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Research article

Impact of short-term exposure to ambient air pollutants and meteorological factors on COVID-19 incidence and mortality: A retrospective study from Dammam, Saudi Arabia

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ABSTRACT

The symptoms of COVID-19 included fever with or without respiratory syndrome, but patients subsequently developed pulmonary abnormalities. Exposure to air pollution, meanwhile, is associated with complications such as acute respiratory inflammations, asthma attack, and deaths from cardiorespiratory disease. To analyze the association of the air quality index (AQI), ambient air pollutants (PM_{10}, SO_2 and O_3) and meteorological parameters (temperature and relative humidity [RH]) with COVID-19 incidence and mortality, a retrospective study was conducted to examine COVID-19 infection, meteorological parameters, ambient air quality and ambient air pollutants in Dammam from 1 January to 30 April 2021. Data of COVID-19 incidence and mortality for Dammam were retrieved from Saudi Arabia Ministry of Health's publicly accessible database. Meteorological data, AQI and average PM_{10}, SO_2 and O_3 values were extracted from the publicly available website of Ministry of Environment, Water and Agriculture. The correlation of COVID-19 incidence and mortality with the independent variables was analysed by Pearson's correlation test or Spearman's rho test as applicable, and a *p*-value less than 0.05 was considered significant. COVID-19 incidence exhibited a positive correlation with temperature ($r = 0.537$, $p =$ .0001) and a negative correlation with RH (r=−0.487, p=.0001). No correlation was observed between the meteorological variables and COVID-19 mortality. COVID-19 incidence showed a positive correlation with AQI (r=0.269, p=.015) and with the ambient air pollutants SO_2 and O_3 (r=0.258, p=.018), and COVID-19 mortality showed a positive correlation with PM_{10} ($r_s = 0.344$, p=.002). Short-term exposure to O_3, SO_2 and higher temperature had direct relationship with COVID-19 incidence, while RH had inverse relationship. PM_{10} is positively associated with COVID-19 mortality.

1. Introduction

COVID-19, one of the larger pandemics in the 21st century, originated in Wuhan, China, in December 2019 and soon spread

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globally, including Saudi Arabia [1,2]. The emergence of COVID-19 to Saudi Arabia prompted investigations into localized environmental factors influencing transmission and mortality rates. As of April 26, 2021, World Health Organization (WHO) reported almost 151.9 million COVID-19 cases and 3.3 million deaths [3]. The incidence of COVID-19 infection and mortality due to it was high globally, but the spread of COVID-19 to Saudi Arabia was delayed due to early implementation of prevention strategies by the Saudi government. The first confirmed case of COVID-19 in Saudi Arabia was reported on March 2, 2020 from Qatif which is approximately 30 km from Dammam; later on the infection spread throughout Saudi Arabia. Therefore, it is worthy to the study meteorological factors and air pollutant levels in Dammam to assess their relationship with susceptibility and severity of COVID-19 infection. According to the Saudi Ministry of Health (MoH), almost 418,411 confirmed COVID-19 cases and 6,968 deaths had been identified as of 30 April 2021, among which approximately 22,000 confirmed cases and 470 deaths were reported in Dammam [4].

As in the early studies conducted in China, person-to-person transmission was deemed one of the main pathway of COVID-19 transmission [5–7]. Based on these findings, WHO recommended preventive measures, such as restriction of international travel, quarantine, social distancing, wearing of facemask, and encouraging hand hygiene, and the Saudi government implemented those preventive strategies throughout the country [8]. The present study seeks to extend this understanding by examining how ambient air pollutants and meteorological conditions in Dammam might influence these transmission dynamics.

A study by Burke et al. (2020) on the active monitoring of confirmed COVID-19 patients in the USA reported that COVID-19 transmission occurred due to person-to-person transmission or travel in the initial phase but not in the later phase, suggesting that the infection's transmission was not limited to the person-to-person transmission [9]. The common symptoms of COVID-19 included fever with or without respiratory syndrome, but it was observed that patients afterwards developed pulmonary abnormalities [10]. Wang et al. (2020) reported that intensive care was required for nearly one-fourth of the patients admitted to the hospital with viral pneumonia [7].

