Long terms assessment of the meteorological indicators with COVID-19 pandemic of Bahrain for second wave measure

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Research Article

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Abstract

The COVID-19 pandemic has significantly impacted the global lifestyle, and the spreading of the virus is unprecedented. This study aims to assess the association between the meteorological indicators such as air temperature (°C), relative humidity (%), and wind speed (w/s) and solar radiation with the COVID-19 total confirmed and death cases in the hot, arid climate of Bahrain. We used the Spearman rank correlation coefficient, Kendall rank correlation coefficient measures, and the Wavelet Transform Coherence approach for econometric analysis. The dataset analysis from April 1, 2020, to January 10, 2021. The result shows that the air temperature and humidity, wind speed, PM_{2.5} indicators have a mild coherence and significant association with the COVID-19 total confirmed cases. In contrast, they have a significant positive association with the COVID-19 total cumulative death cases, especially during the summer period. A positive correlation was indicated between wind speed, PM_{2.5}, and the COVID-19 outbreak. Although this region experienced a high solar radiation incident, the solar radiation has no association with the COVID-19 pandemic total confirmed or death cases. The study suggests that the association between humidity, wind speed, air quality needs to be further examined to spread the outbreak of infectious COVID-19 diseases. The finding of this long-term analysis will help this region's countries take a significant measure to control the second wave of the COVID-19 outbreak.

Highlight Points

- Long terms assessment of the meteorological indicators with COVID-19 pandemic of the hot arid region
- A positive association between the humidity, wind speed, PM_{2.5} and COVID-19 total confirmed and death cases
- A significant positive correlation between air temperature and COVID-19 total death cases during summertime
- Solar radiation has an insignificant impact on the COVID-19 total confirmed or death cases

1. Introduction

On December 31 2019, the World Health Organization (WHO) was informed about a novel infectious disease in Wuhan City, Hubei, China. On January 12 2020, The WHO confirmed that a novel coronavirus was the cause of these diseases. This virus is the seventh member of the family of coronaviruses that infect humans (Zhu et al. 2020). On March 11 2020, the WHO announced that the novel coronaviruses is a COVID-19 outbreak, a global pandemic (Cucinotta & Vanelli 2020). In recent months, the COVID-19 pandemic (Li et al. 2020; Yao et al. 2020) has affected many people across countries (Li et al. 2020), including the Gulf Cooperation Council (GCC) countries in the Middle East. According to Zheng et al. (2021), more than 103 million people are infected, and around 2.23M are fatalities; this number is daily increasing. However, different measures were implemented in other regions to control the virus outbreak until the infected cases line is flattened at the end of October 2020. The second waves infected case of

COVID-19 started gradually increase mainly in the early month of November 2020, reaching a peak in February 2021. The second wave cases have been recorded more than the first wave in different countries around the world, including the Middle East region (Diaz & Vergara 2020; HOPKINS 2021). Many governments continued similar measures that were implemented in the first wave to control the virus spread. According to WHO, the COVID-19 is transmitted mainly by people interaction; the longer the interaction, the higher the transmission rate. The virus can also be transmitted through airborne by the larger droplets and aerosols. Larger droplets turn into aerosols, known as droplet nuclei through evaporation process. However, the relative importance of the larger droplets and the aerosols still not clear as of November 2020, further studies are needed to clarify this fact.

Climate and meteorological indicators play a significant role in disease transmission (Dalziel et al. 2018) and the mortality rate (Biktasheva 2020; Ma et al. in different regions. Studies on global climate change, different regional climatic conditions, different micro-climate conditions of the cities, and the biometrological conditions of a different area in relation to the COVID-19 is still significantly low. A study in the tropical climate of Jakarta, Indonesia (Tosepu et al. 2020), emphasized that the average temperature (°C) was significantly correlated with COVID-19 spread. Similarly, an investigation into the tropical climate of the State of Rio de Janeiro, Brazil (Rosario et al. 2020) concluded that solar radiation, temperature (maximum and average) and wind speed have a negative correlation with the COVID-19 cases. Still, they have the potential to suppress the spread of the virus. Pani, Lin, and Ravindra Babu (2020) confirmed that air temperature and Dew point positively and significantly associated with Singapore's daily cumulative COVID-19 cases. Likewise, Bashir et al. (2020) reported that average temperature, minimum temperature, and air quality were significantly associated with the COVID-19 pandemic in New York, USA. Altamimi and Ahmed (2020) explored Scandinavian countries to emphasize maximum temperature; the average temperature was significantly correlated with the COVID-19 pandemic.

