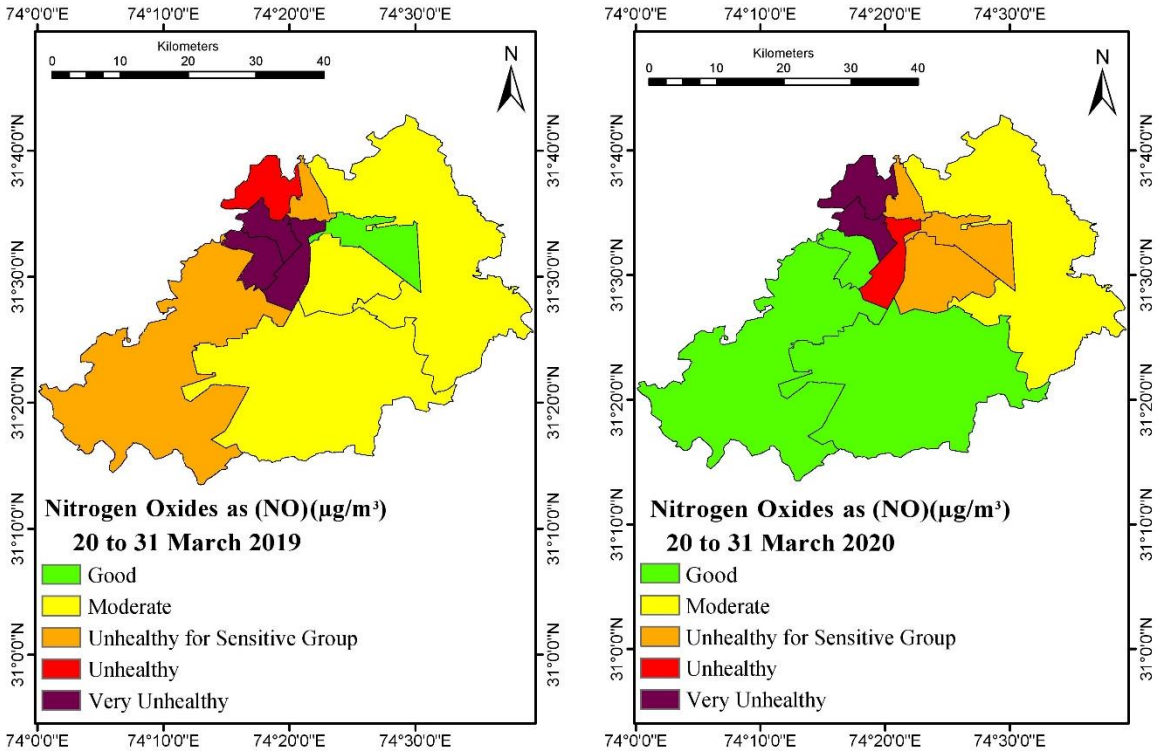

Figure 5. NO level of Lahore in March 2019 and March 2020

3.4 O_3 assessment in March 2019 and March 2020

Figure 6 exhibits the mean concentration level of O_3 in Lahore in March 2019 and the lockdown period of March 2020. In comparison with the results of 2019, the overall situation in terms of O_3 in 2020 was recorded at unhealthy to hazardous levels. Basically, a rise in O_3 usually occurs when the NO level decreases (Quan et al., 2014). In the present case of COVID-19 lockdown, the O_3 mean concentration level rose compared to 2019, which supports the findings of the study conducted by Dantas et al. (2020). Thus, in the current lockdown, the highest concentration of O_3 (unhealthy) was recorded in Iqbal Town (IT) and Shalamar Town (ST). Moreover, the hazardous level of ozone has been recorded in Gulberg Town (GT), Samanabad Town (SBT) and Data Gunj Buksh Town (DBT). Thus analyzing Figure 5, the lower NO concentration helped to increase the concentration of O_3 and supported the results of the study conducted in Italy during lockdown (Collivignarelli et al., 2020).

