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The Effect of Temperature, Dewpoint, and Population Density on COVID-19 Transmission in the United States: A Comparative Study

Virginia C. Hughes*

Medical and Molecular Sciences, University of Delaware, Newark, USA
*Corresponding author: vhughes@udel.edu

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Abstract The number of confirmed cases of COVID-19 peaked in the United States in the month of April, 2020 in the most populated cities. A study was done to assess if temperature, dewpoint, and population density in fifty cities had a significant effect on the number of confirmed cases of COVID-19 in the month of April. Temperature and Dewpoint data for the month of April were accessed from the National Oceanic and Atmospheric Administration (NOAA) and confirmed cases of COVID-19 was accessed from the CDC (Centers for Disease Control and Prevention). Pearson Correlation Coefficient and Multiple Regression statistical analyses were performed. COVID-19 cases in the fifty states largest cities were correlated with average temperature and dewpoint in April, as well as the city's population density. For the Multiple Regression analysis the total number of COVID-19 cases in fifty cities served as the dependent variable and average temperature, average dewpoint, and population density comprised the predictor variables. Correlation coefficient statistics utilizing data for fifty largest cities in each state for COVID-19 cases and average temperature in April 2020 yielded an r of -.097 and $P>.05$; between COVID-19 and average dewpoint for April 2020 yielded an r of -.001 and $P>.05$, and COVID-19 and population density pairing yielded an r of .792 and $P<.01$ for respective cities. Multiple regression analysis yielded statistical significance for the population density variable only. This study demonstrated that cities population density had a significant effect on the number of COVID-19 cases in April 2020, and while both temperature and dewpoint resulted in a negative correlation in association with COVID-19 cases, results were not statistically significant. The seasonal uncertainty and high transmission rate of COVID-19 in the United States suggest that similar analyses should be replicated in the impending summer and winter months of 2020 to further delineate COVID-19 seasonal characteristics.

Keywords: *COVID-19 Temperature Population*

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1. Introduction

Since the first case of COVID-19 infection in the United States was reported on January 20, 2020 infectious disease clinicians have worked arduously with government officials in implementing national guidelines to minimize the spread of the novel coronavirus [1]. COVID-19 is a member of the family *Coronoviridae* in the Nidovirales order which can collectively be described as single-stranded RNA viruses that typically infect the nasal passages, sinuses, and throat. They possess crown-like spikes on their outer surface aiding attachment to host cells and range in size from 65 to 125 nm in diameter [2]. Persons infected with COVID-19 exhibit pneumonia-like symptoms similar to those seen with SARS-CoV (Severe Acute Respiratory Syndrome Coronavirus) generating the name SARS-CoV-2 by the International Committee on Taxonomy of Viruses (ICTV). COVID-19 shares 80% homology [3] with SARS-CoV. It has been documented that COVID-19 originated in Wuhan City in central China in early December 2019, from a Hunan seafood market where live animals are frequently sold. It is thought that COVID-19 was introduced to humans in China by an unknown intermediate host that then spread from human to human. Reports indicated that some patients infected in Wuhan City visited the seafood market, while others did not bringing into question where COVID-19 originated. Human transmission is propagated through respiratory droplets from coughing, sneezing, talking to someone in close proximity, or from aerosols. According to the WHO (World Health Organization), droplets measuring <5μm are deemed droplet nuclei, and those ≥5 μm are denoted respiratory droplets [4]. A person may also be infected by touching surfaces or objects (e.g. fomites) that have attracted viral particles. Airborne transmission of COVID-19 may occur in certain circumstances such as endotracheal intubation, bronchoscopy, open suctioning, or disconnecting patients from a ventilator. COVID-19 has been detected in respiratory fluids, blood, semen, and feces. [5]

