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Possible role of meteorological variables in COVID-19 spread: A case study from a subtropical monsoon country, Bangladesh

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Declaration of competing financial interests

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Abstract

COVID-19, caused by SARS-CoV-2, is responsible for widespread mortality and economic loss across almost 212 countries. The distribution of disease prevalence is, however, uneven and likely dependent on the range of human behavior and/or the pathogen and environmental variables. Here in this research we examined the correlation between daily and total COVID-19 case reports from Bangladesh and meteorological variables (average temperature, average humidity, and average wind speed) against one another using Spearman rank and Kendall correlation tests to highlight significant meteorological variables in relation to COVID-19. The tests revealed that both temperature and humidity had a non-significant correlation with COVID-19 transmission amid epicenter (EC) and non-epicenter (NEC) areas. However, a weak (KCC: 0.168, $p < 0.05$; SCC: 0.271, $p < 0.05$) correlation was found for temperature in ECs. Wind speed showed moderate to strong correlation in ECs with a very high statistical significance to both daily new cases [(KCC: 0.494, $p < 0.01$); (SCC: 0.689, $p < 0.01$)] and total cases [(KCC: 0.426, $p < 0.01$); (SCC: 0.617, $p < 0.01$)]. The COVID-19 transmission was found to have a weak (KCC: 0.354, $p < 0.01$) to moderate (SCC: 0.465, $p < 0.01$) correlation with daily new cases; however, a moderate (KCC: 0.497, $p < 0.01$) to strong (SCC: 0.712, $p < 0.01$) correlation with total cases was found in NECs. The results suggest that temperature and humidity have little influence on COVID-19 transmission, but wind speed may have some influence. Countries should prioritize social engineering to modify human behavior in order to combat the spread of COVID-19 and future pandemics.

Keywords: COVID-19; Meteorological variables; Spearman rank and Kendall correlation; Social engineering; Bangladesh

1. Introduction

From the first instance of COVID-19 in Hubei Province, Wuhan, China, on December 31, 2019 (P Zhou et al., 2020), to the date of writing this manuscript (May 17, 2020), the fast-spreading and unstoppable virus has emerged in 212 countries and territories around the world and two international conveyances. This has resulted in near to 10 million confirmed cases and a death toll exceeding 498,000 worldwide (WHO, 2020a). The initial name “coronavirus disease” was changed to “COVID-19” by the World Health Organization (WHO) and concomitantly, the virus name was changed from “2019-nCoV” to “severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2)” by the Coronavirus Study Group of the International Committee on Virus Taxonomy. The reason behind these changes was to avoid confusion and stigmatization regarding any group or country (Jiang et al., 2020; WHO, 2020e). Since the initial outbreak in a small city in Asia, the virus has had frightful consequences for European countries, followed by the North and South American countries USA and Brazil, respectively (WHO, 2020b; Menezes et al., 2020). The most prevalent symptoms are breathlessness, agitation, drowsiness, pain, and delirium (Lovell et al., 2020). To date, no efficacious pharmaceutical measures for COVID-19 prevention or treatment are available, and affected countries are employing non-pharmaceutical interventions (NPIs) (Ferguson et al., 2020).

On March 8, 2020, Bangladesh witnessed its first three official COVID-19 cases, confirmed by the Institute of Epidemiology, Disease Control and Research (IEDCR), and the first death from the virus occurred 10 days later on March 18, 2020 (WHO, 2020c). Following other emergent countries, Bangladesh also adopted various NPIs, such as case-based isolation, shielding of vulnerable groups, educational institute closures, announcement of general holidays for government and non-government organizations, restriction of public events, and lockdowns to

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control person-to-person transmission of the virus. Moreover, the Government of Bangladesh (GoB) deployed armed forces to make NPIs more effective and keep the virus at bay. However, a time-gap between the announcement of NPI initiatives and armed force deployment resulted in the virus establishing itself across 64 districts within the country. This resulted from the migration of approximately 11 million people from the capital city, Dhaka (the epicenter of the country), and two other garment manufacturing zones (Narayanganj and Gazipur) to their home districts after the immediate announcement of the lockdown (Shammi et al., 2020). The decision to reopen the garment industry approximately one month later caused the people involved in the sector to travel back to their place of work. Moreover, the low testing rate (1,087 per million, as of May 17, 2020) throughout the country (WHO, 2020d) resulted in many silent carriers of the virus. This enabled the virus to transmit rapidly among dense population groups who were not practicing social distancing or safety measures. All this led to the incidence of the first 10,000 cases within 58 days of the initial announcement of the virus, a further 11 days for the second 10,000 cases, and just 7 days for the third 10,000 cases to occur (WHO, 2020d).

High mobility of people is considered one of the vital reasons for person-to-person transmission. Besides person-to-person transmission, the WHO (2020f), Morawska and Cao (2020), and Setti et al. (2020) have made claims relating to the ability of the virus to spread through air under specific conditions. Moreover, experts have reported the possible effects of other weather factors, especially temperature and humidity, with respect to COVID-19 transmission. Some researchers and epidemiological experts (Lipsitch, 2020; J Wang et al., 2020; Bukhari and Jameel, 2020; Hasan and Haque, 2020) have argued that since it is the onset of summer in tropical Asian countries, the weather conditions are not conducive enough for COVID-19 to take full advantage of communities, and there might be a chance of recurrence in the following winter

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(Neher et al., 2020). Despite the dominant presence of the virus in temperate countries far from the equator (Sajadi et al., 2020), the virus also resides in tropical countries such as Bangladesh. Therefore, the present study aims to assess the correlation between COVID-19 transmission and meteorological variables in a representative tropical country (Bangladesh) in an attempt to address the following research questions: (i) do high temperatures and humidity at the onset of summer curb COVID transmission and (ii) what are the effects of high wind speed from the outset and periodically during summer?

