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*Research Article*

# The Effect of Humidity and Temperature on Indoor and Outdoor COVID-19 Infections

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Environmental conditions and their association with COVID-19 have significantly attracted scientists' attention. The current study links COVID-19 with climate indicators by comparing two configurations: indoor infections in a University of Duhok (UOD) building and outdoor infections within the boundaries of the Duhok Governorate (DG). The collected data included temperature and relative humidity (RH) and confirmed cases for indoor and outdoor configurations over 5 and 11 months, respectively. For the indoor infections, data were collected over the period of 5 weekdays, while for the outdoor infections, they were collected on the days when statistics were published. The prospective cross-section design was used for different statistical analyses. The overall indoor infections were very low, and the maximum values for RH and temperature were approximately <24% and <20°C, respectively; in the one-sample *t*-test, the results were significantly correlated ($p$ value <0.05) with the confirmed COVID-19 cases. For outdoor infections, using the correlation bivariate method, the study found that the RH and temperature results significantly correlated ($p$ value <0.05) with the confirmed COVID-19 cases. However, for indoor configuration, other than for $T_{max}$, the results were not associated. As for the outdoor infections, the RH and temperature averages were high enough to put in groups to employ the one-way repeated ANOVA and general linear model with the same results. The means of the $RH_{low}$, $RH_{medium}$, and $RH_h$ groups were significantly correlated ($p$ value <0.05) with COVID-19. However, the means of the medium RH and high RH groups were not significantly associated with the increasing outdoor infections. This study will contribute to the reduction of overall COVID-19 infections.

## 1. Introduction

Since December 2019, coronavirus first identified in Wuhan, China, has threatened people's lives throughout the world [1], and many of the countries went into lockdown. Moreover, COVID-19 has become one of the most global public health concerns with 370,730,367 cases including 5,669,189 deaths recorded as of January 29, 2022 [2].

The potential causes for the COVID-19 outbreak are Wuhan seafood supermarkets, less social distance, and transmission via close human contact [3, 4]. Furthermore, a significant number of scientists published works discussing the possible roles of environmental factors such as temperature and humidity in transmission across the world [1, 5–10]. However, some studies showed no direct relation between COVID-19 and environmental parameters [11–13]. Some researchers revealed that the dissimilarities in the transmission association and environment variables were ascribed to various factors and metrological conditions [14, 15].

To understand the association of COVID-19 cases with environmental factors, this study analyses the association by comparing two configurations over a specific period of time and on a daily basis. One configuration was conducted at a low level of population within a building and the second at a high level of population within the city of Duhok. The association focused on the confirmed cases and environmental conditions. Accordingly, it is hypothesized that both low temperature and relative humidity throughout indoor and outdoor measurements upsurge COVID-19 cases. Four models including the correlation bivariate method, one-sample *t*-test, one-way repeated ANOVA, and general linear model were used for analyzing the association. The study revealed direct connections between confirmed indoor and outdoor cases and climate variables that contribute to the reduction of overall COVID-19 infections.

## 2. Methodology

The Duhok Governorate lies in the western part of the Kurdistan region, northwest of Iraq, and the building of the College of Science (CoS) is on the UOD campus. To have homogeneous and reliable results with feasible data analysis, the indoor and outdoor infections were chosen in the same area.

For the indoor infections, data were collected on five workdays inside the CoS building that comprises of the departments of Computer Science (CS), Mathematics, and Physics housing students, academic staff, and employees. Communication and daily activities including laboratory experiments were manageable. The data collection included temperature and relative humidity in four different positions. The average measurements for each collected data were done to have more accurately measured parameters. Environmental data were recorded daily using the digital temperature humidity meter (HTC-1) device from the brand Plu. The number of people who entered the CoS building during the set period was registered separately in each department. Later, the three departments' data per day were registered. The summation process included the following categories: the number of infections and confirmed cases including students, staff, and employees. Accordingly, the confirmed cases and environmental data for the indoor infections were recorded from Sundays to Thursdays, December 2020–February 2021 and September 2021–October 2021, respectively.

