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# Weather Parameters Impact on Daily COVID-19 Transmission in Bangladesh

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**Abstract:** COVID-19 disease causes millions of human deaths and huge economic losses throughout the world. To limit the disease transmission numerous attempts have been made. Several studies observed associations of weather values on COVID-19 transmission. In the current study, the impacts of weather parameters on daily COVID-19 incidences have been examined in eight different cities in Bangladesh. For this purpose, a whole one-year data set of daily COVID-19 laboratory tests and tested positive identified counts have been collected from the daily press releases of the director general of health services, Dhaka, Bangladesh for all the cities. From these data sets a percentage of positive identified rate has been calculated. As well as daily weather parameter values for all the cities have been collected from the website of world weather online for the whole year. Spearman rank correlation and quasi-poisson generalized linear model have been applied in the daily weather and COVID-19 percentage of positive identified data sets to find associations between them. Significant stable negative impacts have been observed for maximum temperature (correlation estimate: -0.25 to -0.50; model estimate: -0.15 to -0.30) and air pressure (correlation estimate: -0.10 to -0.40; model estimate: -0.08 to -0.17) in both analyses. Mixed (positive, negative, and no) effects have been noticed for other weather factors (humidity, rain, wind speed, minimum temperature, and cloud) on COVID-19 cases. Also, weekly variations of COVID-19 and weather values have been examined here. Comparatively lower values have been observed for maximum temperature during December-February and for air pressure during May-August. Hence, January-February due to lower temperatures, and July-August due to lower air pressure might be more sensitive seasons to the COVID-19 outbreak in Bangladesh. These findings might help the decision-makers of the country to initiate necessary steps before the COVID-19 seasonal outbreak.

**Keywords:** COVID-19, Weather Parameter, Spearman Rank Correlation, Quasi-Poisson Generalized Linear Model, Bangladesh

## Introduction

The new coronavirus (COVID-19) disease was first observed in December 2019 in Wuhan, China (Li *et al*., 2020). Then, the disease quickly spread in China and began to transmit to almost all countries in the world swiftly (Huang *et al*., 2020). Of its severe infectious nature, the World Health Organization revealed the disease as a pandemic on 11 March 2020 (20200311-sitrep-51-COVID-19.pdf (who. int)). The COVID-19 pandemic triggered a tremendous burden on the healthcare systems and led to huge financial losses in almost all affected countries in the world. Also, the pandemic has caused more than 646 million infected cases and over 6.6 million fatalities globally (https://www.worldometers.info/coronavirus/. Accessed on 30 November 2022). Like other affected countries, Bangladesh is also exposed high volume of COVID-19 incidences and deaths due to its highly dense population, lack of health awareness, and more community spreading. On 8 March 2020 the first case of COVID-19 was seen in Bangladesh and from April 2020 the infections and deaths started to increase quickly (Karmokar *et al*., 2022). The total number of fatalities and incidences are 20, 36, 527 29, and 431 respectively until 30 November 2022 based on the Institute of Epidemiology, Disease Control, and Research, Bangladesh information. Bangladesh is recorded in the top 50 global list of total counts of COVID-19 incidences (https://www.worldometers.info/coronavirus/#countries. Accessed on 26 October 2023).

COVID-19 transmission generally occurs through respiratory droplets (Bax *et al*., 2021; Palese *et al*., 2022). Several aspects including weather parameters, geographic features, crowdedness of people, and different communal issues can affect the virus propagation (Liu *et al*., 2020). Several studies have been done worldwide, including in Bangladesh, from the beginning of COVID-19 disease to study the influences of weather values (like temperature, humidity, rainfall, wind speed, cloud coverage, air pollutants, air pressure, etc., on COVID-19 transmission. Varied effects of weather parameters on COVID-19 infection have been observed in those studies. For example, several studies observed negative association of temperature with COVID-19 contamination (Liu *et al*., 2020; Qi *et al*., 2020; Sobral *et al*., 2020; Wu *et al*., 2020; Bherwani *et al*., 2020; Rosario *et al*., 2020; Pahuja *et al*., 2021; Haque and Rahman, 2020), some examined positive associations of temperature and COVID-19 incidence (Al-Rousan and Al-Najjar, 2020; Tosepu *et al*., 2020; Zoran *et al*., 2020; Pani *et al*., 2020; He *et al*., 2021; Sharma *et al*., 2020; Gupta *et al*., 2020a-b; Hridoy *et al*., 2021) and few did not see any significant association of COVID-19 and temperature (Ahmadi *et al*., 2020; Jüni *et al*., 2020) worldwide. Similarly, humidity had been observed to have a significant negative effect (Liu *et al*., 2020; Qi *et al*., 2020; Wu *et al*., 2020; Manik *et al*., 2022a; Haque and Rahman, 2020), a positive linear impact (Pani *et al*., 2020; Islam *et al*., 2021; Hridoy *et al*., 2021; Rahaman *et al*., 2022) and no significant result (Bashir *et al*., 2020; Tosepu *et al*., 2020; Bherwani *et al*., 2020; Pahuja *et al*., 2021) on COVID-19 transmission globally. On different studies throughout the world, wind speed had been examined to have significant negative impact (Rosario *et al*., 2020; Ahmadi *et al*., 2020; Hossain *et al*., 2021; Karmokar *et al*., 2022), positive effect (Islam *et al*., 2021; Rahaman *et al*., 2022) and no effect on COVID-19 transmission (Pahuja *et al*., 2021). Also, in different studies, an inverse relationship has been noticed between air pressure and the spread of COVID-19 (Pani *et al*., 2020; Rahaman *et al*., 2022). On the other hand, a significant positive impact has been observed on COVID-19 transmission by rainfall (Sobral *et al*., 2020; Rahaman *et al*., 2022), air pollutants (Zoran *et al*., 2020; Manik *et al*., 2022b) and cloud (Adhikari and Yin, 2020; Rahaman *et al*., 2022). Furthermore, another study reported that COVID-19 mortality in Wuhan may have happened due to alterations in temperature and humidity (Ma *et al*., 2020). However, another study mentioned that individual weather parameters could not affect COVID-19 transmission (Poirier *et al*., 2020).

COVID-19 daily positive case count data is discrete (Hridoy *et al*., 2021), variance is generally higher than in Poisson distribution (Imai *et al*., 2015), and usually, overdispersion (i.e., the presence of greater variability) occurs in the datasets (Hridoy *et al*., 2021). Previously, the best fit had been obtained by applying the quasi-poisson Generalized Linear Model (GLM) on overdispersed disease count data and weather parameters (Joshi *et al*., 2016; Lin *et al*., 2013). One study suggested COVID-19 incubation time is between 5 and 12 days (Lauer *et al*., 2020). Moreover, another study observed that the COVID-19 average maturation time differs from 8-14 days (Qin *et al*., 2020). One study used a quasi-poisson GLM to observe the impacts of temperature, relative humidity, and absolute humidity on COVID-19 transmission (Nottmeyer and Sera, 2021). Here, the authors considered 0-10 days as the default lags in their analysis. A different study also investigated the impact of meteorological variables at different time lags (1, 3, 5, 7, and 14 days) for COVID-19 transmission (He *et al*., 2021). Almost all the above-mentioned studies directly utilized COVID-19 case counts to inspect the impacts of weather values on COVID-19 transmission. Only one study explored the impacts of weather values on COVID-19 transmission by considering the percentage of per day positive identified COVID-19 test cases (Rahaman *et al*., 2022). In their study, the authors performed correlation analysis for both positively identified numbers and the percentage of positivity identified rate with weather values and found comparatively higher correlation coefficient value for the percentage of positive rate rather than the positively identified count. Based on their results, they concluded that the test positivity rate might be the most optimal way to study the influences of weather parameters on COVID-19 transmission. In their correlation study, the authors applied a fixed 7-day move in weather parameters from daily COVID-19 incidences. However, in their study, they used a cumulative division-specific data set both for COVID-19 and weather parameter values. A division is a large area as shown in supplementary Fig. 1 and generally, the weather values differ from one place to another in a division. Moreover, their analyses included data from 1 May 2020-30 November 2021.

Persuading from the studies (Nottmeyer and Sera, 2021; Rahaman *et al*., 2022) a new study has been made here to examine weather parameters impact on the spread of per day COVID-19 incidences. For this purpose, a whole one-year data set of daily COVID-19 laboratory tests, tested positively identified counts, and a number of deceased have been collected from the daily press releases of the director general of health services, Dhaka, Bangladesh for eight different cities of Bangladesh. From these data sets a Percentage of Positive Identified (PPI) rate has been calculated. This daily COVID-19 PPI data is very different from other studies. As well as daily weather parameter values for all the cities have been collected from the website of world weather online for the whole year. The 5-10 days shifts have been applied in weather parameter values from the COVID-19 cases here. These lagged daily weather and COVID-19 PPI data sets for the cities of a whole year have been analyzed here by applying Spearman rank correlation and quasi-Poisson GLM to find associations of weather parameter values on COVID-19 transmission.