The staggering rate of COVID-19 transmissibility and heightened death rate summarily prompted federal agencies to establish and publish guidelines aimed at mitigating transmission such as wearing face masks, practicing social distancing (e.g. six feet apart), and washing hands frequently. In the United States, the highest number of cases to date occurred nationwide in the month of April. Studies have shown that other RNA viruses, such as *Influenzae*, have higher transmission rates in colder months. The envelope of the *Influenzae* virus is able to form a rubbery gel in colder months which is thought to increase its infectivity from human to human; in warmer months, the virus envelope assumes a liquid state which researchers posit diminishes infectivity [6]. The characteristics of COVID-19 regarding seasonal virulence tactics have not yet been elucidated. This study explores the relationship of temperature, dewpoint, and population density in the most populated cities across fifty states with COVID-19 cases in the month of April. Maximum temperatures in the month of April vary considerably in the United States rendering this study both timely and informative. The dewpoint is the temperature at which air must be cooled to become saturated with water vapor. Upon cooling, airborne water vapor condenses forming dew or liquid water [7]. Persons standing in close proximity to each other speaking yields a cloud of vapor that changes to liquid droplets as the dew point approximates the temperature which conceivably could be infectious. Althouse et al found a significant relationship in children between parainfluenza 3 and Rhinovirus with mean dewpoints in Vietnam in April, May, and June [7]. It is uncertain how long potentially infectious liquid droplets remain suspended in air. Population density is the third variable in the study. The most populated cities in the fifty states have varying population densities which can be defined as the measure of the number of people per unit area. This variable will provide insight into transmission of COVID-19 across a spectrum of population densities in fifty cities. It is hypothesized that the average maximum temperature and dewpoint for the month of April will have an inverse relationship with the number of COVID-19 cases and population density will have a direct relationship.

2. Methods

The unit of analysis in this study was the most populated city in each state. A Pearson's Correlation Coefficient analysis was performed assessing the association between the total number of COVID-19 cases with three variables (average maximum temperature for April 2020, average maximum dewpoint for April 2020 and population density of selected fifty cities). Temperature and dewpoint are expressed as degrees Fahrenheit, and population density as the number of people per square kilometers. The fifty cities (Table 1) were selected by population; the most populated city in each state was included in the study. The total number of COVID-19 cases is the dependent variable and average maximum temperature, average maximum dewpoint, and population density are independent variables. The total number of COVID-19 cases were assessed from the CDC website where the number of cases were documented per county in each state. To ascribe the total number of cases confirmed in the largest cities in each state, research was done into which counties comprise the cities selected for this study through the respective city's website. Maximum temperatures and dewpoints for the month of April 2020 was accessed from the NOAA (National Oceanic and Atmospheric Administration).

A multiple regression analysis was also conducted to determine which of the independent variables have a statistically significant effect on the dependent variable (COVID-19 cases). Significance is defined as $P<.05$.

Table 1. Cities Included In Study With Total Number Of COVID-19 Cases In April 2020 (n=50)

Birmingham (1070)	Omaha (575)
Littlerock (415)	Las Vegas (3110)
Phoenix (3184)	Manchester (885)
Anchorage (114)	Newark (11782)
Los Angeles (20171)	Albuquerque (682)
Denver (2462)	New York (125742)
Bridgeport (9424)	Charlotte (716)
Wilmington (1537)	Fargo (482)
Jacksonville (805)	Columbus (2116)
Atlanta (2209)	Oklahoma City (618)
Honolulu (242)	Portland (591)
Boise (486)	Philadelphia (11100)
Chicago (32017)	Providence (5985)
Indianapolis (4566)	Charleston (302)
Des Moines (909)	Sioux Falls (2010)
Wichita (314)	Nashville (2221)
Louisville (1109)	Houston (7911)
New Orleans (4618)	Salt Lake City (2036)
Portland (332)	Burlington (266)
Baltimore (1881)	VA Beach (320)
Boston (11517)	Seattle (3877)
Detroit (12994)	Charleston (129)
Minneapolis (1534)	Milwaukee (2266)
Jackson (380)	Cheyenne (71)
Kansas City (797)	
Billings (49)	

3. Results

For the fifty most populated cities and predictor variables average temperature, average dewpoint, and population density (Table 2) the Pearson correlation coefficient was -.097, -.001, and .792, respectively (Figure 1 - Figure 3). The P value was statistically significant for the population density predictor variable only (<.01).