The environmental data for the outdoor infections were collected from the official world weather website (https://www.worldweatheronline.com/). The climate data were recorded daily from December 2020 to October 2021. The minimum, maximum, and average data for temperature and relative humidity were extracted. Besides that, the data of confirmed outdoor cases were obtained daily from the following official source: COVID-19: Dashboard-GOV.KRD. For the overall work, all data were recorded. The examined outdoor relative humidity and temperature values were high enough to employ the one-way repeated ANOVA and general linear model. Accordingly, data infections were divided into three groups, low RH ($RH_{low}$), medium RH ($RH_{med}$), and high RH ($RH_h$), and low temperature ($T_{low}$), medium temperature ($T_{med}$), and high temperature ($T_{max}$). The temperature values were as follows: $T_{low} < 25^{\circ}C$, $25 \leq T_{med} < 35^{\circ}C$, and $T_{max} \geq 35^{\circ}C$. The research showed that the comfort relative humidity levels for health quality were between >30% and <70% depending on the various levels of temperatures [16–19]. The levels of comfort relative humidity for the outdoor were between >30% and <60%, that is, the range of $RH_{low}$ was ≤30%, $R_{med} > 30\%$ $RH_{med} \leq 60\%$, and $RH_h > 60\%$. In Duhok, some devices indicated that the uncomfortable level started at 63%, i.e., WS 1700 Hygrometer mit Schimmelalarm device.

## 3. Statistical Analysis

The prospective cross-section design was carried out using different statistical methods including the correlation bivariate, and the one-sample *t*-test and one-way repeated ANOVA were employed to investigate the association under question. Pearson, Kendall, and Spearman correlations were conducted for indoor and outdoor infections. Since the overall environmental variables were very low for the indoor infections, the one-sample *t*-test method was used. For the outdoor infections, the one-way repeated ANOVA and general linear model were adopted to explore the means between the data infections groups.

## 4. Results

*4.1. Descriptive Analysis for Both Indoor and Outdoor Configurations.* The descriptive analysis of the confirmed COVID-19 infections and the environmental parameters which are $T_{min}$, $T_{max}$, $T_{av}$, $RH_{min}$, $RH_{max}$, and $RH_{av}$ data along with standard deviation (SD), skewness, and kurtosis distributions of the aforesaid variables for indoor and outdoor configurations are given in Table 1.

For the indoor configuration, the total number of variables was 101 on 5 working days over five months (December 2020 to February 2021 and September 2021 to October 2021). The data scales showed that the data were positive for kurtosis distributions. For skewness distribution, $H_{min}$, $H_{max}$, and $H_{av}$ were negative, but the rest were positive. Also, for skewness distribution, the negative data refer to the left-skewed distribution, while the positive data represent the right-skewed distributions. Accordingly, the asymmetry range of data was <2.5 around ±1, except for the confirmed COVID-19 cases which were high, namely, 4.18. For kurtosis distribution, the positive kurtosis demonstrates that the data display more extreme outliers than a normal distribution, while negative kurtosis implies that the data expose fewer extreme outliers than normal distribution. Accordingly, all the data ranges were <2.5 except for the confirmed cases, which were extremely high throughout the recorded data.

For outdoor configuration, the total number of variables was 262 days, over 11 months (December 2020 to October 2021). The data scales of $T_{min}$, $T_{max}$, and $T_{av}$ showed that the data were negative for both skewness and kurtosis distributions. On the other hand, $RH_{min}$, $RH_{max,}$ and $RH_{av}$ were entirely positive for skewness, while for kurtosis, $RH_{min}$ was showed only the positive trend. Most of the data were <±1.6 for skewness and kurtosis, except for the confirmed COVID-19 cases which were high, namely, between 2 and 6.

The high statistical values for skewness and kurtosis distributions implied the nonnormality distribution of data. Accordingly, various statistical methods were used to overcome such abnormal data.

*4.2. Overview of Indoor Infection and Its Association with Environmental Variables.* For the indoor infections, the one-sample *t*-test and bivariate methods including Pearson, Kendall's tau-b, and Spearman correlations were used.