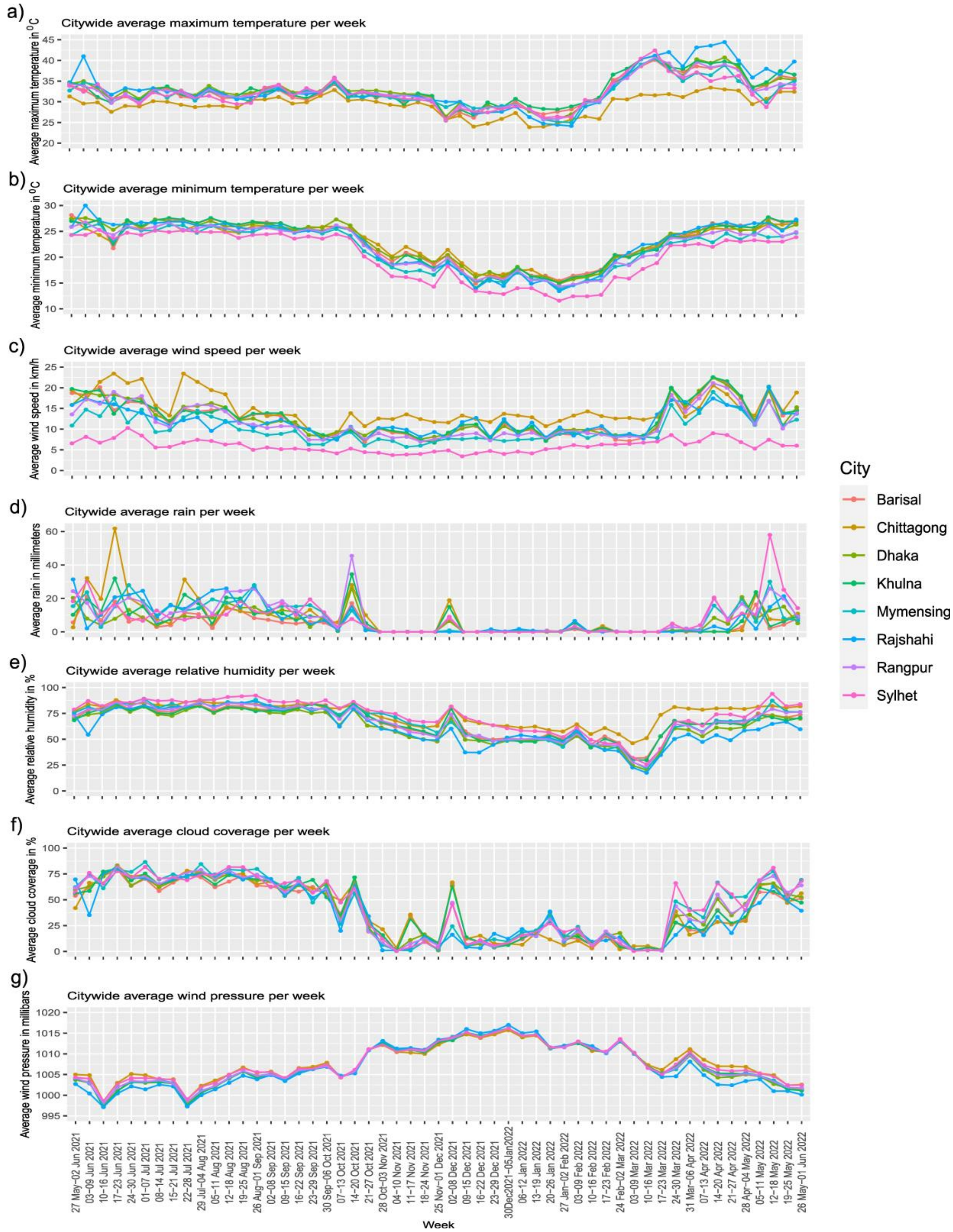


**Fig. 1:** Citywide weekly average variation of weather parameters; (a) Maximum temperature; (b) Minimum temperature; (c) Wind speed; (d) Rain; (e) Relative humidity; (f) Cloud coverage and (g) Air pressure

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## Materials and Methods

### *Data Collection*

Impacts of weather parameters on the spread of per day COVID-19 incidences have been investigated for eight different cities of Bangladesh throughout the year. The cities that are included in this study are Barisal (latitude: 22.700411, longitude: 90.374992), Chittagong (latitude: 22.330370, longitude: 91.832626), Dhaka (latitude: 23.810331, longitude: 90.412521), Khulna (latitude: 22.845640, longitude: 89.540329), Mymensing (latitude: 24.744220, longitude: 90.403010), Rajshahi (latitude: 24.376930, longitude: 88.603073), Rangpur (latitude: 25.740580, longitude: 89.261139) and Sylhet (latitude: 24.903561, longitude: 91.873611). These cities are geographically located in different places in Bangladesh as shown in supplementary Fig. 1. The daily COVID-19 case data have been collected from the daily press releases of the director general of health services, Dhaka, Bangladesh (https://old.dghs.gov.bd/index.php/bd/component/content/article?layout=edit&id=5612). The collected data set contains daily count values of test cases, positive identified cases and deaths of all the cities. The citywide individual daily COVID-19 count data is available from 5 June 2021 on the website. Hence, the COVID-19 daily count data has been collected from 5 June 2021-4 June 2022. There is no COVID-19 press release information for 15 May 2022 on the website. The COVID-19 data for 15 May 2022 was simply removed from the data set. The weather data has been collected from the world weather online (https://www.worldweatheronline.com/). The daily weather data for each city has been obtained from the historical weather information by searching each date separately from the website. This data set contains maximum temperature in centigrade, minimum temperature in centigrade, wind speed in kilometers per hour, rain in millimeters, relative humidity in %, cloud coverage in %, and air pressure in millibars. Weather data have been collected from 27 May 2021-31 May 2022 for all the cities. This data contains information for more than one year to adjust the day's lags for COVID-19 data. The last day (i.e., 1 June 2022) weather data has been used only to calculate per week average variations.

### *Statistical Analysis*

First, basic statistical operations (mean, standard deviation, minimum, median, and maximum) have been performed to observe the city-specific characteristics of COVID-19 positive identified daily new cases and number of deceased as well as weather parameter variables over the year. In total, the weather data has been collected for 371 days for all the cities. This data has been partitioned into 53 weeks by calculating the average per week for all the parameter values of all the cities separately. In total, COVID-19 information has been collected for 364 days for all the cities. For each city, the COVID-19 data has been partitioned separately into 52 weeks. The total number of tested samples per week has been calculated and then transformed the total number into log2 format for each city by log2 (total number of tested samples +1*)*. The same calculations have also been made for the positive identified test cases and number of deceased. Also, the citywide PPI test samples per week have been computed by dividing all test samples to all positive identified test samples and then multiplying by 100.

### *Lagged Day Data Preparation*

One study suggested that COVID-19 approximate development time is 5-12 days (Lauer *et al*., 2020). Likewise, another study stated that the COVID-19 mean incubation period is between 8-14 days (Qin *et al.*, 2020). Also, the Centers for Disease Control and Prevention suggested waiting for at least 5 full days after exposure to COVID-19 before testing to get accurate results if one does not have symptoms (https://www.cdc.gov/coronavirus/2019-ncov/symptoms-testing/testing.html. Accessed on 15 November 2022). Based on the above-mentioned recommendations, six different lagged days (i.e., 5-10 days) data sets have been prepared by using the weather parameters and COVID-19 PPI values to examine the lagged results of weather values on COVID-19 transmission.

### *Association of Weather Parameters and COVID-19 Cases*

The weather and COVID-19 data do not follow the linearity and hence Pearson correlation could not be the appropriate way to apply for their correlation analysis. Instead, Spearman-rank correlation has been applied in this study to find associations between them. Specifically, coefficient estimate (Rho) has been utilized to understand the association strength of weather values and COVID-19 PPI counts for all lagged day data sets for all the cities.

### *Quasi-Poisson GLM to Evaluate Impacts of Weather Parameters on COVID-19 Cases*

The daily counts data of COVID-19 are generally discrete and dispersed and usually variance has higher values than that of poisson distribution. In poisson distribution, the variance is supposed to be identical to the expected value while in a standard linear regression, the variance is assumed to be fixed. In quasi-poisson regression, variance is presumed to be a linear function of the mean. Motivating by earlier investigations (Hridoy *et al.*, 2021; Joshi *et al*., 2016; Lin *et al*., 2013), quasi-poisson GLM has been applied here to examine the impacts of weather values on COVID-19 transmission. All six different day-lagged data sets for all the cities have been analyzed here by the model to observe associations of COVID-19 PPI test samples and weather parameters.

## Results

### *Descriptive Statistics of COVID-19 Incidences and Weather Parameters*

Weather value impacts on daily COVID-19 incidences have been observed in the current study throughout eight different cities in Bangladesh. Table 1 shows descriptive statistics of COVID-19 positive identified counts, number of deceased and weather parameter values for all the cities throughout the whole year. The descriptive statistics show the city-specific characteristics of COVID-19 and weather variables. The highest value of positive incidences per day has been observed in Dhaka and it is 9,487. The lowest value of identified incidences is 0 and it has been examined in all the cities except Dhaka (where the minimum number is 3). The mean, standard deviation, and median values for positively identified cases have been noted as comparatively higher for Dhaka, then for Chittagong and finally smaller values (<100) have been observed for all other cities. Similarly, the highest number of deceased in a single day has been observed in Dhaka, then in Khulna, and Rajshahi, and finally smaller numbers (<20) have been seen in other cities.

