Investigating the impact of COVID-19 lockdowns on environmental health in Kuwait

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Submitted: 22-11-2021

Revised: 20-05-2022

Accepted: 30-05-2022

ABSTRACT

The novel coronavirus (COVID-19) was announced as a global pandemic by the World Health Organization (WHO) on March 11, 2020. In response, the State of Kuwait applied a series of three lockdown measures in 2020. Previous research highlighted the positive impact of lockdown measures on environmental health and safety by reducing air pollution levels. While this prior work demonstrated the effectiveness of lockdown measures on reducing pollution levels in different geographical locations, there is limited evidence that shows whether the lockdowns implemented in Kuwait were effective in terms of reducing air pollution. Thus, the main goal of this study was to investigate the impact of the COVID-19 lockdown measures taken in Kuwait on the concentrations of the following pollutants: Particulate Matter 2.5 ($PM_{2.5}$), Particulate Matter 10 (PM_{10}), Nitrogen Dioxide (NO_2), and Ozone (O_3). Data from two different air monitoring stations (Aljahra and Alahmadi) was used to compare pollution levels from three lockdown intervals – two partial lockdowns and one total lockdown. A sequential approach was utilized in the current study where air quality data during the three lockdown periods was compared with air quality data during the pre-lockdown period. The main findings indicated that NO_2 concentrations decreased by 48%, 63%, and 48% after the first partial, total lockdown, and second partial lockdowns, respectively in Aljahra station. Meanwhile, Ozone concentrations increased by 30-100% across all lockdown periods for both stations. Finally, PM_{10} and $PM_{2.5}$ concentrations did not decrease after the total lockdown. This research urges public policy experts to consider immediate measures to mitigate the environmental, health, and safety risks posed by air pollution.

Keywords: COVID-19; Environment; Health; Lockdown; Pollution; Health and Safety

INTRODUCTION

On February 24, 2020, the State of Kuwait reported its first case of the novel coronavirus (COVID-19), or the severe acute respiratory syndrome corona virus 2 (SARS-CoV-2) (Gasana & Shehab, 2020; Singhal, 2020). A few weeks later on March 11, 2020, the World Health Organization (WHO) declared COVID-19 as a global pandemic urging nations across the globe to implement lockdowns to contain the virus (Koh, 2020). In response, Kuwait applied a series of lockdowns in 2020, which included a military-enforced total lockdown for three weeks where all individuals, except front-line workers, were not allowed to leave their homes (Burhamah et al., 2020).

Lockdowns were thought to be effective since COVID-19 is mainly transmitted through large droplets when people are in close contact (Singhal, 2020), particularly during coughing and sneezing (Jan & Sheikh, 2020). Prior research has demonstrated the effectiveness of lockdowns in reducing COVID-19 cases in numerous locations across the world such as Wuhan (Lau et al., 2020), Nigeria (Ajide et al., 2020), France (Di Domenico et al., 2020), Italy (Cameletti, 2020), Lebanon (Kharroubi & Saleh, 2020), and Thailand (Dechsupa et al., 2020). In fact, evidence from two Chinese provinces found that lockdown measures were helpful in reducing incidence and mortality rates (Figueiredo et al., 2020).

While this prior research discussed the effectiveness of lockdown measures, the lockdowns had negative economic consequences. Indeed, the global lockdown measures have been linked to global economic downfall including unemployment and income losses (Coccia, 2021; Konig & Winkler, 2021) The International Monetary

Fund has labelled the economic crisis with "The Great Lockdown," naming it the worst economic downturn since the Great Depression (Sogani, 2020). As a matter of fact, economists estimated the Gross Domestic Product (GDP) loss to be 4.5 percent globally which translates to ∼4 trillion US dollars in lost economic output (Szmigiera, 2021). The negative economic shock caused by the lockdowns has been linked to global mental health problems (Aragona et al., 2020). For example, Codagnone et al. (2020) found that more than 40% of the populations in the United Kingdon, Spain, Italy are at high risk of anxiety, stress, and depression.

