

What are the Effects of Climate Variables on COVID-19 Pandemic? A Systematic Review and Current Update

Malihe Moazeni^{1,2}, Mohammad Rahimi³, Afshin Ebrahimi^{1,4}

¹Department of Environmental Health Engineering, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran, ²Student Research Committee, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran, ³Department of Combat Desertification, Faculty of Desert Studies, Semnan University, Semnan, Iran, ⁴Environment Research Center, Research Institute for Primordial Prevention of Non-Communicable Disease, Isfahan University of Medical Sciences, Isfahan, Iran

Abstract

The climatological parameters can be different in various geographical locations. Moreover, they have possible impacts on COVID-19 incidence. Therefore, the purpose of this systematic review article was to describe the effects of climatic variables on COVID-19 pandemic in different countries. Systematic literature search was performed in Scopus, ISI Web of Science, and PubMed databases using (“Climate” OR “Climate Change” OR “Global Warming” OR “Global Climate Change” OR “Meteorological Parameters” OR “Temperature” OR “Precipitation” OR “Relative Humidity” OR “Wind Speed” OR “Sunshine” OR “Climate Extremes” OR “Weather Extremes”) AND (“COVID” OR “Coronavirus disease 2019” OR “COVID-19” OR “SARS-CoV-2” OR “Novel Coronavirus”) keywords. From 5229 articles, 424 were screened and 149 were selected for further analysis. The relationship between meteorological parameters is variable in different geographical locations. The results indicate that among the climatic indicators, the temperature is the most significant factor that influences on COVID-19 pandemic in most countries. Some studies were proved that warm and wet climates can decrease COVID-19 incidence; however, the other studies represented that warm location can be a high risk of COVID-19 incidence. It could be suggested that all climate variables such as temperature, humidity, rainfall, precipitation, solar radiation, ultraviolet index, and wind speed could cause spread of COVID-19. Thus, it is recommended that future studies will survey the role of all meteorological variables and interaction between them on COVID-19 spread in specific small areas such as cities of each country and comparison between them.

Keywords: Climate, coronavirus, COVID-19, severe acute respiratory syndrome coronavirus 2

Address for correspondence: Dr. Afshin Ebrahimi, Department of Environmental Health Engineering, School of Health, Hezar-Jerib Ave., Isfahan University of Medical Sciences, Isfahan, 81676 – 36954, Iran.

E-mail: a_ebrahimi@hlth.mui.ac.ir

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INTRODUCTION

The COVID-19 (new coronavirus disease) is confirmed in Wuhan, China, on December 30, 2019. The World Health Organization proved COVID-19 disease as a pandemic that spread to all countries in the world on March 11, 2020.^[1-3] The coronaviruses are a member of the *Coronaviridae* family. They are viruses with single-stranded RNA and infect the human's respiratory system.^[4,5] Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), an agent of COVID-19, is a kind of severe acute respiratory syndrome (SARS) coronavirus

and has genetically varied from SARS coronavirus 1 and the Middle East respiratory syndrome coronavirus.^[6]

Respiratory viruses, especially SARS-CoV-2, can be transmitted through an infected persons' microdroplets and contact with contaminated surfaces.^[7,8] Moreover, COVID-19 spread can be caused by various factors, such as immunity of the host, population density, quality of medical care, and environmental variables.^[5] The relationship between climatic variables, environmental pollution, and COVID-19 incidence is still worrying and under investigation.^[2,9]

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Based on the intergovernmental panel on climate change report, climatic change has been increased, and it can cause changes in the extreme daily temperatures to the second half of the 20th century.^[10] Meteorological factors, such as temperature, wind speed, humidity, precipitation, and solar radiation, that are related to climatic change might impact the epidemics.^[2] There is an epidemiological hypothesis about the transmission of viral infections via droplets in cold and dry environments, with lower absolute humidity and temperature. According to this hypothesis, humid and warmer climates, with higher absolute humidity and temperature, are not a suitable condition for the survival of infection viruses.^[6,11] In addition, *in vitro* experiments have indicated that the SARS-CoV-2 virus can be steady at 4°C.^[7] Therefore, it might survive and cause infectivity differently with the changing climatic parameters.^[6] Thus, the relationship between climatic variables and prevalence of COVID-19 is important.

Many studies have surveyed the effect of climatic variables on the COVID-19 pandemic. The study by Qi *et al.* reported that low humidity and temperature increased COVID-19 incidence in China.^[12] In addition, Ahmadi *et al.* stated that exposure to low amounts of humidity, solar radiation, and wind speed can cause a high COVID-19 incidence in Iran.^[13] Meteorological factors can be different in various geographical locations with different climates.^[10,14] Thus, COVID-19 incidence might be different in various regions. Therefore, the influence of climatic variables with considering geographical areas is important on COVID-19 incidence.^[7] This study as a systematic review aims to describe the effect of climatic variables on the COVID-19 pandemic based on studies of different countries.

MATERIALS AND METHODS

Literature search

A systematic manner of the present study was search in Scopus, ISI Web of Science, and PubMed databases using (“Climate” OR “Climate Change” OR “Global Warming” OR “Global Climate Change” OR “Meteorological Parameters” OR “Temperature” OR “Precipitation” OR “Relative Humidity” OR “Wind Speed” OR “Sunshine” OR “Climate Extremes” OR “Weather Extremes”) AND (“COVID” OR “Coronavirus disease 2019” OR “COVID-19” OR “SARS-CoV-2” OR “Novel Coronavirus”) keywords. The studies search was performed on April 11, 2021. The limitations of the search included: the year in the range from 2020 to 2021 years, English language, and excluded editorials, conference papers, reviews, and letters.

Selection criteria

Inclusion criteria were all relevant manuscripts that assessed the effect of climatic variables on number of COVID-19 cases, deaths, recovery, incidence, etc. Exclusion criteria involved reviews, letters, editorials, conference abstracts and animal or laboratory studies, and poor-quality studies.

