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Effect of climatology parameters on air pollution during COVID-19 pandemic in Jordan

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ABSTRACT

This study aims to explore the real-time impact of the COVID-19 pandemic on measured air pollution in the three largest cities of Jordan (Amman, Irbid and Zarqa). It is hypothesized that a sharp decrease in the emitted amounts of particulate matter (PM10), CO, NO2 and SO2 during COVID-19 pandemic will be obtained, this corresponds with the reduced traffic due to mandated business closures. To achieve this exploration a paired sample t-test is used to compare the concentration of these four pollutants in the three cities over the period from 15 March to 30 June during the years from 2016 to 2020. It is found that there is a significant difference between the emitted concentrations mean values of CO, PM10, SO2 and NO2 during the period of study. This was indicated by the values of p for each species, which was less than 5 % for all these pollutants.

The maximum reduction in SO2 and NO2 concentration during the lockdown period was in Zarqa. Irbid city witnessed the highest percentage reduction in CO and PM10. Furthermore, the correlation test, independent variable importance of multilayer perceptron and global sensitivity analysis using Sobol analysis showed that metrological data (Humidity, wind speed, average temperature and pressure) have a direct relationship with concentrations of CO, PM10, SO2 and NO2 in Amman, Irbid and Zarqa before and after COVID-19 pandemic.

1. Introduction

Since its widespread, COVID-19 pandemic has drastically affected human society in many aspects such as, education, health care, social relationships, and economic structures. As a result, almost all infected countries witnessed different levels of response to this pandemic including closures of businesses and social distancing. The severe health impacts of the COVID-19 emerged as a top priority. The effect of this pandemic on air pollution is an important risk factor due to its cardiovascular and respiratory health outcomes (Burnett et al., 2018). Consequently, it is essential to fully investigate and understand how air pollution is affected by COVID-19, this will provide important clues regarding health and control of air pollution emissions.

Coronavirus disease 2019 (COVID-19), was acknowledged as a global pandemic by the World Health Organization (WHO) on March 11, 2020. It has posed a severe threat to human health and caused widespread panic all around the world (Zhang et al., 2020). Concerns on how this pandemic will affect the concentration of different airborne species has grown and consequently researches have focused their work on this issue (He et al., 2020; Kang et al., 2020; Liu et al., 2020).

In the USA, air quality during the COVID-19 pandemic was investigated by Berman and Ebisu (2020) for fine particulate matter (PM2.5) and Nitrogen dioxide. They conducted their study, using available data during the period from January 8th to March 12th 2020. They compared this available data with that measured during the same period from 2017 to 2019. They found that a significant decrease in Nitrogen oxide (25.5 %) was observed during the current COVID-19 period. Similarly, a drop was observed in PM2.5 concentrations during this period. This drop in both species was significant in urban countries and countries from states instituting early non-essential business closures.

Wang et al. (2020) investigated the emission and meteorology conditions for air pollution during the outbreak of COVID-19 in nine cities in China using the Community Multi-Scale Air Quality model (CMAQ). They concluded that in spite of observable reduction in PM2.5 in these cities, more measures should be taken into consideration to completely avoid severe impact of air pollution.

Bichí (2020) Stated that COVID-19 may be transmitted through air environment, as he indicated that particles that are suspended in air may...
lead to coronavirus travel further in air and hence the pandemic has its sever impact on regions characterized by significant air pollution. As a result, the impact of COVID-19 on regions which suffered lockdown is less sever compared with regions on which lockdown was not imposed, this is due to the effect of improved air quality as a consequence from the lockdown. Finally, he concluded that Countries with high level of air pollution need to take measures to improve their air quality. Based on that, Transport of COVID-19 virus by air pollution particles may be a factor, but it is likely that the reduction in people movement is much more of a factor.

Bashir et al. (2020) analyzed the relation of COVID-19 cases with metrological data in New York including average temperature, minimum temperature, maximum temperature, rainfall, average humidity, wind speed, and air quality. They concluded that, the minimum and maximum temperatures together with air quality are significantly related to the number of COVID-19 positive cases.

