Biological and Clinical Sciences Research Journal
ISSN: 2708-2261
www.bcsrj.com
DOI: https://doi.org/10.54112/bcsrj.v2022i1.122
*Biol. Clin. Sci. Res. J., Volume, **2022**: 122*
Original Research Article

DEVELOPMENT OF AIR QUALITY AND BRICK KILNS DURING THE ONSET OF COVID-19: AN ANALYSIS

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(Received, 17th August 2021, Revised 5th September 2022, Published 10th September 2022)

Abstract: *Coronavirus and air pollution, having a positive correlation, are in auspiciously the greatest challenge of the millennium. Therefore, the study presented the initial outcomes from the analysis of the COVID-19 impact on (1) air quality and, (2) informal sector i.e. old technology brick kiln industry. In order to evaluate the progress, the spatial analysis was carried out, comprising aerosol optical depth, sulfur dioxide, carbon monoxide, carbon dioxide and ozone with the inclusion of metrological element i.e. rainfall and environmental index (NDVI). The results of the spatial data indicated that the air quality of Punjab improved with the lockdown policy. However, improvements vary across the districts and were absent in a few districts where no strict lockdown policy was observed. During lock-down, fluctuation in rainfall and decrease in NDVI, which had no positive impact in reducing the pollutants concentration in the atmosphere, was observed. The spatial correlation results presented that the pandemic lock-down helped in the reduction of the extent of air pollution. In addition, in the COVID-19 anthropause, Government of the Punjab initiated a stringent action to ban outdated brick kilns causing air pollution. Resultant, conversion of old technology brick kilns into Zig-Zag Technology is a remarkable step to mitigate smog.*

Keywords: COVID-19, air, NDVI, Punjab smog, IDZZK

Introduction

Globally, governments imposed lockdowns to mitigate the spread of the SARS-COV2 coronavirus (Samani *et al.*, 2021). Likewise, in March 2020 (Yasmeen and Sohail, 2020) all human (Ramasamy, 2020) and economic activities were suspended in Punjab to seize control over the deadly virus (Saeed *et al.*, 2021). The air pollution (Sterpetti, 2020), metrological condition, low wind speed and high relative humidity have been reported to accentuate the spread of the virus (Coccia 2020). The world-wide lockdown policy not only avoided the risk of COVID-19 (Kotnala *et al.*, 2020) but also improved the urban environment by lowering GHGs emissions (Rume &Islam, 2020). Lockdown also improved the river water quality (Dutta *et al.*, 2020), increased vegetation cover (Saxena *et al.*, 2021), conserved biodiversity (Bang and Khadakkar, 2020) and strengthened the marine ecosystem (Soto *et al.*, 2021). Unfortunately, the smog crisis was on peak prior to lockdown when the first coronavirus case was reported in the province. Due to the smog season, the outdated brick kilns in Punjab were under conversion to the zig-zag technology. Hence, with reference to the present scenario of coronavirus which has strong link with air pollution (Barouki *et al.*, 2021), measures were implemented in Punjab. In order to limit the air emission caused by traditional brick kilns, strict enforcement was initiated against the informal brick industry (Bajracharya *et al.*, 2021) emits noxious air pollutants which are strongly associated with the intense use of cheap, substandard (Nasir *et al.*, 2021) fuels which are listed in Table 1.

Various initiatives are in practice in order to curb air pollution under Paris Agreement (Khan *et al.*, 2021) and Section 11, 14 and 16 of Punjab Environmental Protection Act, 1997 amended 2012. Whereas, the Government of Punjab issued a notification on 15th October, 2020 for the conversion of the traditional brick kilns into the induced draught zig-zag technology.

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Table 1: Air pollution causing fuel used in old technology brick kilns

Fuel	Emission
Coal	Particulate matter ($PM_{10,\ 2.5}$), carbon dioxide (CO_2), carbon monoxide (CO), sulphur dioxide (SO_2), volatile organic compound (VOC) (Alam *et al.*, 2018) and polycyclic aromatic hydrocarbons (Kamal *et al.*, 2014;Saikia *et al.*,2016).
Firewood	($PM_{10,\ 2.5}$), oxides of nitrogen (NOx), methane (CH_4) CO, N_2O, CO_2, SO_2 (Darain *et al.*, 2016).
Wood shavings	($PM_{10,\ 2.5}$), CO, VOC, SO_2, NOx, and ammonia (NH_3) (Sanjel *et al.*, 2016).
Rice husk and sawdust	($PM_{10,\ 2.5}$), CO, VOC and NOx (Sanjel *et al.*, 2016).
Cow and chicken manure	NH_3, CH_4, dioxin and furans (Sanjel *et al.*, 2016).
Waste plastic	Nitrous oxide (N_2O), CO_2, CH_4, total organic carbon (TOC), VOC, dioxin and furans (Sanjel *et al.*, 2016).
Waste leather	($PM_{10,\ 2.5}$), CO, CO_2, VOC, SO_2, heavy metals, hexavalent chromium (Sanjel *et al.*, 2016).
Old tires	Heavy metals, CO_2, CO, NOx, PM_{10}, VOC, SO_2 (Sanjel *et al.*, 2016).

