Study of climatology parameters on COVID-19 outbreak in Jordan

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Abstract
To control the spread of COVID-19 disease and reduce its mortality, an early and precise diagnose of this disease is of significant importance. Emerging research data show that the current COVID-19 pandemic may be affected by environmental conditions. Therefore, the impact of weather parameters on COVID-19 distribution should be explored to predict its development in the next few months. This research aims to study the association between the daily confirmed COVID-19 cases in the three major cities of Jordan; Amman, Zarqa, and Irbid and climate indicators to include the average daily temperature (°C), wind speed (m/s), relative humidity (%), pressure (kPa), and the concentration of four pollutants (CO, NO2, PM10, and SO2). The data were obtained from the World Air Quality Project website and the Jordanian Ministry of Environment. A total of 305 samples for each city was used to conduct the data analysis using multiple linear regression and a feedforward artificial neural network. It was concluded that the multiple linear regression and feedforward artificial neural network could forecast the COVID-19 confirmed cases in the case studies; Amman, Irbid, and Zarqa. Finally, global sensitivity analysis using Sobol analysis indicated that pressure in Amman and Zarqa and the concentration of NO2 in Irbid has a high rate of positive cases that supports the virus’s spread.

Keywords COVID-19 · Air pollution · Regression analysis · Sensitivity test · Climate indicators

Introduction
Since its detection in China in 2019, coronavirus has been subjected to intense studies in many aspects to limit its transmission or suppress it. Recently, research was conducted to investigate the influence of meteorological conditions (the quality of air) and meteorological data (i.e., humidity, ambient temperature, solar radiation) on COVID-19 transmission worldwide.

Huang et al. (2020) conducted research work on the effect of the environment on the spread of SARS-CoV-2 and found that the concentration increases with the environment.

They suggested that this increase implies that coronavirus transmission may increase in large cities in mid-latitudes in autumn 2020.

Xie and Zhu (2020) used a generalized additive model to investigate how the mean air temperature influences the active cases of COVID-19 in 122 cities in China; they concluded that COVID-19 active chances increase linearly with ambient temperature with a threshold of 3 °C. They also concluded that there is no evidence supporting the fact that the positive cases will decline in warmer conditions.

Lian et al. (2020) conducted a study on lockdown caused by COVID-19 on air quality in Wuhan, China. They found that most common pollutants concentrations were significantly reduced during the lockdown, with the average monthly air quality index being 59.7, which is 33.9% less than before the lockdown.

The effect of COVID-19 on the environment in China, USA, Italy, and Spain was investigated by Zambrano-Monserrate et al. (2020). They stated that contingency measures are related to a clean environment, including good air quality, noise reduction, and pristine beaches. However, they concluded that there is a reduction in recycling and an increase in waste that leads to water and land contamination.
Collivignarelli (2020) studied the effect of the lockdown on air quality in Milan Metropolitan/Italy. He concluded that the lockdown caused a significant reduction of pollutants concentration (PM$_{10}$, PM$_{2.5}$, BC, benzene, CO, and NO$_x$) mainly due to the reduced vehicular traffic. While, O$_3$ demonstrated a significant increase, possibly, due to the minor NO concentration. Furthermore, He found that the lockdown led to a substantial decrease in the concentration of SO$_2$ in Milan city.

Pirouz et al. (2020) investigated the effect of climate on active cases of COVID-19 using (multivariate linear regression (MLR)) in an attempt to propose a prediction model. They used the parameters of relative humidity, daily average temperature, and wind speed, with some urban parameters such as population density. Their analysis showed a positive effect of the proposed model on the confirmed cases. They concluded that these findings could be applied by considering several variables showing exact delay in new confirmed COVID-19 cases.