Méndez-Arriaga (2020) used Statistical analysis to investigate the association between the daily local COVID-19 positive cases and both climate characteristics and the regional metrological data in 31 states and the capital city Mexico from February 29 to March 31, 2020. He concluded that there is no concrete association between temperature and positive cases, while precipitation is positively associated to positive cases.

Tobias et al. (2020) studied the effect of lockdown in Barcelona/Spain on the level of atmospheric pollutants, which was achieved by investigating the time evolution of pollutants recorded at urban background and traffic air quality monitoring stations. They found that, after two weeks of lockdown the BC and NO2 emitted pollutants have drastically cut down (~45 to ~51 %), which mainly related to traffic emission, at the same period, the reduction in PM10 was recorded from 28 to 31 %. However, they also found that the quantity of O3 increased from 33 to 57 %. Based on that, we may conclude that only the time of the year affected the pollutant concentration, not the meteorological data.

COVID-19’s impact on the environment resulted in improved environmental conditions, in brief, the positive effects have been reduced GHG (greenhouse gas) emissions, improved water quality, reduced noise pollution, improved air quality and in some cases, wildlife restoration. Negative effects have been increased medical waste, haphazard disposal of personal protective equipment (PPE), increased municipal waste and reduced recycling efforts. In this study, such positive of COVID-19 on the environment in three cities in Jordan is investigated.

The main objective of this study is to explore the real-time impact of the COVID-19 pandemic on measured air pollution in the three largest cities of Jordan (Amman, Irbid and Zarqa). It is hypothesized that a sharp decrease in the emitted amounts of particulate matter (PM10), CO, NO2 and SO2 during COVID-19 pandemic will be obtained, this corresponds with the reduced traffic due to mandated business closures. Furthermore, the sensitivity analysis between metrological data before and after COVID-19 pandemic is conducted using Sobol method and independent variable importance of multilayer perceptron.

2. Methods

2.1. Study area

Jordan lies between latitudes 29°19’ N and 32°35’ N (southern region up to 31°12’ N, middle region up to 32°05’ N, and northern region up to 32°35’ N) (Satieha et al., 2011). The area of Jordan is 89,342 km2. Currently, the total population of Jordan exceeds ten million.

To explore the real-time impact of the COVID-19 pandemic on measured air pollution in Jordan, (Amman, Irbid and Zarqa) the three largest cities of Jordan were selected as case studies based on the availability of data. Unfortunately, these are the only cities with available data in Jordan.

Amman is the capital and largest city of Jordan and the country’s economic, political and cultural center, with a population of 4,007,526. Amman’s terrain is typified by its mountains. The most important areas in the city are named after the hills or mountains they lie on. The area’s elevation ranges from 1000 to 1100 m. In Amman, the climate is overall mild and dry, summers are moderately long, hot and sunny with average temperature around 32 °C. Spring is mildly hot and breezy, where highs reach 28 °C. Spring usually starts between April and May, and lasts about a month. Winter usually starts around the end of November and continues from early to mid-March. Temperatures are usually near or below 17 °C, with snow occasionally falling once or twice a year. Rain averages about 300 mm a year.

Irbid has the second largest metropolitan population in Jordan after Amman, with a population of around 1,911,600. Irbid is located about 70 km north of Amman, and approximately 20 km south of the Syrian border. Irbid has a hot-summer, the climate is a local steppe climate, with daytime temperature around 38 °C. Winter temperatures are similar with those of Amman. Rain averages about 450 mm a year.

Zarqa is the third largest city in Jordan, with a total population of almost 800 thousand. It is located 19 km northeast of Amman. In Zarqa, the climate is desert, the summers are long, hot, arid, and clear and the winters are cold and mostly clear. At the course of the year, the temperature typically varies from 5 °C in winter to 33 °C in summer. Rain averages about 182 mm a year.

2.2. Data collection

In this work, the daily concentration data of CO, NO2, PM10 and SO2 in the three cities (Amman, Irbid and Zarqa) over the period from 15 March to 30 June, from 2016 to 2020, were obtained from the World Air Quality Project website (https://aqicn.org/) and the Jordanian Ministry of Environment. Unfortunately, these are the only daily pollutants concentration data available for Jordan.