The multiple regression analysis employed the total number of COVID-19 cases in the month of April in fifty selected cities as the dependent variable, and average maximum temperature, average maximum dewpoint, and population density as independent variables. The population density variable yielded significance ($P<.01$) and the adjusted R-square was 0.609 indicating variation in the dependent variable can be explained by 60.9% of the predictor variables. Average maximum temperature and dewpoint for the month of April 2020 were not significant variables in the multiple regression analysis nor the correlation coefficient analysis. Referring to Figure 1 to 3, it is clear that there is an outlier data point representing the number of COVID-19 cases in New York City, which was 125,742 in the month of April. The Correlation Coefficient analysis was repeated omitting this data point and revealed an r of -.06, .03, and .654 for average temperature, average dewpoint, and population density, respectively. Statistical significance regarding correlations was present for the correlation between COVID-19 cases and population density only (P<.01). The multiple regression analysis was also repeated omitting the data points for New York City. The results did not change from the original analysis; population density was the only predictor variable yielding statistical significance. However, the adjusted R square value did decrease to 0.405.

Table 2. Temperature, Dewpoint, And Population Densities (PD) For Cities Studied

City	Temp°F	Dewpt°F	PD	City	Temp°F	Dewpt°F	PD
Birmingham	61.5	47.2	1455	Billings	43	23.7	2463
Littlerock	59.6	48.5	1664	Omaha	50.7	34.9	3339
Phoenix	74.4	34.5	3047	Las Vegas	69	32.2	4376
Anchorage	36.4	26.4	167	Manchester	45.8	27.6	3320
Los Angeles	62.7	51.9	8092	Newark	50	33.9	11716
Denver	46.8	25.9	4532	Albuquerque	59.3	20.6	2975
Bridgeport	47.8	34.5	9166	New York	48.4	36.9	26403
Wilmington	51.6	36.7	6557	Charlotte	61.1	43.4	2720
Jacksonville	70.5	58.7	1177	Fargo	39.8	28.5	2604
Atlanta	61.6	44.8	3420	Columbus	49.5	35.8	3625
Honolulu	76.4	64.1	5570	Oklahoma City	57	45.3	1081
Boise	52.2	31	2667	Portland	53.9	40.1	4740
Chicago	47.6	34	11943	Philadelphia	51.5	34.7	11233
Indianapolis	50.7	38.3	2310	Providence	45.3	33	9720
Des Moines	49.5	35.6	2407	Charleston	66.1	52.8	1252
Wichita	55.8	39.9	2405	Sioux Falls	46	31.4	2109
Louisville	56.1	40.3	10172	Nashville	58	42.1	1353
New Orleans	72.7	59.2	2303	Houston	70.5	59.8	3829
Portland	43.1	28.8	1199	Salt Lake City	53.5	28.3	1722
Baltimore	53.2	37.4	7295	Burlington	43.5	25.2	4174
Boston	44.4	30.7	14692	VA Beach	59	44.9	1830
Detroit	45.7	31.8	4926	Seattle	51.6	38.9	8444
Minneapolis	44.7	28.8	7708	Charleston	52.5	37.7	1594
Jackson	64	51.8	1549	Milwaukee	43.3	30.8	6088
Kansas City	54.1	38.7	1529	Cheyenne	41.2	21	1997