Abdelhafez et al. (2021) performed a study to correlate the COVID-19 active cases with metrological components to include: relative humidity (%), the average daily temperature (°C), maximum ambient temperature (°C), pressure (kPa), wind speed (m/s), and average daily solar radiation (W/m$^2$). In their work, they used the Spearman correlation test for data analysis. They concluded that the most effective weather parameter on the active cases of COVID-19 is the average daily solar radiation during the first wave, even though all other tests for other criteria failed. Furthermore, the maximum temperature was the most effective weather parameter in the second wave transmission. Finally, using a global sensitivity analysis using Sobol analysis, it was found that the daily solar radiation has a high rate of active cases that support the spread of the virus.

Khan et al. (2021a) discussed the consequences of the global COVID-19 outbreak by environmental matrices. The review emphasizes environmental wastes and discusses their potential recovery techniques, such as the disposal of pathogen-contaminated soils, the collection, recycling, and final disposal of urban and medical solid waste. Finally, the scientific community has given holistic suggestions for addressing environmental issues.

In their work, Khan et al. (2021b) researched SARS-CoV, MERS-CoV, and SARS-CoV-2 from 2002 to 2020 using a Medline search. They discussed the timing of the three coronaviruses, health workers’ vulnerability, surface and wastewater coronaviruses, diagnostic and treatment measures, and the prevention measures.

A Cloud-based Fuzzy (FCB) diagnosis assistant was designed by Ahmad et al. (2021) to identify patients as COVID-19 patients who are confirmed or suspected. When patients register online at the FCB COVID-19 DA, a database is created in real-time. This database helps to increase diagnostic accuracy because it includes the latest current case updates. A team of doctors, experts, and consultants are integrated into FCB COVID-19 DA to improve consultation and prevention. This proposed FCB COVID-19 DA theory aims to control the pandemic in COVID-19 and speed up its transmission rate among society.

Dabbour et al. (2021) investigated the influence of the COVID-19 pandemic on measured air pollution in Jordan’s three main cities in real-time (Amman, Irbid, and Zarqa). They compared the concentrations of particulate matter (PM$_{10}$), CO, NO$_2$, and SO$_2$ in the three cities from March 15 to June 30 in 2016 to 2020 using a paired sample t-test. During the study period, they discovered a substantial difference between the released concentrations mean values of CO, PM$_{10}$, SO$_2$, and NO$_2$. Furthermore, they demonstrated that metrological data is directly related to CO, PM$_{10}$, SO$_2$, and NO$_2$ concentrations in these three cities.

Mukattash et al. (2021) investigated the experiences and perspectives of patients with coronavirus illness (COVID-19) who received pharmacological therapy during their infection in Lebanon. Two hundred seventy-nine patients completed the questionnaire in single-centered observational research among home-treated COVID-19 patients ($n = 500$). Despite having a favorable impression of pharmacists caring for COVID-19 patients (mean view score: 17.79/25), the participants’ treatment experiences were inadequate (mean experience score: 1.51/4). As a result, the authors concluded that healthcare authorities should intervene in the restructuring, steering, and reviewing unrealized new pharmaceutical services for COVID-19 outpatients.

In this study, the climate indicators, including average daily temperature, relative humidity, wind velocity, pressure, and the concentrations four pollutants (CO, NO$_2$, PM$_{10}$, and SO$_2$) were linked to COVID-19 active cases in Amman, Irbid, and Zarqa, Jordan. To achieve this goal, artificial neural network (ANN) and multiple linear regression are used to predict COVID-19 active cases in the three cities in Jordan using climate indicators as an input. Also, the Sobol method will conduct sensitivity analysis between variables (climate indicators).

Methodology

Study area

The geographical location of Jordan is within latitudes 29° 19’ N and 32° 35’ N (Batieha et al. 2011). According to the Jordanian department of statistics, the area of Jordan is 89,342 km$^2$, and an estimated number of populations around 11n million.

