Impact of novel coronavirus disease (COVID-19) lockdown on ambient air quality of Saudi Arabia

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The impact of COVID-19 lockdown on the ambient air quality of the Kingdom of Saudi Arabia for the first time using data from nine cities was determined in this study. Hourly air quality data, based on concentrations of carbon monoxide (CO), particulate matter (PM<sub>10</sub>), sulfur dioxide (SO<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>) and ozone (O<sub>3</sub>), and meteorological conditions (atmospheric temperature, relative humidity, and wind speed) of the nine cities studied were obtained from Saudi Arabian General Authority of Meteorology and Environmental Protection (GAMEP), for the period between January 2019 to May 2020. Significant variation (p < 0.05) was recorded for the five atmospheric pollutants across the cities before and during the lockdown, with lower concentrations during the lockdown except for the concentration of O<sub>3</sub> in Tabuk, Al Qasim, and Haql. This can be a result of NO and O<sub>3</sub> reaction, causing the inability of effective O<sub>3</sub> depletion. The percentage changes in concentrations of CO (33.60%) and SO<sub>2</sub> (44.16%) were higher in Jeddah; PM<sub>10</sub> (91.12%) in Riyadh, while NO<sub>2</sub> (44.35%) and O<sub>3</sub> (18.98%) were highest in Makkah. However, even though there was a decrease in pollutants concentrations during the lockdown, the concentrations for CO, PM<sub>10</sub>, SO<sub>2</sub>, NO<sub>2</sub>, and O<sub>3</sub> were still above WHO 24 h and annual mean limit levels. The COVID-19 lockdown in the Kingdom of Saudi Arabia revealed the possibility of significant atmospheric pollutant reduction by controlling traffic, activities by industries, and environmentally friendly transportation programs such as green commuting programs.

1. Introduction

COVID-19 have spread globally and rocketed into one of the largest threat to human health and economic crises of the 21st Century (Briz-Redón et al., 2020; Yu et al., 2020), leading to its consideration as one of the major disasters ever recorded to affect the modern world (Singh and Chauhan, 2020). In December 2019, Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) was identified in Wuhan, China. The World Health Organization (WHO) later declared the COVID-19 outbreak as an emergency of public health with international concern on the 30th of January 2020 after enforcement of lockdown. The lockdown was enforced by a way of placing the whole city of Wuhan under quarantine on the 23rd of January 2020 (WHO, 2020). Between February and March 2020, the number of cases in people and death rates caused by coronavirus (COVID-19) was rising exponentially, leading to the enforcement of lockdown in most cities of the world to curb the infection and death rate (Muhammad et al., 2020). Restriction of human activities including mobility was put in place to control the spread of the virus, this led to a reduction of traffic on the roads, closure of commercial, entertainment, and industrial activities.

Kingdom of Saudi Arabia (KSA) is the second largest country in the Arabian world (Algaissi et al., 2020; GASKSA, 2020) and took early measures to prevent and control the COVID-19 outbreak. In preparation before the outbreak, a national committee was set up in early January 2020 to track worldwide updates and make necessary preparations for any eventual outbreak or spread of the virus. The first case of COVID-19 in KSA was on the 2nd of
March 2020. However, before the first case, an early decision made by the government of KSA as a way of responding to the spread of the virus was through the stoppage of flights coming from China to KSA (Algaissi et al., 2020). Later on, the government decided to regulate the entrance of individuals from countries with COVID-19 cases to KSA (Barry et al., 2020). That decision was taken on the 28th of February 2020. Regardless of the measures that were put in place before the first case of COVID-19 in KSA, the cases were still rising at an exponential pattern. When the cases got to 500 towards the end of March 2020, the government of KSA issued a curfew (Badreldin et al., 2020) with a huge penalty of financial type for individuals that refuse to abide by the law. In the long run, the lockdown in some cities and restrictions on movement between provinces was imposed by the government of KSA (Algaissi et al., 2020).