Considering the situation above, to evaluate the urban environment and informal brick sector progress from pre-to-post lockdown, the objectives of the present study are: (1) to evaluate and map aerosol optical depth (AOD), sulfur dioxide (SO_2), carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3), rainfall and NDVI factors(2) to examine the spatial correlation among rainfall and NDVI on air quality and (3) to discuss Government of Punjab initiative towards induced draught zig-zag brick kilns in Punjab. The findings of the current study will help to generate baseline information of the air quality and zig-zag brick kilns that can be utilized to formula teproactive measures to curb the air pollution causing practices.

Methodology

Site description

Figure 1 describes the study area *i.e.* Punjab (Province) (David *et al.*, 2020). Geographically, Punjabis located between 31.17° North to 72.71° East (Khaliq *et al.*, 2021) having 205, 344 km^2 area (Samie *et al.*, 2017) and comprises of thirty six districts (Javid *et al.*, 2019). It shares border with India (Saqib *et al.*, 2017) and fertile by five rivers (Dilshad & Muhammad, 2020) namely Chenab, Indus, Jhelum, Sutlej and Ravi. Simultaneously, grassland, forest and cropland are the dominant land use categories (Samie *et al.*, 2017) existing in Punjab. Climatologically, it lies in an arid to semi-arid zone (Ahmed *et al.*, 2018). Therefore, such climatic parameters as temperature and precipitation vary from north to south. It receives more than 50 percent of rainfall during monsoon season (Yasin *et al.*, 2018). The agrarian (Irfan *et al.*, 2015) province isirrigated (Samie *et al.*, 2017) by a great canal system, which is a dominant practice to produce wheat and rice crops.

Punjab is categorized into small, medium and large scale industries (Pervaiz, 2016). It is the largest hub of the informal sector *i.e.* brick industry of Pakistan consisting of about 10,000 units (Hussain *et al.*, 2021). Due to ever-increasing smog and air pollution generated from the clusters of old brick kilns, its districts are amongst the most polluted cities in the world. In Punjab, bricks are produced throughout the year but the most favorable season of brick business starts from May. Brick manufacturers prefer the brick kilns using old technology due to low investment using cheap fuel (Table 1) and high profit margins. The use of substandard firing techniques in old and retardant brick baking escalates the 'smog' issue in the winter season.

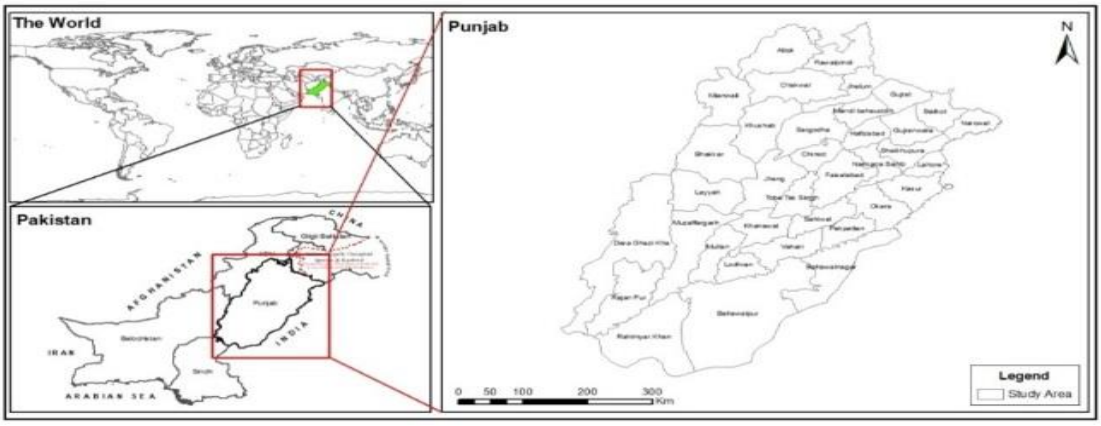

Figure 1. Map of the study site

Data and methods

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Field monitoring is a challenge for developing countries where traditional brick kilns are responsible for air pollution. Therefore, remote sensing (Kaur & Rani, 2016), which is a cost effective approach, is used to generate information.