Data extraction

The studies were saved in EndNote, x8 version, and duplicate articles were removed. Then, titles, abstracts, and keywords

of articles were screened in Stage 1, and relevant articles were selected. Finally, the selected papers were assessed by the reading of the full text in Stage 2. Independent reviewers performed the screening process. Then, the information was extracted from the selected papers including the first author’s family name, year of publication, location of study, climate variables (temperature, humidity, wind speed, precipitation, rainfall, etc.), outcome, and findings of papers (effective climatic indicators and effects of these on outcomes as increase or decrease). The strategy of studies selection is presented in Figure 1.

RESULTS

Results indicate that many studies were done in the United States (US), China, and India concerning the effect of climatic variables on COVID-19 in the range from 23 to 40 articles [Figure 2]. Based on Figure 2, authors in some countries including Italy, Pakistan, Bangladesh, Brazil, Spain, and United Kingdom (UK) had studied the effect of climatic variables on COVID-19 in the range from 12 to 20 papers. Furthermore, eight articles were surveyed the effect of climatic variables on COVID-19 in Iran. Thus, other countries require more attention to the issue and survey of association between meteorological parameters and COVID-19.

Table 1 presents a list of 149 articles that are used in this paper. Based on Table 1, the climatic variables’ effects on COVID-19 incidence are differently related to the climatic area. The relationship between meteorological parameters is variable in geographical location. The results indicate that among the climatic indicators, the temperature is the most significant factor that influences COVID-19 in some countries. Some studies were proved that warm and wet climates can decrease COVID-19 incidence. In contrast, other studies represented that warm location can be a high risk of COVID-19 incidence with considering the effect of more meteorological parameters.

Table 1 shows the results of countries with many studies on the association of meteorological variables and COVID-19.

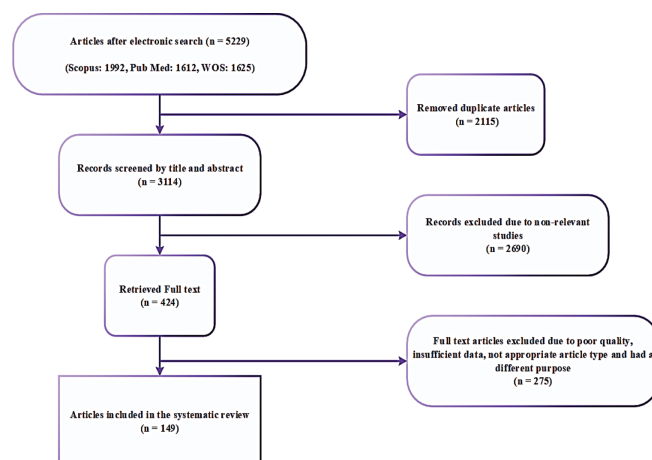


Figure 1: The diagram of the strategy of studies selection

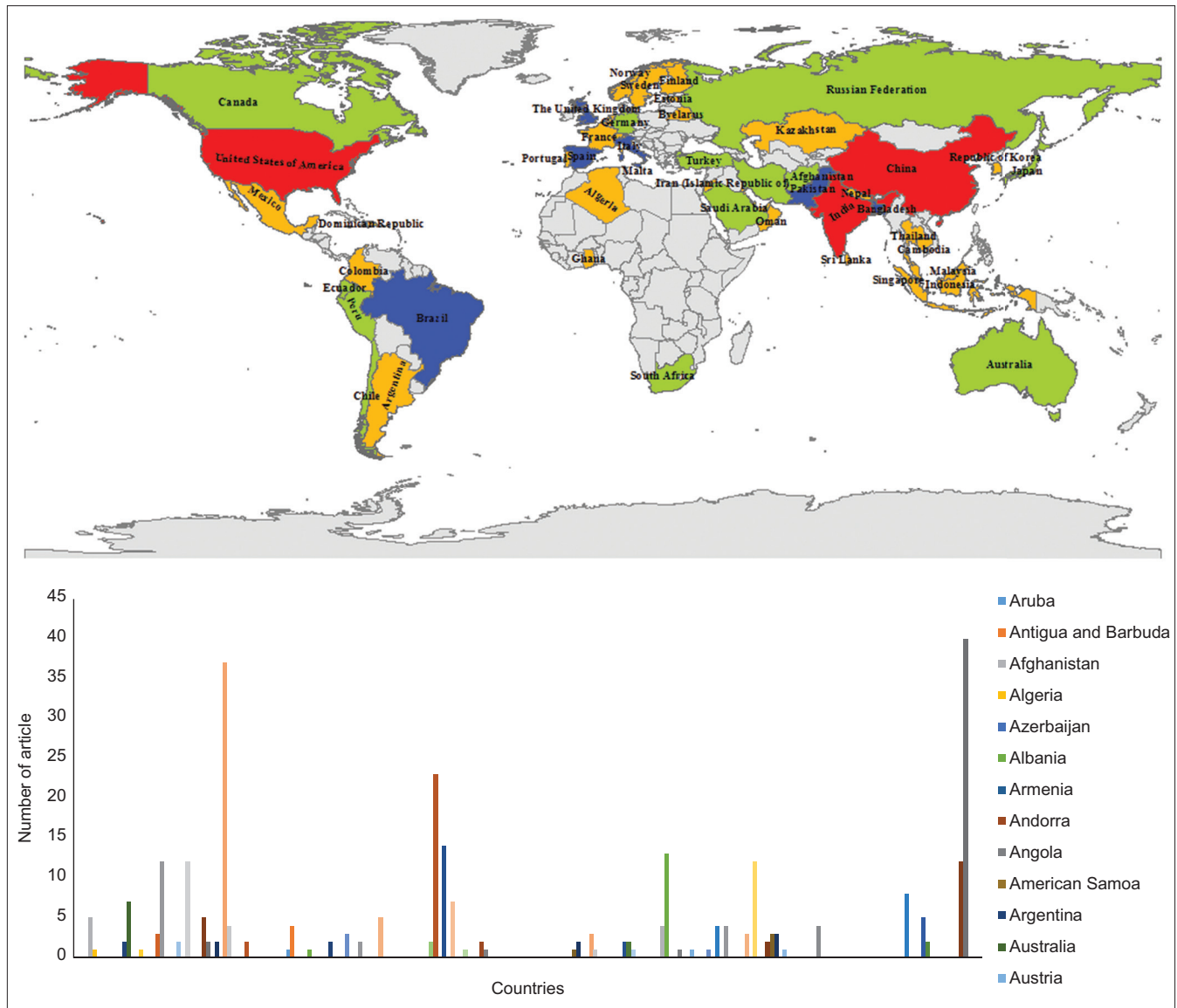


Figure 2: The number of studies included in the systematic review based on geographic area