The response to The COVID-19 outbreak such as the lockdown of cities has been beneficial to the environment looking at the reduction in atmospheric pollution (Bherwani et al., 2020; Sharma et al., 2020a, 2020b). Globally, reports from different studies revealed a decrease in atmospheric pollutants as a result of enforcement of lockdown amidst the COVID-19 outbreak, this is due to a reduction in social and economic activities (Jain and Sharma 2020; Sharma et al., 2020a, 2020b). Correlation between atmospheric pollution and lockdown due to COVID-19 outbreak or spread has been revealed in many parts of the world. For example, a relationship was established between pollutants such as PM2.5, PM10, NO2, and O3 with confirmed cases of COVID-19 (Zhu et al., 2020). Several conclusions were also made in Europe, Asia, Africa, Latin America, and the United States as regards the influence of drastic decrease in anthropogenic activities such as social and economic variables and decline in air pollutants such as PM10, PM2.5, SO2, NO2, and O3 (Muhammad et al., 2020; Nakada and Urban, 2020; Otmani et al., 2020; Xu et al., 2020).

Our study aims to report the impact of COVID-19 lockdown on the ambient air quality of the Kingdom of Saudi Arabia for the first time using data from nine cities in the kingdom.

2. Materials and methods

2.1. Study area

Saudi Arabia is the second largest country in the Arabian world with a population of over 34 million with non-indigenes representing about 37% of the population. The population of the country is dominated by the middle age group of 15–64 years, while 32.4% and 2.8% are within the age groups of 15–64 years and 0–14 years respectively (Algaissi et al., 2020; GASKSA, 2020). Nine cities namely Makkah (21°22′54.33″N and 39°51′24.29″E), Ha’il (27°30′49.48″N and 41°43′10.76″E), Jeddah (21°29′06.96″N and 39°11′28.82″E), Jizan (16°53′28.23″N and 42°34′12.99″E), Tabuk (28°23′06.66″N and 36°33′58.29″E), Al Madinah (24°31′41.19″N and 39°34′09.06″E), Al Qasim (26°14′05.65″N and 43°29′01.45″E), Riyadh (24°43′21.21″N and 46°40′31.06″E) and Haql (29°17′13.96″N and 34°56′42.54″E) were considered for this study (Fig. 1). The nine cities considered in this study were selected due to the increased industrial activities and the human population in these cities. This made the populace requirement for the quality of the environment on the increase as a result of the release of pollutants from the industries and automobiles into the atmosphere, and their human health consequences.

The lockdown in Saudi Arabia took effect around the ending of March 2020 and was eased on 21st of June 2020; as a result, we concluded to carry out this study on the changing pattern of air quality in the months before and after the lockdown (Jan 2019 to Feb 2020) and the months during the lockdown (March 2020 to May 2020).

2.2. Data analyses

Hourly air quality data, based on concentrations of carbon monoxide (CO), particulate matter (PM10), sulfur dioxide (SO2), nitrogen dioxide (NO2) and ozone (O3), and meteorological conditions (atmospheric temperature, relative humidity, and wind speed) of the nine cities studied were obtained from Saudi Arabian General Authority of Meteorology and Environmental Protection (GAMEP) for the period between January 2019 to May 2020. The considered validly of data used was based on hourly concentration above 75% availability (Broomandi et al., 2020).

Significant variations in atmospheric pollutants (CO, PM10, SO2, NO2, and O3) before and during the COVID-19 lockdown across the nine cities studied were determined using One-way analysis of variance (ANOVA): Duncan multiple range test (DMRT). Prior to ANOVA test, the normality of the data was assessed using the Shapiro-Wilk test. Students’ t-test was used to test for significant variation in atmospheric pollutants and meteorological conditions each before and during COVID-19 lockdown. The influence of the lockdown period and meteorological conditions on changes in atmospheric pollutants was determined using correlation base Principal component analysis (PCA).

IBM SPSS v.22.0, GraphPad Prism 5 and Minitab v.17.0 Statistics Software Package were used to analyze the data.

3. Results

3.1. Impacts of COVID-19 lockdown on the air quality of Saudi Arabia

The variation in mean concentrations of atmospheric pollutants before and during COVID-19 lockdown in Saudi Arabia is presented in Tables 1 and 2 respectively. The range for mean concentrations of CO, PM10, SO2, NO2, and O3 before COVID-19 lockdown in Saudi Arabia (Jan 2019 to Feb 2020) were (678.23 ± 13.39) µg m−3 to (2162.01 ± 214.31) µg m−3 in Ha’il and Riyadh, (83.90 ± 5.18) µg m−3 to (518.42 ± 29.98) µg m−3 in Ha’il and Riyadh, (6.40 ± 0.52) µg m−3 to (24.22 ± 3.55) µg m−3 in Ha’il and Jazan, (6.41 ± 1.15) µg m−3 to (44.30 ± 1.99) µg m−3 in Al Qasim and Riyadh and (22.53 ± 1.96) µg m−3 to (93.29 ± 3.71) µg m−3 in Jazan and Tabuk respectively.