Air pollution refers to contamination of atmosphere by any chemical, physical or biological agent which changes its normal characteristics. The air pollutants which have a major impact on human health especially respiratory system includes particulate matter ($PM_{2.5}$ and PM_{10}), Carbon monoxide (CO), Ozone (O_3), Nitrogen dioxide (NO_2) and Sulphur dioxide (SO_2). These pollutants are mainly released into the atmosphere from industries, motor vehicles and household combustion techniques [11].

Studies reported that exposure to chronic air pollution leads to acute respiratory inflammation, asthma attacks, chronic obstructive pulmonary disease exacerbation and deaths from cardiorespiratory disease [12–19]. Researches initiated with the hypothesis that COVID-19 incidence and severity might be associated with air pollution reported association with susceptibility and severity of COVID-19. Studies conducted in China reported that short-term exposure to CO, NO_2, O_3 and PM 2.5 μm or less in diameter and 10 μm or less in diameter (PM_{10}) was significantly associated with confirmed COVID-19 cases and mortality [20,21]. Subsequently, much research was conducted around the globe to explore the relationship of air pollution with COVID-19 cases and mortality, but the results were inconsistent. A few studies described a positive correlation of COVID-19 incidence and severity with some air pollutants, such as NO_2, SO_2, $PM_{2.5}$ and O_3, while others reported a negative relationship of air pollution with COVID-19 transmission [21–30].

Along with air pollution, COVID-19 virus transmission and viability showed a strong association with meteorological parameters. This association highlights the importance of studying meteorological factors viz. air temperature and relative humidity (RH) on the transmission and viability of virus in different regions like Dammam in Saudi Arabia. A study by Lipsitch (2020) predicted that COVID-19 transmission would be highly influenced by temperature [31]. Studies from various regions reported a positive association of COVID-19 incidence with ambient air temperature and a negative correlation with relative humidity (RH), yet some studies reported an inverse correlation with ambient air temperature and average RH [19,22,24,25].

In Saudi Arabia, Abdel-Aal et al. (2022), conducted time series analyses from spring 2020 and 2021 and reported that temperature had a positive correlation with COVID-19 spread, while barometric pressure has a negative correlation [32]. Moreover, they describe discrepancies in the results from different cities and suggest that non-meteorological factors should be explored in combination with meteorological parameters to gain a better insight into the effects of environmental factors on COVID-19 incidence and severity.

The previous studies have shown mixed findings regarding the relationship between environmental factors and COVID-19 incidence and mortality, the present study findings will add evidence to available information. Understanding the effects of the environmental factors on COVID-19 susceptibility and severity might help to inform public health strategies and interventions to restrict the spread of viral infection and to reduce its severity.

To the best of our knowledge, no studies have looked into the association of meteorological parameters and air pollutants with COVID-19 incidence and mortality in Saudi Arabia. This study aimed to analyze the association of meteorological variables (temperature and RH), air quality index (AQI), and air pollutants (PM_{10}, SO_2 and O_3) with COVID-19 incidence and mortality.

2. Material and methods

The present retrospective study was conducted on COVID-19 infection, meteorological parameters, ambient air quality and ambient air pollutants in Dammam from 1 January to 30 April 2021.

Study location: Dammam (26°26′ N, 50°06′ E) is the capital of Saudi Arabia Eastern Province and one of the larger industrial cities in the country, having an area of 800 km^2 and a population of nearly 1.5 million [33]. It features a tropical and subtropical desert climate (BWh) under the Koppen climate classification [34].

Study period: The study period was from 1 January to 30 April 2021, six months after the lifting of the curfew restriction and population's return to normal life, although social distancing and mask wearing were still mandatory. Moreover, it was the period when COVID-19 vaccination had just commenced, so the population's immune response to infection was not completely developed. The study examined the short-term effect of AQI, ambient air pollutants and meteorological parameters on COVID-19 incidence and mortality in this period.