Based on this, low temperature leads to an increase in number of COVID-19 cases and death in the US. In contrast, many studies reported that temperature and humidity have an inverse effect on number of COVID-19-positive cases and death in China. There was an association between COVID-19 incidence and temperature (minimum, maximum, average, and dew point), relative and absolute humidity, and wind speed in India. In addition, some studies proved positive correlation of temperature on COVID-19-positive cases. Similarly, high temperatures, ultraviolet (UV) index, heat index, and wind speed increased COVID-19 incidence; however, humidity and rainfall negatively correlated with COVID-19 incidence in Pakistan. On the other hand, minimum and mean temperature, relative and absolute humidity, and wind speed had a positive correlation with number of COVID-19 new cases in Bangladesh. In addition, the results indicated that there was a positive correlation between temperature and COVID-19 incidence in Singapore.

Furthermore, the study proved that the air pressure caused increase in COVID-19 cases in China and Turkey.

DISCUSSION

There was a role of climatic variables in the transmission and survival of agents of respiratory diseases. Climatic changes have interactions with the infection and mortality rate of respiratory diseases.^[29,150] Briz-Redón *et al.* explained how weather patterns may effect on survival and transmission of COVID-19 disease. They reported the importance of the effect of geographical areas on the link between climate change and COVID-19.^[7] Thus, in this paper, the effect of climatic variables is discussed based on the literature of different countries. Therefore, the studies that were focused on one country were selected.

About 40 studies were done in the US with the aim of the effect of climatic variables on COVID-19 incidence globally

Table 1: Summary of the data from the 149 articles

Author (year)	Location	Climate indicators	Outcomes	Results: effective climate variables (effect of climatic indicators on outcomes)	References
Sarkodie and Owusu (2020)	The US, Spain, Italy, France, The UK, Germany, Turkey, Russia, Iran, China, Brazil, Canada, Belgium, Netherlands, India, Switzerland, Peru, Portugal, Ecuador, and Saudi Arabia	Dew/frost point, temperature, wind speed, RH, precipitation, and surface pressure	Number of COVID-19 confirmed cases, deaths, and recovery cases	High temperature and RH (decrease) Increase in other variables (increase)	[15]
Raza <i>et al.</i> (2021)	Pakistan	Temperature, rainfall, and humidity	Number of COVID-19 cases	High temperature (increase) Increase in rainfall (decrease) Increase in humidity (stop)	[16]
Wang <i>et al.</i> (2021)	China	Ambient temperature	Number of COVID-19 cases	Higher ambient temperature (decrease)	[17]
Kolluru <i>et al.</i> (2021)	India	Temperature, wind speed, and RH	Number of COVID-19 cases and deaths	Temperature (strongly correlation)	[18]
Nottmeyer and Sera (2021)	England	Ambient daily mean temperature, absolute humidity, and RH	Number of COVID-19 test-positive cases	Wind speed and RH (increase) High temperature and increase in absolute humidity (increase)	[19]
Sangkhom <i>et al.</i> (2021)	Bangkok Metropolitan Region (Thailand)	Temperature, RH, absolute humidity, and wind speed	Number of COVID-19 daily cases	Increase in all of the meteorological parameters (increase)	[20]
Mehmood <i>et al.</i> (2021)	Pakistan	Temperature, wind speed, humidity, dew point, and pressure	Number of COVID-19 cases	All of the climatic factors (association)	[21]
Huang <i>et al.</i> (2020)	China	Temperature, absolute humidity	Number of COVID-19 confirmed cases	Temperature at 11.54°C (increase)	[22]
Lin <i>et al.</i> (2020)	China	Temperature, cloud cover, RH, precipitation, wind speed, and air pressure	COVID-19-scaled transmission rate	Absolute humidity of 3-10 g/m3 (increase) Lower temperature (increase)	[23]
Lin <i>et al.</i> (2020)	China	Air pressure, temperature, surface temperature, RH, cumulative precipitation, wind velocity, wind speed, extreme wind speed, duration of sunshine, pressure difference, temperature difference, and surface temperature difference	COVID-19 reproductive ratio	High RH, air pressure, and wind speed (increase) Increase in daily maximum temperature and air pressure (decrease)	[24]
Bolaño-Ortiz <i>et al.</i> (2020)	LAC: Mexico City (Mexico), Santo Domingo (Dominican Republic), San Juan (Puerto Rico), Bogotá (Colombia), Guayaquil (Ecuador), Manaus (Brazil), Lima (Perú), Santiago (Chile), São Paulo (Brazil) and Buenos Aires (Argentina)	Average, minimum, and maximum temperature, rainfall, average RH, and wind speed	Number of COVID-19 daily new cases and deaths.	Average and minimum temperature, and air quality (association) in LAC Humidity, wind speed, and rainfall (association) in other areas	[25]
Ibrahim <i>et al.</i> (2021)	Asia and America	High, low, and average temperature	Number of COVID-19 cases and death	The geographic climate (least impact)	[26]
Doğan <i>et al.</i> (2020)	New Jersey (US)	Temperature and humidity	Number of COVID new cases	High temperature (decrease) High humidity (increase)	[27]

Contd...