Three cities were selected for the analysis based on data available to study the association between climate parameters and the COVID-19 pandemic in Jordan. The Jordanian
Ministry of Environment has only three data stations, that stations are located in the three major cities of Jordan. Amman, the capital city, the administrative and the commercial center with an area of 1700 km\(^2\) and a population of 4.5 million (Al-Khashman 2007). Irbid, the capital of the northern region of Jordan with an area of 410 km\(^2\) and the second populated city with 2 million (Alomary 2013). Zarqa that is an important industrial city in Jordan houses more than 50% of Jordan industry, with an area of 60 km\(^2\) and a population of 1.5 million (Abu-Dieyeh et al. 2010). The location of the three Jordanian cities is presented in Fig. 1.

### Data collection

The daily data of confirmed COVID-19 cases in the three Jordanian cities over the period from 2 March to 31 December 2020 were obtained from the health Jordanian Ministry, while the climate indicators including relative humidity (\%), the average daily temperature (\(^\circ\)C), pressure (kPa), wind speed (m/s), and the concentration of four emitted pollutants (CO, NO\(_2\), PM\(_{10}\), and SO\(_2\)) in the three Jordanian cities were obtained from World Air Quality Project website (https://aqicn.org/) and the Jordanian Ministry of Environment. In this study, 305 samples for each city were used. Figures 2, 3, 4, 5 represent the monthly average climate indicators in the three cities during the period of the data analysis.

### Data analysis

#### Multiple linear regression

A multiple linear regression model has been implemented for predicting confirmed daily cases of the COVID-19 given climate indicators (average daily temperature, relative humidity, wind speed, pressure, and the concentration of the four pollutants (CO, NO\(_2\), PM\(_{10}\), and SO\(_2\)), using the linear approach for modeling the relationship between a scalar...
dependent variable \( Y \) and one or more independent variables or (explanatory variables) denoted \( X \) (Freedman 2012).

In this study, 305 samples for each city were used to obtain the following Linear Equations:

\[
Y_1 = 6.816X_1 + 11.999X_2 - 30.618X_3 + 72.170X_4 - 0.318X_5 + 38.049X_6 + 40.228X_7 + 6.796X_8 - 74096.85 \\
Y_2 = 0.086X_1 + 0.043X_2 - 0.142X_3 + 0.031X_4 - 0.443X_5 + 0.219X_6 - 0.290X_7 + 0.044X_8 - 24.582 \\
Y_3 = 1.862X_1 + 3.327X_2 - 17.783X_3 + 16.533X_4 - 0.416X_5 - 5.327X_6 - 18.111X_7 + 2.968X_8 - 16874.087
\]

\( Y_1, Y_2, Y_3 \) are the number of COVID-19 confirmed cases in Amman, Irbid, and Zarqa, respectively. \( X_1 \) is the average daily temperature, \( X_2 \) is relative humidity, \( X_3 \) is wind speed, \( X_4 \) is pressure, \( X_5 \) is the concentration of CO, \( X_6 \) is the concentration of \( \text{NO}_2 \), \( X_7 \) is the concentration of \( \text{SO}_2 \) and \( X_8 \) is the concentration of \( \text{PM}_{10} \).

Feedforward artificial neural network

A feedforward neural network is a classification algorithm that is biologically inspired. It is made up of a (potentially large) number of basic neuron-like processing units that are layered together. Every unit in a layer is linked to all the units in the layer before it. These connections are not all created equal: each one may differ in terms of strength or weight. The weights on these connections represent a network’s knowledge. The units of a neural network are frequently referred to as nodes.

Data enters at the inputs and flows layer by layer across the network until it reaches the outputs. There is no feedback between layers during normal operation, which is when it functions as a classifier. It is for this reason that they are known as feedforward neural networks.

The feedforward neural network model was designed and tested using MATLAB software. This model correlated the climate indicators with the COVID-19 active cases in Amman, Irbid, and Zarqa, of Jordan.

Sobol sensitivity test

Global sensitivity analysis using variance-based sensitivity analysis (also known as the Sobol method or Sobol indices) is a type of global sensitivity analysis. It decomposes the variance of the model or system’s output into fractions that may be assigned to inputs or sets of inputs, using a probabilistic framework. For example, in a model with two inputs and one output, the volatility in the first input may account for 70% of the output variance, the variance in the second for 20%, and the interactions between the two accounting for 10%. These percentages can be immediately read as sensitivity measures. Variance-based sensitivity measures are appealing because they evaluate sensitivity across the entire input space (i.e., it is a global method), they can handle nonlinear responses, and they can quantify the influence of interactions in non-additive systems.