Data used

Normalized difference vegetation Index

NDVI is the most popular and important index (Guha & Govil, 2021) used to analyze the vegetative information. The following equation 1 was computed by Pervaiz *et al.*, (2019).

NDVI = (NIR – RED) / (NIR + RED)
(Equation 1)

Where NDVI +1 index values signify a vegetative zone to bare land and -1 index values denote a non-vegetative area (Pervaiz *et al.*, 2018).

Metrological data

Punjab Metrological Department (PMD) provided the metrological parameter data *i.e.* rainfall of February, April and October, 2020 to evaluate the air quality.

Satellite data

Aerosol Optical Depth, Sulfur dioxide Surface Mass Concentration kgm^{-3}, Net Ecosystem Carbon dioxide Exchange (NEE), Carbon Monoxide Emission $kgm^{-2}s^{-1}$and Total Column Ozone Dobsons (TO_3) (Filonchyk *et al.*, 2020) were extracted using remote sensing tools *i.e.* Modern-Era Retrospective Research and Applications (Yousefi *et al.*, 2020), Version 2 (MERRA-2) and National Aeronautics and Space Administration (NASA) (Keller *et al.*, 2021) to estimate the concentration of variables before, during and after COVID-19.The complete description of the remote sensed data is listed in Table 2.

Table 2: Description of the satellite sata for analysis

Data Set Name	Resolution (km)	Time
AOD	0.5 x 0.625	February, April & October 2020
SO_2 Surface Mass Concentration kgm^{-3}	0.5 x 0.625	-do-
Net Ecosystem CO_2 Exchange (NEE)	9 x 9	-do-
CO Emission $kgm^{-2}s^{-1}$	0.5 x 0.625	-do-
Total Column Ozone Dobsons (TO_3)	0.5 x 0.625	-do-

Geographic Information System (GIS)

In order to analyze the data, the geographical information system, ArcGIS (Oji & Adamu, 2021) version 10.5 was employed to map the results. Figure 2 provides the detailed description of steps followed for data analysis:

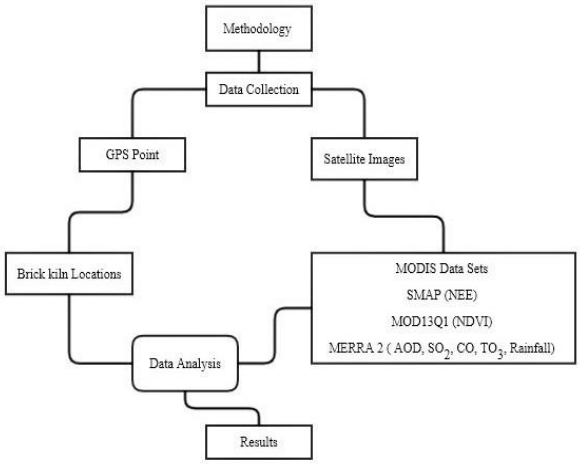

Figure 2: Schematic flowchart of methodology

Results and discussion

Pre to post lockdown assessment of aerosol optical depth

The results of Figure 3 demonstrated that the COVID-19 lockdown (Kumar *et al.*, 2020) helped to reduce the aerosol optical depth (AOD) (Sathe *et al.*, 2021) concentration into the atmosphere. The AOD concentration significantly decreased in Kasur, which used to be ranked first by having the largest number of brick kilns. Concurrently, the low magnitude of AOD has been visualized in the smog prone city 'Lahore' and showed a significant positive impact of lockdown that supported the results of the study conducted in India (Soni, 2021). The low concentration of AOD has also been observed in the northern part of Punjab and the highest value of AOD has been recorded in the southern part of Punjab. The highest values of AOD in the southern part of Punjab may be attributed to the multiple contributors of air pollution such as stubble or refuse burning, construction and industrial activities and vehicular pollution during the lockdown phase. The results of post-lock down period highlighted a rise in the AOD concentration in Mianwali and Bhakkar Districts and the lowest range was recorded in Dera Ghazi Khan. Comparing the results of pre-lockdown vs post-lockdown period, it can be clearly seen that the AOD level was high in most of the regions of Punjab in the pre-lockdown phase. However, the overall results of AOD havepresented the improved quality of air in Aprilduring the lockdown phase and similar findings have been reported in the study byKoo *et al.*, 2020.In turn, spatial correlation with NDVI (Figure 9) presented that the NDVI extent has been decreased during lockdown, which may be attributed to the harvesting season of wheat crop. Similarly, low values of rainfall during lockdown (Figure 8) in the northern region of the province show the negative correlation to decrease the concentration of AOD. In this perspective, lockdown benefited (Balasubramaniam *et al.*, 2020) the urban environment by improving the air quality.