While the lockdowns had a negative impact on global health systems and economies, researchers have highlighted the positive impact of such lockdowns on environment health by reducing pollution levels (Venter et al., 2021). Notably, pollution levels are typically characterized by the following "criteria" pollutants that determine whether a region is meeting air quality standards. Specifically, the criteria include the pollutants: Particulate Matter 2.5 ($PM_{2.5}$), Particulate Matter 10 (PM_{10}), Nitrogen Dioxide (NO_2), and Ozone (O_3) (Vallero, 2014). These pollutants pose a major threat to human health. For example, NO_2 can cause a major irritation to the human respiratory system (Gamble et al., 1987) and can damage the ecosystem by forming acid rain and nitric acid (Mohajan, 2018). Additionally, exposure to particulate matters and ozone have been linked to an increased risk of cardiovascular and respiratory diseases (Khaniabadi et al., 2017). The accumulation of $PM_{2.5}$ and PM_{10} in the air can also cause road safety hazards by reducing the visibility of the road (Wan et al., 2020).

Prior research has reported that lockdown measures can reduce those pollutant levels. For example, evidence from China suggested that concentrations of nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and Particulate Matter ($PM_{2.5}$) decreased during the lockdown in China due to the reduction of industrial and transportation sources of pollution (Marlier et al., 2020). Indeed, Hashim et al. (2021) found that NO_2 emissions were reduced up to 40% in the capital city of Iraq when compared to pre-lockdown periods. Lovric et al. (2021) found similar results in a study in Austria; by using machine learning models, they found that NO_2 and PM_{10} concentrations decreased, while an increase in ozone concentrations was reported. A similar trend was found in a multi-city study in Spain; NO_2 concentrations decreased during the lockdown while ozone concentrations increased (Briz-Redón et al., 2021). This increase in ozone levels is linked to a reduction in motor vehicle usage leading to a decrease in nitrogen oxide concentrations (Siciliano et al., 2020; Wang et al., 2020). In addition to seeing a reduction in pollution levels, a study by Zoran et al. (2020) found that COVID-19 daily cases in Milan, Italy, were positively associated with the air quality index, thereby suggesting the importance of studying air quality patterns during the pandemic.

While this prior work demonstrated the effectiveness of lockdown measures on decreasing air pollution in different geographical locations, there is limited evidence that shows whether the lockdowns implemented in Kuwait were effective in terms of reducing air pollution. Studying the role of lockdowns on air quality in Kuwait is particularly important since prior research has reported that Kuwait's air quality exceeded the allowable range for $PM_{2.5}$, PM_{10}, and NO_2 (Al-Hemoud et al., 2019; Al-Hurban et al., 2021) resulting in poor air quality (Bouhamra & Abdul-Wahab, 1999). In terms of the impact of the COVID-19 lockdowns, a recent study by Alhemoud et al. (2019) found that the $PM_{2.5}$ and PM_{10} levels were less by 18% and 31%, respectively, compared to the corresponding data in previous years. However, this study was based on understanding the impact of only $PM_{2.5}$ and PM_{10}, and not other criteria pollutants such as NO_2 and O_3. Therefore, there is limited evidence on the impact of the reduction in human activities (e.g., lockdowns) on the reduction of air pollution in the State of Kuwait.

In order to fill these research voids, the main objective of this paper is to assess the impact of the COVID-19 lockdown measures on Nitrogen Dioxide (NO_2), Ozone (O_3), Particulate Matter 2.5 ($PM_{2.5}$) and Particulate Matter 10 (PM_{10}) levels in the State of Kuwait across three different lockdown periods in 2020. The findings from this research can be used to guide public policies regarding reducing pollution levels. Specifically, it provides one of the first national evidence on the impact of the reduction of human activities (e.g., motor vehicle emissions and industrial activities) on air pollution levels.

The remainder of this paper is organized as follows: Section 2 describes the methodology used in this study. Section 3 presents the results showcasing the impact of lockdowns during COVID-19 in Kuwait. Section 4 discusses the details of lockdowns effects as well as gives the limitations and future directions for the current study. Finally, conclusions drawn are described in Section 5.