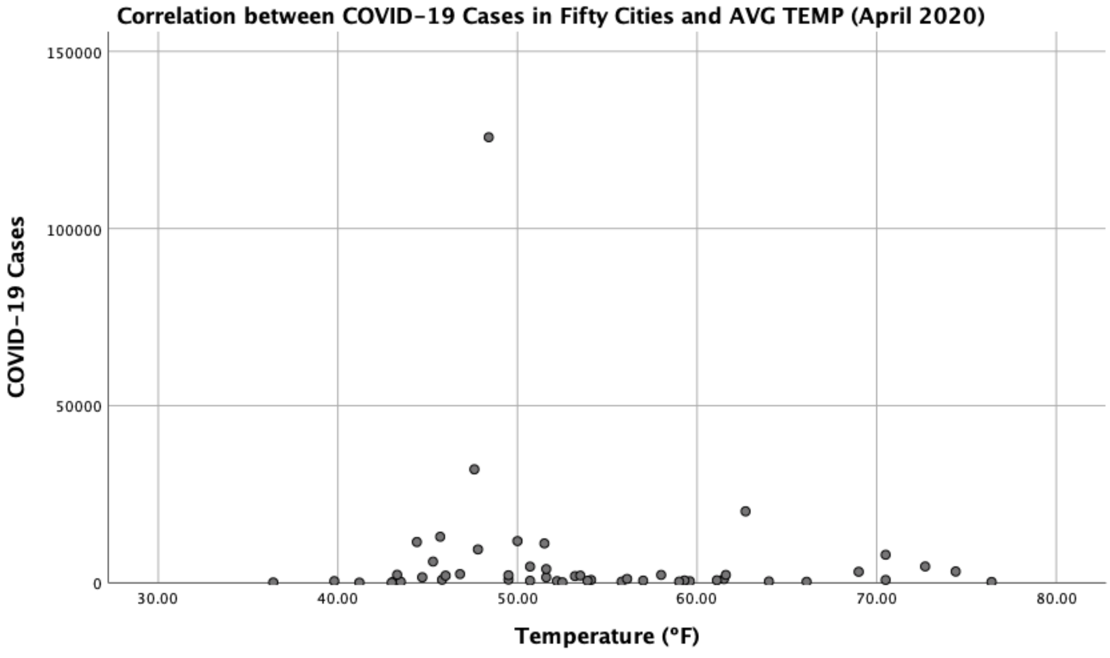

Figure 1. Pearson's Correlation Coefficient analysis between total COVID-19 cases and average maximum temperature in April 2020 in 50 of the largest cities in each state. Outlier data point represents New York City COVID-19 cases (r = -.097, P>.05)