In this work, Paired Sample (t) test was conducted to compare the concentration of the four pollutants (CO, NO2, PM10 and SO2) in the three cities in Jordan. Also, sensitivity analysis between metrological data before and after COVID-19 pandemic was conducted using Sobol method and independent variable importance of multilayer perceptron.

3. Results and discussion

3.1. Pollutants reduction due to COVID-19 pandemic

The concentrations of the emitted pollutants CO, NO2, PM10 and SO2 and the standard error of mean (SEM) in the three cities under consideration, during the period from 15 March to 30 June, within the years from 2016 to 2020 are presented in figures (1 through 3) respectively. As indicated, the emitted amount of PM10 is maximum in 2016 through 2019, followed by that of CO and NO2, while the least emitted amount is that of SO2. Also, it may be noted that all values of species concentrations are reduced in this period in 2020 compared with those during 2016 through 2019, this due to the effect of lockdown imposed during the three months period in 2020.

Figure (4) shows the percentage of reduction in the pollutant concentration in the three selected cities (Amman, Irbid and Zarqa). It can be noticed from this figure that the maximum reduction in the emitted four selected pollutants during the lockdown period was that of SO2, with the maximum reduction in this pollutant was in Zarqa, followed by Amman and then in Irbid. Furthermore, there was a significant reduction in the emitted concentration of NO2, with the maximum reduction in Zarqa city as well. Both cities, Amman and Irbid almost have the same reduction. The high reduction in both SO2 and NO2 are in Zarqa city and this could be attributed to the shutdown of industries in this city during the lockdown period. These industries utilize high sulfur and nitrogen fuel contents as impurities.

Also shown in Fig. 4 that the percentage reduction in the emitted pollutants of CO and PM10 are not as high as that of both NO2 and SO2, with the total reduction of PM10 in the three cities exceeds that of CO.
Irbid city witnessed the highest percentage reduction in these two pollutants, followed by the city of Amman and the least reduction was in Zarqa. It is believed that the main reason caused by this is the transport sector.

Paired Sample t-test was used to compare the daily concentration of the four pollutants (CO, NO\textsubscript{2}, PM\textsubscript{10} and SO\textsubscript{2}) in the three cities. The test results are presented in Table 1 through 3. These tables indicate that there is a significant difference between the mean values of CO, PM\textsubscript{10}, SO\textsubscript{2} and NO\textsubscript{2} emitted concentrations during the three months period in the years (2016 through 2019) and those emitted in 2020, this is indicated by the values of p for each species, which is less than 5 % for all these pollutants.

As shown in Table 1, the daily emitted concentration mean values of CO, NO\textsubscript{2}, PM\textsubscript{10} and SO\textsubscript{2} in Amman were decreased by 0.98, 1.64, 7.37 and 1.25 respectively during the three months lockdown period in 2020 compared to those of (2016–2019) during the same three months. Finally, the 95 % confidence interval for the difference in the concentration of CO is from 0.43 to 1.56, while for NO\textsubscript{2} is from 0.23 to 3.05 and for PM\textsubscript{10} is from 2.15 to 12.5 and for SO\textsubscript{2} it is from 0.94 to 1.58.

While Table 2 indicates that the concentrations of CO, NO\textsubscript{2}, PM\textsubscript{10} and SO\textsubscript{2} in the city of Irbid were decreased in the mean values by 2.98, 1.24, 7.83 and 0.86 respectively during the three months lockdown period considered in this work. Also shown in Table 2 the 95 % confidence interval for the difference in the concentration of CO is from 0.43
to 5.53, while for NO$_2$ is from 0.31 to 2.16 and for PM$_{10}$ is from 3.58 to 12.09 and for SO$_2$ it is from 0.45 to 1.29.

Table 3 indicates that the concentrations of CO, NO$_2$, PM$_{10}$ and SO$_2$ in the city of Zarqa. It may be noticed that the emitted concentrations of these species were decreased in the mean values by 0.47, 7.84, 4.17 and 8.18 respectively during the three months period considered in this work. Also shown in Table 3 the 95% confidence interval for the difference in the concentration of CO is from -2.46 to 3.4, while for NO$_2$ is from 6.05 to 9.58 and for PM$_{10}$ is from -1.39, 9.68 to and for SO$_2$ it is from 7.18 to 9.17.