For the weather parameters, the highest maximum temperature (48°C) has been seen at Rajshahi whereas the lowest maximum temperature (34°C) has been noted at Chittagong. The highest and lowest values for minimum temperature have been observed almost the same for all cities except Rajshahi (comparatively slightly higher value observed) and Sylhet (comparatively tiny, smaller value observed). The same thing happens for wind speed (except for Sylhet where a comparatively lower value was observed) and rain (except Rangpur where comparatively more rain was observed, and Barisal where comparatively reduced average rain was observed). The pattern of relative humidity (except for Chittagong where a comparatively higher minimum value has been observed), cloud coverage, and wind pressure have been observed almost similar for all the cities.

**Table 1:** Statistical description of COVID-19 incidences and weather values

| City | Statistics | New daily cases (persons) | Number of deceased | Maximum temperature (°C) | Minimum temperature (°C) | Wind speed (km/h) | Rain (mm) | Relative humidity (mm) | Cloud (%) | Pressure (mb) |
|---|---|---|---|---|---|---|---|---|---|---|
| Barisal | Mean | 39.00 | 0.53 | 32.24 | 23.02 | 12.39 | 4.34 | 66.90 | 38.30 | 1007.30 |
| | SD | 75.82 | 1.10 | 3.96 | 4.30 | 5.18 | 8.97 | 15.14 | 29.13 | 4.95 |
| | Minimum | 0.00 | 0.00 | 21.00 | 13.00 | 5.00 | 0.00 | 25.00 | 0.00 | 994.00 |
| | Median | 3.00 | 0.00 | 32.00 | 25.00 | 11.00 | 0.20 | 69.00 | 39.50 | 1007.00 |
| | Maximum | 492.00 | 8.00 | 42.00 | 29.00 | 31.00 | 75.30 | 97.00 | 100.00 | 1018.00 |
| Chittagong | Mean | 200.00 | 2.52 | 29.31 | 22.77 | 14.85 | 8.04 | 74.47 | 39.58 | 1007.89 |
| | SD | 327.20 | 4.14 | 2.89 | 3.89 | 5.06 | 18.94 | 11.84 | 30.69 | 4.36 |
| | Minimum | 0.00 | 0.00 | 18.00 | 13.00 | 6.00 | 0.00 | 40.00 | 0.00 | 996.00 |
| | Median | 25.00 | 0.00 | 30.00 | 25.00 | 14.00 | 0.40 | 80.00 | 39.00 | 1008.00 |
| | Maximum | 1466.00 | 18.00 | 34.00 | 28.00 | 33.00 | 177.5 | 94.00 | 100.00 | 1017.00 |
| Dhaka | Mean | 1374.31 | 8.60 | 32.87 | 23.03 | 12.53 | 5.87 | 62.11 | 40.21 | 1007.21 |
| | SD | 1934.22 | 12.15 | 4.20 | 4.17 | 5.01 | 12.56 | 16.59 | 29.91 | 5.01 |
| | Minimum | 3.00 | 0.00 | 20.00 | 13.00 | 4.00 | 0.00 | 18.00 | 0.00 | 995.00 |
| | Median | 386.00 | 3.00 | 33.00 | 25.00 | 11.00 | 0.60 | 64.00 | 46.50 | 1006.00 |
| | Maximum | 9487.00 | 56.00 | 46.00 | 29.00 | 28.00 | 138.9 | 94.00 | 100.00 | 1018.00 |
| Khulna | Mean | 59.10 | 2.00 | 32.84 | 22.79 | 12.65 | 7.04 | 65.79 | 39.89 | 1007.27 |
| | SD | 99.48 | 4.63 | 4.20 | 4.50 | 5.08 | 15.04 | 15.37 | 29.95 | 5.00 |
| | Minimum | 0.00 | 0.00 | 21.00 | 12.00 | 5.00 | 0.00 | 21.00 | 0.00 | 994.00 |
| | Median | 4.00 | 0.00 | 32.00 | 25.00 | 12.00 | 0.30 | 68.00 | 41.00 | 1007.00 |
| | Maximum | 585.00 | 36.00 | 43.00 | 29.00 | 31.00 | 160.80 | 98.00 | 100.00 | 1018.00 |
| Mymensing | Mean | 55.94 | 0.89 | 32.00 | 21.62 | 10.18 | 8.14 | 67.01 | 42.49 | 1007.40 |
| | SD | 96.93 | 1.82 | 4.00 | 4.22 | 4.06 | 13.03 | 17.90 | 32.39 | 4.93 |
| | Minimum | 0.00 | 0.00 | 19.00 | 12.00 | 3.00 | 0.00 | 20.00 | 0.00 | 996.00 |
| | Median | 6.00 | 0.00 | 32.00 | 23.00 | 9.00 | 0.85 | 72.00 | 47.50 | 1007.00 |
| | Maximum | 495.00 | 13.00 | 43.00 | 28.00 | 24.00 | 92.90 | 96.00 | 100.00 | 1018.00 |
| Rajshahi | Mean | 67.35 | 1.24 | 33.23 | 22.61 | 11.79 | 7.55 | 61.39 | 37.22 | 1006.81 |
| | SD | 109.16 | 2.96 | 5.34 | 4.73 | 4.23 | 12.97 | 18.61 | 31.08 | 5.61 |
| | Minimum | 0.00 | 0.00 | 19.00 | 11.00 | 3.00 | 0.00 | 16.00 | 0.00 | 994.00 |
| | Median | 9.00 | 0.00 | 33.00 | 25.00 | 11.00 | 0.40 | 60.50 | 36.00 | 1006.00 |
| | Maximum | 436.00 | 20.00 | 48.00 | 32.00 | 30.00 | 85.20 | 94.00 | 100.00 | 1019.00 |
| Rangpur | Mean | 27.25 | 0.74 | 32.36 | 22.04 | 11.62 | 8.98 | 66.12 | 40.98 | 1007.36 |
| | SD | 49.88 | 1.59 | 4.10 | 4.22 | 4.92 | 18.19 | 17.14 | 31.09 | 4.87 |
| | Minimum | 0.00 | 0.00 | 19.00 | 12.00 | 4.00 | 0.00 | 20.00 | 0.00 | 996.00 |
| | Median | 3.00 | 0.00 | 32.00 | 24.00 | 10.00 | 1.05 | 68.00 | 46.00 | 1007.00 |
| | Maximum | 280.00 | 9.00 | 44.00 | 28.00 | 29.00 | 220.60 | 95.00 | 100.00 | 1018.00 |
| Sylhet | Mean | 74.93 | 1.40 | 31.93 | 20.24 | 5.93 | 8.11 | 73.07 | 43.35 | 1007.77 |
| | SD | 119.68 | 2.77 | 4.15 | 4.77 | 1.92 | 14.84 | 17.13 | 31.98 | 4.63 |
| | Minimum | 0.00 | 0.00 | 18.00 | 9.00 | 3.00 | 0.00 | 24.00 | 0.00 | 997.00 |
| | Median | 10.00 | 0.00 | 31.00 | 23.00 | 6.00 | 1.30 | 76.50 | 52.00 | 1007.00 |
| | Maximum | 555.00 | 17.00 | 43.00 | 26.00 | 15.00 | 111.20 | 98.00 | 100.00 | 1018.00 |

SD: Standard Deviation

*Weekly Variations of Weather Values and COVID-19 Incidences*

Figure 1 displays per week average variations of weather parameter values for all cities. The per week average maximum temperature values are seen with almost similar patterns for all cities with some exceptions as shown in Fig. 1a. Rajshahi has the highest value observed whereas Chittagong has the lowest value for maximum temperature. Comparatively higher values of maximum temperature have been observed from March to June and lower values from December to February. Almost similar values of maximum temperature have been observed for the remaining periods. Similarly, per week average minimum temperature values have been observed with almost similar patterns for all cities as shown in Fig. 1b. Comparatively smaller values of minimum temperature have been observed from November- February whereas the same steady values have been seen during other periods. Sylhet has been noted comparatively smaller values for per week average minimum temperature than other cities. The average wind speed per week has been observed with similar patterns for all cities except for Chittagong (comparatively higher values observed) and Sylhet (comparatively lower values observed) as shown in Fig. 1c. March-June have comparatively higher wind speed values whereas the other periods have lower steady values. Rain has been observed with some values from April-October whereas the other periods have almost zero values for all cities with some exceptions as shown in Fig. 1d. The rain has been seen somewhat peak values during mid-June, mid-October, and mid-May for Chittagong, Rangpur, and Sylhet respectively. An almost similar pattern for relative humidity has been observed for all cities with comparatively lower values from mid of December-March as shown in Fig. 1e. Also, cloud coverage has been observed in almost similar patterns for all cities with lower values during November-March as shown in Fig. 1f. Finally, per week average air pressure has been found similar patterns for all cities as shown in Fig. 1g. An increasing trend for air pressure was observed from the end of July and it plateaued at the end of December and then a downward trend was observed until mid of March. Then, it shows a zigzag pattern for the remaining periods with some exceptions.

The weekly variations of COVID-19 data for all cities throughout the whole year are shown in Fig. 2. The variations of COVID-19 test samples are displayed in Fig. 2a. The Chittagong, Dhaka, and Sylhet cities show almost similar patterns with larger values of number of test cases throughout the whole year. The remaining cities also show a similar pattern with lower values.

Comparatively more samples were tested during July-August and January-February for almost all cities. However, the lowest number of test samples were observed at the end of April-May in all cities. On the other hand, almost similar trends have been observed for both positive identified test samples and PPI test samples with very few exceptions as shown in Figs. 2b-c respectively. Comparatively higher values have been observed during the July-August and January-February periods for both cases.

