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COVID-19 persuaded lockdown impact on local environmental restoration in Pakistan

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Abstract Coronavirus disease 2019 (COVID-19) pandemic adversely affected human beings. The novel coronavirus has claimed millions of lives all over the globe. Most countries around the world, including Pakistan, restricted people's social activities and ordered strict lockdowns throughout the country, to control the fatality of the novel coronavirus. The persuaded lockdown impact on the local environment was estimated. In the present study, we assessed air quality changes in four cities of Pakistan, namely Islamabad, Karachi, Lahore, and Peshawar, based on particulate matter ($PM_{2.5}$), using "Temtop Airing 1000," which is capable of detecting and quantifying $PM_{2.5}$. The Air Quality Index (AQI) was evaluated in three specific time spans: the COVID-19 pandemic pre- and post-lockdown period (January 1, 2020 to March 20, 2020, and May 16, 2020 to June 30, 2020 respectively), and the COVID-19 pandemic period (March 21 2020 to May 15, 2020). We compared land-monitored AQI levels for the above three periods of time. For validation, air quality was navigated by the Moderate Resolution Imaging Spectrometer (MODIS) satellite during the first semester (January 1 to June 30) of 2019 and 2020. It is seen that the concentration of $PM_{2.5}$ was considerably reduced in 2020 (more than 50%), ranging from ~ 0.05 to 0.3 kg·m^3, compared to the same period in 2019. The results revealed that the AQI was considerably reduced during the lockdown period. This finding is a very promising as the inhabitants of the planet Earth can be guaranteed the possibility of a green environment in the future.

Keywords $PM_{2.5}$ · AQI · MERRA-2 · Navigation · Land sensor · Pandemic

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Introduction

The World Health Organization (WHO) declared the COVID-19 outbreak as a sixth Public Health Emergency of International Concern (PHEIC) on January 30, 2020 (Ohannessian et al., 2020). This was the continuation of previous coronavirus outbreaks, which included the Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV) and the Middle East Respiratory Syndrome Coronavirus (MERS-CoV) (Zhou et al., 2020). The COVID-19 was perceived as the third pandemic, which affected more than 200 countries, including Pakistan. Additionally, the pandemic catastrophe had an impact on global energy markets. However, this allowed policymakers to consider and propose new and promising renewable energy sources for the future (Hoang et al., 2021a; Hoang et al., 2021b).

On December 12, 2019, the first case of COVID-19 was detected in the city of Wuhan, China (Sahin et al., 2020). Then, within a couple of months, it spread all around the world (Waris et al., 2020). Around 830 cases were recorded on January 24, 2020, in nine countries: China, Japan, Singapore, Thailand, South Korea, Nepal, Vietnam, the USA, and Taiwan (Hadi et al., 2020). Pakistan, which is a neighboring country to China, met the virus on February 26, 2020 (Ali et al., 2020). The Government sealed the borders, banned national and international air travel, and restricted local transportation of the masses to assess the future effects of COVID-19, for a period of 2 months (March 20, to May 15, 2020). Small facilities, however, such as hospitals and food shops, remained open to the public.

As a consequence of these restrictions, the daily Air Quality Index (AQI) of pollution fell to a moderate level (Albayati et al., 2021). Most cities of the country were observed with a reduced concentration of $PM_{2.5}$ (i.e., the atmospheric particulate matter (PM), which has a diameter of less than 2.5 µm), due to the zero-emission factor of industries, vehicles, airplanes, and other machinery run on fossil fuels (WAQIN, 2020). Meanwhile, a survey report on some cities in the USA, India, UAE, Italy, and China, confirmed a mild index of $PM_{2.5}$ owing to the restrictions imposed by the local authorities (Chauhan & Singh, 2020).

Globally, a significant reduction in NO_2, CO_2, and PM emission was reported during the COVID-19 pandemic lockdown period (January to April 2020), as compared to the same period of 2019 (Hoang et al., 2021a; Hoang et al., 2021b; Hoang et al., 2021c; Le et al., 2020; Nguyen et al., 2021).