Another study in the moderate climate of different cities in Turkey Şahin (2020) highlighted that the highest correlations were observed for population, wind speed for 14 days, and temperature in the daytime, respectively. In Germany, Biktasheva (2020) claimed that habitat's air humidity negatively correlate with COVID-19 morbidity and mortality. Humidity was conformed in the past-time as a factor that contributed to transmitting the influenza diseases. According to Luo et al. (2020), cold and dry environments facilitated spreading droplet-mediated viral disorders, and warm and humid environments attenuated viral transmission. However, different earth regions have different climate conditions impacts differently on the ecosystem and transmitted respiratory diseases. According to Shakil, Munim, Tasnia, and Sarowar (2020) critical review study, most extant studies on COVID-19 have been based on countries with low temperatures, so future research should consider countries with high temperature and humidity. According to Paraskevis et al. (2021), weather and climate variables impact the COVID-19 outbreak, but the containment measures and the public health interventions of the country must be considered in any conducted study. This study investigates the impact of the meteorological indicators on spreading the COVID-19 pandemic under Bahrain's extreme hot arid climate for controlling the second wave of COVID-19 outbreak. The country applied the necessary containment measures strictly, and the ministry of health has daily posted measures and restrictions condition to control the virus outbreak (Health 2021). As

shown in Figure 1, although the total number of cases are high for Bahrain, but the total deaths from the pandemic remains relatively low. Hence, we suggest that assessing the severity of the climate influences on the disease's spread is crucial to determine the mitigation strategies' appropriateness in controlling the disease.

2.1 Middle East And Bahrain Case Study

In the Middle East, where the Gulf countries are located in Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates, it is characterized by desert land with a hot, arid climate. This region does not receive adequate studies regarding the climate impact on the COVID-19 outbreak. Recently this region is severing from the second wave of the COVID-19 pandemic outbreak. In the previous years, this region had experienced a similar disease known as the novel coronavirus (MERS-CoV). The climate was one factor influencing the spreading of the disease (Altamimi & Ahmed 2020). Among these countries, we have selected Bahrain to assess the meteorological factors that impact COVID-19 cases because the country is a small desert island. The meteorological factors such as air temperature, air humidity, and wind speed, solar radiation affecting equally over the island areas throughout the year. Once the climate factor is changed, the country's overall climate is changed, unlike the other countries where their area is large, and the climate is varied due to the variety of the land typology and population density. Further, Bahrain's population density focuses on the north part of the island, and they are not distributed in the whole land like other countries. Because the country is small in size and population, the government was able to apply strict containment measures and public health interventions throughout the last year. These reasons were behind the selection of Bahrain country as a case study for finding an association between the meteorological and pollution indicators with the COVID-19 pandemic in hot, arid climate for controlling the current second wave of the pandemic.

Bahrain features an arid climate with two main seasons, with extreme summer from June to September and a relatively mild winter season from December to March. The main two seasonal variations were separated by two transitional periods from April/May and October/November. From April to October, daytime air temperature gradually increases, and relative humidity dramatically decreases, and the average afternoon air temperatures are 40°C. Sometimes it can reach up to 48°C between June and July. The minimum relative humidity is about 47 %, and the maximum relative humidity between 75% and 80%. However, the intensity of the heat and the humidity make these months thermally discomfort conditions. In the winter months, from December to March, the temperature ranges between 10° C and 20°C, while the humidity rises above 90%. Therefore, the influence of these extreme air temperature and relative humidity variations are investigated in this study. The sky during the winter months is partially cloudy, while during the summertime, the sky is clear. The highest average solar radiation is 800w/m² occurs in June. The mean annual precipitation is very low and limited (70.8mm), and irregular mostly falls between November and April.

During the summer, a southwest hot-dry wind periodically blows sand clouds across the barren southern part of Bahrain toward Manama. During the winter months, the prevailing winds from the southeast bring

damped air over the islands. The sand clouds and the damp air influence the air quality of Bahrain. The seasonal climatic variation also influences human activities. According to the Bahrain event calendar, most outdoor activities were organized during the winter season. The government also officially declares a two-month outdoor labour work ban from midday to evening 4 pm during extreme summer climatic conditions. The climatic factors have a more significant influence on Bahrain environment and behaviour patterns. The study will investigate air temperature, relative humidity, solar radiation, wind velocity, sea level pressure on the prevailing pandemic state in the country between April and August 2020.