2. Material and methods

2.1 Study area

Among the first three cases of COVID-19 in Bangladesh, two were from Narayanganj, which is now considered the second largest epicenter (EC) in the country after the capital city, Dhaka. Following these two districts, Gazipur is the closest peripheral city that has been declared a vulnerable district of Bangladesh as it has the densest population and the largest industrial area after Dhaka. These three areas have the most cases of COVID-19 since the initial outbreak. Therefore, these three districts were selected as the representative EC area of Bangladesh to examine the possible effects of climatic factors on the spread of COVID-19. For easy comparison of these EC areas, some non-epicenters (NECs) were selected, namely Narsingdi, Mymensingh, and Tangail (Fig. 1). A number of additional districts that are less vulnerable to COVID-19 are also discussed; these were selected for their adjacency with the EC districts and easy spatial presentation.

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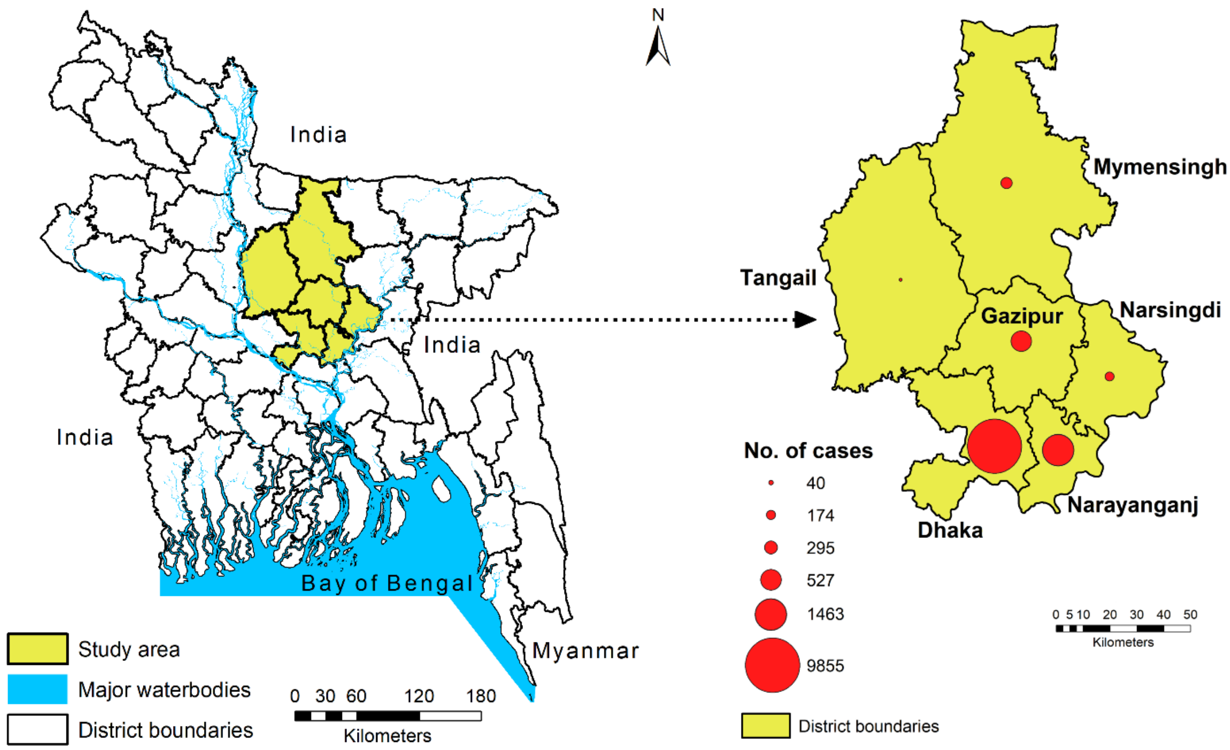

Fig. 1. ECs and NECs of Bangladesh highlighting the study area with total cases (May 17, 2020).

2.2 Data collection

The study was performed using two types of secondary data sources. Daily and district-wise data for both ECs and NECs were collected from the daily COVID-19 national report published by the IEDCR on behalf of the Director General of Health Services, Ministry of Health and Family Welfare, GoB. Data relating to the main meteorological variables, including air temperature (at 2 m height), humidity, and wind speed, within the timeframe of March 8, 2020 to May 17, 2020, were obtained from https://www.timeanddate.com at three-hour intervals. The values of the measured meteorological variables were averaged daily before spatial analysis was carried out.

2.3 Data management and analysis

Data analysis was performed in three sequential steps. A descriptive analysis in MS Excel was first carried out for both daily cases and all meteorological variables to represent their graphical correlation for every single district selected in this study. In the second step, a specific map was developed for each meteorological variable using ESRI ArcMap 10.5 to observe the differences between the areas for the respective variables. As a work around, data for every meteorological variable were interpolated using the spline method, considering the district boundaries as barriers. These maps were represented with 14 days intervals, whereas this time span has been declared the pre-symptomatic period of COVID-19 (Lauer et al., 2020). The Spearman rank and Kendall correlation test was used to measure the linear or monotonic association between meteorological variables and COVID-19. The statistical tests were two-sided, and statistical significance was considered both at $p < 0.05$ and $p < 0.01$. Statistical analyses were conducted using the statistical software IBM SPSS v25. Correlations between the abnormally distributed data of the meteorological variables and COVID-19 were analyzed in the final stage of the study.