Across the USA, a significant reduction of $PM_{2.5}$ has been recorded during the lockdown period (March 15, April 25, 2020) (Chen et al., 2020). In Scotland, during the COVID-19 outbreak lockdown period (March 24, April 23, 2020), AQI was significantly reduced (Dobson & Semple, 2020).

For three cities in central China (Wuhan, Jingmen, and Enshi), Xu et al. (2020a, 2020b) recorded a 30.1% reduction in $PM_{2.5}$ concentration during the pandemic period (Xu et al., 2020b). In India, during the COVID-19 outbreak lockdown period, $PM_{2.5}$ was markedly reduced (Sharma et al., 2020). Ghaziabad is one of the most polluted cities of India, a total reduction of 85.1% in $PM_{2.5}$ concentration has been reported during the lockdown period (March 25, May 31, 2020) (Lokhandwala & Gautam, 2020); more specifically, in the week between March 20 and March 27, 2020, the AQI of $PM_{2.5}$ dropped from 168 to 82 points (Davidson, 2020).

In March 2020, most cities of the country (Pakistan) had a reduced concentration of $PM_{2.5}$. According to the World Air Quality Index (WAQI), the AQI level of the major cities of Pakistan, namely Islamabad, Karachi, Lahore, and Peshawar, dropped from 142 to 85, 146 to 104, 234 to 123, and 167 to 109, respectively. In Islamabad, the lowest level (85 points) of $PM_{2.5}$ was recorded in March 2020 (WAQIN, 2020), attributed to the travel limits imposed by the local authority on public transportation.

In Pakistan, a variety of sources in urban areas release pollutants that provide precursors for $PM_{2.5}$ and hence, inhibit the capability of meeting the PM standard. Coal-based power stations (Dallas Morning News, 2015) and vehicular and industrial emissions (Government of Pakistan, 2012) are typical origins of $PM_{2.5}$. The addition of two-stroke and diesel-run engines has increased the pollution index of the atmosphere (WHO, 2006a; World Bank, 2006). Diesel and furnace oil contain 0.5–1% and 1–3.5% sulfur, respectively, which emit sulfur dioxide and particulate matter into the atmosphere (WHO, 2006a).

The minimum pollution reflects the lower health damage. Epidemiological studies conducted by various researchers in several regions and different environments for various age groups have verified a strong relation among $PM_{2.5}$, and minor restricted activity days (MRADs), respiratory-related restricted activity days (RRADs), hospital admissions, outdoor patient appointments for respiratory and cardiac outcomes, mortality, heart failure, chronic bronchitis, and asthma (Zanobetti et al., 2009). Particulate matter with an aerodynamic diameter of ≤ 2.5 μm causes adverse effects on health, such as premature death rate, cardiac, and pulmonary diseases (McMurry et al., 2004; Pope III et al., 2002; Pope III et al., 2009; Silva et al., 2013). In 1 year, the population pays approximately US$ 482 million for air pollution, along with the death toll reported at 28,000 and the 40 million lung cancer patients (World Bank, 2006).

It has long been a challenge for environmental experts to measure $PM_{2.5}$ globally, using land sensors and monitors. Many land monitors have been installed in America and Europe. On the contrary, air quality has not been thoroughly evaluated in Africa, Asia, Central America, and South America. As a result, there is little amount of environmental data to be analyzed from these regions. Nonetheless, the modern satellite system provides potential solutions, by gathering information of global projection from the fossil fuel emission, and by other data related to dust particles in the ambient environment.

In 2010, a team from Dalhousie University reported on a successful estimation of $PM_{2.5}$ concentration between 2001 and 2006, by two sensors, the Moderate Resolution Imaging Spectroradiometer (MODIS) and Multiangle Imaging Spectroradiometer (MISR) and an additional model of Goddard Earth Observing System (GEOS-Chem) (Van Donkelaar et al., 2010). Using these models, environmental scientists approximated global fine particulates concentration between 1998 and 2014 (Van Donkelaar et al., 2016).