3.2. Air pollution and meteorological data

It is of importance to correlate metrological data variables (Humidity, Wind speed, Average temperature and Pressure) of the three cities to the amount of daily emitted pollutants (CO, NO$_2$, PM$_{10}$ and SO$_2$). Having achieved this, independent variable importance of multilayer perceptron was found and sensitivity analysis between variables was conducted using Sobol method.

3.2.1. Normality test

A normality test was conducted. The basic assumption of Pearson’s correlation for the four variables in the three cities was not achieved. The P-value from the Kolmogorov-Smirnov test of normality was found
to be 0.000, which is less than 0.05. The P-value from the Shapiro-Wilk test of normality was found to be 0.00, which is less than 0.01. Based on these results, the assumption that the normal distribution of the concentration of CO, NO$_2$, PM$_{10}$ and SO$_2$ was found to be not acceptable, as a result, the Spearman correlation test (non-parametric correlation estimation) was used to examine and determine the relationships between the concentration of CO, NO$_2$, PM$_{10}$ and SO$_2$ in Amman, Irbid and Zarqa and weather variables. A bivariate, two-tailed analysis at $\alpha = 95\%$ as a confidence interval was applied.

### 3.2.2. Correlation test

Since normality assumption was not satisfied, Spearman correlation test was used for data analysis. Tables (4) and (5) show the results of the data analysis from 2016 to 2020 for the correlation test including the parameters that are correlated with each emitted pollutant concentration (P-value are less than 0.05) and those who do not correlate (P-value higher than 0.05).

Table 4 below, represents Spearman correlation test results before COVID-19 pandemic from 2016 to 2019 for the three cities under investigation. As indicated, for Amman city, humidity, wind speed, average temperature and pressure were not significantly correlated with CO concentration. Furthermore, humidity, wind speed and pressure were not significantly correlated with NO$_2$ and SO$_2$ concentration, while average temperature was significantly correlated with NO$_2$ and SO$_2$.

![Fig. 3. (a) Mean of the emitted pollutant concentration in Zarqa, (b) Mean Standard Error of emitted pollutants in Zarqa.](image-url)
Finally, humidity, wind speed and pressure were not significantly correlated with PM$_{10}$ concentration, with average temperature being significantly correlated with PM$_{10}$ concentration. Test results in Irbid show that the wind speed and pressure were not significantly correlated with CO concentration, while humidity, and average temperature were significantly correlated with CO concentration. Also shown in the table, humidity, wind speed, average temperature and pressure were not significantly correlated with NO$_2$ concentration. Furthermore, wind speed and pressure were not significantly correlated with SO$_2$ concentration and humidity and average temperature were significantly correlated with SO$_2$ concentration. Finally, for the city of Irbid, it is indicated that, humidity, average temperature and pressure were not significantly correlated with PM$_{10}$ concentration.

Finally, the spearman correlation test results in Zarqa show that the wind speed was not significantly correlated with CO concentration, while humidity, average temperature and pressure were significantly correlated with CO concentration. Also, it is indicated that average temperature, and pressure were not significantly correlated with NO$_2$ concentration, but humidity and wind speed were significantly correlated with NO$_2$ concentration.
correlated with NO concentration. Furthermore, humidity, wind speed, average temperature and pressure were significantly correlated with SO2 concentration. Finally, humidity, wind speed, average temperature and pressure were not significantly correlated with PM10 concentration.

Spearman correlation test results after COVID-19 pandemic in 2020 are represented in Table 5. For the city of Amman, wind speed and pressure were not significantly correlated with CO and NO2 concentrations, while humidity and average temperature were significantly correlated with CO and NO2 concentrations. Also indicated in the table, humidity, wind speed, average temperature and pressure were not significantly correlated with SO2 concentration. Finally, pressure was not significantly correlated with PM10 concentration, with humidity, wind speed, average temperature and pressure being significantly correlated with PM10 concentration.