Meteorological and Ambient air quality data: The meteorological variables, temperature and RH data, along with AQI (a measure which is calculated based on six air pollutant CO, NO_2, O_3, SO_2, $PM_{2.5}$ and PM_{10}) and average ambient air pollutants (PM_{10}, SO_2 and O_3) data, were extracted from the publicly available website of Ministry of Environment, Water and Agriculture (MEWA) [35]. From the 120 days of the study period, data were retrieved for 84 days (70 % of days). The data was entered in the Microsoft spreadsheet by one of the authors and the entry was double-checked by two other authors for any error.

COVID-19 infection data: The data on COVID-19 incidence and mortality for Dammam were retrieved from the Saudi Arabia MoH's publicly accessible database in Microsoft spreadsheet format [4]. A COVID-19 incidence case refers to a 'daily new-suspected case with laboratory confirmation of COVID-19 infection using Polymerase chain reaction (PCR) test' [36]. COVID-19 mortality refers to 'death resulting from a clinically compatible illness in a confirmed or suspected COVID-19 case unless a clear alternative cause of death is evident' [36].

Statistical analysis: IBM SPSS Statistics version 24 was used to analyze the short-term effects of AQI, ambient air pollutants and meteorological parameters on COVID-19 incidence and mortality. The descriptive statistics are reported for the independent and dependent variables as mean value, standard deviation and minimum and maximum value. The AQI and PM_{10} were extremely higher on two days (March 13 and 14, 2021) than on other days, so those two days' data were omitted from the analysis. The outliers were identified by sorting the data followed by interquartile method. The extreme values were excluded as it can influence statistical power and may hide the true effect of the variable on the outcome if present.

The correlation of COVID-19 incidence and mortality with the independent variables was assessed by Pearson's correlation test for normally distributed data (temperature, RH, SO_2 and O_3) and Spearman's rho test for not normally distributed data (AQI and PM_{10}). Further analysis was performed to study the association of the independent variable with COVID-19 incidence using negative binomial regression model as the dispersion statistics was greater than 1 and the association with COVID-19 mortality using the Poisson regression model as the dispersion statistics close to 1. A p-value less than 0.05 was considered statistically significant.

3. Results

The mean temperature of the study period was found to be 26.48 °C with temperature ranging between 13 °C to 43 °C. The RH showed large variation during the study period ranging from 3 % to 87 %. The maximum AQI observed was 81 which reflects that air quality is acceptable. The maximum level of PM_{10} was 81 μg/m^3 and was at the borderline of poor air quality. The maximum SO_2 level [5 ppb (parts per billion)] reflects good air quality but the maximum O_3 level [55 ppbv (parts per billion of volume)] presents a moderate air quality. The mean incidence cases reported during the study period was approximately 18 patients and the average mortality reported was less than one patient. The descriptive details of meteorological parameters, AQI, ambient air pollutants, and COVID-19 incidence and mortality are presented in Table 1.

A maximum of 49 new cases of COVID-19 were reported on 19 April 2021, while AQI was highest on 19 March 2021, corresponding to the highest PM_{10} value 81. During the study period, the maximum COVID-19 mortality was 3 in one day. Fig. 1 shows the trend of AQI and COVID-19 incidence from 1 January to 30 April 2021.

Table 2 shows that COVID-19 incidence had a moderate positive correlation with daily temperature (r=0.537, p=.0001), and a moderate negative correlation with RH (r=−0.487, p=.0001). No correlation was observed between meteorological variables and COVID-19 mortality. COVID-19 incidence showed a mild positive correlation with AQI (r=0.269, p=.015) and the ambient air pollutants SO_2 and O_3 (r=0.258, p=.018), and COVID-19 mortality showed a mild positive correlation with PM_{10} (r_s = 0.344, p=.002).

The negative binomial distribution regression model revealed that COVID-19 incidence had a positive association with daily temperature (Relative Risk (RR) = 1.022, 95 % Confidence Interval (CI): 1.005–1.038, p=.009) and an inverse association with RH (RR = 0.992, 95 % CI: 0.987–0.997, p=.003). Further, AQI showed an inverse association with COVID-19 incidence (RR=0.985, 95 % CI: 0.974–0.997, p=.011), while PM_{10} showed a direct association (RR = 1.015, 95 % CI: 1.006–1.023, p=.001) (Table 3).