Table 1: Contd...	Author (year)	Location	Climate indicators	Outcomes	Results: effective climate variables (effect of climatic indicators on outcomes)	References
	Yuan <i>et al.</i> (2021)	Africa, Asia, Europe, North America, South America, Oceania	RH, daily average temperature, dew point, and average wind speed	Number of COVID-19 daily new cases	Increase in temperature, RH, and wind speed (decrease)	[28]
	Rosario <i>et al.</i> (2020)	State of Rio de Janeiro (Brazil)	Temperature, humidity, solar radiation, wind speed, and rainfall	COVID-19 incidence	Increase in solar radiation, temperature, and wind speed (decrease)	[29]
	Sahin (2020)	Turkey	Temperature, humidity, dew point, and wind speed	Number of COVID-19 cases	Wind speed and temperature (high impacts)	[30]
	Briz-Redón and Serrano-Aroca (2020)	Spain	Temperature (minimum, maximum, mean)	Number of COVID-19 accumulated cases	Temperature (no association)	[31]
	Prata <i>et al.</i> (2020)	Brazil	Annual average temperature	Number of COVID-19 cumulative cases	High temperatures in the range from 16.8°C to 27.4°C (decrease)	[32]
	Sobral <i>et al.</i> (2020)	Worldwide	Temperature (average minimum, and maximum temperature) and precipitation	COVID-19 infections and mortality	Increase in precipitation (increase)	[33]
	Méndez-Arriaga (2020)	Mexico	Temperature, evaporation, and precipitation	Number of COVID-19 confirmed positive cases	High average temperature (decrease)	[34]
	Runkle <i>et al.</i> (2020)	US	Daily average temperature and humidity	COVID-19 morbidity	Increase in precipitation (increase)	[35]
	Iqbal <i>et al.</i> (2020)	Worldwide	Daylight hours, average high and low temperatures	Number of COVID-19 cases	High humidity (increase)	[36]
	Pani <i>et al.</i> (2020)	Singapore	Maximum, average, and minimum temperature, RH, surface pressure, dew point, and wind speed	Number of COVID-19 pandemic cases	Increase in average temperature (decrease)	[37]
	Kumar (2020)	India	Temperature, humidity, and absolute humidity	Number of COVID-19 cases	Average daylight hours (correlation)	[38]
	Guo <i>et al.</i> (2021)	Worldwide (190 countries)	Daily temperature, RH, and wind speed	Number of COVID-19 confirmed cases and death	Increase in temperature, RH, and wind speed (increase)	[39]
	Hossain <i>et al.</i> (2021)	South Asian countries (Afghanistan, Bangladesh, India, Pakistan, and Sri Lanka)	Rainfall, RH, maximum and minimum temperature, surface pressure, and maximum wind speed	Number of COVID-19-confirmed cases	Increase in wind speed had a negative (decrease) in India and Sri Lanka	[40]
	Ficetola and Rubolini (2021)	US, China, and Canada	Temperature and humidity	COVID-19 growth rates	Temperature (both decrease and increase) in four countries in South Asia	[41]
	Yuan <i>et al.</i> (2021)	188 countries (54 African countries, 45 Asian countries, 46 European countries, 23 North American countries, 8 Oceanian countries, and 12 South American countries)	Mean temperature, wind speed, RH, and diurnal temperature range	Number of COVID-19 daily new cases	Increase in rainfall (decrease) in India and (both decrease and increase) in Pakistan	[42]

Contd...

Author (year)	Location	Climate indicators	Outcomes	Results: effective climate variables (effect of climatic indicators on outcomes)	References
Habeebullah <i>et al.</i> (2021)	Western region (Makkah and Madinah cities) of Saudi Arabia	Temperature, RH, and wind speed	Number of COVID-19 daily cases	High temperature (increase) High RH (decrease)	[43]
Loché Fernández-Ahúja and Fernández Martínez (2021)	Spain	Maximum, minimum, mean temperature, atmospheric pressure, daily rainfall, and daily sun hours	COVID-19 ratio of the PCR positives	Increase in wind speed (no correlation) All the weather variables (correlation)	[44]
Diao <i>et al.</i> (2021)	China, England, Germany, and Japan	Ambient temperature and absolute humidity	Number of COVID-19 cases	Absolute humidity and maximum temperature (high correlation)	[45]
Sharif <i>et al.</i> (2021)	New York, Madrid, Lombardy, London and Sao Paulo, Bangladesh, India, Brazil, South Africa, and Australia	Temperature, UV index per day, wind velocity per day	Number of COVID-19 daily cases	Temperature and UV index (correlation)	[46]
Fallahzadeh <i>et al.</i> (2020)	Abarqouh and Qeshm Cities of Iran	Ambient temperature	Number of COVID-19 positive cases	Increase in ambient temperature (decrease)	[47]
Al-Rousan and Al-Najjar (2020)	China	Temperature, short-wave irradiation, pressure, wind direction, rainfall, snowfall, snow depth, humidity	Number of COVID-19 suspected cases	Increase in the weather variables, especially higher temperatures and short wave (increase)	[48]
Meo <i>et al.</i> (2020)	GCC countries in the Middle East (Saudi Arabia, United Arab Emirates, Bahrain, Kuwait, Qatar, and Oman)	Temperature and humidity	Number of COVID-19 daily new cases and deaths	Increase in temperature (increase) Increase in RH (decrease) in GCC countries	[49]
Meo <i>et al.</i> (2020)	Iran, Algeria, Pakistan, India, Mexico, Kuwait, United Arab Emirates, Saudi Arabia, Oman, Ghana and Finland, Canada, Norway, Belarus, Russian Federation, Estonia, Sweden, Kazakhstan, United States of America, and Austria	Heat and humidity	COVID-19 daily basis incidence and mortality	High temperatures and low humidity (decrease) Low temperatures and high humidity (increase)	[50]
Meo <i>et al.</i> (2020)	Russia, UK, Spain, Italy, Germany, Turkey, France, Belgium, Netherlands, and Belarus	Heat and humidity	Number of COVID-19 daily new cases and new deaths	Increase in RH (decrease) Increase in temperature (increase)	[51]
Ding (2021)	US	Temperature difference	Number of COVID-19 daily-confirmed cases	Increasing each one degree of temperature difference (<11.5°C) (decrease) Increasing 1°C in the temperature difference (over 16°C) (increase)	[52]