Test results in Irbid show that the pressure was not significantly correlated with CO concentration, while humidity, wind speed, and average temperature were significantly correlated with CO concentration. Also shown in the table, wind speed and pressure were not significantly correlated with NO2 concentration, while humidity and average temperature were significantly correlated with NO2 concentration. Furthermore, humidity and wind speed were not significantly correlated with SO2 concentration and average temperature and pressure were significantly correlated with SO2 concentration. Finally, for the city of Irbid, it is indicated that, average temperature and pressure were not significantly correlated with PM10 concentration, while humidity and wind speed were significantly correlated with PM10 concentration.

The spearman correlation test results in Zarqa show that the wind speed and pressure were not significantly correlated with CO concentration, while humidity and average temperature were significantly correlated with CO concentration. Also, it is indicated that average temperature and pressure were not significantly correlated with NO2 concentration.

| City | Pollutant | Correlation Coefficient | P-value | Humidity | Wind speed | Temperature | Pressure |
|------|-----------|-------------------------|---------|----------|------------|-------------|----------|
| Amman | CO        | -0.095                  | 0.866   | 0.155    | 0.422      | 0.355      | 0.079    |
|       | NO2       | -0.089                  | 0.361   | 0.112    | 0.000      | 0.373      | 0.007    |
|       | SO2       | -0.016                  | 0.065   | 0.067    | 0.025      | 0.560      | -0.151   |
|       | PM10      | -0.105                  | 0.281   | 0.098    | 0.000      | 0.062      | 0.216    |
| Irbid | CO        | 0.358                   | 0.000   | 0.824    | 0.000      | 0.367      | -0.471   |
|       | NO2       | 0.065                   | 0.506   | 0.707    | 0.871      | 0.942      | -0.007   |
|       | SO2       | -0.248                  | 0.012   | 0.176    | 0.000      | 0.206      | -0.126   |
|       | PM10      | 0.909                   | 0.924   | 0.016    | 0.930      | 0.907      | -0.011   |
| Zarqa | CO        | -0.536                  | 0.000   | 0.728    | 0.000      | 0.774      | -0.794   |
|       | NO2       | -0.381                  | 0.000   | 0.354    | 0.000      | 0.000      | -0.145   |
|       | SO2       | -0.491                  | 0.000   | 0.001    | 0.128      | 0.173      | -0.243   |
|       | PM10      | 0.203                   | 0.060   | 0.337    | 0.191      | 0.470      | -0.079   |

Table 5: Spearman correlation test results after COVID-19 pandemic in 2020.
concentration, but humidity and wind speed were significantly correlated with NO₂ concentration. Furthermore, wind speed, average temperature and pressure were not significantly correlated with SO₂ concentration, while humidity was significantly correlated with SO₂ concentration. Finally, wind speed and pressure were not significantly correlated with PM₁₀ concentration, with humidity, and average temperature being significantly correlated with PM₁₀ concentration.

Based on the spearman correlation test results, it may be noticed that the metrological data of the three cities varies in their effect on the concentration of the four pollutants (CO, NO₂, SO₂, and PM₁₀).

### 3.2.3. Multilayer perceptron (MLP)

Multilayer perceptron (MLP) is a popular feed-forward neural network architecture. MLP consists of three layers, namely input, output, and hidden layers (Ahmadi et al., 2019). Independent variable importance which was conducted by using MLP represents the measuring of how much the network’s model-predicted value changes for different values of the independent variable (Abdelhafez et al., 2021).

Based on trial and error method, MLP technique, with 10 hidden neurons and using 70% of the data for training, 15% testing and 15% for validation, was conducted to obtain the best model for the concentration of the four pollutants (CO, NO₂, SO₂, and PM₁₀).

![Fig. 5. Independent variable importance for Amman, (a) from 2016 to 2019 (b) in 2020.](image-url)
Figure (5-a) and figure (5-b), show independent variable importance in Amman for the period from 2016 to 2019 and in 2020 respectively. As indicated in Fig. 5-a, humidity is the most effective variable on the CO concentration, wind speed is the most effective variable on the NO$_2$ concentration, average temperature is the most effective on the SO$_2$ and pressure is the most effective variable on PM$_{10}$ concentration.