Study Design

The current study investigates the association of meteorological and pollution indicators over the COVID-19 pandemic in Bahrain from April 5, 2020, to January 10, 2021. The total COVID-19 cases, total deaths, and total active cases have been sourced from the John Hopkins coronavirus database. The dataset for temperature, humidity, shortwave radiation, wind speed and PM 2.5 has been obtained from The Supreme Council for Environment, Kingdom of Bahrain database.

Data Analysis

To investigate the COVID-19 pandemic in Bahrain, we rely on Kendall and Spearman rank correlation coefficients and wavelet transform coherence. We use Kendall and Spearman rank correlation test to measure the degree of linear association between variables and has been extensively used in the existing literature as it originates from covariance methodology. Pearson correlation test also provides information about the extent of links among variables under consideration and calculates the nature of such association with empirical estimates ranging between -1 or +1. The mathematical form of the Pearson correlation coefficient can be estimated through equation (1).

$$r_s = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{(x_i - \bar{x})^2} \sqrt{(y_i - \bar{y})^2}} \quad (1)$$

By relying on monotonic function, the rank correlation coefficient (r_s) controls the correlation between variables to assess the monotonic association. If no data reputation can be observed, then -1 or +1 occurs when every variable's in each other's perfect monotonic function. Equation 2 provides the empirical estimation of the coefficient (r_s), where data is explained by n and difference in the rank of the i^{th} element is narrated by d_i . The sign of empirical findings indicates the association between the independent and dependent variable. The spearman correlation coefficient values are positive if the dependent variable's value increases with the inclusion of independent variables or vice versa.

$$r_s = 1 - \frac{6\sum_i d_i^2}{n(n^2-1)} \quad (2)$$

We also use the Kendall rank correlation coefficient to investigate the degree of impact based on the observations' pairs. Kendall rank correlation test is used to analyze the parallels in ordering data when quantiles rank it. While other correlation tests use data observations as a base of correlation, Kendall correlation tests account for such association through discordance among pairs. Equation (3) provides a mathematical form of the Kendall rank correlation test.

$$\mathcal{T} = \frac{n_c - n_d}{\frac{1}{2}n(n-1)} \quad (\text{equation 3})$$

In equation (3), total observations, no of discordant and number of concordant is explained by n, nd and nc. The coefficient estimates are generally smaller than Spearman correlation tests and are most accurate for small dataset.

We further use wavelet transform coherence as a main analytical structure, which provides graphical correlation to examine the association between the current research project's data. In wavelet coherence, arrows are used to explore the correlation's impact and direction from one variable to another. The strength of effects is illustrated by colour in the graphical representations as movement from yellow to blue indicates weak association or vice versa. The cone of influence separates the significant region from the rest with a thick black lining drawn from top to bottom on both sides.

Results And Discussion

Table 1. Kendall and Spearman correlation tests

	Kendall rank correlation test		Spearman rank correlation test	
Variables	Total cases	Total deaths	Total cases	Total deaths
Temperature (°C)	-0.011	-0.014	0.002	-0.005
Relative Humidity	-0.079***	-0.049	-0.131 ***	-0.089
Wind speed	0.381***	0.360***	0.574	0.545
Solar Radiation	0.102***	0.110***	0.155***	0.165 ***
PM _{2.5}	-0.031	-0.032	-0.047	-0.044

Table 1 provides the empirical estimates of Kendall and spearman correlation tests. For cumulative cases, temperature, humidity and $PM_{2.5}$ indicate a negative correlation while humidity and wind speed report a positive correlation. With total cases, total deaths and active cases in Bahrain. The spearman rank correlation test estimates that temperature negatively correlates with total death, while a positive correlation with total and active cases. The estimates of humidity and $PM_{2.5}$ indicate negative, while wind and solar radiation show a positive association with the COVID-19 outbreak in Bahrain's kingdom.

In the current study, we investigate the impact of environmental and meteorological indicators on the COVID-19 pandemic in Bahrain. Our findings indicate that humidity, wind, and solar radiation have significantly impacted the COVID-19 outbreak with temperature and showed insignificant influence. Past literature of Vandini et al. (2013) and Tan et al. (2005) supported such findings with the earlier viral outbreaks of SARS and MARS as they belong to exact coronavirus origins. A recent study by Shi et al. (2020) also concluded that meteorological indicators play a key part in spreading infectious diseases, especially during the winter season.

Humidity, an integral climate indicator, has been well documented in the transfer of infectious diseases, especially during the coronaviruses' seasonal spread (Sajadi et al. 2020). Wang et al. (2020) investigated the outbreak of COVID-19 in Wuhan (China) to report that the outbreak of COVID-19 was positively correlated with climate indicators in Wuhan. The research article further articulated that summer arrival may be influential in reducing the rate of infection from COVID-19 in southern China. Finally, the research team suggested that the association between humidity and air quality needs to be further examined to spread the outbreak of infectious diseases (Chen et al. 2020). Ma et al. (2020) investigated the association between temperature and humidity to explain that temperature and humidity play a significant role in the number of deaths from COVID-19.