Table 1: Contd...	Author (year)	Location	Climate indicators	Outcomes	Results: effective climate variables (effect of climatic indicators on outcomes)	References
Anam and Shar (2021)	Pretoria, Bloemfontein, Cape Town (W), New York, Chicago, Washington, Kabul, Herat, Farah, Islamabad, Karachi, Larkana, Delhi, Mumbai, Chennai, Dhaka Division (Dhaka), Chittagong Division (Chittagong), Rajshahi Division (Rajshahi), Beijing, Shanghai, Hong Kong, Tokyo, Osaka, Chiba	Temperature and humidity	Number of COVID-19 cases	High temperature (decrease) Humidity (no correlation)	[53]	
Abdelhafez <i>et al.</i> (2021)	Jordan	Average daily temperature, maximum ambient temperature, RH, wind speed, wind pressure, and average daily solar radiation	Number of COVID-19 daily confirmed cases	The maximum temperature, wind speed, air pressure, and average daily solar radiation (effective parameters)	[54]	
Adhikari and Yin (2020)	Queens (New York)	Wind speed, temperature, RH, absolute humidity, cloud percentages, and precipitation levels	Number of COVID-19-confirmed cases	Increase in all of the climate variables (increase)	[55]	
Adnan <i>et al.</i> (2021)	Pakistan	Heat index and UV index	Number of COVID-19 daily cases	Heat and UV indexes (decrease)	[56]	
Ahmadi Hedayati (2020)	Iran	Average temperature, average precipitation, humidity, wind speed, and average solar radiation	Number of COVID-19 cases	Low wind speed, humidity, and solar radiation (increase)	[57]	
Ahmed and Ghanem (2020)	Worldwide	Temperature, humidity, precipitation, and wind	Number of COVID-19 deaths	Temperature in range 5°C and 20°C and humidity range between humid and dry-sub humid (increase)	[58]	
Aidoo <i>et al.</i> (2021)	Ghana	Averages of temperature, RH, wind speed, and atmospheric pressure	Number of COVID-19 daily confirmed new cases	Wind speed and atmospheric pressure (increase)	[59]	
Ali <i>et al.</i> (2021)	Pakistan	Wind speed	Number of COVID-19 cases	High temperature and RH (decrease)	[60]	
Aslam <i>et al.</i> (2020)	Pakistan	Wind speed, precipitation level, normal, mean, maximum, and minimum temperature	Number of COVID-19 cases	Increase in wind speed (increase)	[61]	
Auler <i>et al.</i> (2020)	Brazil	High temperatures, intermediate RH, and rainfall	Number of COVID-19 confirmed cases	All of the climate variables (association)	[62]	
Azuma <i>et al.</i> (2020)	Japan	Mean, minimum, and maximum ambient air temperature, precipitation, sunshine hours, wind speed, vapor pressure, RH, and minimum RH	Number of COVID-19 Cases	Higher mean temperatures and average RH (increase) Increase of daily temperature or sunshine hours (increase) Precipitation, wind speed, and humidity (no correlation)	[63]	

Author (year)	Location	Climate indicators	Outcomes	Results: effective climate variables (effect of climatic indicators on outcomes)	References
Babu <i>et al.</i> (2020)	India	Temperature (maximum, minimum, average, and dew point), wind speed, diurnal temperature range, rainfall, and RH	Number of COVID-19 daily-confirmed cases	Increase in temperature (maximum, minimum, average, and dew point) and wind speed (increase)	[64]
Bashir <i>et al.</i> (2020)	New York (USA)	Average, minimum, and maximum temperatures, rainfall, average humidity, and wind speed	Number of COVID-19 cases	Diurnal temperature range, rainfall, and RH (no correlations)	[65]
Basray <i>et al.</i> (2021)	Pakistan	Temperature ranges (maximum, minimum, and average), humidity, and rainfall	Number of COVID-19 cases and mortalities	Average and minimum temperature (association)	[66]
Benedetti <i>et al.</i> (2020)	The UK, Belgium, Washington, Lombardy, Massachusetts, Michigan, Illinois, Connecticut, New Jersey, New York, Pennsylvania, Maryland, Washington, Sicily, Malta, New Mexico, California, Georgia, Arizona, South Carolina, California, Mississippi, Texas, Louisiana, and Florida	Average monthly high temperatures	COVID-19 death rates	Increase in temperature ranges (maximum, minimum, and average) (increase)	[67]
Bilal <i>et al.</i> (2021)	USA	Temperature, humidity, and rainfall	Number of COVID-19 infections and deaths	High humidity and rainfall (decrease)	[68]
Bolaño-Ortiz <i>et al.</i> (2020)	Argentina	Temperature, rainfall, average RH, and wind speed	Number of COVID-19 new cases and deaths	Increase in average monthly high temperatures (no correlation) in March	[69]
Cacho <i>et al.</i> (2020)	Spanish	UV radiation, temperature, and humidity	Number of COVID-19 cases	Increase in average monthly high temperatures (decrease) in April	[70]
Cai <i>et al.</i> (2020)	China	Air temperature, and RH	Number of COVID-19 cases	Among the parameters the temperature (correlation)	[71]
Ceylan (2021)	Italy	Average temperature, RH, wind speed, and air pressure	Number of COVID-19 cases confirmed	Increase in air temperature (decrease) RH (no correlation)	[72]
Chen <i>et al.</i> (2020)	Worldwide	Average temperature, RH, wind speed, and air visibility	Number of COVID-19 daily new-confirmed case counts	Increase in average temperature (increase) Increase in average RH (decrease)	[73]
Chien and Chen (2020)	The US	Temperature, RH, and precipitation	Number of COVID-19 daily new-confirmed cases	Wind speed and air pressure (no correlation) The weather conditions of average temperature at 5°C-15°C, RH at 70% to 80%, wind speed at 1.5-4.5 m/s, and air visibility <10 statute miles (best condition)	[74]