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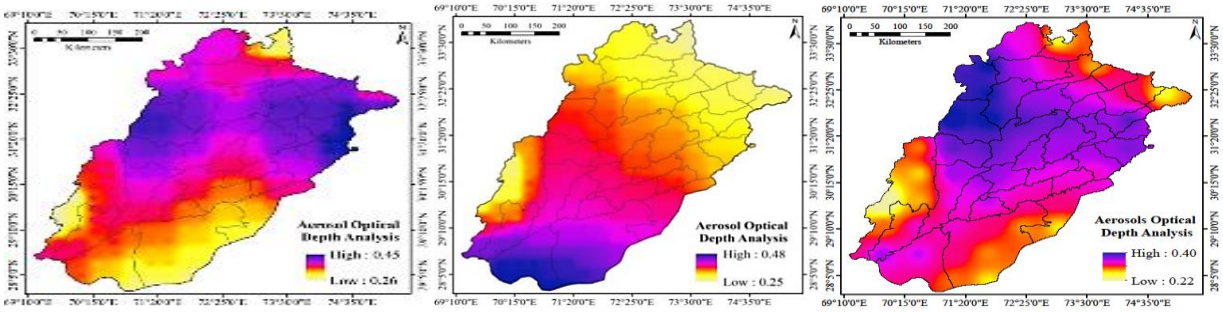

Figure 3: AOD level before, during and after lockdown

Pre to post lockdown assessment of sulfur dioxide

The pre- and post-lockdown phases showed high levels of SO_2 in the province. In turn, the concentration of the sulfur dioxide decreased during the lockdown period. The primary sources of the sulfur emissions are coal and diesel. The spatial results of the study depicted that the combustion of coal and diesel had been reduced during lockdown, as compared to before and after the lockdown period. While evaluating the results of Figure 4 (during lockdown), a noticeable decrease in the SO_2 level was visualized in most of the Punjab, except for the Muzzafargarh and Multan Districts. The reason of this high concentration of SO_2 in both these districts may be attributed to the industrialists who violated the lockdown policy, which supports the findings of the study conducted in Iran (Kumari and Toshniwal, 2020) and Morocco (Otmani *et al.*, 2020).The satellite based post-ockdown results showed that the SO_2 level grew up in most parts of the province and similar rise in $SO_2$was reported in Delhi, India after lockdown and supported the results of the study conducted by Khan (2021). By comparing the results of the pre-to-post lockdown phases, it is noticeable that the stoppage of economic and vehicular activities reduced the SO_2 level in most of the Punjab during lockdown. The rise in the SO_2 concentration is attributed to coal burning, power plants and industrial activities before and after lockdown that scale up when anthropogenic activities resume.

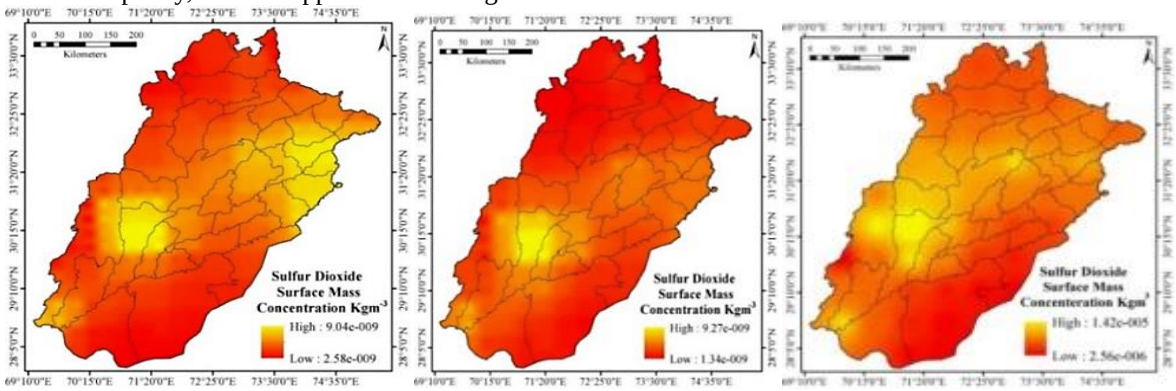

Figure 4: SO_2 level before, during and after lockdown

Pre-lockdown, the highest concentration of sulfur dioxide emission is visible in Lahore, Kasur, Shaikhupura and Nankana Sahib. In turn, in south-western Punjab, sharp rise in SO_2concentration was recorded in Muzafargarh and Multan. The comparison of spatial correlation of the SO_2 level with rainfall (Figure 8) and NDVI (Figure 9) depicts the negative association.