Several studies explored the impact of $PM_{2.5}$ over infectious diseases and how it impacts the COVID-19 outbreak. Wu et al. (2020) examined the association between environmental pollution ($PM_{2.5}$) and COVID-19 to indicate that the mortality rate from COVID-19 outbreak increases by 15% with a one ug/m^3 increase in particulate emissions. Similar findings were reported by Piazzalunga-Expert (2020), Wang et al. (2020) and Fann and Risley, 2013 for Italy, China and the USA. A portion of studies investigates the demographic changes in urban areas. Such a shift in population density can contribute to higher environmental pollution and how it can contribute to chronic illnesses. Pandey et al. (2005) was one of the first to investigate the emission of environmental pollution in New Delhi, India, to conclude that residential areas near industrial cites reported higher environmental pollution and susceptible infectious diseases mainly due to vulnerable immune system especially in children and elderly. The researchers finally concluded that environmental pollution levels in New Delhi were 22 times worse than in other residential complexes (Bilal et al. 2020).

Another perspective of economic literature has investigated a combination of environmental and meteorological indicators and their association with COVID-19, where it was argued that indicators such as solar radiation, $PM_{2.5}$ and surface air pollution contribute significantly to the COVID-19 (Kirby 2020).

Another study investigated the lethality of the COVID-19 and environmental indicators to suggest that lower environmental quality in the urban areas is the main reason for the high infectious trend in urban areas (Ran et al. 2020) to higher deaths and reported cases in the metropolitan vicinities. Shi et al. (2020) empirically analyzed the association between climate indicators such as wind and solar radiation in the Chinese provinces to determine that solar radiation and wind are important indicators in the outbreak of the COVID-19 in Chinese cities. Past studies of Tan et al. (2005) and Vanidini et al. (2013) also investigate such association for SARS and MERS outbreaks and reported similar findings that meteorological indicators are key determinants of infectious diseases, especially during the winter season. Several researchers such as Oliveros et al. 2020, Ma et al. 2020 and Luo et al. 2020 also explored similar association to report that although meteorological indicators increase the risk of getting infected from viral outbreaks such as SARS, MERS and the COVID-19 but solar radiation and temperature needs further research to determine their exact impact over the coronaviruses (Bilal et al. 2020)

Wavelet Transform Coherence

Wavelet transform coherence is a widely used analytical methodology in the econometric literature, which is applied to portray graphical correlation between variables included in the literature. In the current research, we rely on the Morlet wavelet function that has been largely applied in recent literature.

Small arrows indicate the correlation direction from one indicator to another, where color inside the circles indicates such correlation strength. In wavelet transform coherence, the impact from blue to yellow is used to explain as an association from low to high correlation or vice versa. The cone of influence is used to splits the significant area from the insignificant region with a thick black lining drawn from top to bottom on both sides.

Figure 2 represents the impact of meteorological and environmental pollution indicators over total confirmed cases in Bahrain. Figure 2a indicates mild coherence between temperature and total confirmed cases from COVID-19. It can be seen that none of these scenarios are lagging by the zero-degree angle of arrows. Also, a number of yellow areas are distributed throughout figure 2a but do not constitute a significant association. Next, we analyze the coherence between humidity and total confirmed cases from the COVID-19 (figure 2b). In general, it reports a mild coherence, but a significant association can be observed between periods of 3-7, 8-11 and 16-20, indicating that during this time frame, the humidity had a significant impact on the spread of COVID-19 in Bahrain. Figure 2c represents the coherence association between wind and total confirmed cases, which illustrates that generally, the wind has a mild positive coherence over total active cases in Bahrain, but during the period of 3-9, the trend of infections had a positive correlation with the COVID-19 outbreak in the country.

Figure 2d reports the graphical illustration of coherence between COVID-19 outbreak and STR radiation. As Bahrain belongs to the gulf region, the str radiation becomes a significant indicator, especially during the health emergencies such as COVID-19, which can be visible during 5-13. In general, the impact remains insignificant. Finally, we narrate the association between PM_{2.5} and COVID-19. Recent literature

has supported that environmental pollution indicators carry a significant association over infectious diseases such as coronaviruses. As shown in figure 2e, $PM_{2.5}$ has a mild positive coherence with the total confirmed cases, but it has a strong impact during the period of 2-14, indicating that during this time, the rise in environmental pollution was positively correlated with total confirmed cases in Bahrain.