3. Results

3.1 Descriptive status of meteorological variables and COVID-19 cases

The temperature values recorded in the ECs and NECs followed almost the same trend, except for some difference between April 13 and April 23, 2020, with a range of 26.76°C to 28.95°C for EC locations and 26.19°C to 27.71°C for NECs. The highest temperature (>30°C) was recorded on several scattered dates, both in EC and NEC locations. In contrast to the recorded highest temperature dates, peak daily cases were not observed between or on the exact pre-symptomatic period (Fig. 2).

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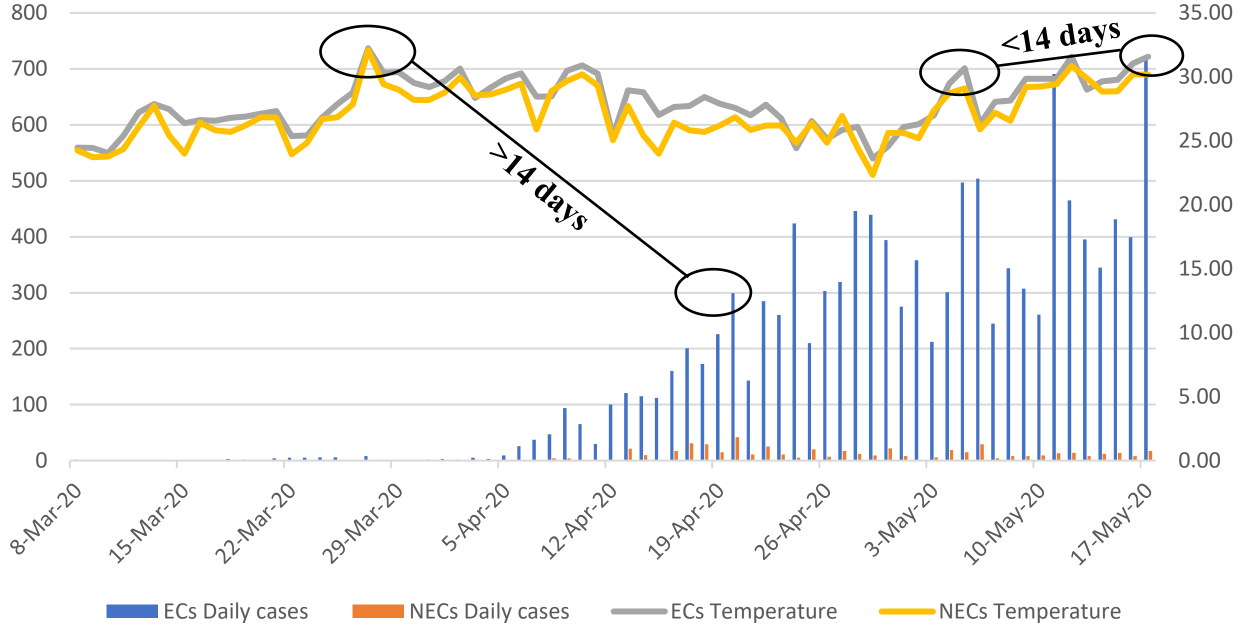

Fig. 2. Average temperature (°C) and daily cases between ECs and NECs.

The highest humidity in both ECs and NECs was observed on April 28, 2020. The daily cases following this date were outside the pre-symptomatic period for both areas. Besides the highest humidity date recorded, some peak humidity values were measured on scattered dates; however, the highest daily cases in ECs or NECs were not observed in the following pre-symptomatic period and/or dates. The average daily humidity values followed similar trends in both the ECs and NECs; however, new cases rose or declined in an irregular pattern, which did not appear to be related to trends in humidity (Fig. 3).

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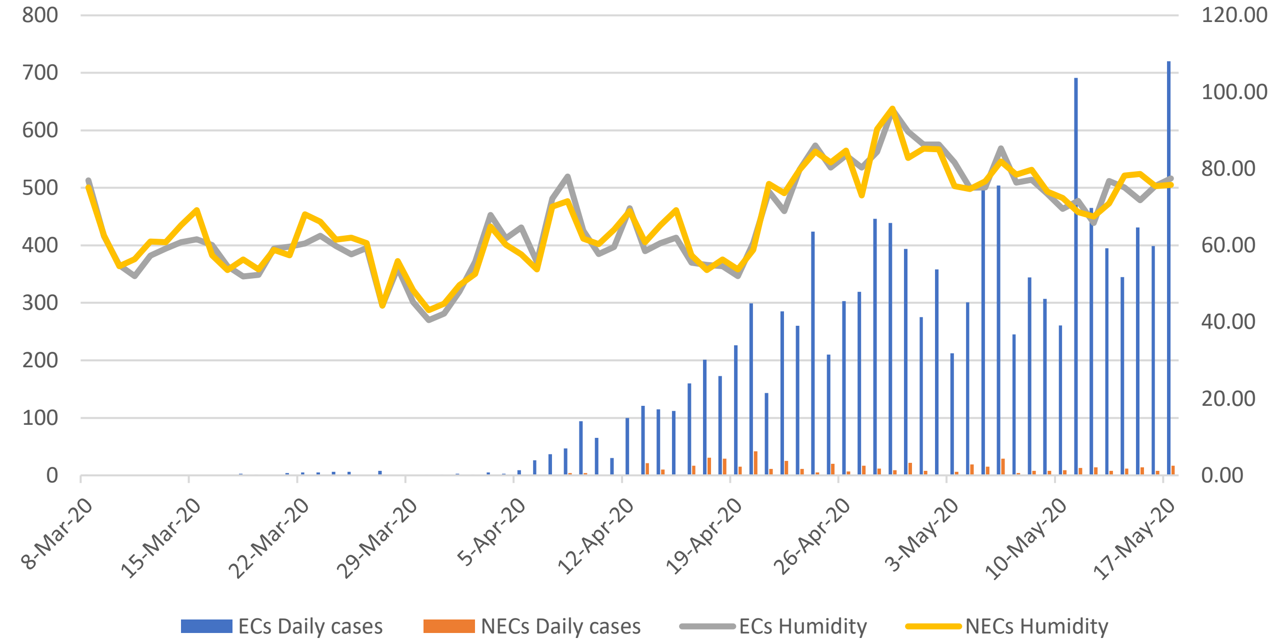

Fig. 3. Average humidity (%) and daily cases between ECs and NECs.