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Table 1: Contd...		Author (year)	Location	Climate indicators	Outcomes	Results: effective climate variables (effect of climatic indicators on outcomes)	References
		Chowdhury <i>et al.</i> (2020)	China and Australia	Temperature, RH, and UVI	Number of COVID-19 cases	UV index, temperature, and RH (significant impact)	[75]
		Daneshvar <i>et al.</i> (2021)	United Arab Emirates and Switzerland	Solar radiation and temperature	COVID-19 outbreak	High temperature in arid regions (increase)	[76]
		Fan <i>et al.</i> (2021)	China	Temperature and RH	Number of COVID-19 cases	Increase in temperature and RH (decrease)	[77]
		Fareed <i>et al.</i> (2020)	China	Average humidity	COVID-19 mortality	High humidity (decrease)	[78]
		Fazzini <i>et al.</i> (2020)	Northern Italy	Temperature, RH, accumulated precipitation, solar radiation, evaporation, and wind direction and intensity	Number of daily positive COVID-19 cases	Increase in temperature (increase)	[79]
		Fu <i>et al.</i> (2021)	Germany, Italy, Spain, and UK	Temperature, absolute humidity, and diurnal temperature range	COVID-19 seven-day case doubling time	The total cumulative effect of temperature and absolute humidity (increase)	[80]
		Ghosh <i>et al.</i> (2020)	London (UK)	Daily averages of maximum and minimum temperatures, humidity, and wind speed.	Number of COVID-19 cases	Climatic parameters (no effect)	[81]
		Goswami <i>et al.</i> (2020)	India	Average temperature and average RH	Number of COVID-19 daily-confirmed cases	Average temperature and average RH (correlation)	[82]
		Guo <i>et al.</i> (2020)	China	Temperature and humidity	Number of COVID-19-confirmed cases	Increase in temperature and humidity (decrease)	[83]
		Gupta <i>et al.</i> (2020)	India	Daily maximum, minimum, mean, and dew point temperature, wind speed, RH, and diurnal range in temperature and RH	Number of COVID-19-confirmed cases	Weather parameters (no correlation)	[84]
		Hao <i>et al.</i> (2021)	USA	Temperature	Number of COVID-19 cases	Increase in temperature (decrease)	[85]
		Haque and Rahman (2020)	Bangladesh	Average temperature and humidity	Number of COVID-19 confirmed cases	High temperature and humidity (decrease)	[86]
		Hassan <i>et al.</i> (2020)	Italy, Switzerland, Iran, and Spain	Temperature	COVID-19 case fatality rate	Increase in temperature (decrease) in Italy and Switzerland	[87]
		Hassan <i>et al.</i> (2021)	Bangladesh	Wind pressure, rainfall, and wind speed	COVID-19 infection rate	Temperature (no correlation) in Italy, Iran, and Spain	[88]
		Heibati <i>et al.</i> (2020)	Finland	Temperature and RH	Number of COVID-19 daily counts	Wind pressure, rainfall, and wind speed (association)	[89]
		Hoang and Tran (2021)	Korea	Temperature	Number of COVID-19 daily confirmed cases	Daily temperature (no correlation)	[90]
		Hridoy <i>et al.</i> (2021)	Bangladesh	Mean temperature, RH, precipitation, and wind speed	Number of COVID-19 case	Daily temperature (nonlinear correlation) When the temperature was below 8°C, each 1°C rise in temperature (9% increase)	[91]
		Hu <i>et al.</i> (2020)	China	Temperature	Number of COVID-19 daily newly-confirmed cases	Increase in mean temperature, RH, and wind speed (increase)	[92]
						Daily precipitation (decrease)	
						Increase in the maximum temperature (increase)	

Contd...

Table 1: Contd...		Location	Climate indicators	Outcomes	Results: effective climate variables (effect of climatic indicators on outcomes)	References
Huang <i>et al.</i> (2020)	China	Average temperature, wind speed, RH, and precipitation	COVID-19 mortality rate	Wind speed, RH, and precipitation (no correlation)	[93]	
Ince <i>et al.</i> (2020)	Turkey	Air temperature, RH, and air pressure	Number of COVID-19 case numbers	Higher average temperatures and precipitation (increase)	[94]	
Iqbal <i>et al.</i> (2020)	Wuhan (China)	Average temperature	Number of COVID-19 daily new-confirmed cases	Increase in air temperature, air pressure, and RH (increase)	[95]	
Islam <i>et al.</i> (2021)	Worldwide	Temperature, humidity (relative and absolute), wind speed, UV index, cloud cover, precipitation, sea-level air pressure, and daytime length	Number of COVID-19 cases	High temperature (increase)	[96]	
Islam <i>et al.</i> (2020)	Bangladesh	Minimum and mean temperature, wind speed, RH, and absolute humidity	Number of COVID-19-confirmed cases	The 7-day-lagged temperature, RH, UV index, and wind speed (no correlation)	[97]	
Islam <i>et al.</i> (2021)	Bangladesh	Mean temperature, mean RH, and rainfall	Number of COVID-19-confirmed cases	Increase in 14-day-lagged temperature (increase)	[98]	
Jahangiri <i>et al.</i> (2020)	Iran	Annual average temperature	Number of COVID-19 cumulative cases	Increase in 14-day-lagged wind speed (decrease)	[99]	
Jain <i>et al.</i> (2021)	Afghanistan, Bangladesh, India, Nepal, Pakistan, and Sri Lanka	Temperature, air pressure, and humidity	Number of COVID-19-confirmed cases	Increase in the minimum and mean temperature, wind speed, RH, and absolute humidity (increase)	[100]	
Thanganiyal <i>et al.</i> (2020)	Worldwide (138 countries)	Duration of sunshine, average minimum temperature, and average maximum temperature	Number of COVID-19 cumulative-confirmed cases, deceased, and recovered cases	Increase in the subtropical climate (mean temperature about 26.6°C, mean RH 64%, and annually rainfall approximately 3 mm) (increase)	[101]	
Jiang <i>et al.</i> (2020)	China	Temperature, relative humidity, and wind	COVID-19 daily incidence	*High temperature (no correlation)	[102]	
Jiang and Xu (2020)	Wuhan, China	Temperature	Number of COVID-19 daily death number	Meteorological parameters (correlation)	[103]	
Arifur Rahman <i>et al.</i> (2020)	China	Temperature and relative humidity	Number of COVID-19-confirmed cases	High temperature and high humidity (increase)	[104]	
Jüni <i>et al.</i> (2020)	Worldwide	Temperature and humidity	COVID-19 epidemic growth	Higher average maximum temperature and longer sunshine duration (association)	[105]	
Kulkarni <i>et al.</i> (2021)	India	Air temperature, RH, air pressure, wind speed, and rainfall	COVID-19 daily case counts	Increase in average sunshine duration (decrease)	[106]	
				High humidity (increase)		
				Temperature (no correlation)		
				Increase in diurnal temperature (increase)		
				High temperature (decrease)		
				Humidity (no correlation)		
				Temperature (no associations)		
				High RH (decrease)		
				Increase in mean daily air temperature (decrease)		
				Wind speed (increase)		