Table 1: The descriptive analysis of confirmed COVID-19 cases and environmental data.

| Configuration | Total number | Parameters | Max. | Mean | SD | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| Indoor | 101 | Confirmed cases | 7 | 0.5050 | 1.11914 | 4.180 | 21.472 |
| | | $T_{min}$ | 24.40 | 13.0003 | 3.85200 | 1.312 | 2.484 |
| | | $T_{max}$ | 24.80 | 14.2543 | 3.69736 | 1.114 | 2.026 |
| | | $T_{av}$ | 24.50 | 13.6506 | 3.72013 | 1.232 | 2.375 |
| | | $RH_{min}$ | 22.00 | 18.5149 | 2.54799 | −1.120 | 0.316 |
| | | $RH_{max}$ | 24.00 | 19.9010 | 2.68516 | −1.160 | 0.445 |
| | | $RH_{av}$ | 22.75 | 19.3545 | 2.49259 | −1.250 | 0.649 |
| Outdoor | 262 | Confirmed cases | 1564.00 | 297.4618 | 292.63516 | 2.163 | 5.989 |
| | | $T_{min}$ | 32.00 | 15.6107 | 10.09690 | −0.215 | −1.311 |
| | | $T_{max}$ | 45.00 | 26.3931 | 11.96619 | −0.240 | −1.550 |
| | | $T_{av}$ | 37.50 | 21.3363 | 10.86612 | −0.179 | −1.492 |
| | | $RH_{min}$ | 85.00 | 25.6870 | 17.67787 | 1.113 | 0.701 |
| | | $RH_{max}$ | 98.00 | 45.0305 | 22.38292 | 0.564 | −0.745 |
| | | $RH_{av}$ | 90.38 | 35.7890 | 20.12430 | 0.724 | −0.432 |

Table 2: One-sample *t*-test correlations between meteorological factors and COVID-19-infected cases for indoor configuration.

| Statistical method | Configuration | Environmental variables | *P* value |
|---|---|---|---|
| One-sample *t*-test | Indoor | $T_{min}$ (°C) | <0.05 |
| | | $T_{max}$ (°C) | <0.05 |
| | | $T_{av}$ (°C) | <0.05 |
| | | $RH_{min}$ (%) | <0.05 |
| | | $RH_{max}$ (%) | <0.05 |
| | | $RH_{av}$ (%) | <0.05 |

Table 3: Pearson, Kendall's tau-b, and Spearman correlations between meteorological factors and COVID-19-infected cases for indoor configuration.

| Statistical method | Configuration | Environmental variables | Correlation | *P* value |
|---|---|---|---|---|
| Pearson | Indoor | $T_{min}$ (°C) | 0.127 | 0.206 |
| | | $T_{max}$ (°C) | 0.200 | 0.045 |
| | | $T_{av}$ (°C) | 0.178 | 0.076 |
| | | $RH_{min}$ (%) | 0.052 | 0.608 |
| | | $RH_{max}$ (%) | 0.073 | 0.466 |
| | | $RH_{av}$ (%) | 0.077 | 0.445 |
| Kendall's tau-b | Indoor | $T_{min}$ (°C) | 0.033 | 0.684 |
| | | $T_{max}$ (°C) | 0.096 | 0.231 |
| | | $T_{av}$ (°C) | 0.078 | 0.331 |
| | | $RH_{min}$ (%) | 0.090 | 0.290 |
| | | $RH_{max}$ (%) | 0.129 | 0.130 |
| | | $RH_{av}$ (%) | 0.112 | 0.169 |
| Spearman | Indoor | $T_{min}$ (°C) | 0.038 | 0.708 |
| | | $T_{max}$ (°C) | 0.116 | 0.249 |
| | | $T_{av}$ (°C) | 0.093 | 0.357 |
| | | $RH_{min}$ (%) | 0.107 | 0.287 |
| | | $RH_{max}$ (%) | 0.152 | 0.129 |
| | | $RH_{av}$ (%) | 0.137 | 0.172 |

For the one-sample *t*-test, the results revealed that confirmed COVID-19 cases for the indoor infections were significantly linked to the environmental parameters ($p$ value <0.05) as given in Table 2. Supporting our findings, research studies validated those environmental parameters, $RH_{min}$, $RH_{max}$, $RH_{av}$, $T_{min}$, $T_{max}$, and $T_{av}$, and boosted the prevalence of COVID-19, and dry and cool weather conditions potentially spread COVID-19 [5, 7, 8, 20–22].