METHODS

The main goal of this study is to evaluate the impact of three different COVID-19 lockdown measures on air pollution levels in Kuwait. In order to address this research objective, air pollution data was collected from the Kuwait Environmental Protection Agency (K-EPA). The remainder of this section outlines the methodological approach taken in the current study.

Study Area

The State of Kuwait is located in the Middle East in the northwestern part of the Arabian Gulf. Kuwait shares a northern border with Saudi Arabia and a southern border with Iraq (Casey et al., 2007). The land of Kuwait spans 16,000 square kilometers and the nation has a population of ∼4.3 million (Al-Herz et al., 2021). There are 15 air quality monitory stations in Kuwait that fall under the supervision of the Kuwait Environmental Protection Agency (K-EPA) (Al-Hurban et al., 2021). For the purposes of this study, data from the following two stations were selected for analyses: Aljahra and Alahmadi, Figure 1 depicts their geographical locations. The selection of

Figure 1. Geographical locations of Aljahra and Alahmadi in Kuwait

these two stations was based on the variety of land uses and the diversity of the geography. Specifically, AlAhmadi is an industrial area South side of Kuwait that includes the nation's main oil refineries. Meanwhile, AlJahra is a residential area in the West side of Kuwait.

Data Sources

The study presented in this paper is based on annual air pollution data collected from the KEPA. The dataset included air pollution data during five different periods, as shown in Table 1. Specifically, the dataset provided included daily concentrations of Nitrogen Dioxide (NO_2), Ozone (O_3), Particulate Matter 2.5 ($PM_{2.5}$) and Particulate Matter 10 (PM_{10}) from January 01, 2020, to December 31, 2020. The pre-lockdown period was assumed to be from the first of January to 22 March, see Table 1. Meanwhile, there were two partial lockdown periods. The first partial lockdown happened from March 23, 2020, to May 10, 2020, and the other partial lockdown occurred from May 31, 2020, to August 31, 2020. The total lockdown occurred from May 11, 2020, to May 30, 2020.

Finally, the period from September 01, 2020, to December 31, 2020, is defined in this paper as the post-lockdown period.

Table 1: Lockdown periods in Kuwait.

Period	Description
01-01-2020 to 22-03-2020	Before the lockdown
23-03-2020 to 10-05-2020	Partial lockdown
11-05-2020 to 30-05-2020	Total lockdown
31-05-2020 to 31-08-2020	Partial lockdown
01-09-2020 to 31-12-2020	Post-lockdown

The first partial lockdown involved a nationwide curfew from 5pm until 4am where all individuals, except frontline workers, were not allowed to leave their homes (Burhamah et al., 2020). Meanwhile, the total lockdown involved a 24-hr curfew where all individuals, except for front-line workers, were not allowed to leave their homes round-the-clock. The second partial lockdown also involved a nationwide curfew from 6pm to 6am. Notably, all lockdowns were implemented involuntary and were military-enforced, and violators of the lockdowns faced legal prosecutions. All three lockdowns have led restaurants, gyms and entertainment venues to be closed, in addition, to air traffic reduction (Burhamah et al., 2020).

Data Analysis

Munir et al. (2021) suggested two main analytical approaches to analysing air quality data to assess the impact of COVID-19 lockdowns. First, the sequential approach compares air quality data in the pre-lockdown periods with the lockdown periods. Second, the parallel approach compares air quality data from 2019 or earlier years with air quality for the equivalent time during the lockdowns in 2020. This study utilized the sequential approach where the pre-lockdown air quality data (Rodríguez-Urrego & Rodríguez-Urrego, 2020; Tobías et al., 2020) were compared with the lockdown data to ascertain whether the lockdown had an impact on reducing pollutants during consecutive time periods.

Python (Lutz, 2001) programming language was used to perform data analysis for this study. For instance, the KNN Imputer algorithm from sklearn.impute Python library (Pedregosa et al., 2011) was applied to handle missing values. This algorithm utilizes the mean value from k-nearest neighbors to impute missing values. Python was used to prepare data and generate several figurative forms to visualize and analysis data efficiently. Figure 2 outlines the data analyses plan used in this study.