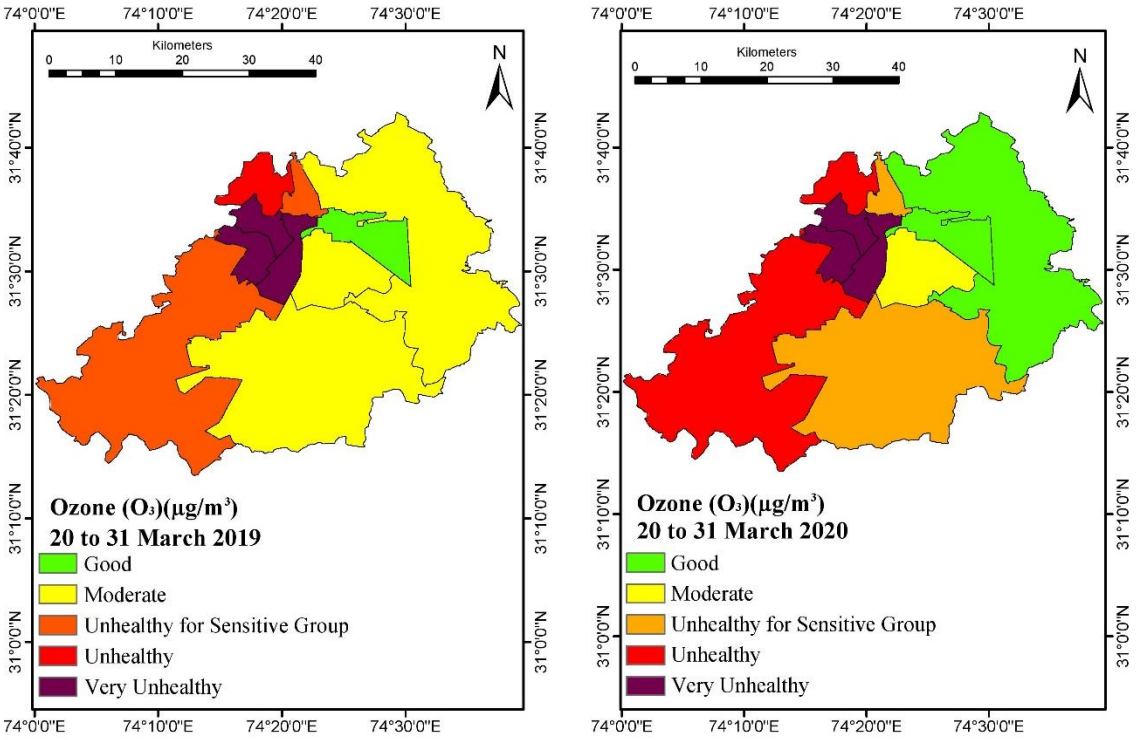

Figure 6. O_3 level of Lahore in March 2019 and 2020

3.5 $PM_{2.5}$ assessment in March 2019 and March 2020

According to Figure 7, $PM_{2.5}$ mean concentration level has dropped from unhealthy to moderate level during lockdown as compared to the last year data. Further, it is evident from results that eight out of nine towns have a moderate range of $PM_{2.5}$. This is because the main social and economic restrictions were enforced during the lockdown period. Similarly, not only the noticeable fall of $PM_{2.5}$ concentration was witnessed in Lahore, but also recorded in the several cities of India during the precautionary measures of COVID-19 (Sharma et al., 2020). Further, the results of Figure 7 also state that $PM_{2.5}$ concentration is inconsistent all over the Lahore in 2019 due to the operational sources of air pollutants such as commercial, industrial and transportation. On the other side, metrological variables of 2019 were also the leading cause to elevate the concentration of air pollution which is documented in the study of EEA (2020). Hence, the significant reduction in $PM_{2.5}$ encourages and motivates us to mitigate unnecessary social activities to avoid the havoc of air pollution and get a chance to breathe in the clean air.

3.6 PM_{10} assessment in March 2019 and March 2020

PM_{10} is well documented for the disastrous health effects on urban dwellers. In addition, with the combination of coronavirus, the pollutant became adverse for human life in metropolitan cities. Similarly, Lahore is the leading city of Pakistan which experiences the worst air pollution level and also choked in pandemic. But the adopted control measures of COVID-19 have improved the air quality of Lahore within a short period. Conversely from $PM_{2.5}$, notable reduction was recorded in PM_{10} during lockdown period (Figure 8). Moreover, the similar results of PM_{10} reduction are also reported in the current study conducted in Delhi, India during lockdown (Mahato et al., 2020). Nevertheless, the basic reasons behind the moderate tendency of PM_{10} levels are the closure of construction sites, economic and social activities during the pandemic. Closing these dominant sources of air pollutants in towns such as Lahore improved the AQI, i.e., good to moderate. In addition, another study of Otmani et al. (2020) also reported the similar results in the wake of lockdown. Overall, after comparison with 2019, it is exhibited that the moderate level of PM_{10} is measured throughout the study period which is also attributed with the metrological conditions. Thus, the minimal level of PM_{10} is clear evidence that Lahore can achieve its emissions reduction targets by adopting concrete measures to avoid air borne diseases.