The wind speed in the ECs and NECs followed different trends. On some particular dates (e.g., April 18, 2020), when peak wind speed (6.61 km/h) was recorded in EC regions, NEC regions experienced one of the lowest wind speed values (4.25 km/h). Following this date, ECs experienced their daily highest number of recorded new cases on the pre-symptomatic date (May 1, 2020) than the previous date counts. In contrast, NECs experienced a drop in new cases on the same pre-symptomatic date, compared to their previous date records (Fig. 4). The same incident was observed on May 3, 2020; however, the wind speed value between the ECs and NECs was not antithetical for this time.

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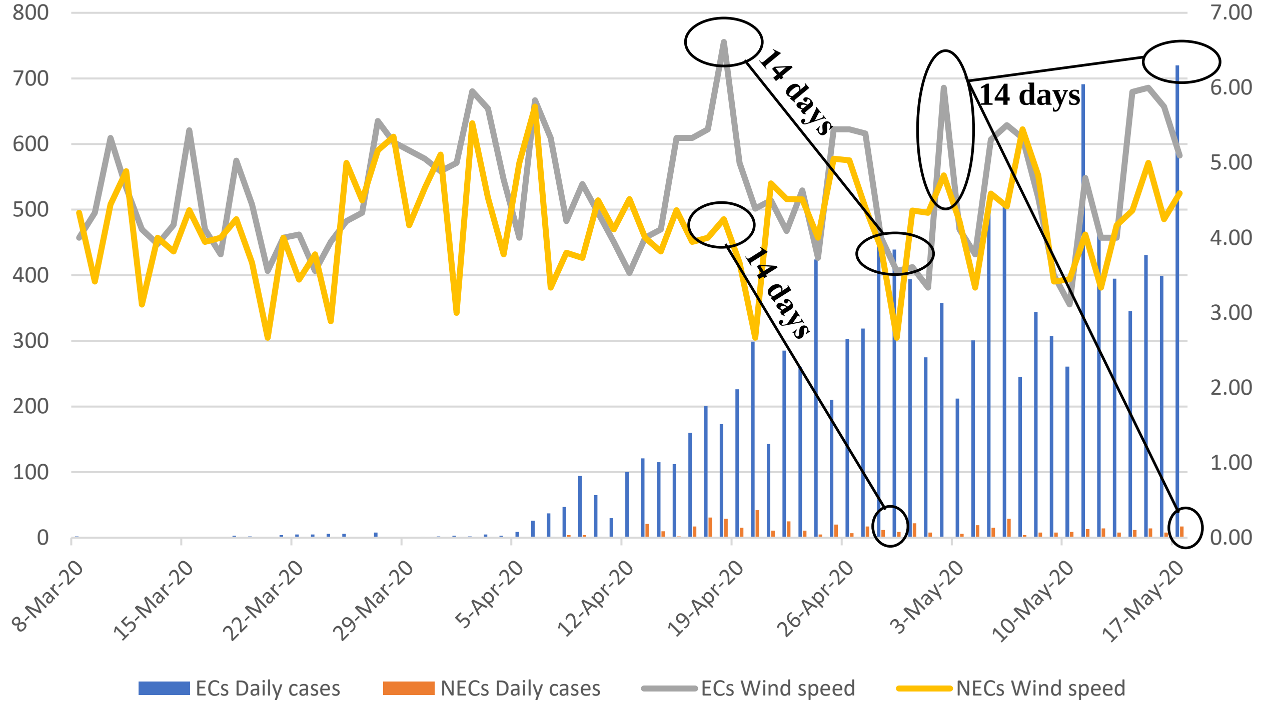

Fig. 4. Average wind speed (km/h) and daily cases between ECs and NECs.

3.2 Spatial analogy of meteorological variables between ECs and NECs

The spatial analogy of all meteorological variables for both ECs and NECs was observed at 14 days intervals on six different dates over the entire study period. Between these dates, the highest temperature (31.6°C) was recorded on the last study date (May 17, 2020) in all selected areas of ECs, along with one area (Narsingdi) from NECs. From the date-wise temperature record, the second highest temperature (30.2°C) was recorded on April 5, 2020, in only one area (Gazipur) from ECs, and the lowest temperature (22.4°C) was recorded on March 8, 2020, in one area (Mymensingh) from NECs (Fig. 5).