The Poisson regression model revealed no association of meteorological variables with COVID-19 mortality. However, the ambient

Table 1
Descriptive statistics of meteorological parameters, air quality index, ambient air pollutants and COVID-19 incidence and mortality.

	Mean	Standard Deviation	Minimum	Maximum
Meteorological parameters (82 days)				
Temperature (°C)	26.48	6.59	13	43
Relative Humidity (%)	32.51	21.69	3	87
Air Quality Index	29.57	12.02	11	81
Air Pollutants (82 days)				
PM_{10} (μg/m^3)	20.22	12.57	3	81
SO_2 (ppb)	2.01	1.10	0	5
O_3 (ppbv)	24.12	12.63	4	55
COVID-19 infection (82 days)				
Incidence	18.08	9.23	2	49
Mortality	0.60	0.83	0	3

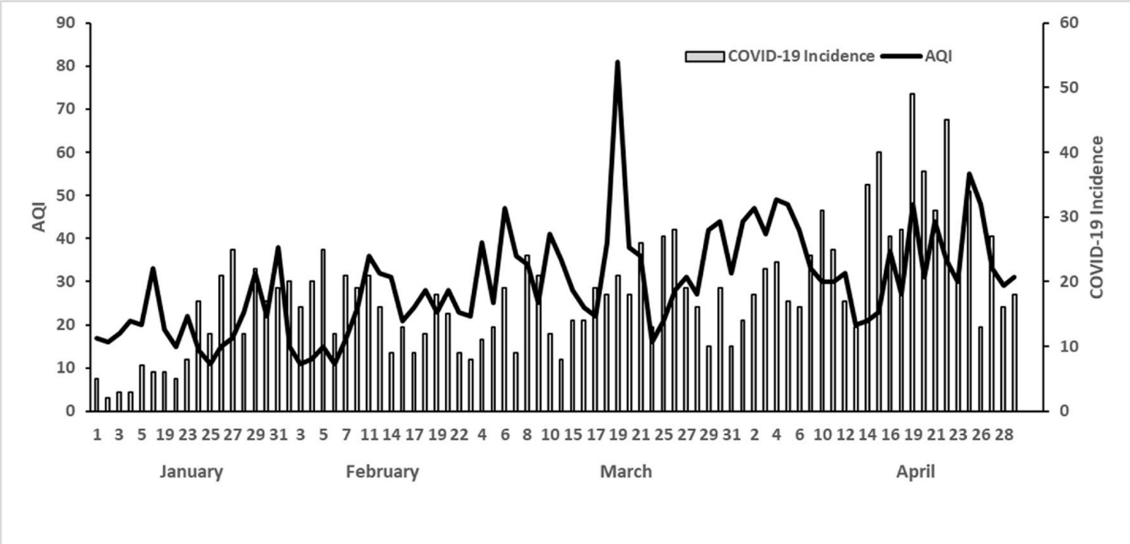

Fig. 1. AQI and COVID-19 incidence from 1st January to 30th April 2021.

Table 2
Correlation of COVID-19 incidence and mortality with meteorological parameters, air quality index and ambient air pollutants.

	COVID-19 Incidence		COVID-19 Mortality	
	r	p-value	r	p-value
Meteorological parameters (82 days)				
Daily Temperature (°C)	0.53	0.0001[a]	0.189	0.086
Relative Humidity (%)	−0.487	0.0001[a]	−0.098	0.377
[b]Air Quality Index	0.269	0.015[a]	0.107	0.337
Air Pollutants (82 days)				
[b]PM_{10} (μg/m^3)	0.140	0.211	0.344	0.002[a]
SO_2 (ppb)	0.258	0.018[a]	0.155	0.159
O_3 (ppbv)	0.258	0.018[a]	0.189	0.086

[a] p-value significant.
[b] Spearman's rho test.

air pollutant PM_{10} showed a positive association with COVID-19 mortality (RR = 1.048, 95 % CI: 1.005–1.094, p=.030) (Table 4).