Ranges of mean concentrations for CO, PM10, SO2, NO2, and O3 during the lockdown (March 2020 to May 2020) were (528.70 ± 1.546) µg m−3 to (1557.87 ± 218.75) µg m−3 in Ha’il and Riyadh, (24.10 ± 4.78) µg m−3 to (160.50 ± 20.36) µg m−3 in Riyadh and Al Qasim, (5.07 ± 0.20) µg m−3 to (18.83 ± 1.05) µg m−3 in Riyadh and Makka, (5.70 ± 0.26) µg m−3 to (39.60 ± 5.81) µg m−3 in Al Qasim and Al Madinah, and (20.43 ± 2.92) µg m−3 to (110.57 ± 1.27) µg m−3 in Al Madinah and Tabuk respectively. Significant variation (p < 0.05) was recorded for the five atmospheric pollutants across the cities before and during the lockdown, with lower concentrations during the lockdown except for the concentration of O3 in Tabuk, Al Qasim, and Haql. Percentage change was further used to ascertain the significant variation in atmospheric pollutants and presented in Table 3. Similarities and differences between our results and results reported from other previous studies are shown in Table 4.

The percentage changes in concentrations of CO (33.60%) and PM10 (518.42 ± 29.98) µg m−3 to (24.10 ± 4.78) µg m−3, and SO2 (19.44 ± 2.12 to 7.53 ± 1.74) µg m−3, PM10 (518.42 ± 29.98 to 24.10 ± 4.78) µg m−3, and NO2 (24.22 ± 3.55) µg m−3 to (1557.87 ± 218.75) µg m−3 were significant.
Fig. 1. Map of Saudi Arabia showing nine cities used for this study (2020). Source: Geographic Information System (GIS) using ArcGIS 10.3 Software.

Table 1
Mean (mean ± SE) concentrations of pollutants before COVID-19 lockdown.

| City   | CO     | PM$_{10}$ | SO$_2$     | NO$_2$     | O$_3$     |
|--------|--------|-----------|------------|------------|-----------|
| Makkah | 966.53 ± 38.65$^{cd}$ | 195.06 ± 6.03$^b$ | 20.80 ± 2.46$^a$ | 22.05 ± 2.06$^{cd}$ | 50.85 ± 21.16$^{de}$ |
| Ha'il  | 678.23 ± 13.39$^c$ | 83.09 ± 5.18$^b$ | 6.40 ± 0.52$^a$ | 18.86 ± 4.11$^a$ | 69.27 ± 2.25$^b$ |
| Jeddah | 1116.95 ± 70.07$^{ab}$ | 190.19 ± 12.38$^b$ | 19.44 ± 2.12$^a$ | 35.59 ± 3.29$^b$ | 56.72 ± 5.95$^{cd}$ |
| Jazan  | 1289.82 ± 57.60$^{cd}$ | 98.54 ± 14.94$^a$ | 24.22 ± 3.55$^b$ | 19.16 ± 2.20$^b$ | 22.53 ± 1.96$^a$ |
| Tabuk  | 1182.64 ± 110.25$^{cd}$ | 94.95 ± 3.51$^a$ | 12.96 ± 0.52$^a$ | 12.39 ± 1.23$^b$ | 93.29 ± 3.71$^a$ |
| Al Madinah | 1159.40 ± 56.79$^{d}$ | 116.60 ± 7.96$^b$ | 15.66 ± 2.05$^b$ | 42.19 ± 3.49$^a$ | 29.96 ± 2.41$^a$ |
| Al Qasim | 997.15 ± 128.83$^{cd}$ | 186.99 ± 7.34$^a$ | 6.51 ± 0.75$^a$ | 6.41 ± 1.15$^a$ | 41.53 ± 1.75$^{df}$ |
| Riyadh | 2162.01 ± 214.31$^a$ | 518.42 ± 29.96$^{ab}$ | 10.62 ± 1.81$^a$ | 44.30 ± 1.99$^a$ | 46.36 ± 6.31$^{df}$ |
| Haql   | 757.92 ± 71.89$^d$ | 174.57 ± 10.79$^b$ | 15.21 ± 3.06$^a$ | 23.95 ± 7.43$^{cd}$ | 79.61 ± 7.87$^{ab}$ |
| F value | 18.968 | 2.298 | 7.700 | 11.593 | 7.722 |
| P value | 0.000 | 0.025 | 0.000 | 0.000 | 0.000 |

Mean±S.E with different superscripts (a-g) along the same column were significantly different (p < 0.05).