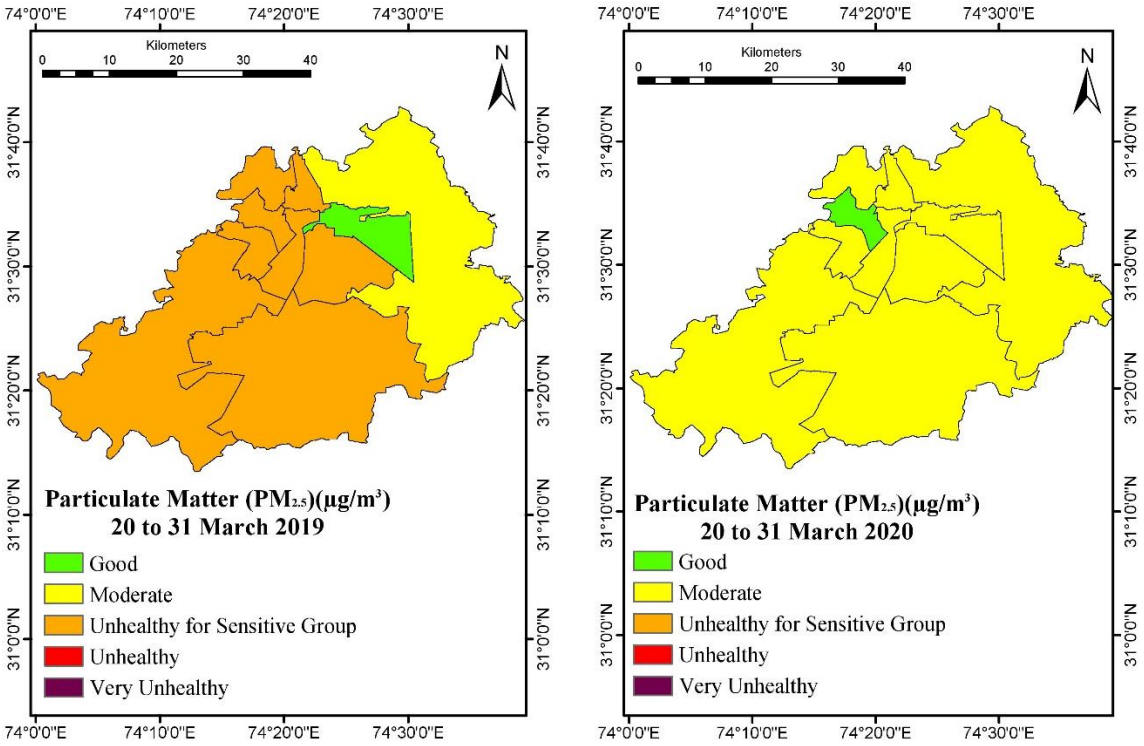

Figure 7. $PM_{2.5}$ level of Lahore in March 2019 and 2020

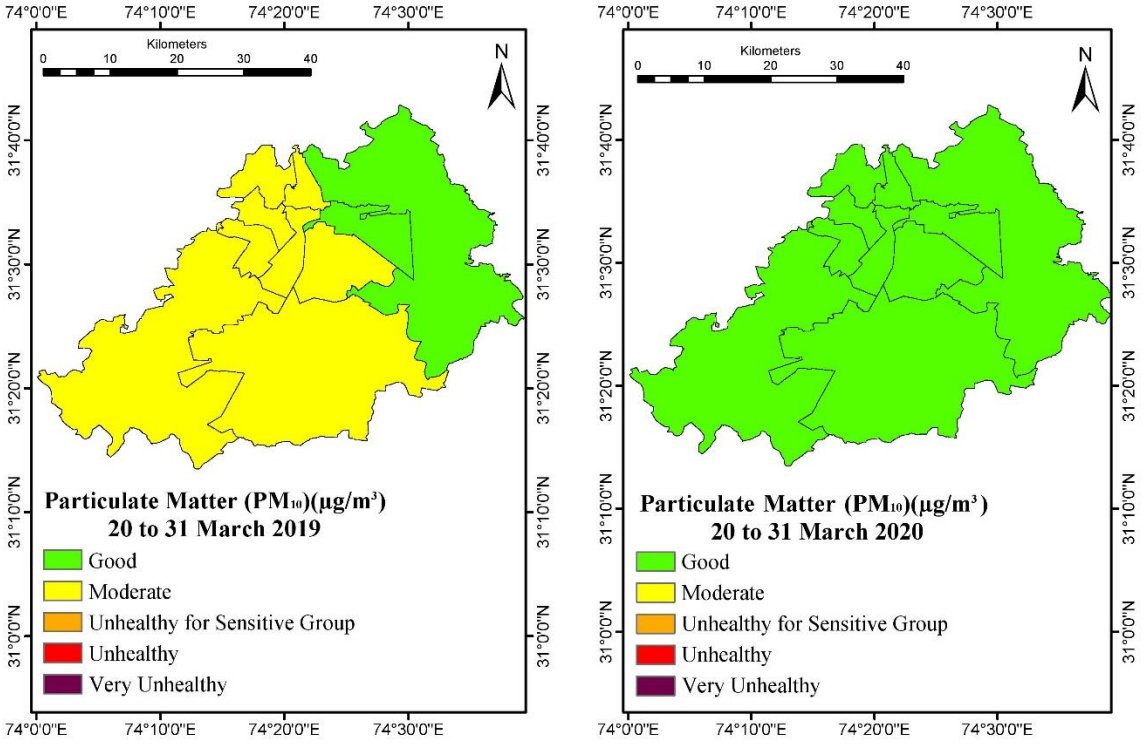

Figure 8. PM_{10} Level of Lahore in March 2019 and March 2020

3.7 SO_2 assessment in March 2019 and March 2020

SO_2 is one of the leading pollutants that are infamous for smog and their presence in the air is highly poisonous for the respiratory system of humans. Notably, since 2016 Lahore is experiencing its worst episode of smog during October to February. During February, when the city was facing the havoc of smog, the fatal pandemic broke out. In this regard, the adopted contingency measures to overcome pandemic has altered the concentration level of air pollutants and resulted in a significant reduction of SO_2 range in Lahore. Thus, according to the present

findings (Figure 9), the concentration level of SO_2 is recorded under the maximum prescribed limit of PEQs. This may be attributed to major SO_2 emitting industries being non-functional during the pandemic lockdown. Besides, the metrological aspect in terms of scattered rains has also improved the quality of air in a short span of time (Table 1). So, the overall air quality index in all towns of Lahore is remarkably visible under the category of 'Good'. Further, comparing results with 2019, the SO_2 levels were also under the permissible level of Punjab's ambient air quality standards and categorized in good to moderate in all towns. But in 2020, the AQI range of SO_2 is improved and associated with the suspension of industrial activities (Otmani et al., 2020) and attributed with the frequent rainfall which cleaned the air during coronavirus lockdown (Kapil, 2020).