The present study reports on the air quality of pollutants from $PM_{2.5}$ in Pakistan during the lockdown period, in comparison with normal days, using the "Temtop 1000" particle detector. Auxiliary data from MODIS-NASA were used for validation. The ultimate aim of this work is to reveal the potential for restoring an ambient environment to its former purified state, provided that environmental policies will be applied in the future.

Experimental methodology

Study area

Four cities in Pakistan were selected on account of their geographical importance, namely Islamabad (ISL), being the capital of the country, Karachi (KHI), Lahore (LHE), and Peshawar (PEW), which are provincial capitals (the code names of the four stations are seen in the parentheses).

Study period

The ambient atmosphere was monitored at the above four nominated stations for a period of six months, between January 1, 2020 and June 30, 2020. The specific type of $PM_{2.5}$ of the pollutant was pursued in these stations. To arrest the maximum number of particulates, we chose the peak hours and the most densely populated areas for the selected stations. The peak hours were between 08:00 in the morning and 06:00 in the evening, when circulation, industrial activities, schooling, and public transportation are in full swing. The average concentration of the pollutant $PM_{2.5}$ was measured in micrograms per cubic meter. The time-series concentration of $PM_{2.5}$ was recorded at each station. Considering the international standards of units, all the concentration levels were converted to the US-EPA AQI standard.

Temtop Airing-1000

The $PM_{2.5}$ concentration levels were measured using a lightweight, portable and cost-effective "Temtop Airing 1000" particle detector with a measurement range of 0–999 $\mu g \cdot m^{-3}$ and a resolution of 0.1 $\mu g \cdot m^{-3}$. The instrument detects $PM_{2.5}$ and displays its time-series concentration. Four sets of sensors were used simultaneously to monitor the concentration of $PM_{2.5}$ at the locations of the selected stations.

MODIS

The Global Modeling and Assimilation Office (GMAO), working under the authority of the National Aeronautics and Space Administration (NASA), abandoned the old version of the Modern-Era Retrospective Analysis for Research and Applications (MERRA-1), which was superseded (MERRA-2). MERRA-1 was functional until the end of 2015, and MERRA-2 was launched and has been employed since March 2016 (NASA GMAO, 2020). It replaced the previous re-analysis with the same resolution and products (Gelaro et al., 2017). For aerosol product assimilation, MERRA-2 takes Aerosol Optical Depth (AOD) at 550 nm as an input. The MODIS onboard

NASA's Aqua and Terra satellites collect AOD for MERRA-2 (Randles et al., 2017). The source, transportation, sinking, and concentration factors of dust (DU), sea salt (SS), black carbon (BC), sulfate (SO_4), and organic carbon (OC), are simulated independently, by different models, such as the GEOS and the Goddard Global Ozone Chemistry Aerosol Radiation and Transport (GOCART). The AOD at 550 nm constitutes an integrated optical column, which involves factors of each type of the pollutants. These forms are categorized on the basis of aerosol optical response, clouds database, and mass concentration. MERRA-2 assimilates aerosol data globally with a resolution of $0.5° \times 0.625°$ and 73 vertical levels from 1980 (Chin et al., 2002; Colarco et al., 2010; Randles et al., 2017).

We assimilated AOD by MERRA-2 for $PM_{2.5}$ estimation over the grid reference of Pakistan (Acker & Leptoukh, 2007). We retrieved the temporal concentration and frequency time-series of $PM_{2.5}$ for the normal period of 6 months in 2019 (between January 1 and June 30, 2019) and the same months in the COVID-19 pandemic period (January 1 2020 to June 30, 2020).