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Table 1: Contd...		Location	Climate indicators	Outcomes	Results: effective climate variables (effect of climatic indicators on outcomes)	References
Kumar and Kumar (2020)	Mumbai (India)	Minimum temperature, maximum dew point, minimum, maximum, and mean of RH, and surface pressure	Number of COVID-19 case	Temperature, dew point, RH, and surface pressure (important correlation)	[107]	
Ladha <i>et al.</i> (2020)	Delhi (India)	Temperature and RH	Number of COVID-19 cases	Maximum and average temperatures, and average RH (no correlation)	[108]	
Leichtweis <i>et al.</i> (2021)	Worldwide (52 countries)	Temperature, RH, and solar radiation index	Number of COVID-19-confirmed cases	The temperature (linear relationship) The RH (no correlation)	[109]	
Li <i>et al.</i> (2020)	Wuhan and XiaoGan (China)	Daily, highest, and lowest temperatures, temperature difference, and sunshine duration	COVID-19 incidence	The solar radiation (nonlinear relationship)	[110]	
Lin <i>et al.</i> (2020)	Mainland China, Hong Kong, and Singapore	Temperature, RH	Number of COVID-19-confirmed cases	Among meteorological parameters, the temperature (correlation)	[111]	
Lin <i>et al.</i> (2020)	Worldwide	Temperature and RH	COVID-19 number of confirmed cases	High temperature (increase) High RH when the temperature is low (increase) Increase in temperature and RH (increase)	[112]	
Liu <i>et al.</i> (2020)	China	Ambient temperature, diurnal temperature range, and absolute humidity	COVID-19 case counts	The weather with low temperature, mild diurnal temperature range, and low humidity (favorable condition)	[113]	
Lorenzo <i>et al.</i> (2021)	Singapore	Rainfall, humidity, and temperature	Number of COVID-19 daily confirmed case	High temperature (increase) Increase in rainfall and humidity (increase)	[114]	
Mia <i>et al.</i> (2020)	Wuhan (China)	Temperature, humidity, and diurnal temperature	Number of COVID-19 daily death	Increase in diurnal temperature range (increase)	[115]	
Sarkodie and Owusu (2021)	Africa, Asia, Europe, North America, South America, and Oceania	Wind speed, temperature, humidity	Number of COVID-19-confirmed case	Increase in RH (decrease) Increase in wind speed (increase) High RH and ambient temperature (decrease)	[116]	
Zhang <i>et al.</i> (2021)	Worldwide (124 countries)	Temperature and RH	Number of COVID-19 cases	High temperature and RH (increase)	[117]	
Menebo <i>et al.</i> (2020)	Oslo (Norway)	Minimum temperature, maximum temperature, precipitation average, normal temperature, precipitation level, and wind speed	Number of COVID-19 daily confirmed case	Increase in maximum and normal temperature (increase)	[118]	
Meraj <i>et al.</i> (2021)	India	Temperature	Number of COVID-19 cases	High temperature (increase)	[119]	
Meyer <i>et al.</i> (2020)	Worldwide	Average temperature and RH	Number of COVID-19 confirmed local cases	Increase in average temperature (decrease) RH (no correlation)	[120]	
Mofijur <i>et al.</i> (2020)	Dhaka (Bangladesh)	Humidity, minimum temperature, precipitation, maximum temperature, mean temperature, and wind speed	Number of COVID-19 new cases	Only, minimum and the average temperatures (correlation)	[121]	
Mozumder <i>et al.</i> (2021)	Worldwide	Temperature and RH	Number of COVID-19 daily new cases	High temperature (decrease) RH (no correlation)	[122]	

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Table 1: Contd...					
Author (year)	Location	Climate indicators	Outcomes	Results: effective climate variables (effect of climatic indicators on outcomes)	References
Paez <i>et al.</i> (2020)	Spain	Temperature, humidity, and sunshine	Number of COVID-19 cases	Higher temperatures, sunshine, and higher levels of humidity (decrease)	[123]
Pahuja <i>et al.</i> (2021)	Delhi (India)	Ambient temperature, humidity, and wind speed	Number of weekly corona cases	High temperature (decrease)	[124]
Paliatol <i>et al.</i> (2020)	Worldwide (416 regions)	Temperature	Number of COVID-19 cases	Humidity and wind speed (no correlation)	[125]
Pan <i>et al.</i> (2021)	Australia, Canada, US, China, Germany, Italy, Japan, and UK	Temperature, RH, wind speed, and UV radiation	COVID-19 daily numbers of cases	Temperature (decrease up to 8.98%)	[126]
He <i>et al.</i> (2021)	China	Average temperature and RH	Number of COVID-19 new cases	radiation (no correlation)	[127]
Pequeno <i>et al.</i> (2020)	Brazil	Temperature, solar radiation, air humidity, and precipitation	COVID-19 cumulative number of confirmed cases	Increase in average temperature and RH (decrease)	[128]
Pirouz <i>et al.</i> (2020)	Italy	Daily average temperature, RH, and wind speed	Number of COVID-19-confirmed cases	As a 1°C increase in temperature (decrease of 8%)	[129]
Kaplin <i>et al.</i> (2021)	Northern Hemisphere countries	Minimum and median temperature	Number of COVID-19-confirmed cases and morbidity	Climate parameters (correlation)	[130]
Pramanik <i>et al.</i> (2020)	Russia	Average temperature and average RH	Number of COVID-19 cases	The correlation between temperature and confirmed cases was 47% greater than death cases	[131]
Qi <i>et al.</i> (2020)	Mainland China	Daily average temperature and RH	COVID-19 daily cases count	Temperature in the humid continental region and sub-arctic region (highest effect)	[12]
Rehman and Rehman (2020)	Pakistan	Wind, temperature, humidity, and sun	COVID-19 daily incidence rate, mortality rate, and recoveries	Increase in temperature and humidity (decrease)	[132]
Rendana (2020)	Jakarta (Indonesia)	Wind speed, temperature, sunshine hours, rainfall, and humidity	Number of COVID-19 cases	Temperature, humidity, wind, and daily sun (no correlation)	[133]
Rouen <i>et al.</i> (2020)	Italy, UK, France, Sweden, Iran, USA, South Korea, and Australia	Atmospheric temperature	COVID-19 daily new cases growth rate	Increase in wind speed, temperatures, and sunshine hours (decrease)	[134]
Sahoo <i>et al.</i> (2021)	India	Rainfall and temperature	Number of COVID-19 cases	Humidity and rainfall (no correlation)	[135]
Sahoo (2021)	India	Daily diurnal temperature range, mean temperature, RH, absolute humidity, air pressure, rainfall, wind speed, and wind direction	Number of COVID-19 daily reported infected cases	High temperature (decrease)	[136]
Sehra <i>et al.</i> (2020)	US	Maximum daily temperature, precipitation, UV light	Number of COVID-19 daily-reported cases	Increase in temperature and dew point (increase)	[137]
Sfica <i>et al.</i> (2020)	Worldwide	UV radiation, air temperature, and RH	Number of COVID-19 cases	High temperature (increase) High RH (decrease)	[138]