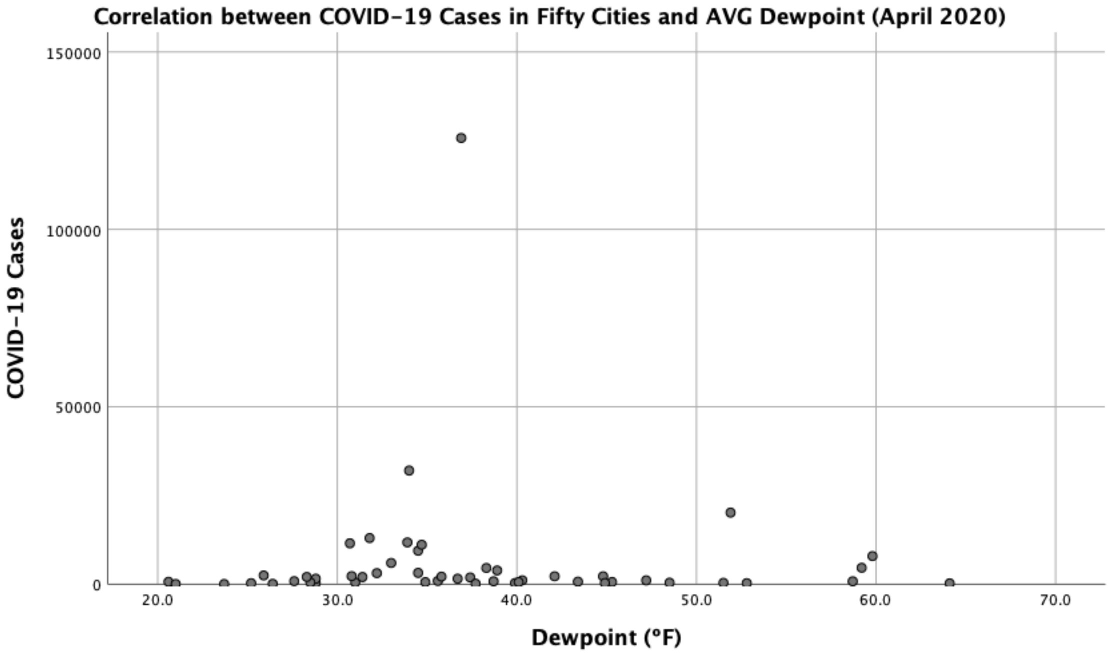

Figure 2. Pearson's Correlation Coefficient analysis between total COVID-19 cases and average maximum dewpoint in April 2020 in 50 of the largest cities in each state. Outlier data point represents the number of COVID-19 cases in New York City (r = -.001, P>.05)

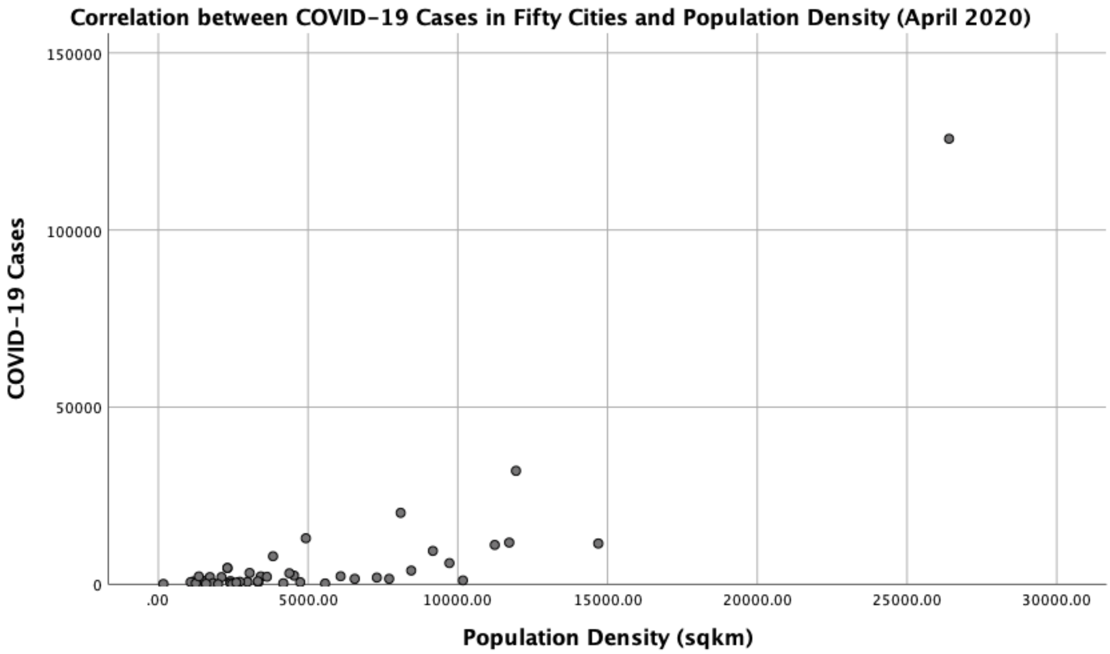

Figure 3. Pearson's Correlation Coefficient analysis between total COVID-19 cases and population density per square km in April 2020 in 50 of the largest cities in each state. Outlier data point represents the number of COVID-19 cases in New York City (r=0.792, P<.01)