Next, we observe the association between environmental and climate indicators over total confirmed deaths from the COVID-19 outbreak in Bahrain. Figure 3a reports the association between temperature and total deaths from the COVID-19, and it reports a significant positive association. It is visible that during the time scale of 50-180 days, the pandemic is significantly influenced the variations in daily temperature, while it also reports a mild positive association between 2nd and 15th periods; hence, signifying that during the current wave of the pandemic, the temperature may play a significant role. Figure 3b examines the association between humidity and deaths from COVID-19. During 1st and 16th period, deaths from COVID-19, a significant and positive association with humidity especially during period of 7 to 15, which is supported due to extreme summer conditions, humidity becomes an important indicator in the spread of infectious diseases such as SARS, MERS and the COVID-19.

Next, Figure 3c reports the impact of wind on the deaths from COVID-19 in Bahrain's kingdom. Though it reports a mild association in general, a significant impact can be observed between the time period of 7 to 15. As stated earlier, weather conditions are integral in spreading infectious diseases in countries suffering from extreme weather, such as Bahrain. Furthermore, we analyze the association between STR radiation and deaths from the COVID-19 outbreak. Though it general, it does not report a significant association between the variables mentioned above, but a mild significance can be observed from 4 to 7. Lastly, we mention the coherence association between $PM_{2.5}$ and deaths from the COVID-19 outbreak in Bahrain. Though it displays similar association with STR radiation, environmental pollution had a significant impact on the pandemic deaths during the period of 4 to 6 and 8 to 13. It is supported by the recent literature, which stipulates that due to higher urbanization and change in lifestyles, environmental pollution carries a significant impact on the immune system, leading population over 60 years of age vulnerable to infectious diseases.

Conclusion

This study investigates the association between COVID-19 total cumulative confirmed and death cases in Bahrain's hot arid climate region. The findings indicate that air temperature, humidity, $PM_{2.5}$ are associated with the COVID-19 total death cases, and they are mildly associated with the COVID-19 confirmed cases. Simultaneously, wind speed has a significant positive correlation with the COVID-19 total confirmed cases over the country and has a mild correlation with the total death cases.

Gulf countries in recent times have faced a significant rise in the COVID-19 cases. Thus these countries are taking extreme measures to prevent further COVID-19 cases. The study concludes that, in general, weather conditions are integral in the spread of infectious diseases in countries suffering from extreme weather, such as Bahrain. The pandemic has significantly influenced daily temperature variations,

signifying that the temperature may play a significant role in the second wave of the pandemic in the coming summertime. Humidity and wind speed are important indicators in the spread of infectious diseases of the COVID-19 in Bahrain. Environmental pollution such as PM2.5 had a significant impact on the confirmed and deaths cases from the pandemic. This finding will help gulf regions' governments take other measures to control the COVID-19 virus for the second wave's outbreak.

The current study investigated initial governmental efforts and public safety measures to analyze the exposure from meteorological and environmental pollution indicators. The limited availability of public health measures was contributors to the spread of COVID-19 cases, especially in the elderly. In this regard, we advise the policymakers to follow the COVID-19 prevention strategies of China, Germany and the UK to integrate state and federal resources to provide medical assistance to limit the exposure from the COVID-19 pandemic. Finally, we highlight some of the limitations of a current research project. First, we have investigated Bahrain, a small island nation with financial resources to overcome the COVID-19 pandemic. Hence, we urge researchers to further incorporate gulf countries to examine the association between meteorological, climate and environmental pollution indicators over a larger sample size, which will provide significant suggestions to deal with future pandemics. Second, though wavelet coherence is a popular econometric methodology, it must be interpreted cautiously. Finally, inter-regional comparison between gulf nations will be a useful addition in analyzing the difference in governmental and health officials' response in Arab countries to provide policy implications to formulate cohesive response towards the COVID-19 outbreak.

Declarations

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author contributions

Adeb Qaid analyzed the data and was a major contributor in writing the manuscript. Muhammad Farhan BASHIR provided guidance on statistical analysis and interpretation to the data. Dilshan Remaz Ossen help in writing manuscript. Khurram Shahzad organized the plan of research.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Figures

Figure 1

Total number of cases and death rate of COVID-19 pandemic in Bahrain.

Figure 2

The impact of meteorological and environmental pollution indicators over total confirmed cases in Bahrain.

Figure 3

The association between environmental and climate indicators over total confirmed deaths from the COVID-19 outbreak in Bahrain.