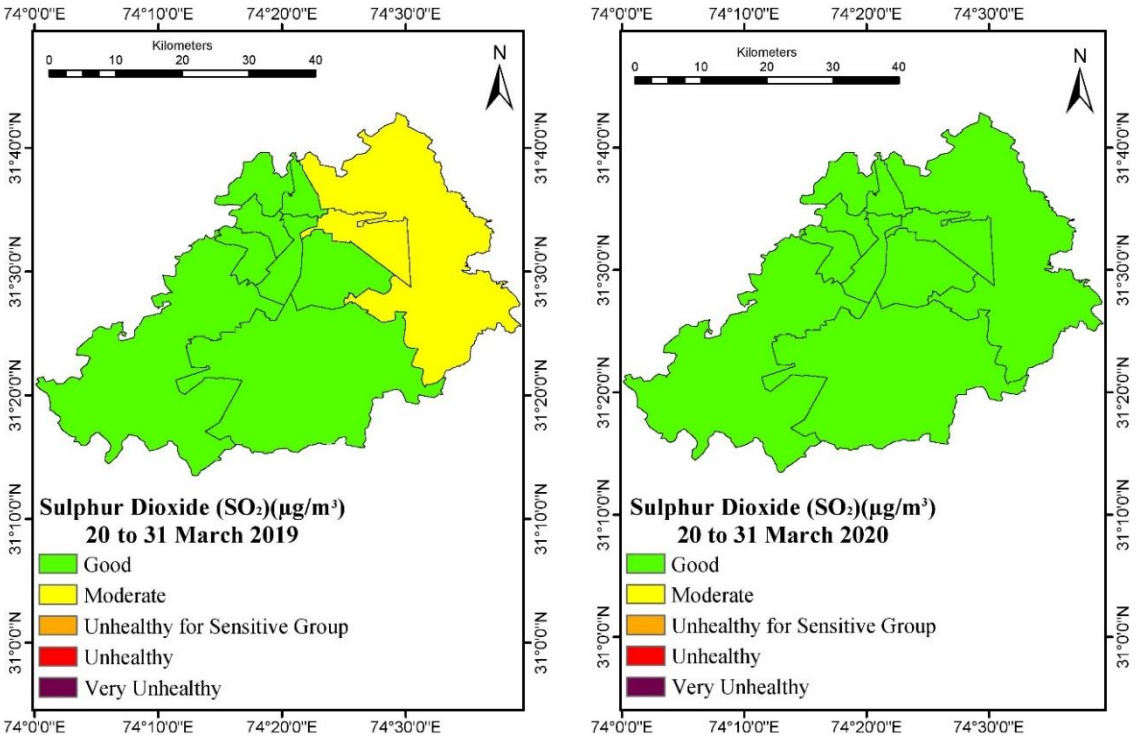

Figure 9. SO_2 level in March 2019 and 2020

4. CONCLUSION

The findings of the present study infer that quarantine and metrological factors strongly influence the air quality. Thus, the cohesive situation of the pandemic lockdown combining with the weather influence has benefitted the air by lowering the magnitude of NO, PM_{10}, $PM_{2.5}$ and SO_2 in the study area. Although the diffusion of air pollutants is diminishing for a short span of time due to control measures of COVID-19, this practice cannot be carried out on a long term basis when the pandemic will be over. Therefore, the regulatory authorities should take necessary measures to reconsider the existing mechanism and redevelop strategies to combat deteriorated air. Moreover for the time being, the air quality can be maintained using the same steps which are initiated during lockdown such as to promote remote working, expand online dealings, and discourage unnecessary travelling. Moreover, the new technologies should be introduced in the industrial sector like zig zag technology in the brick kiln industry to overcome the air pollution level.

REFERENCES

Abas N, Saleem MS, Kalair E, Khan N. Cooperative control of regional transboundary air pollutants. Environmental Systems Research 2019;8(1):10.

Alam K, us Sahar N, Iqbal Y. Aerosol characteristics and radiative forcing during pre-monsoon and post-monsoon seasons in an urban environment. Aerosol and Air Quality Research 2013;14(1):99-107.

Ali M, Athar M. Air pollution due to traffic, air quality monitoring along three sections of National Highway N-5, Pakistan. Environmental Monitoring and Assessment 2008;136(1-3):219-26.

Ali G, Bao Y, Ullah W, Ullah S, Guan Q, Liu X, et al. Spatiotemporal trends of aerosols over urban regions in Pakistan and their possible links to meteorological parameters. Atmosphere 2020;11(3):306.

Aloi A, Alonso B, Benavente J, Cordera R, Echániz E, González F, et al. Effects of the COVID-19 Lockdown on urban mobility: Empirical evidence from the city of Santander (Spain). Sustainability 2020;12(9):3870.

Ahmad T, Khan M, Khan FM, Hui J. Are we ready for the new fatal Coronavirus: scenario of Pakistan? Human Vaccines and Immunotherapeutics 2020;16(3):736-38.

Akhtar MM, Zhonghua T, Sissou Z, Mohamadi B. Assess arsenic distribution in groundwater applying GIS in capital of Punjab, Pakistan. Natural Hazards and Earth System Sciences Discussions 2015;3(3):2119-47.