This is based on the breakdown in summary variances of the input parameters of model output variance into increasing dimensionality (Saltelli et al. 1999 and Sobol 2001). Furthermore, its analysis, which may be carried out via the global sensitivity analysis toolbox in MATLAB, is useful in quantifying the interactions between parameters. This can be achieved by evaluating first-order, second-order, higher-order, and overall sensitivity indices (Abdelhafez et al. 2021). The Sobol sensitivity test was used in this work to assess the potential of variables in predicting climatic indicators (CO, \( \text{NO}_2 \), \( \text{PM}_{10} \) and \( \text{SO}_2 \)), as well as average daily temperature, relative humidity, wind speed, and pressure.

Results and discussion

Since the World Health Organization declared COVID-19 a pandemic, the number of active cases has steadily increased worldwide (Cucinotta and Vanelli 2020). The Jordanian Ministry of Health officially reported the first confirmed
COVID-19 case on March 2nd, 2020 (Abdelhafez et al. 2021). The number of positive cases escalated to 712,077 on May 1st, 2021, and the number of recovered cases was 685,010, while 18,196 cases were still under treatment. The total death numbers were 8871 cases. Figure 6 shows the number of confirmed COVID-19 cases over the period from 2nd March to 31st December 2020 in Amman, Irbid, and Zarqa, respectively. It may be noticed that the total number of the confirmed cases in Amman Irbid and Zarqa during the data analysis was 131,000, 1804, and 29,700 respectively. Furthermore, the total daily number of confirmed cases during the period from 2nd March to 1st September is extremely low as indicated in the figure.

Multiple linear regression

Table 1 shows the performance of the multiple linear regression, the mean absolute error (MAE) for Amman over the testing set is 0.327, which indicates that, on average, the predicted values using multiple linear regression depart from the true value by 47.66% and the coefficient of correlation ($R$) for Amman is equal to 0.638.

The performance of the multiple linear regression, MAE for Irbid over the testing set is 0.246, which indicates that, on average, the predicted values using multiple linear regression depart from the true value by 47.66%, and $R$ for Irbid is equal to 0.366.

The performance of the multiple linear regression, MAE for Zarqa over the testing set is 0.391, which indicates that, on average, the predicted values using multiple linear regression depart from the true value by 47.66%, and $R$ for Zarqa is equal to 0.500.

Feedforward artificial neural network

Feedforward artificial neural network with neuron numbers (8, 20, 1) was designed and tested within MATLAB. A total of 305 model samples were attained from previous experimental data and used as the ANN network’s input. Furthermore, 70% of this data is used for training, 15% is used for validation, and 15% is used for testing. The tangent sigmoid function is applied in the hidden layer, and the linear transfer function is used in the output layer. In this analysis and based on many trials and errors, 20 was selected as the number of the hidden layer. The proposed network was trained using Levenberg–Marquardt (trainlm) algorithm.

The scatter plots of training, testing, and validation for Amman, Irbid, and Zarqa are given in Figs. 7, 8, 9. Figure 7 illustrates the scatter plot results of the COVID-19 active cases in Amman utilizing the Feedforward neural network during training, validation, and testing. The highest values of $R$ in training, validation, and testing for the proposed network were found to be 0.9144, 0.67347, and 0.73043, respectively. Figure 8 depicts good scatter plot results obtained utilizing the suggested model during training, validation, and testing of the COVID-19 active cases in Irbid. It’s worth noting that the moderate $R$ values in training, validation, and testing are, respectively, 0.72455, 0.083538, and 0.056712. Figure 9 illustrates that the suggested model produced good scatter plot results during training, validation, and testing of the COVID-19 active cases in Zarqa. It’s worth noting that $R$’s good values in training, validation, and testing are 0.70131, 0.50815, and 0.47102, respectively.