Table 2
Mean (mean ± SE) concentrations of pollutants during COVID-19 lockdown.

| City   | CO     | PM$_{10}$ | SO$_2$     | NO$_2$     | O$_3$     |
|--------|--------|-----------|------------|------------|-----------|
| Makkah | 705.27 ± 10.37$^{cd}$ | 114.37 ± 10.37$^{bcd}$ | 18.83 ± 1.05$^a$ | 8.50 ± 2.43$^a$ | 34.63 ± 0.64$^e$ |
| Ha'il  | 528.70 ± 15.46$^b$ | 81.57 ± 1.13$^{cd}$ | 5.80 ± 0.29$^{ef}$ | 17.10 ± 0.85$^b$ | 67.10 ± 1.01$^b$ |
| Jeddah | 654.47 ± 14.12$^a$ | 98.10 ± 23.60$^{bcd}$ | 7.53 ± 1.74$^{de}$ | 31.63 ± 2.83$^b$ | 46.37 ± 3.25$^e$ |
| Jazan  | 1176.33 ± 33.26$^{ab}$ | 25.73 ± 2.18$^b$ | 13.13 ± 0.34$^a$ | 8.40 ± 1.14$^b$ | 21.87 ± 2.95$^{ab}$ |
| Tabuk  | 731.43 ± 21.20$^{cd}$ | 73.07 ± 11.10$^{cd}$ | 9.10 ± 0.06$^{cd}$ | 7.10 ± 1.05$^c$ | 110.57 ± 1.27$^a$ |
| Al Madinah | 783.17 ± 75.90$^{cd}$ | 125.03 ± 13.18$^{bcd}$ | 10.40 ± 0.35$^a$ | 39.60 ± 5.81$^a$ | 20.43 ± 2.92$^d$ |
| Al Qasim | 957.27 ± 180.79$^{hr}$ | 160.50 ± 20.36$^a$ | 5.90 ± 0.60$^{ef}$ | 5.70 ± 0.26$^c$ | 49.23 ± 0.73$^e$ |
| Riyadh | 1557.87 ± 218.75$^a$ | 24.10 ± 4.78$^b$ | 5.07 ± 0.20$^b$ | 29.10 ± 8.55$^a$ | 28.27 ± 1.36$^{cd}$ |
| Haql   | 702.93 ± 70.00$^{cd}$ | 130.93 ± 23.36$^{ab}$ | 8.40 ± 0.12$^b$ | 13.13 ± 1.64$^a$ | 82.40 ± 0.89$^{ab}$ |
| F value | 18.968 | 2.298 | 7.700 | 11.593 | 7.722 |
| P value | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 |

Mean±S.E with different superscripts (a-g) along the same column were significantly different (p < 0.05).
NO\textsubscript{2} (22.05 ± 2.06 to 8.50 ± 2.43) \text{gm}^{-3}, and O\textsubscript{3} (50.85 ± 21.16 to 34.63 ± 0.64) \text{gm}^{-3} were recorded in Jeddah, Riyadh and Makkah respectively (Fig. 2).

3.2. Meteorological changes and its influence on air quality during COVID-19 lockdown

Variations in meteorological conditions such as relative humidity (H), temperature (T), and wind speed (WS) before and during COVID-19 lockdown, are presented in Table 5. Generally, there was no obvious change or variation between the values for meteorological conditions (Humidity, temperature, and wind speed) between pre-lockdown (Jan 2019 to Feb 2020) and the COVID-19 lockdown period (March 2020 to May 2020).

Students' t-test \((p < 0.05)\) revealed no significant variation between meteorological conditions before lockdown and lockdown period for the nine cities under study, except for Jeddah where significant variation was observed in relative humidity (Table 4).

Principal component analysis (PCA) biplot for atmospheric pollutants and meteorological conditions in nine cities of Saudi Arabia studied before the lockdown and during the lockdown period is presented in Fig. 3. Component 1 and 2 accounted for 53.64%, 60.65%, 56.85%, 79.84%, 69.85%, 59.22%, 54.11%, 62.12%, and 56.45% of the total variation in Makkah, Ha'il, Jeddah, Jazan, Tabuk, Al Madinah, Al Qasim, Riyadh, and Haql respectively.