Results and discussion

Land monitor data

The Pakistan Environmental Protection Agency (AK-EPA) has classified AQI standards of $PM_{2.5}$ into 6 main groups: good (0–50), moderate (51–100), unhealthy for sensitive group (101–150), unhealthy (151–200), very unhealthy (201–300), and hazardous (> 300). Based on these standards, the findings from the three time spans are illustrated in Fig. 1. It is immediately seen that AQI was declined in the COVID-19 lockdown period.

The AQI was evaluated during the COVID-19 pandemic pre-lockdown period (January 1, 2020 to March 20, 2020), the COVID-19 pandemic lockdown period (March 21, 2020 to May 15, 2020), and the COVID-19 pandemic post-lockdown period (May 16, 2020 to June 30, 2020). The results are illustrated in Fig. 2 and listed in Table 1. More specifically:

The AQI levels for $PM_{2.5}$ of ISL were 142 ± 55 (January) and 131 ± 53 (February) during the COVID-19 pandemic pre-lockdown period (January 1, 2020 to March 20, 2020). It is worthy of note that, considering the fact that this is the capital of the country with the least pollution sources, the city demonstrates a quite healthy AQI. Nevertheless, during the COVID-19 pandemic lockdown period (March 21, 2020 to May 15, 2020) in the next 3 months, the AQI levels were markedly reduced to 82 ± 34, 77 ± 32, and 81 ± 34, respectively, which are considerably low levels of AQI. Zhang et al. have also reported seasonal changes in the air quality index (Zhang et al., 2020). Moreover, according to the Pakistan Meteorological Department (PMD), the pollen-grain season starts at the beginning of March and lasts until the end of April every year (PMD, 2020). Thus, the AQI could be further improved when taking into account the pollen-grain contribution to the pollution level.

KHI is the station in the most heavily-populated area. In the 2 months of the COVID-19 pandemic pre-lockdown period (January 1, 2020 to March 20, 2020), the AQI levels were 146 ± 56 and 145 ± 56. In the COVID-19 pandemic lockdown period (March 21, 2020 to May 15, 2020), a pronounced reduction in AQI levels was recorded as 89 ± 37, 80 ± 33, and 84 ± 35. On the other hand, LHE was the most polluted station. During the 2 months of

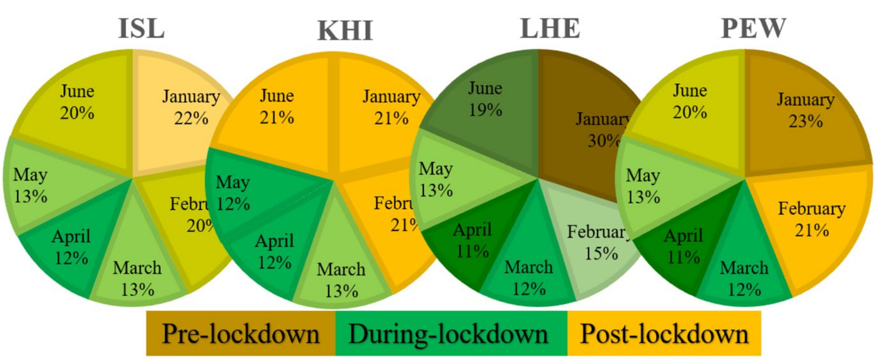

Fig. 1 Pie-charts for the presentation of the evaluation of AQI throughout the 6 months of the pre-lockdown, the lockdown, and the post-lockdown COVID-19 periods