Table 2 shows results obtained from the feedforward artificial neural network model. As shown, the value of $R$ for Amman, Irbid, and Zarqa; 0.83527, 0.32461, and 0.63873, respectively. Also, it is found that the mean absolute error (MAE) for Amman, Irbid, and Zarqa are 0.3467, 0.0835, and 0.4235, respectively.

Sobol sensitivity test

As stated above, Sobol sensitivity test decomposes the variance of the model or system's output into fractions that may be assigned to inputs or sets of inputs, using a probabilistic framework. In this work, the input variables used are eight variables. It is expected that the Sobol method will break down these input variables into fractions, with each assigned fraction to each variable indicating how sensitive the output (positive cases) is to this variable.
Figure 10 represents the results obtained using the MATLAB toolbox for global sensitivity analysis for the Sobol sensitivity analysis. As indicated in this figure, the first-order effect of each input parameter on the confirmed cases in the three cities is represented. In general, it may be noticed from Fig. 10 that the eight parameters have a different effect on COVID-19 confirmed cases in the selected cities in this study.

For the city of Amman, it is clear that pressure is the most effective variable with a first-order effect value of 0.7233. This is followed by humidity, emitted NO2 concentration, wind speed, SO2 concentration, temperature, PM10 concentration, and the least first effective variable is assigned to CO with a value of 0.0013.

Also, the figure shows that pressure is the most dominant variable that affects the COVID-19 positive cases in Zarqa city, with a value of 0.5694 assigned for the first effect order, while MP10 concentration is in the second place followed by humidity, SO2 concentration, wind speed, temperature and emitted concentration of NO2 being the lease variable that affects the confirmed cases with a value of 0.0246.

The figure also shows that the confirmed cases in Irbid city were mostly affected by the variable NO2 concentration, which has a corresponding value of first-order effect equals to 0.3015, followed by CO concentration, PM10 concentration, Humidity, SO2 concentration, pressure, temperature, and wind speed has the least effect on confirmed cases with a value of 0.0349.
Conclusion

In this work, the ability of certain climate indicators to predict the daily COVID-19 confirmed in three Jordanian major cities (Amman, Zarqa, and Irbid) was successfully investigated using multiple linear regression and a feedforward artificial neural network, with a total of 305 samples for each city was used to conduct this analysis. In addition, the Sobol sensitivity test was conducted to find the most climate-effective indicator on the positive cases in each city.

It may be concluded that

1. Multiple linear regression could forecast the COVID-19 confirmed cases in the three cities, and the coefficient of correlation ($R$) for Amman, Irbid, and Zarqa was 0.638, 0.366, and 0.500 respectively.
2. Feedforward Artificial Neural Network could predict the COVID-19 confirmed cases in the three cities, and the coefficient of correlation ($R$) for Amman, Irbid, and Zarqa was 0.83527, 0.32461, and 0.63873 respectively.
3. Global sensitivity analysis using Sobol analysis indicated that pressure in Amman and Zarqa is the most dominant indicator on the confirmed cases in these two cities, with first-order effect values of 0.7233 in Amman and 0.5694 for Zarqa. The dominant indicator on the confirmed cases in Irbid is the concentration of NO$_2$ most dominant indicator on the confirmed cases with a first-order effect value of 0.3015.
Table 2  Performance of feedforward artificial neural network

|          | R     | Test accuracy | MAE   |
|----------|-------|---------------|-------|
| Amman    | 0.83527 | 60.895%       | 0.3467 |
| Irbid    | 0.32461 | 16.45%        | 0.0835 |
| Zarqa    | 0.63873 | 50.34%        | 0.4235 |

Fig. 9  Scatter plot of the model for Zarqa

Fig. 10  First-order effect of Sobol sensitivity analysis for Amman, Irbid, and Zarqa
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Declarations

Conflict of interest The authors declared that they have no conflict of interests.

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