In Makkah, there was an influence of COVID-19 lockdown on PM\textsubscript{10}, CO, and O\textsubscript{3} with also a positive correlation between these three pollutants and temperature. The influence of the lockdown on PM\textsubscript{10} was also recorded in the city of Ha'il, but in contrast, PM\textsubscript{10} was negatively correlated with humidity. The city of Jeddah presents a different situation from Makkah and Ha'il with a lockdown period influencing NO\textsubscript{2}, O\textsubscript{3} and SO\textsubscript{2} with a positive correlation with humidity and wind speed. CO and O\textsubscript{3} were influenced by the lockdown and a negative correlation was established between CO, O\textsubscript{3}, humidity, and wind speed.

For the city of Tabuk, PM\textsubscript{10}, O\textsubscript{3} and SO\textsubscript{2} were revealed to have been impacted during COVID-19 lockdown, besides correlating positively with WS and temperature. In Al Madinah, more importantly, PM\textsubscript{10} was influenced by the introduction of lockdown and also a negative correlation with wind speed and humidity. The lockperiod in the city of Al Qasim influenced PM\textsubscript{10}, CO, O\textsubscript{3}, NO\textsubscript{2} and SO\textsubscript{2}, and revealed a positive correlation between these five atmospheric pollutants and humidity. A negative correlation was also revealed between PM\textsubscript{10} and humidity, and wind speed in Riyadh. However, the impact of the lockdown on PM\textsubscript{10} was also established. A similar outcome was realized in the city of Haql, with the impact of the lockdown on PM\textsubscript{10} but also includes NO\textsubscript{2} and O\textsubscript{3}. Moreover, a negative correlation existed between PM\textsubscript{10}, NO\textsubscript{2} and humidity, and wind speed correlating positively with O\textsubscript{3}.

4. Discussion

The decrease in the concentration of CO, PM\textsubscript{10}, SO\textsubscript{2}, NO\textsubscript{2}, and O\textsubscript{3} in KSA regarding the nine cities under study are a result of the COVID-19 lockdown that led to the decrease in pollution emissions from traffic after the outbreak of COVID-19.

However, the contrasting pattern of O\textsubscript{3} as compared to other atmospheric pollutants in Tabuk, Al Qasim, and Haql is a result of NO and O\textsubscript{3} reaction, causing the inability of effective O\textsubscript{3} deple- tion. Other reasons could be conditions that are favorable to reac- tions by photochemical which are linked to a decrease in NO\textsubscript{2} and upsurge in solar insolation. This causes changes in photochemical reactions responsible for the buildup and destruction of O\textsubscript{3} (Broomandi et al., 2020; Sharma et al., 2020a, 2020b; Xu et al., 2020). Usually, a negative correlation exists between O\textsubscript{3} and NO\textsubscript{x}. Factors that influence O\textsubscript{3} accumulation in the atmosphere are the principal chemistry that exists between the concentration of O\textsubscript{3} and emissions due to human activities. For example, NO\textsubscript{4} in an environment with low VOC together with meteorological conditions (Broomandi et al., 2020; Jain and Sharma, 2020). A decrease in NO\textsubscript{2} concentration leads to a decrease in NO concentration and causes a reduction in the possibility of reaction between NO and O\textsubscript{3} resulting in prevention in O\textsubscript{3} accumulation. Azarmi and Arhami (2017) have also reported road vehicles as the cause for emission of oxides of nitrogen (NO\textsubscript{x}), PM\textsubscript{10} and CO in their study on challenges of atmospheric pollution in a megacity.

The percentage change in atmospheric pollutant between the period before the lockdown and during lockdown is in line with the findings by several authors such as Mahato et al. (2020) and Xu et al. (2020) where they report a significant decrease in
atmospheric pollutants during the period of COVID-19 lockdown in Delhi and Wuhan. Their studies were to assess the impact of COVID-19 lockdown on atmospheric pollutants when compared with the pre-COVID-19 lockdown.