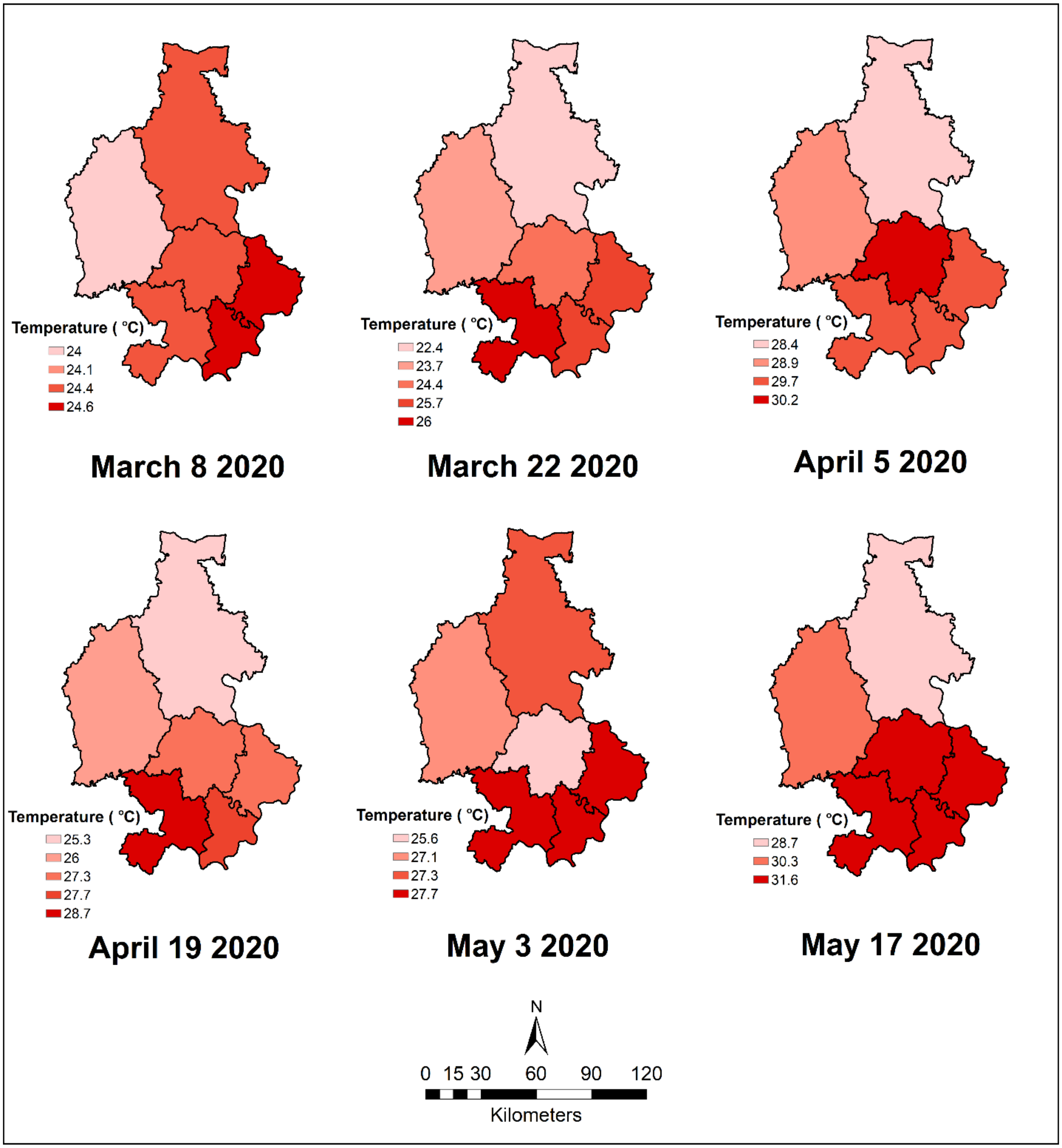

Fig. 5. Temperature (°C) variation between the ECs and NECs on different dates of the pre-symptomatic period following the date of detection of the first case.

Fig. 6 presents the humidity on selected dates over the study period in ECs and NECs and the observed fluctuating highest and lowest humidity records in different areas on different observed dates. The highest humidity (88.1%) was observed in one EC area (Gazipur) on May 3, 2020, while the lowest (40.4%) appeared on April 19, 2020, in another EC area (Narayanganj).

The wind speed followed a wavy change pattern on selected observed dates between the EC and NEC areas. On the first study date (March 8, 2020), the highest wind speed (5 km/h) was recorded in two EC areas (Dhaka and Narayanganj) and one NEC area (Narsingdi), while the lowest wind speed value (2 km/h) was recorded in Gazipur, a representative EC area. This difference in wind speed was somewhat similar to values recorded on March 22, 2020, and May 03, 2020, in terms of the highest and lowest recorded wind speed areas; however, the lowest recorded wind speed changed to Tangail, an NEC area, on March 22, 2020 (Fig. 7). On the following two dates (April 5, 2020 and April 19, 2020), the highest wind speeds (7 and 6 km/h, respectively) were recorded in the areas that previously showed the lowest recorded speeds, the NEC area of Tangail (March 22, 2020). On April 19, 2020, the lowest wind speed (4 and 5 km/h) was observed in all other areas from both ECs and NECs, except for Mymensingh. On the final study date (May 17, 2020), the highest and lowest wind speeds were recorded in several areas from both ECs and NECs (Fig. 7).