RESULTS

This study aimed at studying the role of COVID-19 lockdown measures on air pollution levels in the State of Kuwait in the year 2020 using data from two different air monitoring stations. In order to address this research objective, statistical analyses were computed using SPSS 27.0, and a significance level of 0.05 was used in all analyses, unless otherwise denoted.

To analyze pollution levels at each station (Aljahra and Alahmadi), four Kruskal-Wallis one-way analysis of

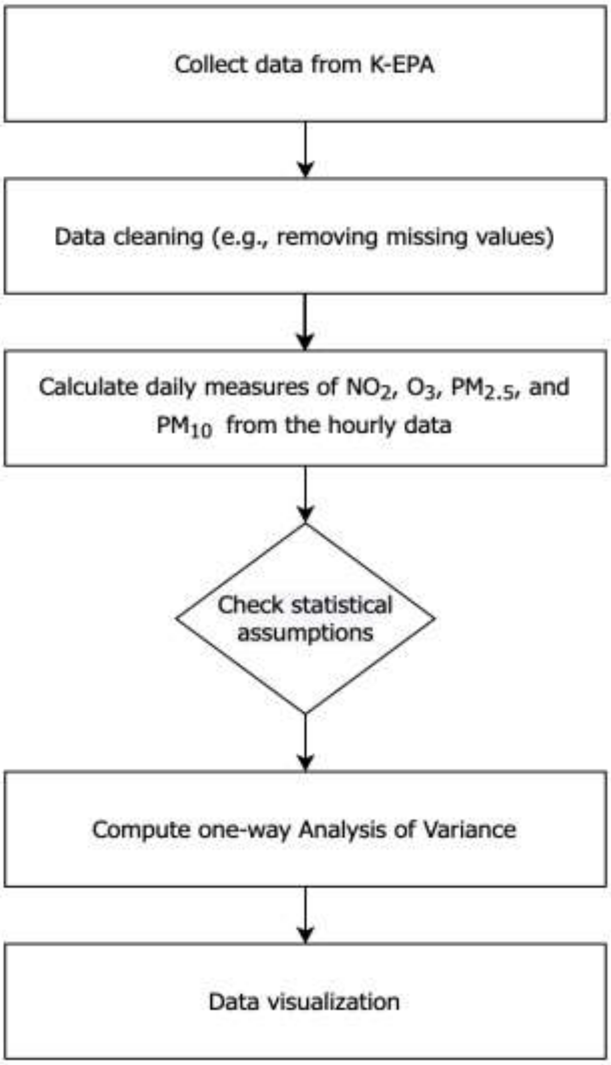


Figure 2. Flow diagram for the statistical analyses conducted in this study

variances (ANOVAs) (McKight & Najab, 2010) were computed for each station's data with the independent variable being the time period (before lockdown, the first partial lockdown, total lockdown, the second partial lockdown, post lockdown). Meanwhile, the dependent variables were the NO_2, O_3, $PM_{2.5}$, and PM_{10} pollution levels for the first, second, third, and fourth ANOVA tests, respectively. A non-parametric test was computed since the data was not normally distributed according to the Kolmogorov-Smirnov and Shapiro-Wilk tests $p < 0.05$ (Miot, 2017).

Table 2. Summary statistics of the Kruskal-Wallis ANOVA tests (note: all tests were statistically significant – p < 0.01)

Pollutant	AlJahra	ϵ^2	Alahmadi	ϵ^2
NO_2	$\chi^2(4) = 196.35$	0.53	$\chi^2(4) = 111.48$	0.29
O_3	$\chi^2(4) = 91.62$	0.24	$\chi^2(4) = 122.96$	0.32
PM_{10}	$\chi^2(4) = 22.36$	0.05	$\chi^2(4) = 48.69$	0.12
PM2.5	$\chi^2(4) = 217.97$	0.59	$\chi^2(4) = 14.90$	0.025

Before running the statistical analyses, the necessary assumptions were checked. First, the box and-whisker plot (Dawson, 2011) revealed 4, 2, 7, and 15 outliers from the NO_2, O_3, $PM_{2.5}$ and PM_{10} dependent variables from Aljahra station. Additionally, there were 2, 15, and 16, outliers from the NO_2, $PM_{2.5}$ and PM_{10} dependent variables from Alahmadi station. In order to determine the impact of the outliers on the results, the statistical analyses were conducted with and without the outliers. The outliers did not have an impact on the significance of the results and therefore, the full analysis (with outliers) was used in the current analysis.