Pre- to post-lockdown assessment of carbon dioxide

Figure 5 demonstrates that the COVID-19 lockdown decreased the CO_2 concentration in the atmosphere. The noticeable decline of CO_2 has been visualized in most of the districts which support the findings of the studies reported by Mitra *et al.*, (2020). Before lockdown, a high rise in the CO_2 concentration was recorded in most of the province, which is attributed to multiple anthropogenic sources. The overall results revealed that the CO_2 reduction in atmosphere was short-lived during the lockdown phase, which elevated right after lockdown (Khan, 2020). The distribution map of CO_2, rainfall (Figure 8) and NDVI (Figure 9) presents low trends during the lockdown phase. Therefore, a reduction in the CO_2 concentration level has a negative correlation with rainfall and NDVI. Thus, a decrease of CO_2 during the shutdown phase shows a link with the COVID-19 lockdown. After lockdown, low extent of carbon dioxide in Lahore, Kasur and Narowal illustrates the implementation of the Government of Punjab orders to mitigate air pollution. When comparing results, it is suggested that reducing the CO_2 emissions requires stringent implementation at

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a provincial level for better air quality in all districts.

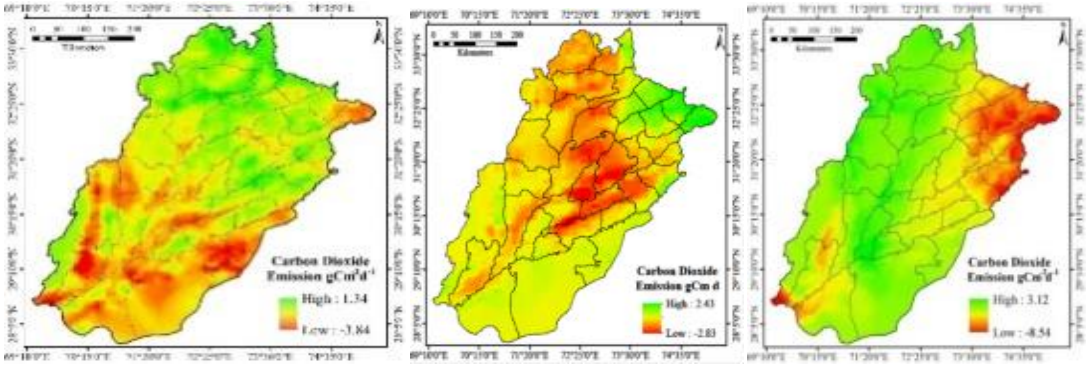

Figure 5: CO_2 level before, during and after lockdown

Pre to post lockdown assessment of carbon monoxide

CO (Raispour and Khosravi, 2020) is one of the emissions released from vehicles (Khuda, 2020) and incomplete combustion of fossil fuels (Ramasamy, 2020). Figure 6 presents the spatial results of CO over 36 districts of the Punjab. A comparison of the pre-lockdown and lockdown phase presents that the magnitude of CO pollution reduced to a noticeable level during the pandemic lockdown and support the findings of the research carried out in China and East Asia (Ghahremanloo *et al.,* 2021).In turn, high concentration of CO was visualized over Sheikhupura, Lahore, Kasur, Faisalabad, Nankana Sahib and Hafizabad irrespective of the lockdown, which could be linked with the essential activities which were not suspended during lockdown and support the results of the study conducted in Saudi Arabia (Anil and Alagha, 2021). The magnitude of CO was increased in Okara and Bahawalnagar as the Okara district is well-known for rice cultivation. Therefore, the rise in carbon monoxide after the pandemic lockdown may be attributed to rice stubble burning, whereas the low concentration level of CO is correlated with rainfall. In the current scenario vehicular emission may be the leading factor for the excess amount of CO in Lahore. In turn, low extent of rainfall (Figures 8 and 9) shows the negative spatial correlation as in most of the Punjab, the level of CO is persistent throughout the pandemic.