The highest number of positive identified test samples per week has been observed in Dhaka and then in Chittagong. Conversely, the highest PPI test samples have been observed in Rajshahi and then in Barisal. Nevertheless, the number of deceased has been observed comparatively higher during the June-August periods for all cities as shown in Fig. 2d. Comparatively lower number of deceased values have been seen during the remaining periods for all cities whereas some cities have zero values. The highest number of deceased per week has been observed in Dhaka from the end of July to the start of August period.

*Associations of Weather Parameters and COVID-19 Incidences*

After examining weekly variations of weather parameters and COVID-19 test samples, Spearman rank correlation has been applied between the COVID-19 PPI test samples and weather parameters. Here, impacts of weather values for COVID-19 transmission have been observed at different day lags (5-10 days). Almost identical patterns have been observed for all-day lags for all cities with minor exceptions as shown in Fig. 3. Significant negative correlations have been examined for maximum temperature and air pressure with COVID-19 PPI values. Conversely, cloud coverage, humidity, and rain have significant positive correlations with PPI test samples. Finally, the minimum temperature and wind speed have somewhat positive correlations with PPI test samples (both significant and non-significant correlation results have been observed). Dhaka has the highest negative correlation value whereas Sylhet has the lowest negative correlation value for maximum temperature with COVID-19 PPI cases. In contrast, Sylhet has the highest negative correlation value whereas Dhaka has the lowest negative correlation value for air pressure with COVID-19 PPI cases. Khulna has the highest positive correlation value for rain whereas Rajshahi has the highest positive correlation values for relative humidity and cloud coverage. The detailed correlation results are shown in Supplementary Table 1.

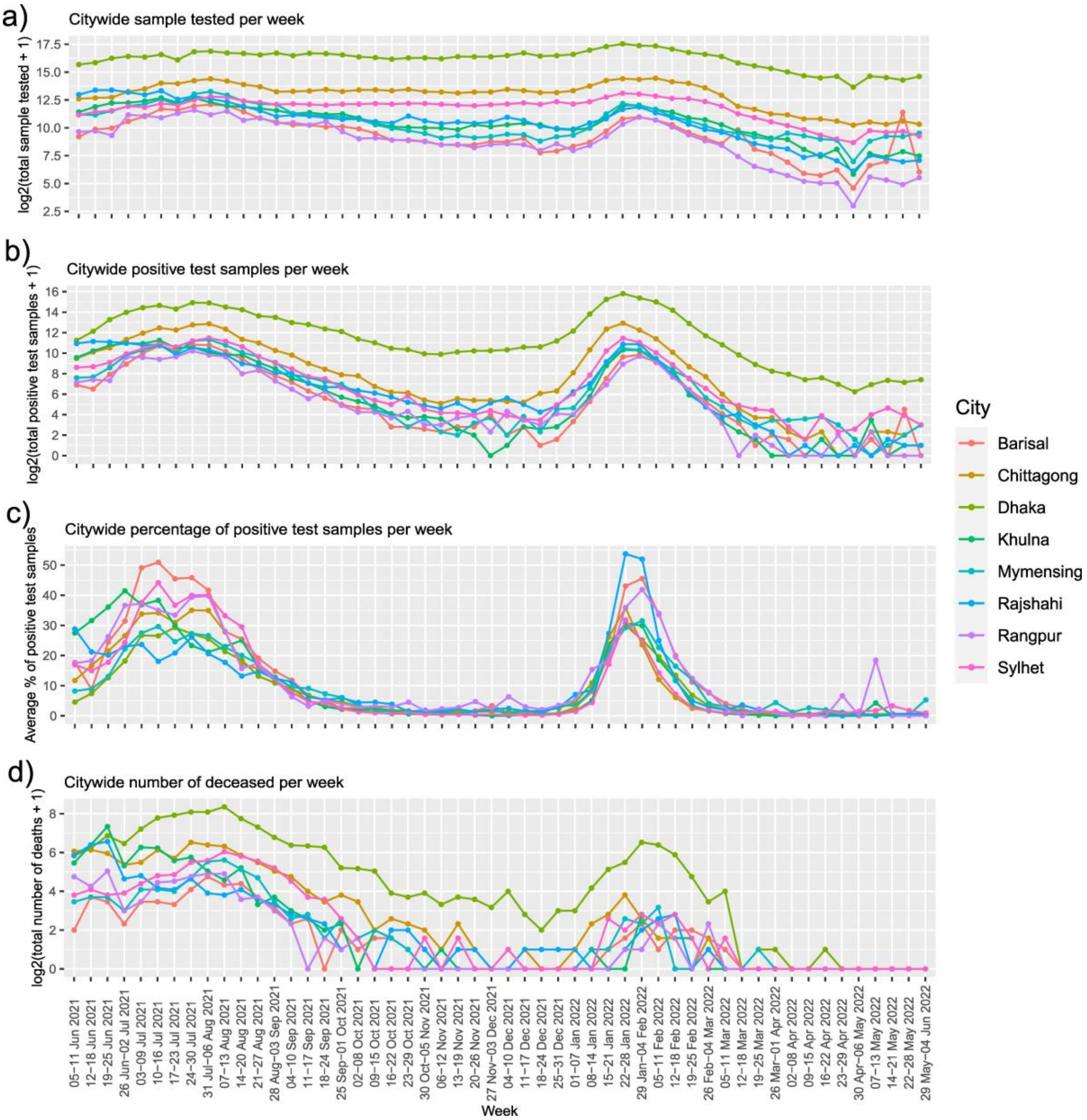


**Fig. 2:** Citywide weekly average variation of COVID-19 incidences; (a) Sample tested; (b) Positive identified samples; (c) Positive identified samples percentage and (d) Number of deceased

### *Impacts of Weather Values on COVID-19 Incidences*

From the model output, almost similar patterns have also been observed for all-day lags for all cities with minor exceptions as shown in Fig. 4. Significant negative effects of maximum temperature, relative humidity, and air pressure have been observed on COVID-19 PPI test cases for all cities. In this case, maximum temperature has the highest effect, then air pressure and lastly relative humidity has a minor effect on COVID-19 PPI cases. The highest effect for maximum temperature has been observed in Chittagong, whereas the highest effect for air pressure has been observed in Sylhet. The minimum temperature has a somewhat positive effect on COVID-19 PPI test cases whereas wind speed, rain, and cloud coverage have no mentionable significant effects on COVID-19 incidences in any city. The model's detailed outcomes are presented in Supplementary Table 2.

## Discussion

In the current study, per day weather parameters impact on COVID-19 cases have been investigated in eight cities in Bangladesh. The investigation has been performed based on the data collected throughout the whole year. Bangladesh is a small country with almost similar weather patterns throughout the country (Fig. 1). The statistical values of weather parameters are almost the same for the eight cities with some exceptions (Table 1). The maximum temperature, wind speed and rain have some variations over the cities (Table 1). From the results, it has been observed that COVID-19-positive test cases are comparatively high during the periods of July to mid-August and mid-January to mid-February for all cities as shown in Figs. 2b-c.

From the results, maximum temperature and air pressure have been observed to have mentionable inverse influences for COVID-19 cases (Figs. 3-4). These findings have also been observed in different studies for maximum temperature (Liu *et al*., 2020; Qi *et al*., 2020; Sobral *et al*., 2020; Wu *et al*., 2020; Bherwani *et al*., 2020; Rosario *et al*., 2020; Pahuja *et al*., 2021) and air pressure (Pani *et al*., 2020) throughout the world. These outcomes also have been seen in different studies in Bangladesh for maximum temperature (Haque and Rahman, 2020) and air pressure (Rahaman *et al*. 2022).