The Kruskal-Wallis ANOVA tests revealed a statistically significant difference in NO_2, O_3, $PM_{2.5}$ and PM_{10} across the lockdown periods for both Aljahra and Alahmadi stations, as listed in Table 2. Subsequently, in order to obtain pairwise comparisons, Bonferroni corrections were used to make multiple comparisons (Dunn, 1964). Notably, all pairwise comparisons with the before lockdown period were statistically significant indicating there was a change in the pollution levels, $p < 0.05$. Table 3 outlines the summary statistics of the pairwise comparisons, and Table 4 outlines the percentage changes of the pollutants for both Aljahra and Alahmadi stations, respectively. The visualization of the air pollution differences is illustrated in (Alsager Alzayed et al., 2022).

ime Period	Average NO_2		Average O_3		Average PM_{10}		Average $PM_{2.5}$	
	A ljahra	A lahmadi	A ljahra	A lahmadi	A ljahra	A lahmadi	A ljahra	A lahmadi
st partial lockdown	1 30.288 ±19.043	6 .974 ±18.426	1 43.223 ±19.043	1 09.415 ±18.426	8 .160 ±19.043	7 .745 ±18.426	2 4.619 (19.043)	2 6.305 ±18.426
otal lockdown	1 88.989 ±25.766	3 5.345 ±37.798	1 95.410 ±25.766	1 91.012 ±37.798	8 3.751 ±25.766	2 2.564 ±37.798	1 27.564 (25.766)	4 9.366 ±37.798

nd partial lockdown	130.469 ±16.032	33.009 ±15.498	87.538 ±16.032	155.523 ±15.498	9.256 ±16.032	90.037 ±15.498	105.710 (16.032)	33.982 ±15.498
ost-lockdown	23.781 ±15.106	130.235 ±14.572	65.088 ±15.106	52.697 ±14.572	27.683 ±15.106	-56.529 ±14.572	204.294 ±15.10	1.308 ±4.572

Table 3: Summary statistics of the pairwise comparisons between average concentrations of (NO_2, O_3, $PM_{2.5}$ and PM_{10}) between the period before the lockdown and during the lockdown periods (Test statistic presented with ± standard error)

Table 4: Percentage changes of average concentrations of (NO_2, O_3, $PM_{2.5}$ and PM_{10}) between the period before the lockdown and during the lockdown periods (pollutants measured in $\mu g/m^3$)

Time Period	Average NO_2		Average O_3		Average PM_{10}		Average $PM_{2.5}$	
	Al jahra	Alahmadi	Al jahra	Alahmadi	Al jahra	Alahmadi	Al jahra	Alahmadi
Before the lockdown	0.019	0.027	0.022	0.014	126.745	87.593	25.226	53.975
1st partial lockdown	0.010	0.028	0.034	0.022	139.809	86.155	26.143	47.274
Percentage change	-47.638%	3.704%	54.545%	57.143%	10.307%	-1.642%	3.635%	-12.415%
Total lockdown	0.007	0.028	0.040	0.028	162.262	111.452	27.850	55.554
Percentage change	-63.158%	3.704%	81.818%	100%	28.022%	27.238%	10.402%	2.925%
2nd partial lockdown	0.010	0.033	0.029	0.025	117.269	126.974	27.484	62.500
Percentage change	-47.638%	22.222%	31.818%	78.571%	-7.476%	44.959%	8.951%	15.794%
Post-lockdown	0.021	0.048	0.027	0.017	112.443	89.194	31.642	40.870

Percentage change	10.526%	77.778%	22.727%	21.429%	-11.284%	1.828%	25.434%	-24.280%