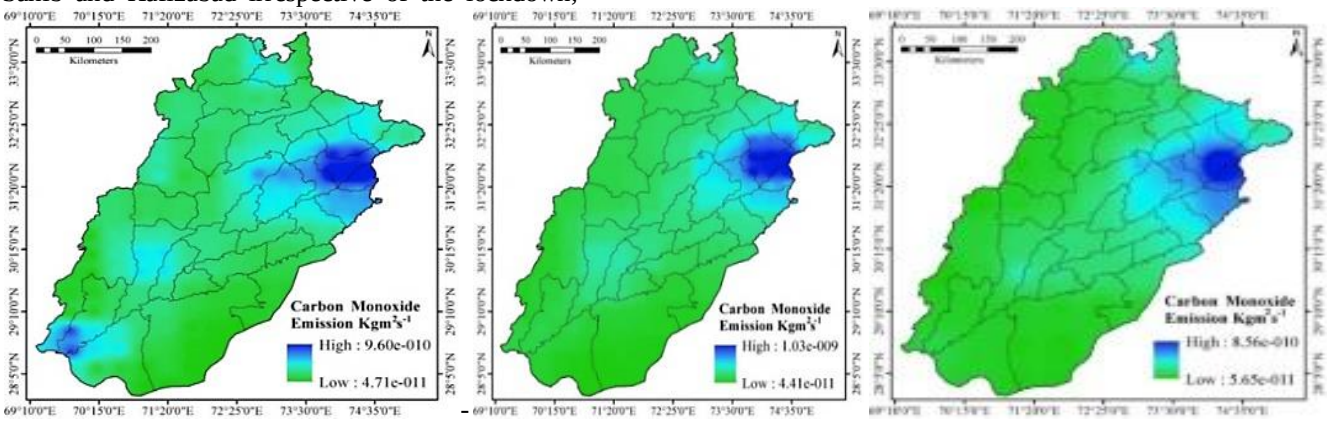

Figure 6: CO level before, during and after lockdown

Pre to post lockdown assessment of ozone

The analysis of Figure 7 indicates that highest concentration of O_3 is visible in northern Punjab and supports the results of the study conducted in China (Shi and Brasseur, 2020). The basic reason behind the ozone level elevation in Punjab is the reduction in the NO level reported in the recent studies of Zheng *et al.,* (2021) and Fan *et al.,* (2021) carried out in China during lockdown. The ozone level after lockdown exhibited that the concentration of ozone in northern and north-western Punjab remained unaffected and reported the similar findings in the recent study conducted by Allu *et al.,* (2021). The results of the pre-to-post lockdown show the fluctuation of the ozone level in most of the districts and high level has been visualized in the northern part of Punjab before and during lockdown. Further, the magnitude of ozone has also been shifted from north to north-western parts of the province after the lockdown period. The restoration of ozone level is obviously associated with the reduction in the NO concentration (Hashim *et al.,* 2021) and does not show association with rainfall and NDVI. Therefore,

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it is proposed to formulate short-term pollution control action plans to curb winter smog (Czerwińska and Wielgosiński 2020) from October to November.