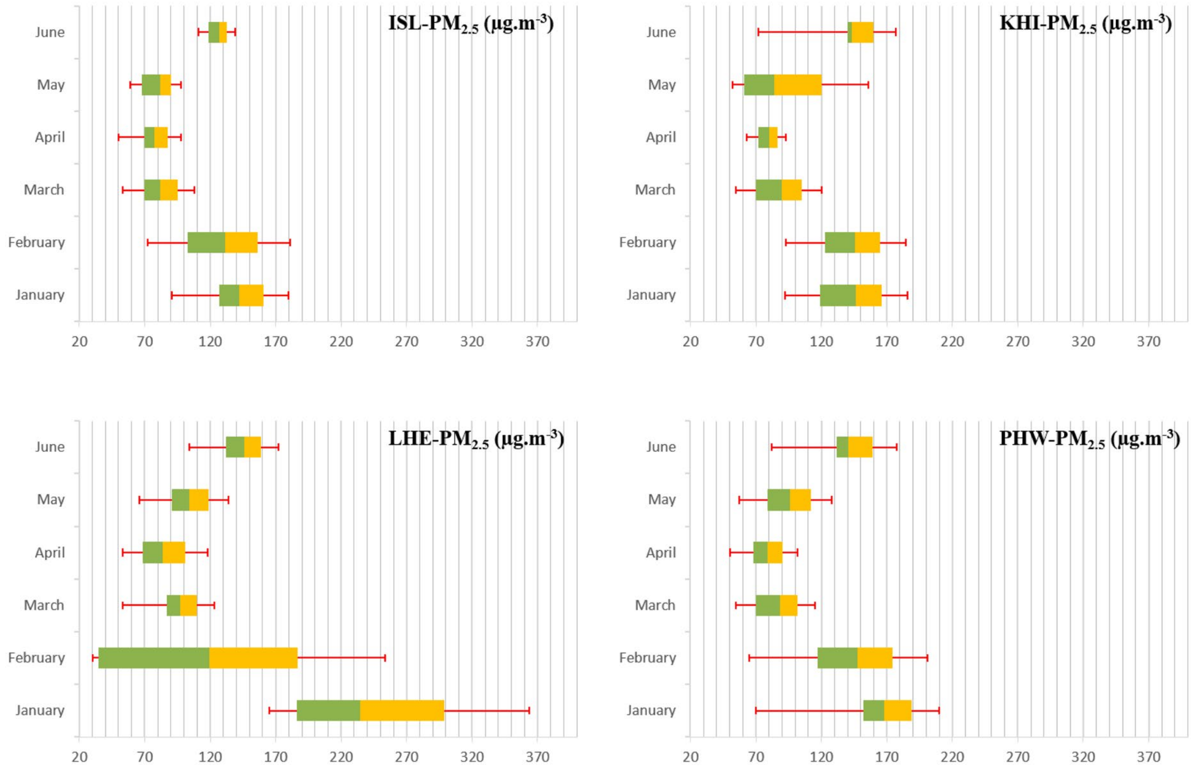

Fig. 2 Box and whisker plots of monthly average AQI in ISL, KHI, LHE, and PHW, in the 6 months which include the lockdown period and the normal days. The top and bottom of each box represent the 75th percentile and 25th percentile, respectively, and the upper and lower whiskers represent the 90th and 10th percentile, respectively. The vertical bar in each box represents the data median

the COVID-19 pandemic pre-lockdown period (January 1, 2020 to March 20, 2020), the AQI levels were 234 ± 74 and 119 ± 50. During the COVID-19 pandemic lockdown period (March 21, 2020 to May 15, 2020), the city has been reported with 97 ± 40, 83 ± 35, and 103 ± 42 points of AQI. Finally, in the PHW station, during the COVID-19 pandemic pre-lockdown period (January 1, 2020 to March 20, 2020), the AQI levels were 167 ± 61 (January) and 147 ± 56 (February). A significant decline to 88 ± 37, 78 ± 33, and 95 ± 40 AQI was observed in the following 3 months in the COVID-19 pandemic lockdown period (March 21, 2020 to May 15, 2020). Consequently, the COVID-19 lockdown imposition led to a significant improvement in air quality of the local environment (Xu et al., 2020a).