DISCUSSION

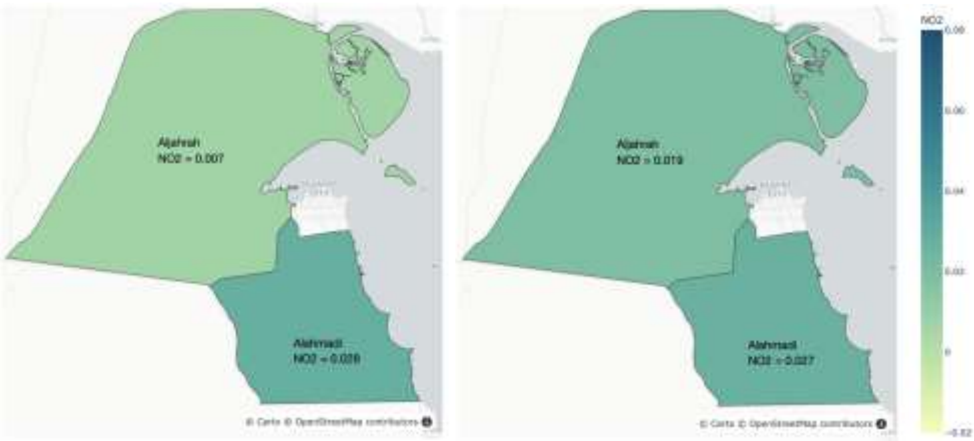
The main goal of the study presented in this paper was to assess the impact of three different COVID-19 lockdown measures on Nitrogen Dioxide (NO_2), Ozone (O_3), Particulate Matter 2.5 ($PM_{2.5}$) and Particulate Matter 10 (PM_{10}) levels in the State of Kuwait in 2020. The main findings from the study are the following:

- NO_2 concentrations decreased by 48%, 63%, and 48% after the first partial, total lockdown, and the second partial lockdowns, respectively at Aljahra station.
- Ozone concentrations increased by 30-100% across all lockdown periods for both stations.
- PM_{10} and $PM_{2.5}$ concentrations remained steady without decreasing during the total lockdown period.

The implications of these results are discussed in the remainder of this section.

The first key finding from this study highlighted that the nitrogen dioxide concentrations decreased across all lockdowns for Aljahra station, see Table 3. Specifically, NO_2 concentrations decreased by 48%, 63%, and 48% after the first partial lockdown, total lockdown, and the second partial lockdowns, respectively. Meanwhile, in Alahmadi station, there was a 3.7% increase in NO_2 concentrations after the first partial lockdown and total lockdown, and a 22% increase in NO_2 concentrations after the second partial lockdown. Notably, Aljahra station resembled a residential area in Kuwait while Alahmadi station resembled an industrial area. The Alahmadi area includes Kuwait's main oil refineries (Saleh et al., 1989) that continued operating throughout the lockdowns meaning that the area did not really endure a significant reduction in motor vehicle traffic and/or industrial operations which contribute to air pollution. While NO_2 concentrations decreased across the three lockdowns, we see that NO_2 concentrations increased by 10.5% and 77.8% in Aljahra and Alahmadi stations, respectively in the period post-lockdown, indicating that the concentrations were returning to the "status quo". These results further confirm the impact of the lockdowns on reducing NO_2 concentrations.

As an illustrative example, the two maps in Figure 3 depict the main changes in NO_2 concentrations for Aljahrah and Alahmadi. The map in Figure 3(b) represents the span before the lockdown, while the map in Figure 3(a) depicts NO_2 concentrations during the total lockdown period. It is evident that NO_2 concentrations decreased in Aljahra throughout the given interval. For instance, NO_2 concentrations dropped from 0.019 ($\mu g/m^3$) to 0.007 (($\mu g/m^3$), during the total lockdown. In contrast, NO_2 concentrations in Alahmadi remained steady with a minor increase of 0.001 (ug/m^3).