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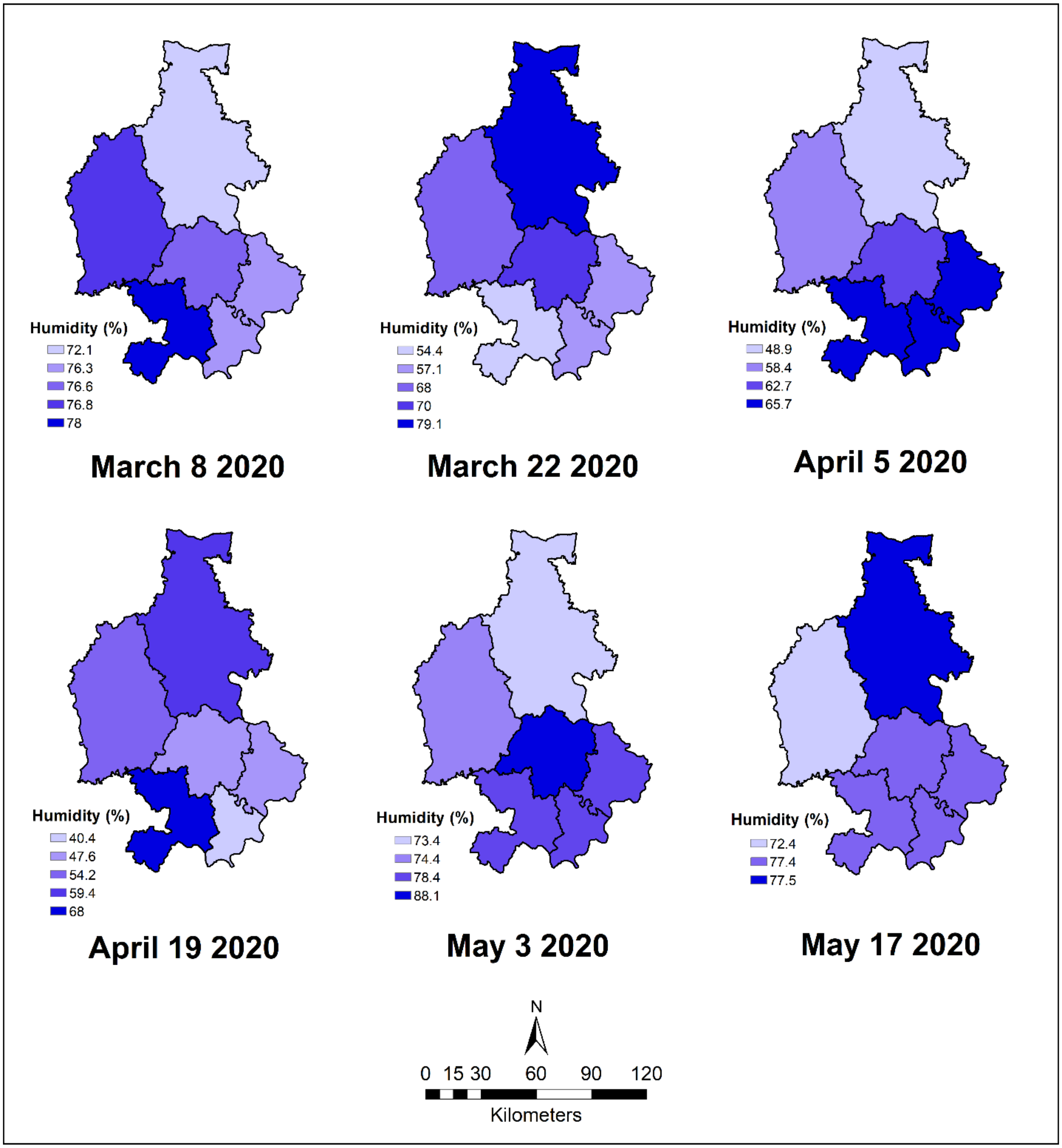

Fig. 6. Humidity (%) variation between the ECs and NECs on different dates of the pre-symptomatic period following the date of detection of the first case.

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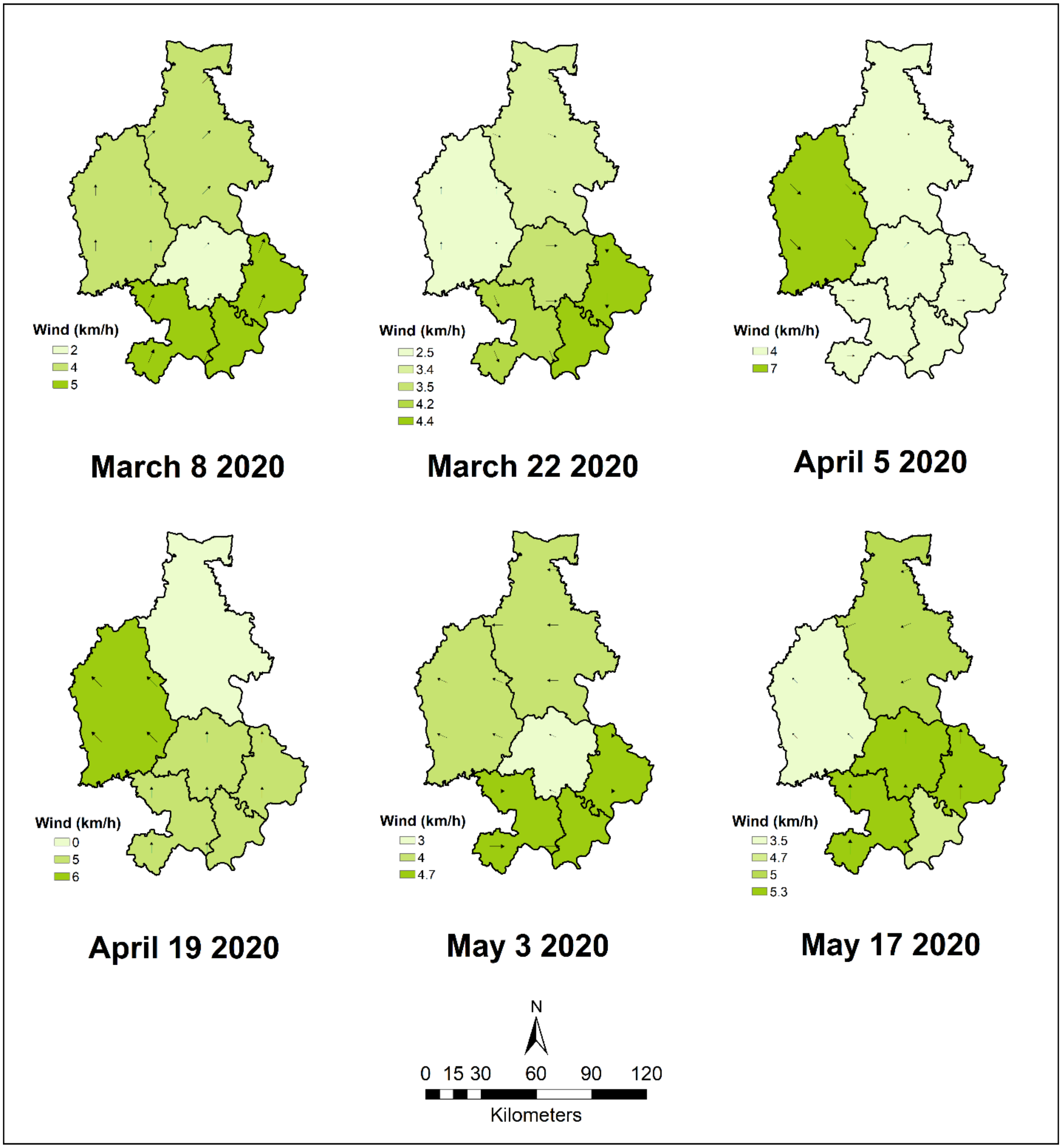
212 