4. Discussion

The outbreak of COVID-19 in China in late December 2019 coupled to its high rate of transmission globally led the WHO to declare a global health emergency on January 30th and classify the virus a pandemic on March 11, 2020 [8]. This declaration prompted leaders in government to seek guidance from epidemiologists and physicians in identifying measures to minimize infection from a novel coronavirus that is proficient in human to human transmission from both symptomatic and asymptomatic persons. Washington State was the first to declare a national emergency after a man residing outside Seattle in his 50s died from COVID-19 on February 28, 2020. California followed suit on March 4th after their first death was reported, and Maryland on March 5th after three persons had tested positive.

Eventually all fifty states and the Trump administration would declare a national emergency to operationalize cogent strategies with the aim of stopping the spread of the virus. Social distancing guidelines were implemented by the Federal government on March 16th which harkened Americans to avoid social gatherings involving groups of ten or more people and to avoid public spaces, and in addition to practice safe hygiene. While the guidelines were structured at 15 day increments initially, they were extended to April 30th. On April 1st the US reported 213,372 cases; on April 30th more than a million people had been infected and more than 57,000 deaths were reported [9]. April was an optimal month to study as not only did the number of COVID-19 cases peak supported by widespread testing, but in addition some states started to incrementally reopen in the last week of April based on federal guidelines. Reopening was delineated in three phases [10] predicated on a downward trajectory of influenza-like illnesses and COVID-19 cases within a 14-day period; a downward trajectory of documented cases or positive tests within a 14-day period; and hospitals having a salient program in place for testing employees. Reopening paved the way for American's to reclaim their livelihood, while at the same time be exposed to the virus from persons who chose not to wear a mask or practice social distancing potentially leading to a spike in cases. Another salient rationale for studying cases in the month of April relates to the temperature variable; temperatures vary considerably across the fifty cities studied rendering determination of an association between temperature and COVID-19 infection feasible.

New York City has the highest population density (26403) and highest number of COVID-19 cases (125,742) in the month of April, with an average maximum temperature of 48.4°F. Boston has the next highest population density at 14,692 with 11,517 cases and an average maximum temperature of 44.4°F. In contrast, Anchorage has a population density of 167 and reported 114 cases in the month of April with a maximum average temperature of 36.4°F. Oklahoma City has a population density of 1081 and reported 618 cases with an average maximum temperature of 57°F. Cities recording the lowest maximum temperatures for the month of April were Anchorage and Fargo. Fargo had a maximum average temperature of 39.8°F with 482 cases, and a population density of 2604. Cities recording the highest maximum temperatures (>70°F) for the month of April were Phoenix, Houston, New Orleans, Honolulu, and Jacksonville. Phoenix reported 3184 cases with a population density of 3047, Houston reported 7911 cases with a population density of 3829, New Orleans reported 4618 cases with a population density of 2303, Honolulu reported 242 cases with a population density of 5570, and Jacksonville reported 805 cases with a population density of 1177. The predictor variables utilized revealed great variability across the fifty largest cities in each state. New York City reported the greatest number cases and has the highest population density with maximum average temperature in the high 40's; Honolulu recorded the highest maximum average temperature for the month of April, 76.4°F with cases in the 25th percentile, and a population density approximately one-fifth of New York City. Anchorage recorded the lowest recorded temperature and low number of cases. These variations among variables substantiate the weak negative and statistically insignificant correlation coefficient found in this study for the temperature variable. The dew points for the month of April never approximated the temperature in cities studied, negating the possibility of vapor turning to water droplets and factoring into transmissibility. Nonetheless, like temperature, the dew point also yielded a negative insignificant correlation. The predictor variable that yielded statistical significance in both the multiple regression analysis and correlation coefficient analysis was population density. The manner of human transmission for COVID-19 via respiratory droplets lends credence to the notion that persons residing in cities with high population densities are more at risk for contracting COVID-19 than states with lower population densities. This study found that as the population density increases the number of cases increases.