Table 1 Daily air quality index (AQI) of PM$_{2.5}$ between January and June 2020, calibrated on US-EPA (AQI)

Sensor location	*AQI*					
	January	*February*	*March*	*April*	*May*	*June*
Islamabad (ISL)	142 ± 55	131 ± 53	82 ± 34	77 ± 32	81 ± 34	126 ± 52
Karachi (KHI)	146 ± 56	145 ± 56	89 ± 37	80 ± 33	84 ± 35	143 ± 56
Lahore (LHE)	234 ± 74	119 ± 50	97 ± 40	83 ± 35	103 ± 42	145 ± 56
Peshawar (PHW)	167 ± 61	147 ± 56	88 ± 37	78 ± 33	95 ± 40	140 ± 55

Good (0–50), moderate (51–100), unhealthy for sensitive group (101–150), unhealthy (151–200), very unhealthy (201–300), and hazardous (> 300)

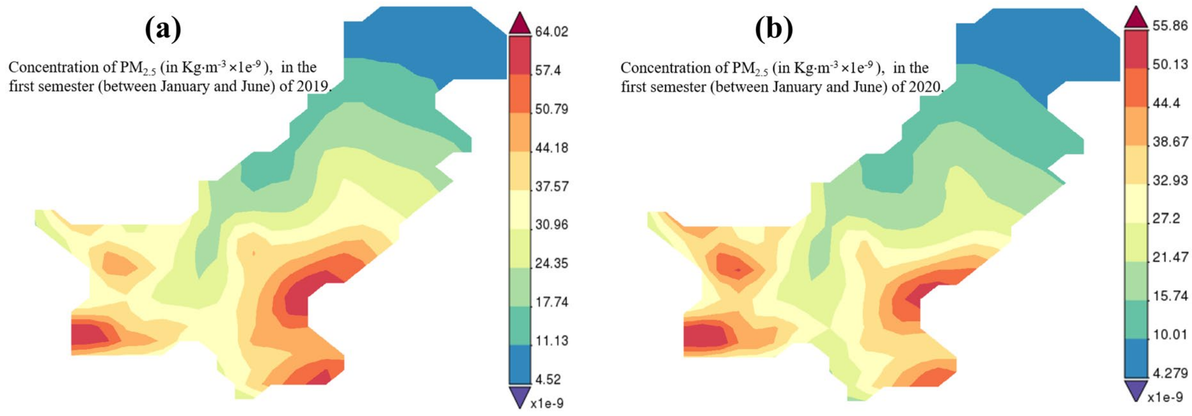

Fig. 3 Maps of monthly average dust surface mass concentration of $PM_{2.5}$ (in $Kg{\cdot}m^{-3}$) in the first semester (between January and June) of **a** 2019, and **b** 2020

The above conclusion is further supported by the data obtained after the lockdown period (May 16, 2020 to June 30, 2020). Indeed, from May 16, 2020 to June 15, 2020, the AQI geared up to126 $\pm$ 52, 145 $\pm$ 56, 143 $\pm$ 56, and 140 $\pm$ 55 in ISL, LHE, KHI, and PHW, respectively. This noticeable increase is ascribed to the lifting of the ban on public transportation and the re-opening of all machinery and industries on the occasion of Eid-ul-Fitar (i.e., a religious ceremony of Muslims).

Satellite data

Figure 3 compares the temporal projection of $PM_{2.5}$ throughout the whole territory of Pakistan, retrieved for a period of 6 months between January 1 and June 30, for the year 2019 (Fig. 3a) and the year 2020 (Fig. 3b). The reader must notice that in the contour-map for 2019, the upper limit of the scale-bar is 64.02×10^{-9} $kg{\cdot}m^{-3}$, whereas the upper limit of the scale-bar in the contour-map for 2020 is 55.86×10^{-9} $kg{\cdot}m^{-3}$, (the low limits in the scale-bars are similar, i.e., 4.52×10^{-9} and 4.28×10^{-9} $kg{\cdot}m^3$, respectively). Therefore, the maximum $PM_{2.5}$ concentration was clearly reduced by 8.16×10^{-9} $kg{\cdot}m^{-3}$ in the first semester of 2020, which corresponds to the period of taking strong measures against COVID-19, compared to the same semester in 2019.