For the bivariate method, Pearson, Kendall's tau-b, and Spearman correlations showed that the confirmed COVID-19 cases were not significantly correlated to the environment conditions ($p$ value >0.05) except for $T_{max}$ ($p$ value <0.05), as given in Table 3. Throughout the calculations, confirmed COVID-19 cases were positively correlated with all environmental conditions. These findings were consistent with the studies that confirmed that environmental conditions

Table 4: Pearson, Kendall's tau-b, and Spearman correlations between meteorological factors and COVID-19-infected cases for outdoor configuration.

| Statistical method | Configuration | Environmental variables | Correlation | $P$ value |
|---|---|---|---|---|
| Pearson | Outdoor | $T_{min}$ (°C) | 0.604 | <0.05 |
| | | $T_{max}$ (°C) | 0.594 | <0.05 |
| | | $T_{av}$ (°C) | 0.604 | <0.05 |
| | | $RH_{min}$ (%) | −0.467 | <0.05 |
| | | $RH_{max}$ (%) | −0.465 | <0.05 |
| | | $RH_{av}$ (%) | −0.479 | <0.05 |
| Kendall's tau-b | Outdoor | $T_{min}$ (°C) | 0.526 | <0.05 |
| | | $T_{max}$ (°C) | 0.518 | <0.05 |
| | | $T_{av}$ (°C) | 0.518 | <0.05 |
| | | $RH_{min}$ (%) | −0.402 | <0.05 |
| | | $RH_{max}$ (%) | −0.390 | <0.05 |
| | | $RH_{av}$ (%) | −0.405 | <0.05 |
| Spearman | Outdoor | $T_{min}$ (°C) | 0.717 | <0.05 |
| | | $T_{max}$ (°C) | 0.718 | <0.05 |
| | | $T_{av}$ (°C) | 0.721 | <0.05 |
| | | $RH_{min}$ (%) | −0.588 | <0.05 |
| | | $RH_{max}$ (%) | −0.571 | <0.05 |
| | | $RH_{av}$ (%) | −0.594 | <0.05 |

Table 5: One-way ANOVA and general linear model correlations between meteorological factors and COVID-19-infected cases for outdoor configuration.

| Statistical method | Dependent variable | Parameter | Parameter in relation | $P$ value |
|---|---|---|---|---|
| One-way ANOVA and general linear model | Confirmed cases | $RH_{low}$ | $RH_{med}$ | <0.05 |
| | | | $RH_h$ | <0.05 |
| | | $RH_{med}$ | $RH_{low}$ | <0.05 |
| | | | $RH_h$ | 0.246 |
| | | $RH_h$ | $RH_{low}$ | <0.05 |
| | | | $RH_{med}$ | 0.246 |
| One-way ANOVA and general linear model | Confirmed cases | $T_{low}$ | $T_{med}$ | <0.05 |
| | | | $T_h$ | <0.05 |
| | | $T_{med}$ | $T_{low}$ | <0.05 |
| | | | $T_h$ | <0.05 |
| | | $T_h$ | $T_{low}$ | <0.05 |
| | | | $T_{med}$ | <0.05 |

have not alleviated (or have no connection) in relation with the prevalence of COVID-19 if the ventilation system is highly functional [23]. While, $T_{max}$, which is < 25°C (Table 1), alleviated in the relation with the prevalence of COVID-19 [20].

*4.3. Overview of Outdoor Infections and Its Association of Environmental Conditions.* For the outdoor infections, three statistical methods were used to examine the association between the confirmed COVID-19 cases and the environmental parameters results: the bivariate method including all of Pearson, Kendall's tau-b, and Spearman correlations, the one-way repeated ANOVA, and general linear method.