It is not yet known how COVID-19 differs in transmission between winter and summer months. However, other Coronaviruses have been investigated. Friedman et al [11] analyzed nasopharyngeal samples from 1,910 patients exhibiting influenza like illness between September 2015 and April 2016 in different communities in Israel. Approximately 44% of samples were positive for Influenza viruses, 9.32% were positive for RSV (Respiratory syncytial virus), and 10.36% positive for HCoVs (Human Coronaviruses). Authors noted that multiple samples were positive for both Influenza and HCoV or RSV. Seasonally more HCoV and RSV infections were seen during October and March, and Influenza from December to February. Regarding HCoV subtypes, HCoV-OC-43 was most prevalent during winter months while HCoV-HKU1 was most prevalent during spring and summer months. Seventy-four coronavirus infections were reported in Australia in winter months with HCoV-HKU1 being the most common [12]. Chiu et al [13] found that HCoV-NL63 infection peaked in the spring and summer months in children hospitalized with fever and acute respiratory symptoms in Hong Kong. Additionally, they found that HCoV-OC3 infection was prevalent in the fall and winter months. In 2011, Cui et al [14] reported that both HCoV-N63 and HCoV-HKU1 peaked in the summer, with HCoV-NL63 also occurring in the fall and winter months. These seasonal variations among HCoV's support the need for continued adherence to measures that prevent the spread of COVID-19.

Cities examined in this study indicated higher population densities correlate positively and significantly with increased COVID-19 cases. New York City, Newark, Chicago, Philadelphia all have high population densities and a high number of cases. The 1968 influenza epidemic in Hong Kong also placed population density front and center for disease transmission of a respiratory virus. Hong Kong can be described as an overpopulated city precipitating rapid virus dissemination from person to person via droplets like COVID19. Chang [15] posited in the case of influenza the spread was not hindered by increased temperatures in the summer months but that the high population density of Hong Kong rendered the virus contagious in both summer and winter, with infections peaking in late July with all age groups affected. Population density was also reported as a salient factor in the super-spreading transmission of MERS-CoV (Middle East Respiratory Syndrome coronavirus) and SARS. An outbreak of MERS in South Korea occurred in 2015 taking 36 lives and placed thousands in quarantine. The SARS-CoV outbreak in Guangdong Province in southeast China took 774 lives and infected 8,096 people. Interestingly, both MERS-CoV and SARS-CoV were transmissible in both winter and summer months.

The limitations of this study include an outlier in the data, namely the number of COVID-19 cases in New York City. It was prudent to include New York City in the study as it was the epicenter of COVID-19 transmission in the study period. To address the outlier, statistical analyses were repeated omitting the data points for this city. Results were similar regarding statistical significance for the population density variable in the correlation and multiple regression analysis. The adjusted R square value also decreased in the multiple regression analysis. Interestingly, the negative correlation coefficient between COVID-19 cases and average temperature remained suggesting cases of COVID-19 tend to increase with a fall in temperature, albeit this correlation was not statistically significant.

5. Conclusion

This study analyzed fifty of the most densely populated cities in the United States and found a negative correlation with the number of COVID-19 cases and temperature and dew point for the month of April 2020. While the correlation was found to be negative, indicating a rise in the number of COVID-19 cases with a fall in temperature and dew point, the correlation was not found to statistically significant. This study also found a statistically significant positive correlation between number of COVID-19 cases in cities analyzed and the population density of respective cities. Multiple regression analyses confirmed the significance of the population density variable. The results of this study will add to the knowledge surrounding this novel coronavirus. With the variability in seasonal transmission reported on other Coronaviruses the public should remain vigilant in practicing measures that prevent the spread of COVID-19, particularly in the most densely populated cities.

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