Fig. 5-b, shows independent variable importance in Amman in 2020. The results show humidity is the most effective variable on the CO concentration, wind speed is the most effective variable on the PM$_{10}$ concentration, average temperature is the most effective on the SO$_2$, Pressure is the most effective variable on NO$_2$ and PM$_{10}$ concentration.

Figure (6-a) and figure (6-b), show independent variable importance in Irbid for the period from 2016 to 2019 and in 2020 respectively. As indicated in Fig. 6-a, humidity is the most effective variable on the PM$_{10}$ concentration, wind speed is the most effective variable on the NO$_2$ concentration, average temperature is the most effective on the SO$_2$, Pressure is the most effective variable on NO$_2$ concentration and Lockdown is the most effective variable on NO$_2$ concentration. While Fig. 6-b, show humidity is the most effective variable on the PM$_{10}$ concentration, wind speed is the most effective variable on the CO concentration.

Fig. 6. Independent variable importance for Irbid, (a) from 2016 to 2019 (b) in 2020.
concentration, average temperature is the most effective on the PM$_{10}$, Pressure is the most effective variable on SO$_2$ concentration.

Figure (7-a) and (7-b) show independent variable importance in Zarqa for the period from 2016 to 2019 and 2020 respectively. Fig. 7-a shows that humidity is the most effective variable on the SO$_2$ concentration, wind speed is the most effective variable on the PM$_{10}$ concentration, average temperature is the most effective on the CO concentration, Pressure is the most effective variable on NO$_2$ concentration. While Fig. 7-b shows that humidity is the most effective variable on the NO$_2$ concentration, wind speed is the most effective variable on the CO concentration, average temperature is the most effective on the PM$_{10}$, Pressure is the most effective variable on NO$_2$ concentration.

Based on the independent variable importance by using MLP for the three cities, it may be noticed that the metrological data and the lockdown of the three cities in Jordan varies in their effect on the concentration of the four pollutants (CO, NO$_2$, SO$_2$, and PM$_{10}$).

3.2.4. Sobol sensitivity test

Sobol sensitivity test to examine the importance of variables in the prediction of the concentration of the four pollutants (CO, NO$_2$, SO$_2$, and PM$_{10}$) was conducted. It is based on the decomposition of model output variance into summands of variances of the input parameters in increasing dimensionality (Saltelli et al., 1999; Sobol, 2001).

Sobol sensitivity analysis is applied in quantifying how much
variability in the model output is depending on each of the input parameter or the interactions between parameters (Abdelhafez et al., 2021). Sobol sensitivity analysis can be achieved by computing the first-order, second-order, higher-order, and the overall sensitivity indices.

Global sensitivity analysis toolbox in MATLAB is used to conduct the Sobol sensitivity analysis. Figure (8-a) and (8-b) show the significance and sensitivity analysis of the Sobol method for the concentration of the four pollutants (CO, NO$_2$, SO$_2$, and PM$_{10}$) in Amman from 2016 to 2020 and in 2020 respectively. It may be noticed from Fig. 8-a that humidity is the most important variable in PM$_{10}$ concentration, wind speed is the most important variable in SO$_2$ concentration, average temperature is the most important variable in NO$_2$ concentration, pressure is the most important variable in PM$_{10}$ concentration and lockdown is the most important variable in CO concentration.

Fig. 8-b shows that humidity is the most important variable in SO$_2$ concentration, wind speed is the most important variable in SO$_2$ concentration, average temperature is the most important variable in NO$_2$ concentration, pressure is the most important variable in SO$_2$ concentration.