The bivariate method, Pearson, Kendall's tau-b, and Spearman correlations showed that the confirmed COVID-19 cases were significantly connected to the environmental conditions, RH and temperature values ($p$ value <0.05), as given in Table 4. Throughout the calculations, the cases correlated with minimum, maximum, and average RH, while the confirmed ones were positively correlated with the minimum, maximum, and average temperature. These findings were consistent with the studies that related the minimum, maximum, and average RH with the prevalence of COVID-19 [6, 8, 24]. Likewise, the outdoor temperature in New York, USA, was significantly related to the transmission of the COVID-19 epidemic [6].

One-way repeated ANOVA and general linear methods showed that the confirmed cases were significantly connected to most environmental conditions including the whole temperature categories and partially the RH average groups [25, 26]. The temperature categories were significantly correlated ($p$ value <0.05) with outdoor infections as advocated by the previous studies [25, 27]. On the other hand, $RH_{low}$ with both $RH_{med}$ and $RH_h$, $RH_{med}$ with $RH_{low}$, and $RH_H$ with $RH_{low}$ were significantly ($p$ value <0.05) correlated with the COVID-19 cases [25, 26], yet $RH_{med}$ was not significantly connected with $RH_h$, as given in Table 5.

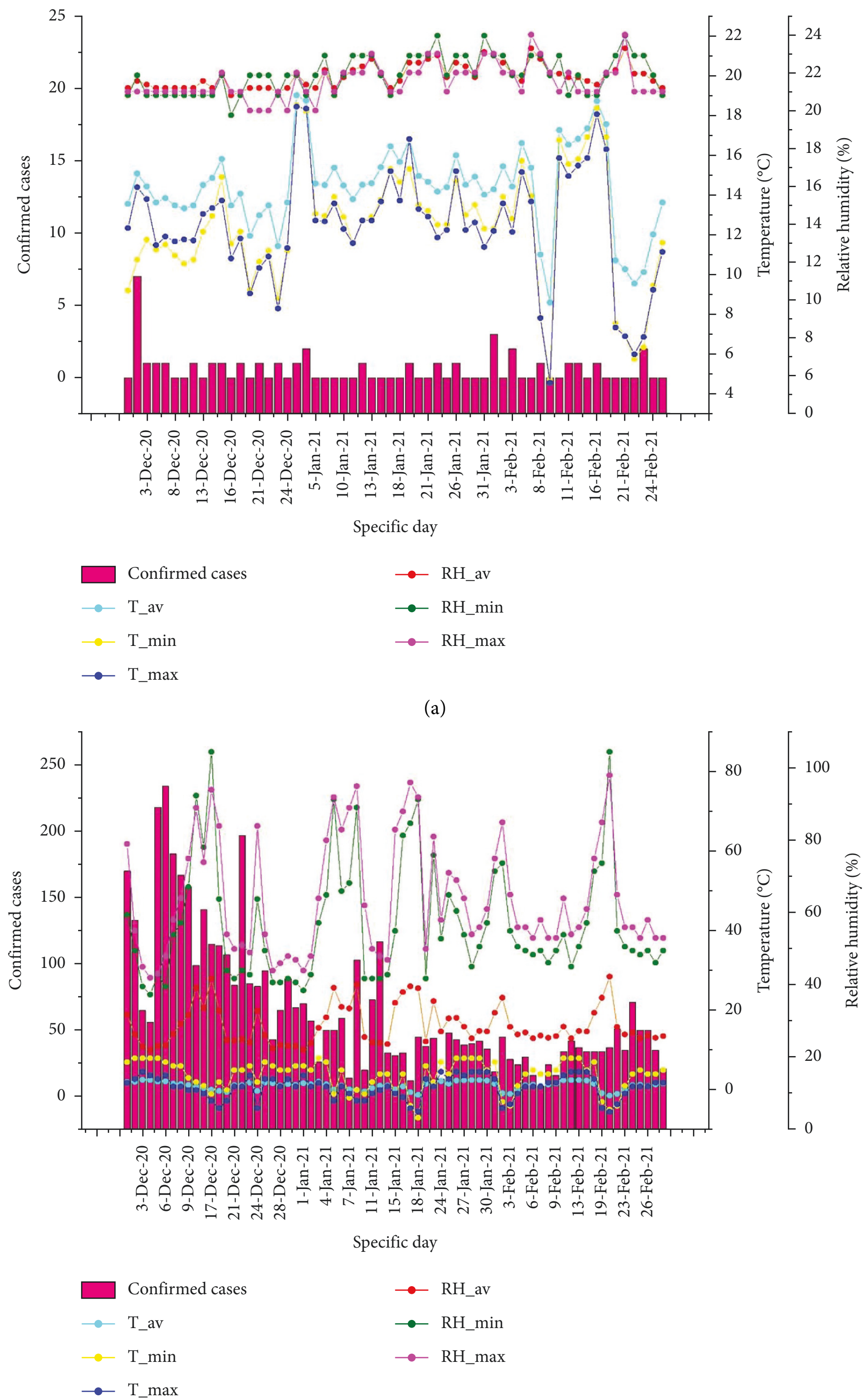


FIGURE 1: Total confirmed COVID-19 cases and environmental variables before starting the vaccination process in KRI for (a) indoor configuration and (b) outdoor configuration.

## 5. Discussion

Scientists argued that environmental conditions could contribute to the spread of COVID-19 [7, 13, 20–22]. For the indoor infections, different methods were used to examine the association between the environmental conditions ($T_{min}$, $T_{max}$, $T_{av}$, $RH_{min}$, $RH_{max}$, and $RH_{av}$) and the confirmed COVID-19 cases. The one-sample *t*-test showed a significant relation with these cases, and the bivariate method showed that $T_{min}$, $T_{max}$, $T_{av}$, $RH_{min}$, $RH_{max}$, and $RH_{av}$ were not significantly correlated. The mean RH and temperature values were not significantly different, and they were within the range of <24. This could be due to the use of personal protective equipment (PPE) provided by the KRI government, the directions of the UOD, and the observance of the people who entered the building. In addition, the healthy ventilation in enclosed spaces such as laboratories and classrooms on workdays could play an effective role in diminishing the pandemic [26].