213 *Fig. 7. Wind speed (km/h) and wind direction variation between the ECs and NECs on different*
214 *dates of the pre-symptomatic period following the date of detection of the first case.*

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3.3 Spearman rank and Kendall correlation test

Data regarding the COVID-19 cases and meteorological variables were included in the Spearman rank and Kendall correlation test to obtain their specific correlation coefficient values [Spearman correlation coefficient (SCC) and Kendall correlation coefficient (KCC)]. Daily new cases must show a strong correlation with the total number of cases, as new cases are rapidly pushing the tally of total cases each day. Therefore, the correlation between these two similar variables was not included, rather these two variables were examined for their correlation with meteorological variables. Among the meteorological variables, only average wind speed showed moderate (KCC: 0.494, $p < 0.01$) to strong correlation (SCC: 0.689, $p < 0.01$) status, with a very high statistical significance to new cases of ECs. For the same pair of variables (average wind speed and new cases) weak (KCC: 0.354, $p < 0.01$) to moderate (SCC: 0.465, $p < 0.01$) correlations were observed in NECs (Table 1). In the same dataset, the average wind speed had the same moderate (KCC: 0.426, $p < 0.01$) to strong (SCC: 0.617, $p < 0.01$) correlation to total cases for ECs. The exception is that, for NECs, the average wind speed had a moderate (KCC: 0.497, p <0.01) to strong (SCC: 0.712, $p < 0.01$) correlation with total cases. Moreover, the average temperature in ECs was weakly correlated (KCC: 0.180, $p < 0.05$; SCC: 0.245; $p < 0.05$) to total cases (Table 1). Average temperature and average wind speed of ECs did demonstrate a correlation; however, this correlation was considered to be weak (KCC: 0.168, $p < 0.05$; SCC: 0.271, $p < 0.05$). The average humidity of ECs also showed a significantly weak (KCC: -0.203, p < 0.05; SCC: -0.333, $p < 0.01$) correlation with average temperature; however, it was negative (Table 1).

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Table 1 Correlation between the epicenter and non-epicenter environmental variables with daily new cases and total cases of COVID-19

Epicenters	**Spearman correlations coefficient**				
	Daily new cases	Total cases	Average temperature	Average humidity	Average wind speed
Daily new cases	1				
Total cases	0.875**	1			
Average temperature	0.086	0.245*	1		
Average humidity	0.068	0.078	-0.333**	1	
Average wind speed	0.689**	0.617**	0.271*	-0.160	1
	Kendall correlation coefficient				
	Daily new cases	Total cases	Average temperature	Average humidity	Average wind speed
Daily new cases	1				
Total cases	0.817**	1			
Average temperature	0.068	0.180*	1		
Average humidity	0.039	0.078	-0.203*	1	
Average wind speed	0.494**	0.426**	0.168*	-0.099	1
Non-epicenters	**Spearman correlations coefficient**				
	Daily new cases	Total cases	Average temperature	Average humidity	Average wind speed
Daily new cases	1				
Total cases	0.800**	1			
Average temperature	0.077	0.198	1		
Average humidity	-0.045	0.059	-0.224	1	
Average wind speed	0.465**	0.712**	0.151	0.063	1
	Kendall correlation coefficient				
	Daily new cases	Total cases	Average temperature	Average humidity	Average wind speed
Daily new cases	1				
Total cases	0.624**	1			
Average temperature	0.052	0.152	1		

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Average humidity	-0.030	0.049	-0.155	1	
Average wind speed	0.354**	0.497**	0.102	0.056	1

** Correlation is significant at the 0.01 level (two-tailed)
* Correlation is significant at the 0.05 level (two-tailed)

4. Discussion

The transmission factors of several members of the coronavirus family, including SARS-CoV-2 (Yang and Wang, 2020), remain unknown due to their highly variable characteristics (e.g., spread via both water and air, enveloped in layers of fatty molecules or non-enveloped) (Wigginton and Boehm, 2020). Significant association of primary factors like virulence of COVID-19 (Cascella et al., 2020; Chen et al., 2020), host behavior and number of contacts (Riou and Althaus, 2020; Y Wang et al., 2020), personal hygiene practices, host defense potential (Lei et al., 2018; Cui et al., 2019), age of the host (Onder et al., 2020; Wu and McGoogan, 2020), underlying health conditions (Mehta et al., 2020; Young et al., 2020; F Zhou et al., 2020), population density (Gilbert et al., 2020; Hoehl et al., 2020), and social distancing or community consciousness (Wilder-Smith and Freedman, 2020) makes it difficult to assess the actual effect of secondary factors, i.e., meteorological parameters (atmospheric temperature, humidity, wind speed, and/or airflow etc.). This is mainly due to insufficient data regarding these secondary factors over the short period of time since the onset of virus spread. However, spatial data researchers, along with other frontline researchers, attempted to determine the relationship between COVID-19 transmission and meteorological variables once the virus began to reveal its devastating nature and unstoppable spread globally. This article is an addendum to previous attempts of spatial researchers and epidemiologists from different parts of the world.