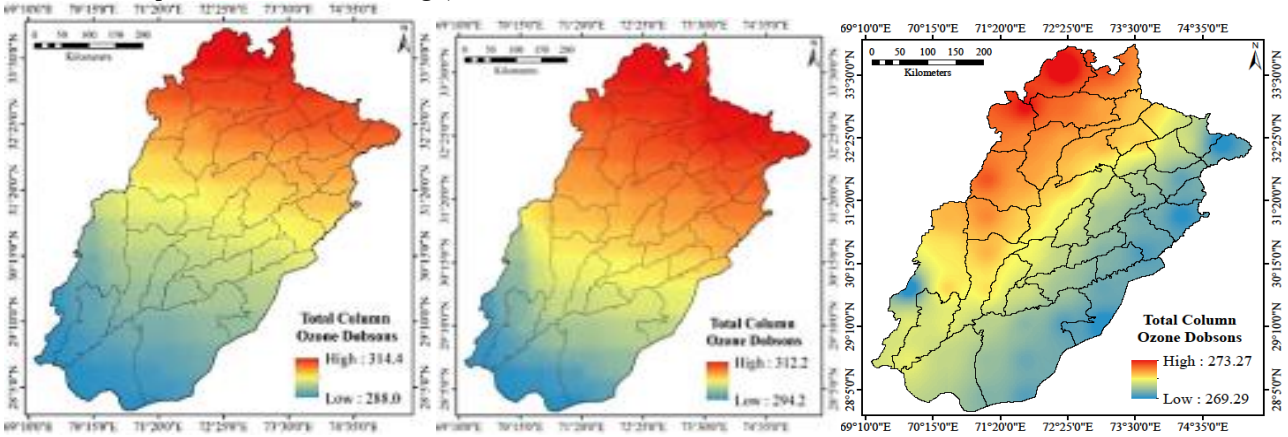

Figure 7: Ozone level before, during and after lockdown

Pre- to post-lockdown assessment of rainfall

The meteorological factor (Dhaka *et al.,* 2020) such as wind plays an imperative role in the transport of air pollutants (Radzka, 2020) whereas rainfall (Panda *et al.,* 2021) reduces the air pollutants level (Fu*et al.,* 2020). During the lockdown in China, the rainfall has been reported to decrease the pollution level (Xin *et al.,* 2021). However, in the case of Punjab, no significant drop was observed in the level of environmental pollution (Figures8). The post-lockdown spatial results demonstrated the distribution of rainfall received in Attock, Mianwali, Chakwal and Khushab districts but no dilution in air pollutants concentration was visualized in these parts too. The study by Han *et al.,* (2014) reported that once the air pollution level is increased, the rate of subsiding of pollutants becomes relatively slow after rainfall. Therefore, the findings obtained by Han *et al.,* (2014) support the findings of the present research during and after the COVID-19 lockdown. Hence, better air quality is associated with pandemic lockdown (Bahukhandi *et al.,* 2020) that has a negative correlation with rainfall and NDVI.

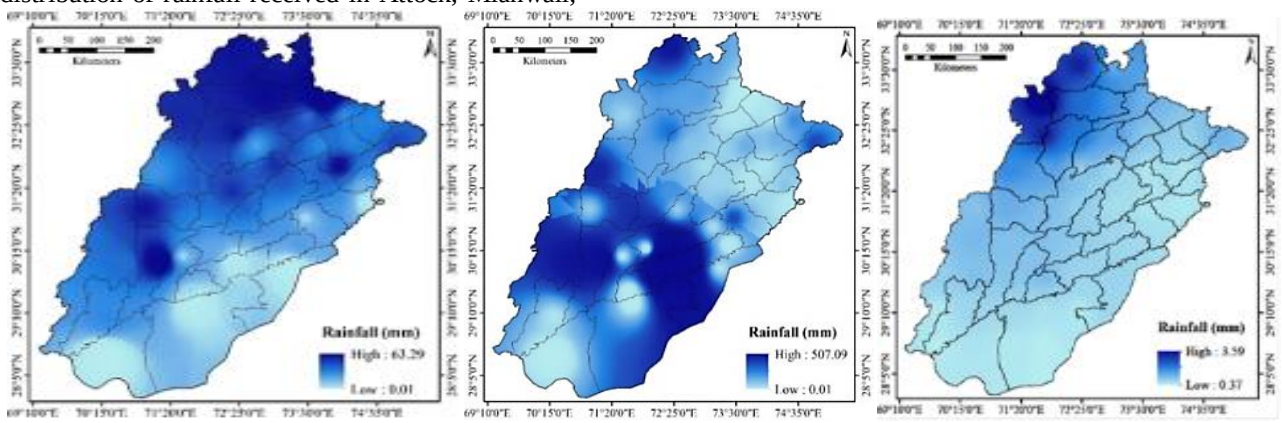

Figure 8: Rainfall trend before, during and after lockdown

Pre- to post-lockdown assessment of normalized difference vegetation index

High vegetation cover is known to supply good air. The district wise NDVI(El Garouani *et al.,* 2021) exhibits a positive trend in vegetation cover prior to lockdown, which is Rabi crop season (Figure 9). During lockdown in April 2020, the NDVI level plummeted which may be attributed to the ripening and harvesting period of wheat crop (Jethva *et al.,* 2019) and show the contrary results of NDVI that were obtained in India during lockdown (Saxena *et al.,* 2021). The post-lockdown spatial results show the positive trend of NDVI at a significant level due to two factors (i) monsoon season, and (ii) cultivation of Kharif crop. In contrast, the lowest values of NDVI can be clearly seen in Southern Punjab before, during and after lockdown that may be attributed to aridity and seasonal variation *i.e.* hotter days. Despite harvesting, the wheat stubble was also burnt down for sowing of next crop (Kaur and Rani, 2016). In the winter season, the air pollutants dispersion level decreases due to temperature inversion and the stubble burning produces smog.