All the recorded metrological data of indoor configuration were addressed in the low trend, which can in turn stimulate the pandemic according to the previous studies [20, 28]. Consequently, the minimum and maximum values for the temperature and RH and the maximum confirmed cases on 5 workdays over 5 months were 4.75°C, 24.80°C, and 12%, 24%, and 16 cases, respectively. The maximum value of the 16 confirmed cases was recorded in December 2020. No minimum and maximum values of metrological parameters were detected, which could mean that the vaccination campaign has decreased the prevalence of COVID-19 [29].

On the other hand, when the vaccination doses were not administered during the data collection process, the minimum and maximum temperature and RH values and maximum indoor cases in three months were 4.75°C, 20.20°C, and 18%, 24%, and 16 cases, respectively. The minimum value of RH on 5 workdays, 18%, was observed in December 2020, but the maximum RH and minimum/maximum temperature were not reported at this time. As a result, the low-recorded data could be attributed to the outbreak. The indoor configurations before the vaccination are graphed, as shown in Figure 1(a).

For the outdoor infections, the three methods used to investigate the association between the metrological conditions and the confirmed cases gave similar results. The bivariate method showed that $T_{\min}$, $T_{\max}$, $T_{\mathrm{av}}$, $\mathrm{RH}_{\min}$, $\mathrm{RH}_{\max}$, and $\mathrm{RH}_{\max}$ significantly correlated with the cases, which is in agreement with the previous studies specially for low RH [15, 20]. The one-way ANOVA and general linear model were also utilized to explore the connection. The means of the environmental variables were significantly correlated ($p$ value <0.005) with the increasing outdoor infections. In this regard, the temperature categories were significantly correlated ($p$ value <0.05) with the outdoor COVID-19 cases [24, 25, 27]. Researchers also indicated that outdoor RH and temperature were inversely correlated to COVID-19 [29, 30]. On the other hand, the relation of outdoor temperature in Spain was not significant [10]. Although the means of $\mathrm{RH}_{\mathrm{low}}$, $\mathrm{RH}_{\mathrm{med}}$, and $\mathrm{RH}_{\mathrm{h}}$ were significantly connected with infections, $\mathrm{RH}_{\mathrm{med}}$ and $\mathrm{RH}_{\mathrm{h}}$ were not. In this study, it was observed that the minimum and maximum values for the temperature, RH, and maximum confirmed cases reported by the National Health Sector (NHS) throughout 11 months were −7°C, 45°C, and 6%, 98%, and 20572 cases, respectively. The maximum value (20572) was recorded in July 2021. The minimum and maximum values of humidity and temperature were not recorded on this date. The minimum and maximum of RH were 7% and 34%, and the maximum value of temperature was 43°C, which is high. The lowest and maximum temperature values were 26°C, which is medium. Furthermore, when the recorded values of the confirmed cases were over 15000 per month, the maximum RH values were <37%; the minimum and maximum temperatures were 25°C and 45°C.