(a) During total lockdown (b) Before lockdown

Figure 3. NO_2 concentrations ($\mu g/m^3$) before and during total lockdown

The second key finding from this paper indicated that ozone concentrations increased across all lockdown periods for both Aljahra and Alahmadi stations, as listed in Table 3. In Aljahra, the average ozone concentrations increased by 54.5%, 81.8% and 31.8% after the first partial lockdown, total lockdown, and the second partial lockdown, respectively, see Figure 2 in (Alsager Alzayed et al., 2022). Similarly, in Alahmadi, the average ozone concentrations increased by 57.1%, 100% and 78.6% after the first partial lockdown, total lockdown, and the second partial lockdown, respectively. These findings corroborate the findings from a study by Hashim et al. (2021) that reported an increase in ozone concentrations across a series of lockdowns in Baghdad, Iraq. Further, these findings confirm previous research that discussed an inverse relationship between environmental ozone and nitrogen dioxide concentrations (Siciliano et al., 2020; Wang et al., 2020; Zoran et al., 2020).

While the first two findings highlighted the impact of the total lockdown in reducing NO_2 and O_3 concentrations, the third key finding from this study indicated that the total lockdown was not effective in the reduction of $PM_{2.5}$ and PM_{10} concentrations. In fact, PM_{10} and $PM_{2.5}$ levels increased at Aljahra and Alahmadi stations, as illustrated in Figures 3 and 4 in (Alsager Alzayed et al., 2022). However, we saw some decreases in PM_{10} and $PM_{2.5}$ from the partial lockdowns. For example, PM_{10} decreased by 7.47% during the second partial lockdown. Meanwhile, both $PM_{2.5}$ and PM_{10} decreased by 12.41% and 1.64% respectively. These findings partially confirm a recent parallel study by Alhemoud et al. (2019) that found that the combination of the first partial lockdown and total lockdown (March-May 2020) reduced PM_{10} and $PM_{2.5}$ levels by 18% and 31%, respectively when compared to the same periods in the years 2017-2019.

The study presented in this paper is one of the first to examine the role of COVID-19 lockdowns on air pollution in Kuwait. However, there are several limitations that could lead to novel areas for future research. First, while this study examined pollution at two air monitoring stations, future research is warranted to extend the findings across the remaining air monitoring stations in Kuwait. Second, while prior research has attributed road vehicles as being a main contributor to air pollution (Siciliano et al., 2020; Wang et al., 2020), vehicle data from Aljahra and Alahmadi was not readily available at the time of this study. Thus, future research is warranted to examine the impact of motor vehicles on the road pre-and-post- lockdown periods on the reduction of pollution levels in the State of Kuwait. Third, while this study displayed a series model that compared air pollution levels from January-March 2020 to the different lockdown periods, future studies should replicate this study with a parallel model (Sharma et al., 2020; Sicard et al., 2020; Siciliano et al., 2020) that compares air pollution during the lockdown periods with the air pollution data in the same periods in the previous years. Finally, a possible future extension of this work is to implement a machine learning model to predict pollution levels, such a model will be trained and validated based on data from previous years. The model can predict pollutant levels during lockdowns which can allow for the investigation of the variation in pollutant levels in a robust manner.

CONCLUSION

This paper aimed at studying the impact of three different COVID-19 lockdown measures on the concentrations of the following four different pollutants in the State of Kuwait: Nitrogen Dioxide (NO_2), Ozone (O_3), Particulate Matter 2.5 ($PM_{2.5}$) and Particulate Matter 10 (PM_{10}) levels across three different lockdown periods in 2020. The main findings from this paper indicated that NO_2 concentrations decreased by 48%, 63%, and 48% after the first partial, total lockdown, and the second partial lockdowns, respectively in Aljahra station. Ozone concentrations increased by 30-100% across all lockdown periods for both stations. Finally, PM_{10} and $PM_{2.5}$ concentrations did not decrease during the total lockdown. The results from this study add to the existing body of evidence on the impact of the reduction of motor vehicle emissions and industrial activities on air pollution levels. However, this study warrants future research that could examine air pollution levels across other regions of Kuwait. The findings from this study provide strong evidence that strict public policy measures (e.g., lockdowns) could have a significant impact on achieving a reduction in pollution levels (Aaker & Bagozzi, 1982). Notably, the results from this study show that even a partial reduction in human activities (e.g., partial lockdown) could result in more than 40% reduction in NO_2 levels. Given the effectiveness of such measures, as evident in this study, this research urges public policy experts to consider immediate measures to mitigate the environmental, health, social, and economical risks posed by air pollution.

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