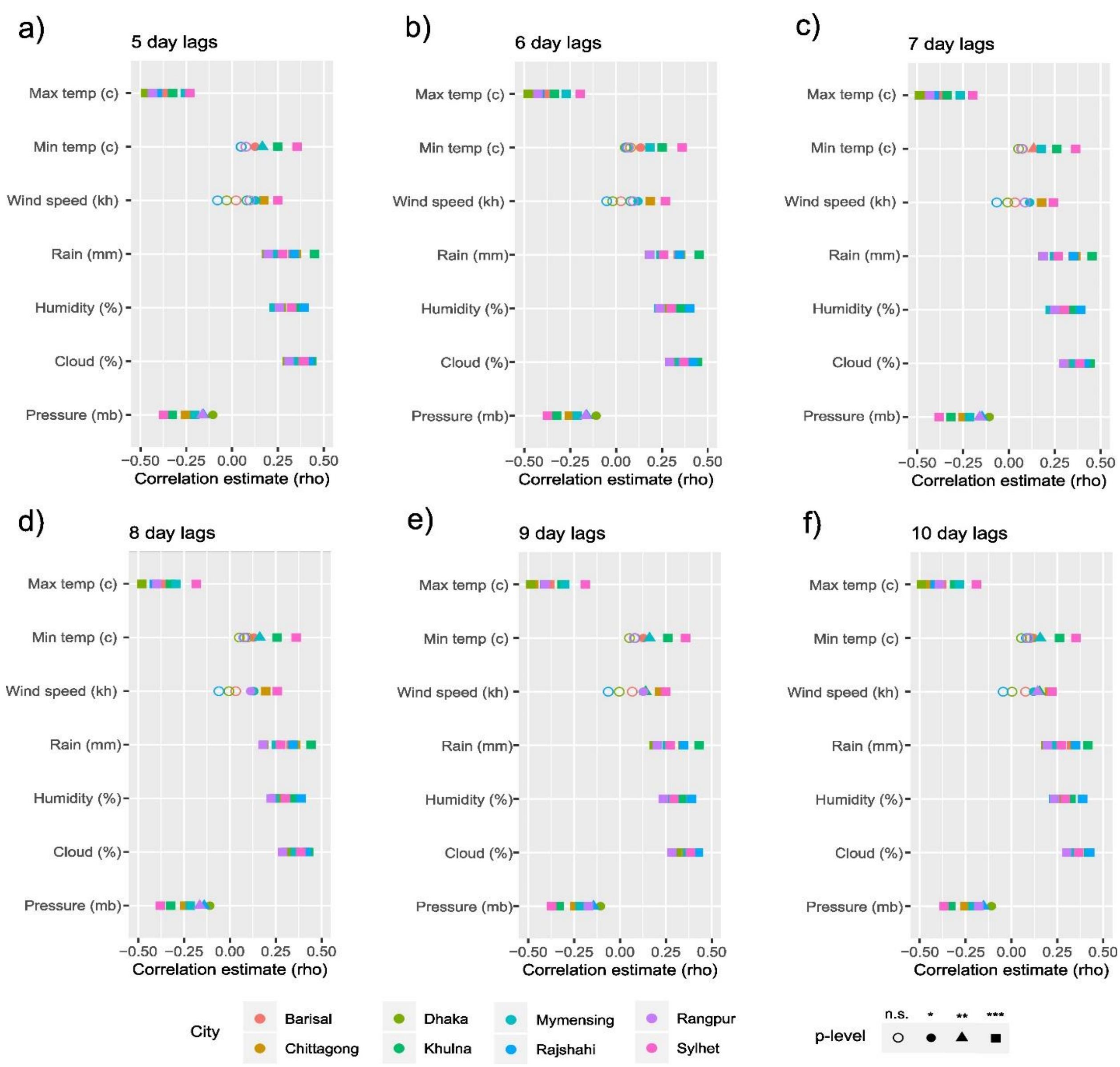


**Fig. 3:** Citywide correlation between weather parameters and daily percentage of positive identified COVID-19 cases at different lag days; (a) 5 Day lag; (b) 6 Day lag; (c) 7 Day lag; (d) 8 Day lag (e) 9 Day lag and (f) 10 Day lag

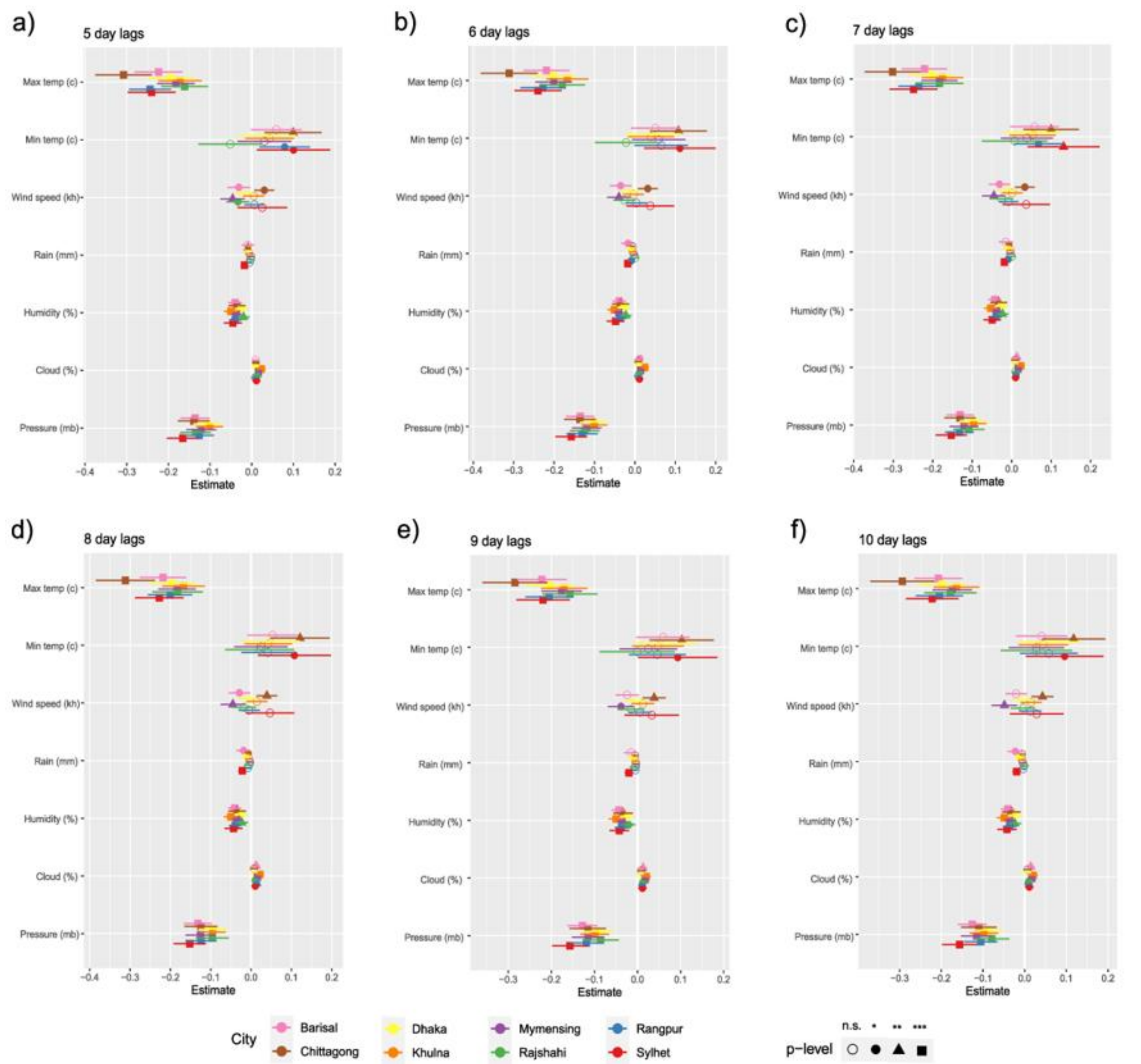


**Fig. 4:** Citywide weather value impacts on the daily percentage of positive identified COVID-19 incidences at different lag days; (a) 5 Day lag; (b) 6 Day lag; (c) 7 Day lag; (d) 8 Day lag; (e) 9 Day lag and (f) 10 Day lag

The relative humidity, rain, and clouds have a positive relation with COVID-19 cases (Fig. 3), whereas the model shows a somewhat inverse effect of relative humidity, positive effect of cloud coverage and almost no effect of rain for COVID-19 transmission (Fig. 4). Similar correlation findings have also been observed through different studies for humidity (Pani *et al*., 2020), rainfall (Sobral *et al*., 2020) and cloud (Adhikari and Yin, 2020). According to the model output for humidity, several studies have also observed negative effects on COVID-19 cases (Liu *et al*., 2020; Qi *et al*., 2020; Wu *et al*., 2020; Manik *et al*., 2022a). Several studies in Bangladesh have observed a linear relationship between humidity on COVID-19 incidences (Rahaman *et al*., 2022; Islam *et al*., 2021; Hridoy *et al*., 2021) whereas another study found negative effects of humidity for COVID-19 incidences (Haque and Rahman, 2020). Also, one study examined that cloud has a linear connotation with COVID-19 incidences in Bangladesh (Rahaman *et al*., 2022). Likewise, one study observed somewhat positive impacts of excess rainfall on COVID-19 cases (Hossain *et al*., 2021).

Wind speed has been observed to have a positive impact in correlation analysis for several cities (Fig. 3), whereas in model output it has almost no mentionable relations with COVID-19 PPI cases (Fig. 4). One recent study in Bangladesh also observed that wind speed has positive impacts to percentage of COVID-19 test cases (Rahaman *et al*., 2022). Although other studies have found negative impacts of wind speed on COVID-19 incidences, no one applied a percentage rate of confirmed incidences in their studies. This finding aligns with the outcome of the current study. The minimum temperature has been observed somewhat positive associations with daily PPI test cases both for correlation and model analyses (Figs. 3-4). The same finding for minimum temperature has also been examined in different studies in Bangladesh (Karmokar *et al*., 2022; Mofijur *et al*., 2020; Rahaman *et al*., 2022).

From both the correlation analyses and model output, stable significant inverse impacts have been observed for maximum temperature and air pressure on COVID-19 incidences. Then again, from the analyses of per-week variations, comparatively higher values of positive identified test cases have been observed during the July-August and January-February periods (Fig. 2b-c). However, comparatively lower values of positive identified test cases have been observed from March to the start of June and September-December periods for all cities (Fig. 2b-c). In contrast, maximum temperature has been observed with comparatively higher values from March to June and lower values from December to February in almost all cities (Fig. 1a). These observations also suggest inverse associations between maximum temperature and COVID-19 cases here. Also, wind pressure has been observed with comparatively higher values during the September-April periods and lower values for the remaining periods (Fig. 1g). This finding also aligns with the results of the current study.