4. Discussion

Many studies have contended that COVID-19 incidence and mortality are linked with air pollution and meteorological conditions. To date, however, no study from Saudi Arabia had focused on whether air pollution affects COVID-19 incidence and mortality. This

Table 3
Negative binomial distribution regression model for COVID-19 incidence.

Parameters	Regression Coefficient	Risk ratio	95 % CI	p-value
Meteorological parameters				
Daily Temperature (°C)	0.022	1.022	1.005–1.038	0.009[a]
Relative Humidity (%)	−0.008	0.992	0.987–0.997	0.003[a]
Air Quality Index	−0.015	0.985	0.974–0.997	0.011[a]
Air Pollutants				
PM_{10} (μg/m^3)	0.015	1.015	1.006–1.023	0.001[a]
SO_2 (ppb)	0.010	1.010	0.939–1.086	0.796
O_3 (ppbv)	0.010	1.010	0.999–1.020	0.063

[a] p-value significant.

Table 4
Poisson regression model for COVID-19 mortality.

Parameters	Regression Coefficient	Risk ratio	95 % CI	p-value
Meteorological parameters				
Daily Temperature (°C)	0.068	1.070	0.991–1.155	0.082
Relative Humidity (%)	0.020	1.020	0.998–1.042	0.073
Air Quality Index	−0.032	0.968	0.919–1.020	0.229
Air Pollutants				
PM_{10} (μg/m^3)	0.047	1.048	1.005–1.094	0.030[a]
SO_2 (ppb)	0.173	1.189	0.845–1.673	0.320
O_3 (ppbv)	0.013	1.013	0.972–1.057	0.535

[a] p-value significant.

study sought to provide evidence to fill this lacuna.

Correlation of meteorological parameters with COVID-19 incidence and mortality: The present study found a direct relationship of COVID-19 incidence with temperature and an indirect relationship with RH. These findings concord with the study of Abdel-Aal et al. (2022), which reports a positive correlation of COVID-19 incidence with temperature and a negative correlation with barometric pressure [32]. Similarly, a study by Adhikari and Yin, (2020) reports daily average temperature to be positively associated with COVID-19 incidence; in contrast with present study's findings, however, their study reports a positive association of average RH with newly confirmed COVID-19 cases [22]. This difference might have raised due to the difference in the time of study, in the present study the data were collected three months after lifting of curfew (January–April 2021) in Saudi Arabia to assess the effect of short term exposure of environmental factors on COVID-19 incidence and mortality, while the above study from United States collected data during the peak of COVID-19 pandemic (March 1 to April 20, 2020). Further, the geographical area of the study were different, which might had led to the differences in the study results. Moreover, the average RH levels in the above study was higher than the present study (69.20 % vs. 32.51 %) which might have also resulted in this discrepancy.

Another study also reported the contrary results that high temperature, air pressure and efficient ventilation reduce the transmissibility of COVID-19 infection [37]. Li et al. (2020) similarly describe an inverse correlation of ambient temperature with COVID-19 incidence [19]. In the present study, the meteorological parameters showed no association with the mortality due to COVID-19, but Jiang and Xu (2021) report an inverse association of temperature with COVID-19 deaths [24]. The differences in the study finding of present study and above mentioned studies might be due to the different study period, the above mentioned studies were conducted one year before the present study when the COVID-19 related incidence and mortality were high.

Correlation of AQI and air pollutants with COVID-19 incidence and mortality: The present study's results indicate a positive correlation of COVID-19 incidence with AQI, SO_2 and O_3 levels. Further, the negative binomial distribution regression model found a direct association of COVID-19 incidence with PM_{10}, which was also the only air pollutant showing a positive association with COVID-19–related mortality. Similar to present study's findings, Zhang et al. (2020) report that the spread of coronavirus increases by 5–7% as the AQI increases by 10 units [19]. Further, Li et al. (2020) also support the present study's finding of PM_{10}'s association with COVID-19 incidence and mortality [25]. A study by Semczuk-Kaczmarek et al. (2022) on long-term exposure to air pollutants, especially $PM_{2.5}$, PM_{10}, SO_2, NO_2 and O_3, reports that these pollutants played a significant role in COVID-19 incidence and mortality [27].