Ashraf A, Butt A, Khalid I, Alam RU, Ahmad SR. Smog analysis and its effect on reported ocular surface diseases: A case study of 2016 smog event of Lahore. Atmospheric Environment 2019;198:257-64.

Aziz A, Bajwa IU. Minimizing human health effects of urban air pollution through quantification and control of motor vehicular carbon monoxide (CO) in Lahore. Environmental Monitoring and Assessment 2007;135(1-3):459-64.

Aziz A, Ahmad I, Mayo SM, Hameed R, Nadeem O. Urbanization and its impacts on founded areas of big cities in Pakistan: Case studies of "Ichra" and "Sanda" areas in Lahore. University of Engineering and Technology Taxila Technical Journal 2015;20(1):71-75.

Badshah SL, Ullah A, Badshah SH, Ahmad I. Spread of novel coronavirus by returning pilgrims from Iran to Pakistan. Journal of Travel Medicine 2020;27(3):1-3.

Bao R, Zhang A. Does lockdown reduce air pollution? Evidence from 44 cities in northern China. Science of the Total Environment 2020;29:139052.

Bashir MF, Bilal BM, Komal B. Correlation between environmental pollution indicators and COVID-19 pandemic: A brief study in Californian context. Environmental Research 2020;13:109652.

Barone-Adesi F, Dent JE, Dajnak D, Beevers S, Anderson HR, Kelly FJ, et al. Long-term exposure to primary traffic pollutants and lung function in children: Cross-sectional study and meta-analysis. PloS One 2015;10(11):1-16.

Batool SA, Ch MN. Municipal solid waste management in Lahore city district, Pakistan. Waste Management 2009;29(6):1971-81.

Bauwens M, Compernolle S, Stavrakou T, Müller JF, van Gent J, Eskes H, et al. Impact of coronavirus outbreak on NO_2 pollution assessed using TROPOMI and OMI observations. Geophysical Research Letters 2020;3:1-9.

Camargo JA, Alonso Á. Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. Environment International 2006;32(6):831-49.

Chattopadhyay S, Gupta S, Saha RN. Spatial and temporal variation of urban air quality: A GIS approach. Journal of Environmental Protection 2010;27;1(03):264-77.

Chauhan A, Singh RP. Decline in $PM_{2.5}$ concentrations over major cities around the world associated with COVID-19. Environmental Research 2020:187;109634.

Chen TM, Kuschner WG, Gokhale J, Shofer S. Outdoor air pollution: Nitrogen dioxide, sulfur dioxide, and carbon monoxide health effects. American Journal of the Medical Sciences 2007;333(4):249-56.