Even though there was a decrease in pollutants concentration during the lockdown, the concentrations for CO, PM10, SO2, NO2, and O3 were still above WHO 24 h and annual mean limit levels. This confirms non-traffic source emission contributing to an increase in atmospheric pollutants. This can be stationary sources from the industries with the combustion of fossil fuel playing a key role in the complex source mix (Halek et al., 2004). Kerimray et al. (2020) report similar findings in Almaty, stating the reason for pollutants exceeding levels of WHO during the COVID-19 lockdown due to contribution by non-traffic sources. A study similar to our work was carried out in Eastern China with a reported result revealing a significant decrease of 30% and 20% in concentrations for NO2 and CO respectively. It was attributed to reduced anthropogenic activities link to urban transportation and growth in the economy during the period of COVID-19 lockdown (Filonchyk et al., 2020).

In another study in Iran on the impact of COVID-19 event on the air quality of 12 locations, reports a total reduction of −13%,
Table 5
Variation in meteorological conditions (mean ± SE) during COVID-19 lockdown relative to pre-lockdown period.

| City         | PL  | Makkah | Ha'il | Jeddah | Al Madinah | Tabuk | Al Qasim | Riyadh | Haql   |
|--------------|-----|--------|-------|--------|------------|-------|----------|--------|--------|
| Humidity     | 36.43 ± 2.56 | 54.68 ± 3.07 | 54.68 ± 3.07 | 38.48 ± 1.16 | 35.45 ± 0.11 | 34.45 ± 0.11 | 35.45 ± 0.11 | 28.50 ± 3.41 | 26.91 ± 2.54 |
| Temperature | 29.75 ± 1.44 | 30.17 ± 1.07 | 30.17 ± 1.07 | 24.45 ± 1.71 | 30.45 ± 0.11 | 30.45 ± 0.11 | 30.45 ± 0.11 | 24.01 ± 2.41 | 26.91 ± 2.54 |
| WS           | 1.32 ± 0.04  | 1.70 ± 1.02  | 1.70 ± 1.02  | 1.85 ± 0.11  | 2.06 ± 0.08  | 2.06 ± 0.08  | 2.06 ± 0.08  | 2.26 ± 0.08  | 2.26 ± 0.08  |

F value | 1.751 | 1.599 | 0.945 | 1.964 | 3.334 | 4.464 | 5.803 | 3.703 | 8.255 |
P value | 0.206 | 0.225 | 0.346 | 0.181 | 0.088 | 0.052 | 0.029 | 0.125 | 0.012 |

Despite the enforcement of lockdown in Saudi Arabia during the period captured in this study, there was a partial activity in some cities by some of the important parastatals such as the petroleum industries. Generally, the enforcement of the lockdown varies with the cities at the beginning of the lockdown. This might have been the cause of SO2 involvement in some of the relationships and the spread aided by meteorological conditions such as wind speed (Alaissi et al., 2020). SO2 are produced mainly from activities of coal and petroleum combustion and smelting of ores containing sulfur. Our results are in line with other findings such as Lokhandwala and Gautam (2020); Navinya et al. (2020), and Xu et al. (2020).
Fig. 3. Principal component analysis biplot for the influence of meteorological data and pollutants concentration before and during COVID-19 lockdown in a) Makkah, b) Ha'il, c) Jeddah, d) Jazan, e) Tabuk, f) Al Madinah, g) Al Qasim, h) Riyadh and i) Haql. L = Lockdown, PL = Before lockdown.
5. Conclusions

In this article, the effect of COVID-19 lockdown in the Kingdom of Saudi Arabia on atmospheric pollutants (CO, PM10, SO2, NO2, and O3) using data from nine cities was determined. Significant variation \((p < 0.05)\) was recorded for the five atmospheric pollutants across the cities before and during the lockdown, with lower concentrations during the lockdown except for the concentration of O3 in Tabuk, Al Qasim, and Haql. The percentage changes in concentrations of CO (33.60%) and SO2 (44.16%) were higher in Jeddah; PM10 (91.12%) in Riyadh, while NO2 (44.35%) and O3 (18.98%) were highest in Makkah.

The significant decrease in atmospheric pollutants during the pandemic captured in this study was due to enforcement of the lockdown which affects industrial production and traffic. A significant change was not recorded in meteorological conditions before and during the lockdown for the nine cities under study except for Jeddah where significant variation was observed in relative humidity. However, even though there was no significant change in meteorological conditions during the lockdown, they still influence changes associated with concentrations of pollutants. The COVID-19 lockdown in the Kingdom of Saudi Arabia revealed the possibility of significant atmospheric pollutant reduction by controlling traffic, activities by industries, and environmentally friendly transportation programs such as green commuting programs.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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