Likewise, a study by Pansimi and Fornacca (2021) identified more viral infections in areas experiencing high $PM_{2.5}$ and NO_2, and they note that poor air quality correlates with COVID-19 deaths [26]. A study from England reports that a slight rise in air pollution causes a huge escalation in COVID-19 infectivity and mortality [28]. Further, Zhu et al. (2020) support the present findings by reporting a positive association of $PM_{2.5}$, PM_{10}, NO_2 and O_3 with newly confirmed COVID-19 cases [21]. Yao et al. (2020) report that an increased COVID-19 fatality rate is associated with increased PM_{10} levels [29]. In a subsequent study, Yao et al. (2020) indicate that increased levels of inhalable $PM_{2.5}$ and PM_{10} are linked with higher fatality rates of COVID-19 cases [38]. Bashir et al. (2020) report that the ambient air pollutants PM_{10}, $PM_{2.5}$, SO_2, NO_2 and CO are significantly correlated with COVID-19 incidence and mortality [23].

In the present study, we found that AQI had an indirect association with COVID-19 incidence (RR = 0.985, 95 % CI: 0.974–0.997, p=.011). Zhang et al. (2020) study also found that air pollution had negative interactive effects on COVID-19 transmission [19]. Contradicting the present study's findings, Jiang and Xu (2020) report a positive correlation of AQI (mainly $PM_{2.5}$) with COVID-19 deaths and a negative association of PM_{10}, SO_2 and CO with COVID-19 mortality [24]. The discrepancies between the present study's findings and those of other studies may be due to different methods of counting COVID-19 deaths. Furthermore, the AQI and the pollutants level in Saudi Arabia were good and within acceptable levels, whereas the other studies had very different levels of pollution compared to Saudi Arabia.

Limitations: To the best of our information, this is the first study in Saudi Arabia to examine short-term exposure to air pollutants and meteorological parameters in association with COVID-19 incidence and mortality. However, the study has limitations. First, the number of days studied was small. Second, only three air pollutants (O_3, SO_2 and PM_{10}) were studied, and many other pollutants that may affect the transmission and pathogenesis of COVID-19, such as NO_2 and $PM_{2.5}$, were not considered, as data were not available for the study period. Moreover, the data were collected from fixed monitors at King Fahad International Airport, Dammam which is about 30–35 km from the city, so the data may not represent the actual exposure level for people infected with COVID-19, especially those living far from the monitoring station. Despite these limitations, the study's findings provide insight into the interaction of air pollutants, AQI and meteorological parameters with COVID-19 incidence and mortality.

Future area of research: In future studies should be performed in the nations which have similar environmental condition and healthcare system to address the air pollutants especially NO_2, and $PM_{2.5}$ which are crucial air pollutant affecting respiratory system. Further, the study should include larger number of days focusing on all the air pollutants.

5. Conclusion

Short-term exposure to air pollutants (O_3 and SO_2) and one meteorological parameter (temperature) were directly related to COVID-19 incidence, and RH was indirectly associated with COVID-19 incidence. Furthermore, PM_{10} was positively associated with COVID-19 mortality.

Statements and declarations

"All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the "Instructions for Authors".

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Data availability

Data included in article/supp. material/referenced in article.

Ethical approval

Not required as the present study utilized population-level data which were open data publicly available in Saudi MOH and MEWA web pages.

Consent to participate

Not applicable.

Consent to publish

Not applicable.

CRediT authorship contribution statement

Manal Mutieb Almutairi: Writing – review & editing, Methodology, Data curation, Conceptualization. **Nargis Begum Javed:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Soni Ali Sardar:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Amal Yousef Abdelwahed:** Writing – review & editing, Writing – original draft, Conceptualization. **Razan Fakieh:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Mohammed AL-Mohaithef:** Writing – review & editing, Writing – original draft, Conceptualization.

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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