Cheng M, Jiang H, Guo Z. Evaluation of long-term tropospheric NO_2 columns and the effect of different ecosystem in Yangtze River Delta. Procedia Environmental Sciences 2012;13: 1045-56.

Colbeck I, Nasir ZA, Ahmad S, Ali Z. Exposure to PM_{10}, $PM_{2.5}$, PM_1 and carbon monoxide on roads in Lahore, Pakistan. Aerosol and Air Quality Research 2011;11:689-95.

Colbeck I, Sidra S, Ali Z, Ahmed S, Nasir ZA. Spatial and temporal variations in indoor air quality in Lahore, Pakistan. International Journal of Environmental Science and Technology 2019;16(6):2565-72.

Collivignarelli MC, Abbà A, Bertanza G, Pedrazzani R, Ricciardi P, Miino MC. Lockdown for COVID-2019 in Milan: What are the effects on air quality? Science of the Total Environment 2020;732:139280.

Dantas G, Siciliano B, França BB, da Silva CM, Arbilla G. The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil. Science of the Total Environment 2020;729:139085.

European Environment Agency (EEA). Air quality and COVID-19 [Internet]. 2020. [cited 2020 April 11]. Available from: https://www.eea.europa.eu/themes/air/air-quality-and-covid19 /air-quality-and-covid19.

Elder M, Olsen SH. The design of environmental priorities in the SDGs. Global Policy 2019;10:70-82.

Environment Protection Department (EPD). Air quality monitoring; Government of the Punjab, Pakistan [Internet]. 2020a [cited 2020 March 20]. Available from: https://epd.punjab.gov.pk/air_quality.

Environment Protection Department (EPD). Rules and regulations; Government of the Punjab, Pakistan [Internet]. 2020b [cited 2020 March 20]. Available from: https://epd.punjab.gov.pk/rules_regulations.

Gatto M, Bertuzzo E, Mari L, Miccoli S, Carraro L, Casagrandi R, et al. Spread and dynamics of the COVID-19 epidemic in Italy: Effects of emergency containment measures. Proceedings of the National Academy of Sciences 2020;117(19):10484-91.

Gautam S. The influence of COVID-19 on air quality in India: A boon or inutile. Bulletin of Environmental Contamination and Toxicology 2020;11:1-3.

Ghaffar A. Use of geospatial techniques in monitoring urban expansion and land use change analysis: A case of Lahore, Pakistan. Journal of Basic and Applied Sciences 2015;11: 265-73.

Gorai AK, Tuluri F, Tchounwou PB, Ambinakudige S. Influence of local meteorology and NO_2 conditions on ground-level ozone concentrations in the eastern part of Texas, USA. Air Quality, Atmosphere and Health 2015;8(1):81-96.

Goyal SK, Ghatge SV, Nema PS, Tamhane SM. Understanding urban vehicular pollution problem vis-a-vis ambient air quality-case study of a megacity (Delhi, India). Environmental Monitoring and Assessment 2006;119(1-3):557-69.

Guo H, Gu X, Ma G, Shi S, Wang W, Zuo X, et al. Spatial and temporal variations of air quality and six air pollutants in China during 2015-2017. Scientific Reports 2019;9(1):1-11.

Gupta P, Khan MN, da Silva A, Patadia F. MODIS aerosol optical depth observations over urban areas in Pakistan: Quantity and quality of the data for air quality monitoring. Atmospheric Pollution Research 2013;4(1):43-52.

Haider R, Yasar A, Tabinda AB. Urban emission patterns at a semi-arid site in Lahore, Pakistan. Polish Journal of Environmental Studies 2017;26(1):59-68.

İban MC. Geospatial data science response to COVID-19 crisis and pandemic isolation tracking. Turkish Journal of Geosciences 2020;1(1):1-7.

Ilyas SZ. A review of transport and urban air pollution in Pakistan. Journal of Applied Sciences and Environmental Management 2007;11(2):113-21.

Isaifan RJ. The dramatic impact of Coronavirus outbreak on air quality: Has it saved as much as it has killed so far? Global Journal of Environmental Science and Management 2020; 6(3):275-88.

Jan B, Iqbal M. Urbanization trend and urban population projections of Pakistan using weighted approach. Sarhad Journal of Agriculture 2008;24(1):173-80.

Jafary ZA, Faridi IA. Air pollution by roadside dust and automobile exhaust at busy road-crossings of Lahore. Pakistan Journal of Physiology 2006;2(2):20-3.

Javid K, Akram MA, Ranjha MM, Pervaiz S. GIS-based assessment of aridity over Punjab Province, Pakistan, by using climatic indices. Arabian Journal of Geosciences 2020; 13(7):1-12.