During the process of data collection when vaccination was not available, the minimum/maximum temperature and RH values and maximum outdoor infections over 3 months were −7°C, 16°C, and 24%, 98%, and 2768, respectively. The maximum number (2768) of cases was recorded in December 2020. The minimum RH and maximum temperature values during this period were 24% and 16°C, where only maximum temperatures were recorded. The minimum RH value, 24%, was observed in December 2020 and January 2021, but the maximum value was only reported in February 2021. The prevaccination indoor configurations are shown in Figure 1(b).

Although the indoor and outdoor data were configured together, the indoor configuration was carried on for 5 months and the outdoor configuration for 11 months. This is due to the complexity of the KRI government policy, especially regarding the UOD's housed population on the campus. Overall, the indoor results were similar to those obtained by previous scholars in terms of the disease association with the atmospheric parameters [5, 20, 22, 31–34]. Nevertheless, some contradictory results were observed where the infection had no significant link with indoor conditions. This suggests that PPE could have a potential effect on the mitigation of COVID-19 in the community. The outdoor results did not agree with the previous works concerning the environmental conditions relationship and the open areas being safer than the enclosed ones [34–36] because the KRI lockdown failed to support the population's socioeconomic conditions [37]. During June, July, and August, citizens in Duhok went on picnics in the countryside and did not adhere to COVID-19 precautions. As a result, all the high infection rates were recorded in hot summer, and the number of confirmed cases increased from 5 to above 100 per day and fatalities went from 1% up to 3.4% [37].

## 6. Conclusion

This study assumes that parameters such as temperature and humidity have an impact on increased COVID-19 infections. This work was carried on two indoor and outdoor configurations using different statistical methods to gain a comprehensive perception, which is a valuable addition to the scientific legacy.

Although the range of indoor configurations was low, the study results found significant correlations. If PPE and regulations are observed in enclosed areas, COVID-19 could be abated. Furthermore, the bivariate method did not show any significant association between COVID-19 and the environmental parameters.

For outdoor configuration, overall statistical methods showed significant correlations between confirmed COVID-19 cases and the environmental conditions. Moreover, means of the low RH values were significantly linked with the confirmed infections, whereas the means of the medium and high RH categories were not.

The current study advocates for the commitment to the WHO and governments' protective protocols including mobile teams to raise awareness about PPE usage in rural areas, especially in summer to lessen the spread of SARS-CoV-2 in the community.

The novelty of the current study lies on its analytical association between COVID-19 and climate indicators by drawing a comparison between two configurations (indoor and outdoor infections). Still, further work needs to be conducted between multiple indoor configurations (more buildings) and outdoor infections to have even more feasible outcomes.

The metrological variables were collected from official online websites due to the local authorities' regulations regarding data access. Using local data in future studies will help us understand their association with the transmission of COVID-19 cases. Finally, other parameters such as the speed of wind and various ventilation modes can be investigated to offer interesting scientific health insights [38–41].

## Data Availability

The data used to support this study are included within Supplementary Materials.

## Conflicts of Interest

The author declares that there are no conflicts of interest.

## Supplementary Materials

The data of the current research, which are confirmed cases, $T_{min}$, $T_{max}$, and $T_{av}$, RHmin, RHmax, and RHav were collected for indoor and outdoor configurations in the same era. The data have been plotted and provided in the research article as Figure 1 (a and b). Accordingly, Figure 1 shows total confirmed COVID-19 cases and environmental variables before starting the vaccination process in KRI for (a) indoor configuration and (b) outdoor configuration. (*Supplementary Materials*)

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