In Fig. 4, the concentrations of $PM_{2.5}$ which were most frequently recorded in the same period

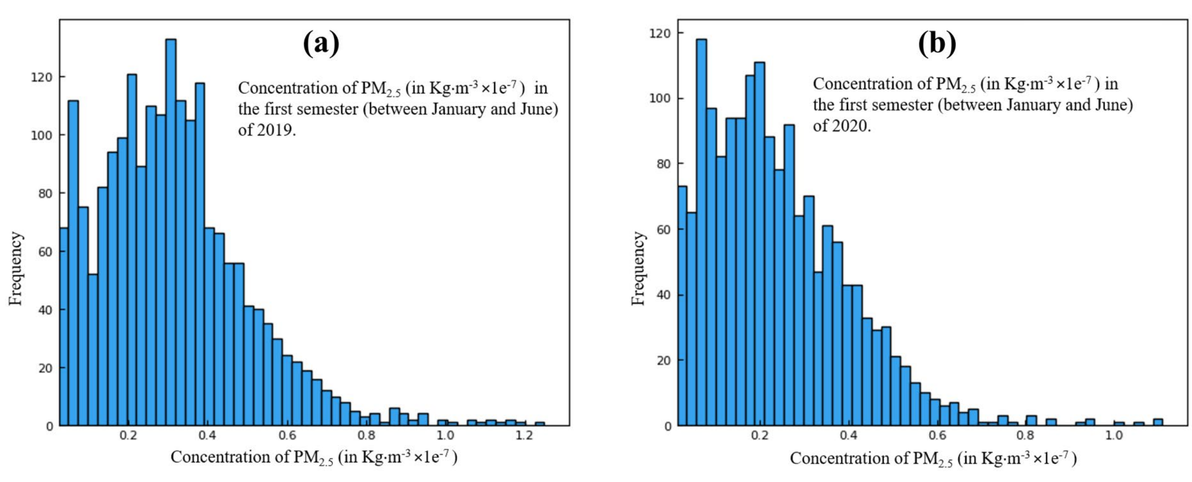

Fig. 4 Histograms of the distribution of the concentrations of $PM_{2.5}$ (in $Kg{\cdot}m^{-3}$) in the first semester (between January and June) of **a** 2019, and **b** 2020

of time (i.e., in the first semester, between January 1 and June 30) in 2019 (Fig. 4a) and 2020 (Fig. 4b) are illustrated in the form of histograms. In the first semester of 2019, the concentration of $PM_{2.5}$ was rather high, i.e., ~ 0.25 to 0.42 kg·m^{-3}. It is clearly seen that the concentration of $PM_{2.5}$ was considerably reduced in 2020 (more than 50%), ranging from ~ 0.05 to 0.3 kg·m^{3}, compared to the same period in 2019.

Conclusions

The AQI was monitored by the land sensor "Temtop 1000" in the major cities of Pakistan, during the COVID-19 pandemic pre-lockdown period (January 1, 2020 to March 20, 2020), the COVID-19 pandemic lockdown period (March 21, 2020 to May 15, 2020), and the COVID-19 pandemic post-lockdown period (May 16, 2020 to June 30, 2020).

The temporal pattern of the monthly air quality index was navigated by MERRA-2 over the grid reference of Pakistan. The results showed that the mean concentration of $PM_{2.5}$ measured during the lockdown period was reduced by ~ 50%. The lockdown resulted in a reduction of $PM_{2.5}$ concentration by 8.16×10^{-9} kg·m^{-3}, as recorded by MERRA-2 navigation.

Conseqeuently, the AQI was unequivocally reduced considerably during the lockdown period. Accordingly, if environmental policies will be adopted, then humans will surely live in a cleaner environment.

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Author contribution Data were collected by AJ, YB, and SA. SMH and SK used statistical tools. AH, SA, and SZI wrote the manuscript and analyzed the results. The manuscript was checked and reviewed by all the authors.

Data availability The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

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