Kambalagere Y. A study on air quality index (AQI) of Bengaluru, Karnataka during lockdown period to combat coronavirus disease (Covid-19): Air quality turns 'better' from 'hazardous'. Studies in Indian Place Names 2020;40(69):59-66.

Kapil S. 78% cities recorded 'good', 'satisfactory' AQI during COVID-19 lockdown: CPCB [Internet]. 2020 [cited 2020 April 22]. Available from: https://www.downtoearth.org.in /news/air/78-cities-recorded-good-satisfactory-aqi-during-covid-19-lockdown-cpcb-70621.

Kaplan G, Avdan ZY. COVID-19: Spaceborne nitrogen dioxide over Turkey. Eskişehir Technical University Journal of Science and Technology A-Applied Sciences and Engineering 2020;21(2):251-5.

Kerimray A, Baimatova N, Ibragimova OP, Bukenov B, Kenessov B, Plotitsyn P, et al. Assessing air quality changes in large cities during COVID-19 lockdowns: The impacts of traffic-free urban conditions in Almaty, Kazakhstan. Science of the Total Environment 2020:730;139179.

Kinney PL. Climate change, air quality, and human health. American Journal of Preventive Medicine 2008;35(5):459-67.

Liaqat H, Waheed A, Malik NA, Vohra IA. Measuring urban sustainability through compact city approach: A case study of Lahore. Journal of Sustainable Development Studies 2017; 10(2):61-81.

Lodhi A, Ghauri B, Khan MR, Rahman S, Shafique S. Particulate matter ($PM_{2.5}$) concentration and source apportionment in Lahore. Journal of the Brazilian Chemical Society 2009; 20(10):1811-20.

Mabahwi NA, Leh OL, Omar D. Human health and wellbeing: Human health effect of air pollution. Procedia-Social and Behavioral Sciences 2014;153:221-9.

Mahato S, Pal S, Ghosh KG. Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. Science of the Total Environment 2020:730;139086.

Malashock D, Khwaja HA, Fatmi Z, Siddique A, Lu Y, Lin S, Carpenter D. Short-term association between black carbon exposure and cardiovascular diseases in Pakistan's largest megacity. Atmosphere 2018;9(11):420.

Mansha M, Ghauri B, Rahman S, Amman A. Characterization and source apportionment of ambient air particulate matter ($PM_{2.5}$) in Karachi. Science of the Total Environment 2012;425: 176-83.

Mellouki A, George C, Chai F, Mu Y, Chen J, Li H. Sources, chemistry, impacts and regulations of complex air pollution: Preface. Journal of Environmental Science (China) 2016; 40:1-2.

Mitra A, Ray Chadhuri T, Mitra A, Pramanick P, Zaman S. Impact of COVID-19 related shutdown on atmospheric carbon dioxide level in the city of Kolkata. Parana Journal of Science and Education 2020;6(3):84-92.

Munzi S, Ochoa-Hueso R, Gerosa G, Marzuoli R. (E)merging directions on air pollution and climate change research in Mediterranean Basin ecosystems. Environmental Science and Pollution Research 2017;24(34):26155-9.

Najjar YS. Gaseous pollutants formation and their harmful effects on health and environment. Innovative Energy Policies 2011;1:1-9.

Nawaz A, Shahbaz MA, Javed M. Management of organic content in municipal solid waste: A case study of Lahore. International Journal of Environment and Waste Management 2015; 15(1):15-23.

Ogen Y. Assessing nitrogen dioxide (NO_2) levels as a contributing factor to the coronavirus (COVID-19) fatality rate. Science of the Total Environment 2020;726:138605.

Otmani A, Benchrif A, Tahri M, Bounakhla M, El Bouch M, Krombi MH. Impact of Covid-19 lockdown on PM_{10}, SO_2 and NO_2 concentrations in Salé City (Morocco). Science of the Total Environment 2020;735:139541.

Pakistan Bureau of Statistics. Provisional summary results of 6th population and housing census 2017. Islamabad [Internet]. 2017 [cited 2020 March 22]. Available from http://www.pbscensus.gov.pk/.

Pakistan Today. Pakistan among 12 worst countries in environmental pollution: EPI report [Internet]. 2020 [cited 2020 March 28]. Available from: https://www.pakistantoday.com.pk/2018/01/24/pakistan-among-12-worst-countries-in-environmental-pollution-epi-report/.

Pervaiz S, Javid K, Khan FZ, Talib B, Siddiqui R, Ranjha MM, Akram MA. Spatial analysis of vegetation cover in urban green space under new government agenda of clean and green Pakistan to tackle climate change. Journal of Ecological Engineering 2019;20(4):245-55.

Quan J, Tie X, Zhang Q, Liu Q, Li X, Gao Y, et al. Characteristics of heavy aerosol pollution during the 2012-2013 winter in Beijing, China. Atmospheric Environment 2014;88:83-9.