Figure (9-a) and (9-b) show the significance and sensitivity analysis of the Sobol method for the concentration of the four pollutants (CO, NO$_2$, SO$_2$, and PM$_{10}$) in Irbid for the period from 2016 to 2019 and in 2020 respectively. Fig. 9-a shows that humidity is the most important variable in NO$_2$ concentration, wind speed is the most important variable in NO$_2$ concentration, average temperature is the most important variable in NO$_2$ concentration, average temperature is the most important

![Graph showing the significance and sensitivity analysis of the Sobol method for Amman from 2016 to 2019 and in 2020.](image)

![Graph showing the significance and sensitivity analysis of the Sobol method for Irbid from 2016 to 2019 and in 2020.](image)

Fig. 8. First order effect of Sobol sensitivity analysis for Amman (a) from 2016 to 2019 (b) in 2020.
variable in SO\textsubscript{2} concentration, pressure is the most important variable in PM\textsubscript{10}. On the other hand, Fig. 9-b shows that humidity is the most important variable in SO\textsubscript{2} concentration, wind speed is the most important variable in PM\textsubscript{10} concentration, average temperature is the most important variable in NO\textsubscript{2} concentration, pressure is the most important variable in PM\textsubscript{10} concentration.

Figure (10-a) and (10-b) show the significance and sensitivity analysis of the Sobol method for the concentration of the four pollutants (CO, NO\textsubscript{2}, SO\textsubscript{2}, and PM\textsubscript{10}) in Zarqa for the period 2016 to 2019 and for 2020 respectively. As indicated in Fig. 10-a, humidity is the most important variable in NO\textsubscript{2} concentration, wind speed is the most important variable in PM\textsubscript{10} concentration, average temperature is the most important variable in CO concentration, pressure is the most important variable in SO\textsubscript{2}. Furthermore, Fig. 10-b indicates that humidity is the most important variable in CO concentration, wind speed is the most important variable in NO\textsubscript{2} concentration, average temperature is the most important variable in PM\textsubscript{10} concentration, pressure is the most important variable in CO concentration.

Based on the sobol sensitivity test results for the three cities, it can be noticed that the metrological data and the lockdown of the three cities in Jordan varies in their effect on the concentration of the four pollutants (CO, NO\textsubscript{2}, SO\textsubscript{2}, and PM\textsubscript{10}).

Based on all the above statistical analysis, which show that the meteorological changes have contributed substantially to the observed changes in most air pollutants, meteorological factors must be considered in evaluating the impacts of pollutant source changes on air quality.
during the specific event of COVID-19 lockdown, and in assessing the source-oriented risks. It is to be noted that, this result is in agreement with that outlined in Ref, (Zhao et al., 2020).

4. Conclusion

In this study, the real-time impact of the COVID-19 pandemic on measured air pollution in the three largest cities of Jordan (Amman, Irbid and Zarqa) was explored. To achieve this goal, Paired Sample t-test was used to compare the concentration of the four pollutants (CO, NO\textsubscript{2}, PM\textsubscript{10} and SO\textsubscript{2}) in the three cities. The followings were concluded:

1. There is a significant difference between the emitted concentration mean values of CO, PM\textsubscript{10}, SO\textsubscript{2} and NO\textsubscript{2} during the three months period in the years (2016–2019) and those emitted in 2020, this was indicated by the values of p for each species, which was less than 5\% for all these pollutants.
2. The maximum reduction in the emitted four selected pollutants during the lockdown period was that of SO\textsubscript{2}, with the maximum reduction in this pollutant was in Zarqa, followed by that in Amman and the least emitted quantity was in Irbid.
3. There was significant reduction in the emitted concentration of NO\textsubscript{2}, with the maximum reduction was in Zarqa city as well. Irbid city

Fig. 10. First order effect of Sobol sensitivity analysis for Zarqa (a) from 2016 to 2019 (b) in 2020.
witnessed the highest percentage reduction in CO and PM$_{10}$, followed by the city of Amman and the least reduction was in Zarqa.

4. Based on correlation test, independent variable importance of multilayer perceptron and global sensitivity analysis by using Sobol analysis, it may be concluded that the metrological data (Humidity, Wind speed, Average Temperature and Pressure) of the three cities play an important role in the air pollutants concentration.

Credit author statement

Eman Abdelhafez: Conceptualization, Methodology and Formal analysis and investigation. Loai Dabbour: Data collection, Writing-Reviewing and Editing. Mohammad Hamdan: Writing- original draft preparation.

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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