From the above discussions, changes in results have been observed on the impact of COVID-19 transmission of several weather parameter values for correlation and model analyses. These variations may have occurred because in correlation analysis the over-dispersion zeros in the PPI values had not been addressed effectively, however, in model analysis, the quasi-Poisson GLM handled the over-dispersion zero values in the PPI counts efficiently. Also, altered variants of the COVID-19 virus may exhibit dissimilar rates of transmission. There is no COVID-19 variant information on the website from where the data had been collected. So, no variant data had been added to the manuscript. Maybe, this is also a reason for the alteration of analysis findings in this study. Most findings align with the results of the study (Rahaman *et al*., 2022) except for the maximum temperature. Although more studies need to be conducted, this finding may also suggest COVID-19 PPI rates may be more suitable than the direct COVID-19 count values to estimate relationships with weather parameters.

Several aspects can also affect COVID-19 cases including population density, social status of the people of the city, awareness of the people, vaccine coverage of the people, government-imposed lockdown throughout the city, and so on. No such factors have been considered in the current study. Only weather parameters have been considered for COVID-19 transmission in the present analyses. Although some mentionable results have been noted from the current study it is required to consider other factors in combination with weather parameters as well as different cities with changes of weather parameter values to conclude a final decision on COVID-19 transmission.

## Conclusion

This observation suggests that weather parameters may have effects on daily COVID-19 cases. Based on the findings of the current study, the maximum temperature and air pressure may have a strong opposite influence on daily COVID-19 transmission in Bangladesh. From this study, comparatively higher values of positive identified test cases have been observed during the July-August and January-February periods. On the other hand, maximum temperature has been observed comparatively lower values from the December-February period in almost all cities. Also, air pressure has been observed comparatively lower values from the May-August period for all cities. Therefore, January-February due to lower temperatures, and July-August due to lower air pressure might be more sensitive seasons to the COVID-19 outbreak in Bangladesh. These outcomes might help the decision-makers of the country to take necessary initiatives (e.g., raise people's awareness, boost vaccine coverage and so on) before the seasonal changes of COVID-19 outbreaks.

### *Supplementary Information*

Supplementary Fig. 1 Bangladesh map showing the eight different cities situated at different locations.

Supplementary Table 1. Correlation of percent of confirmed COVID-19 test samples and weather parameters.

Supplementary Table 2. Quasi-Poisson GLM output for percent of positively identified COVID-19 test samples and weather parameters.

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## Ethics

This article is original and contains unpublished material. There are no ethical issues involved in the manuscript.

### *Data Availability*

Openly accessible datasets were evaluated in this study and can be obtained from here: https://old.dghs.gov.bd/index.php/bd/component/content/article?layout=edit&id=5612;https://www.worldweatheronline.com/. The processed data can be made available on request (Email: hkj_cse@ru.ac.bd).

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## Supplementary Fig. 1


## Supplementary Tables

**Supplementary Table 1:** Spearman's rank correlation between percent of positive identified covid-19 test samples and weather parameters

| | | Maximum temperature | | Minimum temperature | | Wind speed | | Rain | | Humidity | | Cloud | | Pressure | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| City | Lags | Rho | p-value | Rho | p-value | Rho | p-value | Rho | p-value | Rho | p-value | Rho | p-value | Rho | p-value |
| Barisal | Day 5 | -0.370083 | 2.94E-13 | 0.125712 | 0.016410 | 0.021719 | 0.679600 | 0.331410 | 8.85E-11 | 0.245688 | 2.09E-06 | 0.342899 | 1.76E-11 | -0.21574 | 3.31E-05 |
| | Day 6 | -0.367549 | 4.38E-13 | 0.134181 | 0.010380 | 0.027113 | 0.606100 | 0.339945 | 2.69E-11 | 0.246921 | 1.85E-06 | 0.342626 | 1.83E-11 | -0.22226 | 1.87E-05 |
| | Day 7 | -0.365867 | 5.69E-13 | 0.134905 | 0.009973 | 0.032825 | 0.532400 | 0.350314 | 5.99E-12 | 0.244607 | 2.33E-06 | 0.348145 | 8.24E-12 | -0.22582 | 1.36E-05 |
| | Day 8 | -0.363933 | 7.68E-13 | 0.130086 | 0.012990 | 0.031887 | 0.544200 | 0.334009 | 6.18E-11 | 0.239667 | 3.76E-06 | 0.335526 | 5.00E-11 | -0.22736 | 1.19E-05 |
| | Day 9 | -0.383547 | 3.34E-14 | 0.127961 | 0.014570 | 0.067173 | 0.201000 | 0.346621 | 1.03E-11 | 0.242837 | 2.77E-06 | 0.340358 | 2.53E-11 | -0.23667 | 5.00E-06 |
| | Day 10 | -0.379436 | 6.56E-14 | 0.121555 | 0.020350 | 0.076903 | 0.143100 | 0.328154 | 1.38E-10 | 0.232124 | 7.65E-06 | 0.332867 | 7.24E-11 | -0.24406 | 2.46E-06 |
| Chittagong | Day 5 | -0.451108 | 2.20E-16 | 0.076183 | 0.146900 | 0.172959 | 0.000921 | 0.351191 | 5.27E-12 | 0.260290 | 4.75E-07 | 0.331288 | 9.00E-11 | -0.25331 | 9.76E-07 |
| | Day 6 | -0.465098 | 2.20E-16 | 0.079415 | 0.130500 | 0.187592 | 0.000320 | 0.352824 | 4.14E-12 | 0.261829 | 4.04E-07 | 0.335038 | 5.36E-11 | -0.25427 | 8.86E-07 |
| | Day 7 | -0.473836 | 2.20E-16 | 0.073698 | 0.160600 | 0.177840 | 0.000653 | 0.364587 | 6.94E-13 | 0.273208 | 1.19E-07 | 0.348761 | 7.53E-12 | -0.25001 | 1.36E-06 |
| | Day 8 | -0.480605 | 2.20E-16 | 0.095195 | 0.069670 | 0.195668 | 0.000172 | 0.357865 | 1.94E-12 | 0.265359 | 2.78E-07 | 0.351715 | 4.87E-12 | -0.24517 | 2.20E-06 |
| | Day 9 | -0.469578 | 2.20E-16 | 0.083778 | 0.110600 | 0.216463 | 3.11E-05 | 0.342995 | 1.74E-11 | 0.259198 | 5.33E-07 | 0.335998 | 4.68E-11 | -0.24653 | 1.93E-06 |
| | Day 10 | -0.447552 | 2.20E-16 | 0.101494 | 0.053030 | 0.207548 | 6.62E-05 | 0.343604 | 1.59E-11 | 0.250426 | 1.31E-06 | 0.329072 | 1.22E-10 | -0.25427 | 8.86E-07 |
| Dhaka | Day 5 | -0.471599 | 2.20E-16 | 0.050709 | 0.334700 | -0.02927 | 0.577800 | 0.188537 | 0.000298 | 0.268364 | 2.01E-07 | 0.301003 | 4.64E-09 | -0.10495 | 0.045400 |
| | Day 6 | -0.478358 | 2.20E-16 | 0.050571 | 0.336000 | -0.01828 | 0.728100 | 0.182065 | 0.000482 | 0.271938 | 1.36E-07 | 0.303564 | 3.38E-09 | -0.10826 | 0.038980 |
| | Day 7 | -0.487401 | 2.20E-16 | 0.052668 | 0.316300 | -0.00691 | 0.895500 | 0.184176 | 0.000412 | 0.278850 | 6.32E-08 | 0.310388 | 1.44E-09 | -0.10741 | 0.040550 |
| | Day 8 | -0.479044 | 2.20E-16 | 0.051733 | 0.325000 | -0.00516 | 0.921800 | 0.184557 | 0.000401 | 0.276760 | 7.99E-08 | 0.305930 | 2.52E-09 | -0.10966 | 0.036510 |
| | Day 9 | -0.485949 | 2.20E-16 | 0.052148 | 0.321100 | -0.00355 | 0.946200 | 0.185334 | 0.000379 | 0.275462 | 9.24E-08 | 0.306940 | 2.22E-09 | -0.10636 | 0.042570 |
| | Day 10 | -0.490091 | 2.20E-16 | 0.054833 | 0.296800 | 0.003065 | 0.953500 | 0.188439 | 3.00E-04 | 0.272838 | 1.24E-07 | 0.309411 | 1.62E-09 | -0.10888 | 0.037860 |
| Khulna | Day 5 | -0.324241 | 2.35E-10 | 0.248779 | 1.54E-06 | 0.081245 | 0.121800 | 0.449802 | 2.20E-16 | 0.347934 | 8.50E-12 | 0.433963 | 2.20E-16 | -0.32629 | 1.78E-10 |
| | Day 6 | -0.335467 | 5.04E-11 | 0.251762 | 1.14E-06 | 0.080368 | 0.125900 | 0.453683 | 2.20E-16 | 0.353519 | 3.73E-12 | 0.443679 | 2.20E-16 | -0.32361 | 2.55E-10 |
| | Day 7 | -0.337446 | 3.82E-11 | 0.261328 | 4.26E-07 | 0.088730 | 0.090960 | 0.453206 | 2.20E-16 | 0.350926 | 5.48E-12 | 0.442948 | 2.20E-16 | -0.31605 | 6.92E-10 |
| | Day 8 | -0.323979 | 2.43E-10 | 0.256589 | 6.98E-07 | 0.130364 | 0.012800 | 0.442178 | 2.20E-16 | 0.343095 | 1.71E-11 | 0.428781 | 2.20E-16 | -0.32248 | 2.97E-10 |
| | Day 9 | -0.316111 | 6.87E-10 | 0.260689 | 4.56E-07 | 0.139794 | 0.007562 | 0.431677 | 2.20E-16 | 0.336538 | 4.34E-11 | 0.427679 | 2.20E-16 | -0.33122 | 9.09E-11 |
| | Day 10 | -0.309774 | 1.55E-09 | 0.261894 | 4.02E-07 | 0.153378 | 0.003351 | 0.416854 | 2.20E-16 | 0.324592 | 2.24E-10 | 0.419501 | 2.20E-16 | -0.33105 | 9.30E-11 |
| Mymensing | Day 5 | -0.255067 | 8.16E-07 | 0.165130 | 0.001570 | 0.128272 | 0.014330 | 0.247930 | 1.68E-06 | 0.229874 | 9.42E-06 | 0.335664 | 4.91E-11 | -0.20291 | 9.67E-05 |
| | Day 6 | -0.271465 | 1.44E-07 | 0.185035 | 0.000387 | 0.120455 | 0.021530 | 0.244454 | 2.36E-06 | 0.232852 | 7.15E-06 | 0.349231 | 7.03E-12 | -0.21155 | 4.74E-05 |
| | Day 7 | -0.266003 | 2.60E-07 | 0.176618 | 0.000712 | 0.112895 | 0.031290 | 0.248705 | 1.55E-06 | 0.224798 | 1.49E-05 | 0.355953 | 2.59E-12 | -0.21442 | 3.71E-05 |
| | Day 8 | -0.294155 | 1.07E-08 | 0.162967 | 0.001812 | 0.124020 | 0.017930 | 0.254077 | 9.03E-07 | 0.242055 | 2.99E-06 | 0.357039 | 2.20E-12 | -0.21582 | 3.29E-05 |