Raja S, Biswas KF, Husain L, Hopke PK. Source apportionment of the atmospheric aerosol in Lahore, Pakistan. Water, Air, and Soil Pollution. 2010;208(1-4):43-57.

Ramasamy D. Enchanted improvements in air quality across India: A study from COVID-19 lockdown perspective. Adalya Journal 2020;9(5):101-25.

Rana IA, Bhatti SS. Lahore, Pakistan-Urbanization challenges and opportunities. Cities 2018;72(1):348-55.

Rasheed A, Aneja VP, Aiyyer A, Rafique U. Measurement and analysis of fine particulate matter ($PM_{2.5}$) in urban areas of Pakistan. Aerosol and Air Quality Research 2015;15(2):426-39.

Rehman SA, Cai Y, Siyal ZA, Mirjat NH, Fazal R, Kashif SU. Cleaner and sustainable energy production in Pakistan: Lessons learnt from the Pak-Times model. Energies 2019; 13(1):1-21.

Riaz O. Impact of Population Growth on Urban Expansion in Lahore, 1951-1998 [dissertation]. University of the Punjab; Lahore, Pakistan: 2010.

Sabir S, Anjum GA. Problems and prospects of curbside parking in Lahore: Policy implications for effective management.

Mehran University Research Journal of Engineering and Technology 2017;4:867-80.

Sadiq N, Qureshi MS. Climatic variability and linear trend models for the five major cities of Pakistan. Journal of Geography and Geology 2010;2(1):83-92.

Saqlain M, Munir MM, Ahmed A, Tahir AH, Kamran S. Is Pakistan prepared to tackle the coronavirus epidemic? Drugsand Therapy Perspectives 2020;36:213-4.

Shahid MA, Ahmad N, Hussain K, Naseem S. Compound phase analysis of solid aerosols collected from different locations of Faisalabad and Lahore (Pakistan) using matrix-flushing method. Peak Journal of Physical and Environmental Science Research 2013;1:54-65.

Sharma S, Zhang M, Gao J, Zhang H, Kota SH. Effect of restricted emissions during COVID-19 on air quality in India. Science of the Total Environment 2020;728:138878.

Shirwani R, Gulzar S, Asim M, Umair M, Al-Rashid MA. Control of vehicular emission using innovative energy solutions comprising of hydrogen for transportation sector in Pakistan: A case study of Lahore City. International Journal of Hydrogen Energy 2019;45(32):16287-97.

Sidra S, Ali Z, Nasir ZA, Colbeck I. Seasonal variation of fine particulate matter in residential micro-environments of Lahore, Pakistan. Atmospheric Pollution Research 2015; 6(5):797-804.

Singh A, Agrawal M. Acid rain and its ecological consequences. Journal of Environmental Biology 2007;29(1):15-24.

Stone E, Schauer J, Quraishi TA, Mahmood A. Chemical characterization and source apportionment of fine and coarse particulate matter in Lahore, Pakistan. Atmospheric Environment 2010;44(8):1062-70.

Tariq S, Ali M. Satellite and ground-based remote sensing of aerosols during intense haze event of October 2013 over Lahore, Pakistan. Asia-Pacific Journal of Atmospheric Sciences 2016;52(1):25-33.

Tiwari TN, Ali M. Air quality index for Calcutta and its monthly variation for various localities. Indian Journal of Environmental Protection 1987;7:172-6.

Wang P, Chen K, Zhu S, Wang P, Zhang H. Severe air pollution events not avoided by reduced anthropogenic activities during COVID-19 outbreak. Resources, Conservation and Recycling 2020;158:104814.

Waris A, Khan AU, Ali M, Ali A, Baset A. COVID-19 outbreak: Current scenario of Pakistan. New Microbes and New Infections 2020;35:100681.

Xu K, Cui K, Young LH, Wang YF, Hsieh YK, Wan S, et al. Air quality index, indicatory air pollutants and impact of COVID-19 event on the air quality near central China. Aerosol and Air Quality Research 2020;20:1204-21.

Yen MC, Peng CM, Chen TC, Chen CS, Lin NH, Tzeng RY, et al. Climate and weather characteristics in association with the active fires in northern Southeast Asia and spring air pollution in Taiwan during 2010 7-SEAS/Dongsha Experiment. Atmospheric Environment 2013;78:35-50.

Zambrano-Monserrate MA, Ruano MA, Sanchez-Alcalde L. Indirect effects of COVID-19 on the environment. Science of the Total Environment 2020;728:138813.

Zha S, Zhang S, Cheng T, Chen J, Huang G, Li X, et al. Agricultural fires and their potential impacts on regional air quality over China. Aerosol and Air Quality Research 2013;13(3):992-1001.