Both Spearman rank and Kendall correlation tests were performed to determine the linear relationship between daily COVID-19 cases following the total cases and meteorological variables within a number of designated EC and NEC regions. Kendall correlation was to be used as an extension of Spearman rank. However, in this instance, Kendall correlation resulted in a more accurate and generalized result compared to Spearman rank (Akoglu, 2018). In both ECs and NECs, temperature followed almost the same trend, with the exception of a few dates. This finding was not correlated with the onset of COVID-19 within the declared pre-symptomatic period of the virus for NECs. In addition, only a weak correlation was observed in ECs. The viruses causing respiratory-borne infectious diseases such as influenza and SARS, both being genetic cousins of COVID-19, survived best under certain temperature conditions, and high temperatures restricted their transmission (Tan et al., 2005; Lowen et al., 2007). For COVID-19, Yao et al. (2020) and Xie and Zhu (2020) demonstrated no association between viral transmission and temperature. In contrast, other predisposing factors such as poor hygiene, close contact, high population density, and marginal living conditions have been shown to increase viral transmission rates (Huang et al., 2020; Li et al., 2020). The average humidity in both ECs and NECs also followed a trend similar to that of temperature; however, no interdependency was observed with daily new cases or total cases, resulting in irregular increases and decreases in the numbers of new cases within the pre-symptomatic period from the dates when the highest humidity was recorded. In the SARS-2003 and MERS-2012 outbreaks, droplet-mediated viruses were able to survive in low absolute humidity (cold and dry weather), and viral transmission was attenuated in high absolute humidity conditions (warm and humid weather) (Lowen and Steel, 2014). Contradictory results to this research have been reported regarding both temperature and humidity in different parts of the world. Liu et al. (2020) showed that both temparure and humidity aided the transmission of COVID-19 in China; Jahangiri et al. (2020) found that COVID-19 transmission exhibited low sensitivity to changes in the ambient temperature in Iran; Bashir et al. (2020) showed that temperature presented a significantly complex association with the COVID-19 pandemic in New York, USA; Tosepu et al. (2020) indicated that average

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temperature was significantly correlated with the COVID-19 pandemic in Jakarta, Indoneisa; and Tobías and Molina (2020) showed that a 1°C increase in maximum temperature resulted in a decrease in the COVID-19 incidence rate by 7.5% on the same day in Barcelona, Spain. Among the observed meteorological variables, average wind speed demonstrated a significant and standalone correlation with COVID-19 transmission. This correlation ranged from moderate to strong with respect to new cases and total cases in ECs, respectively. The correlation in NECs ranged from weak/moderate to moderate/strong for new cases and total cases of COVID-19, respectively. Yuan et al. (2006) argued that the peak spread of SARS occurred at wind speeds of 2.8 ms^{-1}, and this result may also be true for COVID-19. For COVID-19, the most common route of transmission is via droplets of different sizes (respiratory droplets > 5–10 μm; droplet nuclei < 5 μm) and community contact (WHO, 2015; Chan et al., 2020; Huang et al., 2020). Moreover, droplets <5 μm have higher aerosol and surface stability (Van Doremalen et al., 2020), which aids the transmission of the virus to over 6 feet through air (Setti et al., 2020). Dbouk and Drikakis (2020) marked the virus transmissible via saliva droplets. Again, these saliva droplets are wind speed dependent and can travel up to 6 feet when the wind speed is zero and approximately 18 feet when the wind speed varies from to 4–15 km/h. With respect to wind speed, opposing results have been reported by other researchers. For example, Coccia (2020) analyzed wind speed data of hinterland zones in northern Italy and suggested that high wind speed likely lowered the number of infected individuals. Eslami and Jalili (2020) also suggested that the incidence of COVID-19 decreases with increasing wind speed.

Our results regarding meteorological variables might be contradictory due to the different data inclusion patterns adopted by different researchers. Some researchers considered new cases visà-vis meteorological variables, while others included the cumulative incidence rate in their analysis. The asymmetry of population size and population density in different geographical locations is also responsible for variable results regarding the same issue from country to country (Jahangiri et al., 2020). Moreover, even though different countries follow the same strategies of lockdown, testing–tracing–isolating of infected individuals, and social distancing, the degree of enforcement varies. Non-reporting of facts during the initial cases of COVID-19 in various countries has also skewed findings.

5. Conclusion

This study considered different meteorological variables against the daily new cases and total cases of some selected ECs and NECs of Bangladesh to draw a conclusion on COVID-19 prevalence and its sustainable correlation with the selected variables. The data were double screened by Spearman rank and Kendall correlation tests to uncover any contributing meteorological variables for COVID-19 transmission in Bangladesh, a representative tropical monsoon country. From the meteorological factors analyzed, temperature and humidity were found to have no impact on COVID-19 transmission. Hence, increasing the temperature and humidity should not decrease the rate of spread. Therefore, summer conditions have little chance of flattening the curve in subtropical Bangladesh. On the other hand, wind speed had a somewhat significant correlation with the transmission rate. However, this also depends on the direction of wind. Further research is necessary to confirm the effects of wind on the spread of COVID-19. In general, the results revealed that climate was not the primary cause of the rapid transmission of the pandemic in Bangladesh. The main cause of transmission is through community activities and events. This warrants the necessity for social distancing. Proper social engineering needs to be applied to modify our behavior in lockdown to minimize the excessive transmission rate of SARS-CoV-2. In addition, hand washing with soaps and sanitizers, avoiding touching the face, using masks, practicing respiratory hygiene at a standard level, etc., can help to effectively flatten the pandemic curve.

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