**Supplementary Table 1:** Continue

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Day 9 | -0.300830 | 4.74E-09 | 0.161307 | 0.002021 | 0.127783 | 0.014700 | 0.257390 | 6.43E-07 | 0.245025 | 2.23E-06 | 0.368606 | 3.71E-13 | -0.21652 | 3.10E-05 |
| | Day 10 | -0.283865 | 3.57E-08 | 0.156667 | 0.002724 | 0.121059 | 0.020880 | 0.247580 | 1.74E-06 | 0.229533 | 9.72E-06 | 0.350571 | 5.77E-12 | -0.20898 | 5.87E-05 |
| Rajshahi | Day 5 | -0.406484 | 6.47E-16 | 0.048540 | 0.355800 | -0.07913 | 0.131800 | 0.339527 | 2.85E-11 | 0.392353 | 7.62E-15 | 0.421431 | 2.20E-16 | -0.15672 | 0.002715 |
| | Day 6 | -0.416668 | 2.20E-16 | 0.058383 | 0.266600 | -0.05007 | 0.340800 | 0.347259 | 9.38E-12 | 0.402339 | 1.35E-15 | 0.419833 | 2.20E-16 | -0.15919 | 0.002319 |
| | Day 7 | -0.406470 | 6.49E-16 | 0.069453 | 0.186100 | -0.06624 | 0.207400 | 0.352465 | 4.36E-12 | 0.391605 | 8.65E-15 | 0.414786 | 2.20E-16 | -0.14647 | 0.005112 |
| | Day 8 | -0.412709 | 2.20E-16 | 0.080853 | 0.123600 | -0.05979 | 0.255200 | 0.344379 | 1.42E-11 | 0.388285 | 1.52E-14 | 0.415676 | 2.20E-16 | -0.13999 | 0.007475 |
| | Day 9 | -0.410856 | 2.95E-16 | 0.080182 | 0.126800 | -0.06361 | 0.226000 | 0.347844 | 8.61E-12 | 0.390449 | 1.05E-14 | 0.425609 | 2.20E-16 | -0.14394 | 0.005939 |
| | Day 10 | -0.416428 | 2.20E-16 | 0.081654 | 0.119900 | -0.04518 | 0.390100 | 0.350003 | 6.28E-12 | 0.388196 | 1.54E-14 | 0.426856 | 2.20E-16 | -0.15169 | 0.003720 |
| Rangpur | Day 5 | -0.433961 | 2.20E-16 | 0.074124 | 0.158200 | 0.097194 | 0.063980 | 0.197500 | 0.000149 | 0.258313 | 5.84E-07 | 0.310449 | 1.42E-09 | -0.16203 | 0.001927 |
| | Day 6 | -0.425547 | 2.20E-16 | 0.067461 | 0.199100 | 0.094851 | 0.070690 | 0.184132 | 0.000414 | 0.239582 | 3.79E-06 | 0.292789 | 1.26E-08 | -0.16465 | 0.001622 |
| | Day 7 | -0.431558 | 2.20E-16 | 0.070205 | 0.181400 | 0.088281 | 0.092610 | 0.186747 | 0.000341 | 0.250118 | 1.35E-06 | 0.299681 | 5.46E-09 | -0.15908 | 0.002334 |
| | Day 8 | -0.398758 | 2.53E-15 | 0.075774 | 0.149100 | 0.113384 | 0.030560 | 0.180828 | 0.000527 | 0.225125 | 1.45E-05 | 0.287321 | 2.39E-08 | -0.16457 | 0.001630 |
| | Day 9 | -0.408712 | 4.34E-16 | 0.077573 | 0.139600 | 0.129107 | 0.013700 | 0.203304 | 9.37E-05 | 0.235600 | 5.53E-06 | 0.283062 | 3.91E-08 | -0.17195 | 0.000988 |
| | Day 10 | -0.393034 | 6.78E-15 | 0.091454 | 0.081420 | 0.142337 | 0.006525 | 0.196489 | 0.000162 | 0.235437 | 5.62E-06 | 0.301020 | 4.63E-09 | -0.17866 | 0.000616 |
| Sylhet | Day 5 | -0.230799 | 8.65E-06 | 0.354279 | 3.33E-12 | 0.249604 | 1.42E-06 | 0.274399 | 1.04E-07 | 0.324632 | 2.23E-10 | 0.392523 | 7.40E-15 | -0.37301 | 1.85E-13 |
| | Day 6 | -0.194890 | 0.000183 | 0.361222 | 1.17E-12 | 0.269575 | 1.77E-07 | 0.259503 | 5.16E-07 | 0.300857 | 4.73E-09 | 0.370064 | 2.95E-13 | -0.37349 | 1.71E-13 |
| | Day 7 | -0.196611 | 0.0001599 | 0.363870 | 7.76E-13 | 0.242275 | 2.92E-06 | 0.267733 | 2.16E-07 | 0.303821 | 3.28E-09 | 0.385762 | 2.31E-14 | -0.38095 | 5.12E-14 |
| | Day 8 | -0.183140 | 0.000445 | 0.361555 | 1.11E-12 | 0.258746 | 5.58E-07 | 0.276099 | 8.61E-08 | 0.302666 | 3.78E-09 | 0.386516 | 2.04E-14 | -0.37931 | 6.70E-14 |
| | Day 9 | -0.188706 | 0.0002941 | 0.357743 | 1.98E-12 | 0.249208 | 1.48E-06 | 0.272788 | 1.24E-07 | 0.293460 | 1.16E-08 | 0.384589 | 2.81E-14 | -0.37212 | 2.13E-13 |
| | Day 10 | -0.191167 | 0.0002439 | 0.351487 | 5.04E-12 | 0.220896 | 2.11E-05 | 0.270988 | 1.51E-07 | 0.293473 | 1.16E-08 | 0.366778 | 4.94E-13 | -0.36815 | 3.98E-13 |

**Supplementary Table 2:** Quasi-poisson GLM output for percent of positive identified covid-19 test samples and weather parameters