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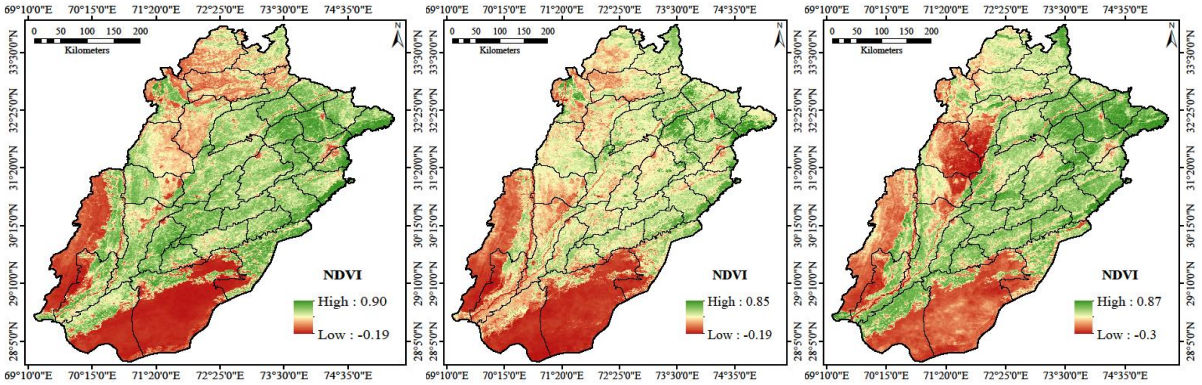

Figure 9: NDVI level before, during and after lockdown

Induced draught zig-zag brick kilns

Out of 20,000 brick kilns (Hussain *et al.,* 2021), 10,347 (PBC, 2016) are located in Punjabin or around the province as reported in the Punjab Clean Air Action Plan. Moreover, 87, 134 laborers are linked with informal brick industries (Ercelawn and Nauman 2004). The largest infrastructure of brick kilns are established in Kasur, Multan and Faisalabad (PBC, 2016). Whereas, Bahawalpur, Khanewal, Vehari, Toba Tek Singh, Sargodha and Muzafargarh are other six prominent districts of brick kiln industry. The zig-zag technology has been reported to decrease 60% of particulate emission (Figure10) and reduce coal consumption by 40-50% (Bajracharya *et al.*,, 2021) as compared to traditional brick kilns and helpful in smog reduction. In addition, bricks obtained through zigzag brick kilns (ZZBK) technology produce better quality of bricks (ICIMOD, 2021). Thus, by keeping in view of the environmental and financial benefits of ZZBK, the Government of Punjab imposed a complete ban on the old technology brick kilns during COVID-19.

Figure 10: Old technology brick kilns vs induced draught zig-zag brick kilns in Punjab
Source: The Punjab Clean Air Action Plan 2017

So, analyzing the results of Figure 3, it was inferred that the AOD trend went down during the lockdown in Kasur, where a very large number of brick kilns are located. On the other side, the AOD extent in Faisalabad and Multan was high during the pandemic lockdown. The SO_2 (Figure 4) and CO (Figure 6) levels did not drop where the lockdown restriction was not taken seriously. The analysis of ozone results (Figure 7) indicated deteriorated air during lockdown in all over Punjab where brick kilns occur in high number. On the basis of the results shown in above Figures 3 to 7, it was revealed that COVID-19 convert the old brick kilns into eco-friendly zig-zag technology which exerts a significant influence on future air quality.

Conclusion

The present spatial study was carried out to examine the COVID-19 effects on air quality and NDVI of Punjab, Pakistan. Punjab has been in the limelight of the air pollution concerns originating from the old technology of brick kilns since 2017. The results of the present study indicated that all districts of Punjab have huge clusters of brick units which are one of the major environmental sources of air pollution and smog. The findings of the present study systematically provide the view of air quality which substantially improved after the execution of the lock-down policy in Punjab. The analysis of the results indicated that the concentration level of air pollutants such as aerosol particles, sulfur dioxide

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and carbon dioxide fluctuated before, during and after lockdown phases, while the carbon monoxide level was found persistent in Lahore and Sheikhupura before, during and after lockdown and the reason may be attributed to the fact that strict lockdown policy was not adopted in particular districts. Hence, the findings of the study showed that the concentration of pollutants surged up after lockdown. In addition, the NDVI level and rainfall concentration decreased during the lockdown period. Hence, spatial correlation clearly stated that neither NDVI nor rainfall helped to decrease the magnitude of air pollutants. Thus, its credit for cleaning the foul air goes directly to pandemic lockdown. Parallel to this, the robust clean air initiative was taken by the Government of Punjab on 15th October, 2020 to convert the traditional brick kilns into induced draught zig-zag brick kilns (IDZZK). Consequently, after the COVID-19 lockdown, the outdated brick kilns have been replaced with the zig-zag technology. In nutshell, the findings of the present study provide a systematic insight to identify the problematic zones in terms of air pollution. This study also demonstrated that the remote sensing technique can be employed where no routine surveillance mechanism exists for regular monitoring to obtain up to date information regarding air quality, extent of green cover and brick kilns emissions etc.

Conflict of Interest

Authors declare that they have no conflict of interest.

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