| | | Barisal | Chittagong | Dhaka | Khulna | Mymensing | Rajshahi | Rangpur | Sylhet |
|---|---|---|---|---|---|---|---|---|---|
| 5 Day lags | Max_temp_C | -0.22 *** | -0.31 *** | -0.19 *** | -0.17 *** | -0.18 *** | -0.16 *** | -0.24 *** | -0.24 *** |
| | | (0.03) | (0.03) | (0.03) | (0.03) | (0.02) | (0.03) | (0.03) | (0.03) |
| | Min_temp_C | 0.06 | 0.10 ** | 0.04 | 0.04 | 0.03 | -0.05 | 0.08 * | 0.10 * |
| | | (0.03) | (0.03) | (0.04) | (0.03) | (0.03) | (0.04) | (0.03) | (0.04) |
| | Wind_speed_kh | -0.03 * | 0.03 * | -0.02 | 0.00 | -0.05 ** | -0.03 * | 0.01 | 0.03 |
| | | (0.01) | (0.01) | (0.01) | (0.01) | (0.02) | (0.01) | (0.01) | (0.03) |
| | Rain_mm | -0.01 | -0.01 ** | -0.01 | -0.01 | 0.00 | 0.00 | -0.01 | -0.02 *** |
| | | (0.01) | (0.00) | (0.00) | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) |
| | Humidity_percent | -0.04 *** | -0.04 *** | -0.03 *** | -0.05 *** | -0.04 *** | -0.02 ** | -0.04 *** | -0.05 *** |
| | | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| | Cloud_percent | 0.01 | 0.01 * | 0.01 * | 0.02 *** | 0.02 *** | 0.01 ** | 0.01 | 0.01 * |
| | | (0.00) | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) | (0.00) | (0.00) |
| | Pressure_millibars | -0.14 *** | -0.14 *** | -0.11 *** | -0.10 *** | -0.12 *** | -0.13 *** | -0.13 *** | -0.17 *** |
| | | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| 6 Day lags | Max_temp_C | -0.22 *** | -0.31 *** | -0.20 *** | -0.17 *** | -0.20 *** | -0.18 *** | -0.23 *** | -0.24 *** |
| | | (0.03) | (0.04) | (0.03) | (0.03) | (0.02) | (0.03) | (0.03) | (0.03) |
| | Min_temp_C | 0.05 | 0.11 ** | 0.05 | 0.04 | 0.06 | -0.02 | 0.07 | 0.11 * |
| | | (0.03) | (0.04) | (0.04) | (0.03) | (0.03) | (0.04) | (0.03) | (0.05) |
| | Wind_speed_kh | -0.04 * | 0.03 * | -0.01 | 0 | -0.04 ** | -0.03 | 0 | 0.04 |
| | | (0.01) | (0.01) | (0.01) | (0.01) | (0.02) | (0.01) | (0.01) | (0.03) |
| | Rain_mm | -0.02 * | -0.01 | -0.01 * | -0.01 | 0 | 0 | -0.01 * | -0.02 *** |
| | | (0.01) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| | Humidity_percent | -0.04 *** | -0.04 ** | -0.03 *** | -0.05 *** | -0.04 *** | -0.02 ** | -0.04 *** | -0.05 *** |
| | | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| | Cloud_percent | 0.01 * | 0.01 | 0.01 * | 0.02 *** | 0.01 *** | 0.01 * | 0.01 | 0.01 * |
| | | (0.00) | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) | (0.00) | (0.00) |
| | Pressure_millibars | -0.14 *** | -0.14 *** | -0.10 *** | -0.10 *** | -0.12 *** | -0.12 *** | -0.13 *** | -0.16 *** |
| | | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| 7 Day lags | Max_temp_C | -0.22 *** | -0.30 *** | -0.20 *** | -0.18 *** | -0.18 *** | -0.18 *** | -0.23 *** | -0.25 *** |
| | | (0.03) | (0.04) | (0.03) | (0.03) | (0.02) | (0.03) | (0.03) | (0.03) |
| | Min_temp_C | 0.06 | 0.10 ** | 0.05 | 0.05 | 0.04 | 0.01 | 0.07 * | 0.13 ** |
| | | (0.03) | (0.04) | (0.04) | (0.03) | (0.03) | (0.04) | (0.03) | (0.05) |
| | Wind_speed_kh | -0.03 * | 0.03 * | -0.01 | 0 | -0.05 ** | -0.03 | -0.01 | 0.04 |
| | | (0.01) | (0.01) | (0.01) | (0.01) | (0.02) | (0.02) | (0.01) | (0.03) |
| | Rain_mm | -0.01 | -0.01 * | -0.01 * | 0 | 0 | 0 | -0.01 * | -0.02 *** |
| | | (0.01) | (0.00) | (0.00) | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) |
| | Humidity_percent | -0.04 *** | -0.03 ** | -0.03 *** | -0.05 *** | -0.04 *** | -0.02 ** | -0.04 *** | -0.05 *** |
| | | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| | Cloud_percent | 0.01 ** | 0.01 | 0.01 | 0.02 *** | 0.02 *** | 0.01 | 0.01 * | 0.01 * |
| | | (0.00) | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) | (0.00) | (0.00) |
| | Pressure_millibars | -0.13 *** | -0.13 *** | -0.10 *** | -0.10 *** | -0.12 *** | -0.11 *** | -0.13 *** | -0.15 *** |
| | | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| 8 day lags | Max_temp_C | -0.22 *** | -0.31 *** | -0.20 *** | -0.17 *** | -0.18 *** | -0.18 *** | -0.20 *** | -0.23 *** |
| | | (0.03) | (0.04) | (0.03) | (0.03) | (0.02) | (0.03) | (0.03) | (0.03) |
| | Min_temp_C | 0.05 | 0.12 ** | 0.05 | 0.04 | 0.02 | 0.02 | 0.04 | 0.11 * |
| | | (0.03) | (0.04) | (0.04) | (0.03) | (0.03) | (0.04) | (0.03) | (0.05) |
| | Wind_speed_kh | -0.03 * | 0.04 ** | -0.01 | 0.01 | -0.05 ** | -0.02 | 0 | 0.05 |
| | | (0.01) | (0.01) | (0.01) | (0.01) | (0.02) | (0.02) | (0.01) | (0.03) |
| | Rain_mm | -0.02 * | -0.01 * | -0.01 * | 0 | 0 | -0.01 | -0.01 | -0.02 *** |
| | | (0.01) | (0.00) | (0.01) | (0.00) | (0.00) | (0.01) | (0.00) | (0.01) |
| | Humidity_percent | -0.04 *** | -0.03 ** | -0.03 ** | -0.05 *** | -0.04 *** | -0.02 ** | -0.04 *** | -0.04 *** |
| | | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| | Cloud_percent | 0.01 ** | 0.01 | 0.01 | 0.02 *** | 0.02 *** | 0.01 * | 0.01 ** | 0.01 * |
| | | (0.00) | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) | (0.00) | (0.01) |
| | Pressure_millibars | -0.13 *** | -0.12 *** | -0.10 *** | -0.10 *** | -0.13 *** | -0.10 *** | -0.12 *** | -0.15 *** |
| | | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| 9 Day lags | Max_temp_C | -0.22 *** | -0.28 *** | -0.20 *** | -0.17 *** | -0.18 *** | -0.16 *** | -0.21 *** | -0.22 *** |

**DOI: 10.3844/ajessp.2023.72.86**

**Supplementary Table 2:** Continue

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | (0.03) | (0.04) | (0.03) | (0.03) | (0.02) | (0.03) | (0.03) | (0.03) |
| | Min_temp_C | 0.06 | 0.10 ** | 0.06 | 0.05 | 0.03 | 0 | 0.05 | 0.09 * |
| | | (0.03) | (0.04) | (0.04) | (0.03) | (0.03) | (0.04) | (0.03) | (0.05) |
| | Wind_speed_kh | -0.02 | 0.04 ** | -0.01 | 0.01 | -0.04 * | -0.02 | 0.01 | 0.03 |
| | | (0.01) | (0.01) | (0.01) | (0.01) | (0.02) | (0.02) | (0.01) | (0.03) |
| | Rain_mm | -0.01 | -0.01 | -0.01 * | 0 | 0 | -0.01 | 0 | -0.02 *** |
| | | (0.01) | (0.00) | (0.01) | (0.00) | (0.00) | (0.01) | (0.00) | (0.01) |
| | Humidity_percent | -0.04 *** | -0.03 ** | -0.03 ** | -0.05 *** | -0.04 *** | -0.02 * | -0.04 *** | -0.04 *** |
| | | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| | Cloud_percent | 0.01 ** | 0.01 | 0.01 | 0.02 *** | 0.02 *** | 0.01 * | 0.01 * | 0.01 * |
| | | (0.00) | (0.00) | (0.00) | (0.01) | (0.00) | (0.01) | (0.00) | (0.01) |
| | Pressure_millibars | -0.13 *** | -0.12 *** | -0.09 *** | -0.10 *** | -0.11 *** | -0.09 *** | -0.12 *** | -0.16 *** |
| | | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| 10 Day lags | Max_temp_C | -0.21 *** | -0.29 *** | -0.20 *** | -0.16 *** | -0.17 *** | -0.18 *** | -0.20 *** | -0.22 *** |
| | | (0.03) | (0.04) | (0.03) | (0.03) | (0.02) | (0.03) | (0.03) | (0.03) |
| | Min_temp_C | 0.04 | 0.12 ** | 0.06 | 0.04 | 0.03 | 0.03 | 0.06 | 0.10 * |
| | | (0.03) | (0.04) | (0.04) | (0.03) | (0.03) | (0.04) | (0.04) | (0.05) |
| | Wind_speed_kh | -0.02 | 0.04 ** | 0 | 0.02 | -0.05 ** | 0 | 0.01 | 0.03 |
| | | (0.01) | (0.01) | (0.01) | (0.01) | (0.02) | (0.02) | (0.01) | (0.03) |
| | Rain_mm | -0.02 * | -0.01 | -0.01 * | -0.01 | 0 | 0 | 0 | -0.02 *** |
| | | (0.01) | (0.00) | (0.01) | (0.00) | (0.00) | (0.01) | (0.00) | (0.01) |
| | Humidity_percent | -0.04 *** | -0.03 ** | -0.02 ** | -0.05 *** | -0.04 *** | -0.02 ** | -0.04 *** | -0.04 *** |
| | | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| | Cloud_percent | 0.01 ** | 0.01 | 0.01 | 0.02 *** | 0.02 *** | 0.01 * | 0.01 | 0.01 * |
| | | (0.00) | (0.00) | (0.00) | (0.01) | (0.00) | (0.01) | (0.00) | (0.01) |
| | Pressure_millibars | -0.13 *** | -0.11 *** | -0.09 *** | -0.10 *** | -0.12 *** | -0.08 *** | -0.11 *** | -0.16 *** |
| | | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |

*** p<0.001; ** p<0.01; * p<0.05