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Author (year)	Location	Climate indicators	Outcomes	Results: effective climate variables (effect of climatic indicators on outcomes)	References
Shahzad <i>et al.</i> (2020)	China	Temperature	Number of COVID-19 daily cases	High temperature in Hubei, Human, and Anhui (decrease)	[139]
Shahzad <i>et al.</i> (2020)	Spain	Daily average temperature	Number of COVID-19 daily new cases	High temperature in Zhejiang and Shandong (increase)	[140]
Sharma <i>et al.</i> (2020)	India	The minimum temperature at 2 m, the maximum temperature at 2 m, the temperature at 2 m, and RH	Number of COVID-19 cases	The minimum, and maximum temperatures at 2 m, and humidity at 2 m (correlation)	[141]
Sharma <i>et al.</i> (2021)	USA, India, Brazil, Russia, Spain, UK, Italy, Peru, Iran, and Chile	Temperature, humidity, air pressure, and wind speed	Number of COVID-19-confirmed cases and deaths	Air pressure, humidity, and temperature (strong association)	[142]
Shi <i>et al.</i> (2020)	China	Daily mean temperatures	Number of COVID-19 daily-confirmed cases	Increase in temperature and air pressure (decrease)	[143]
Singh <i>et al.</i> (2020)	Delhi (India)	Maximum, minimum and mean temperature, RH, bright sunshine hours, wind speed, evaporation, and rainfall	COVID-19 daily data	Temperature (with a peak at 10°C) (association)	[144]
Singh <i>et al.</i> (2021)	Worldwide (83 countries)	Temperature	Number of COVID-19-positive cases	Temperature at values below and above 10°C (decrease)	[145]
Spina <i>et al.</i> (2020)	Italia	Temperature and humidity	Number of COVID-19 cases	Increase in maximum, minimum, and mean temperatures, RH, evaporation, and wind speed (increase)	[146]
Suhaimi <i>et al.</i> (2020)	Malaysia	Humidity and ambient temperature	Number of COVID-19 daily new cases	Bright sunshine hours and rainfall (no correlation)	[147]
To <i>et al.</i> (2021)	Canada	Ambient temperature	COVID-19 incidence	High temperature (decrease)	[148]
Tobias <i>et al.</i> (2021)	Catalonia (Spain)	Mean temperature, absolute humidity, and solar radiation	COVID-19 cumulative incidence	High RH (increase)	[149]
Tosepu <i>et al.</i> (2020)	Jakarta (Indonesia)	Minimum temperature, maximum temperature, temperature average, humidity, and amount of rainfall	Number of COVID-19 cases	High ambient temperature (decrease)	[150]
Tzampoglou and Loukidis (2020)	Worldwide	Air temperature, RH, cumulative precipitation, and cloud cover	Number of COVID-19 case and death rates	Ambient temperature (no association)	[151]
Ujite <i>et al.</i> (2020)	Japan	Average temperature	Cumulative number of COVID-19 case	Meteorological parameters (association)	[152]
Ward <i>et al.</i> (2020)	New South Wales (Australia)	RH, temperature, rainfall, and wind speed	Number of COVID-19 cases	Warm and wet climates (decrease)	[153]
				Among the meteorological parameters, the only average temperature (correlation)	
				Among the climatic parameters, the average temperature (correlation)	
				Low temperature (increase)	
				High RH (decrease)	
				Temperature, rainfall, or wind speed (no correlation)	

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Table 1: Contd...					
Author (year)	Location	Climate indicators	Outcomes	Results: effective climate variables (effect of climatic indicators on outcomes)	References
Ward <i>et al.</i> (2020)	New South Wales (Australia)	Daily rainfall, 9 am, and 3 pm temperature, and 9 am and 3 pm RH	Number of COVID-19 cases	RH (association)	[154]
Wei <i>et al.</i> (2020)	China	Daily temperature, precipitation, RH, sunshine duration, and wind speed	Number of COVID-19-confirmed cases	Low temperature and moderate precipitation (correlation) Warm areas can also be at higher risk of the disease with the increasing wind speed	[155]
Wu <i>et al.</i> (2020)	Worldwide (166 countries)	Temperature and RH	Number of COVID-19 daily new cases and new deaths	High temperature and RH (decrease)	[156]
Xie <i>et al.</i> (2020)	Mainland China	Average temperature	Number of COVID-19 cumulative-confirmed cases	The average temperature in winter at 11°C-16°C (increase)	[157]
Yang <i>et al.</i> (2021)	Wuhan, Beijing, Urumqi, and Dalian (China)	Daily maximum temperature, minimum temperature, average temperature, temperature range, RH, average wind speed, and total precipitation	Number of COVID-19 infected case	Temperature and RH (main effective factors) In summer, the increase in RH and the decrease in maximum temperature in arid inland cities (increase) The decrease in RH in coastal cities (increase) In humid cities, the reduction of RH and the lowest temperature in the winter (increase)	[158]
Yu (2020)	US metropolitan areas	Temperature	Number of COVID-19 cases and deaths	Warm temperature (decrease)	[159]
Xie and Zhu (2020)	China	Ambient temperature	Number of COVID-19-infected case	High mean temperature (increase)	[160]
Zhu <i>et al.</i> (2020)	Ecuador, Rio de Janeiro, Brazil, Peru, Santiago, and Chile (South America)	Average temperature, maximum temperature, minimum temperature, average wind speed, visibility, and absolute humidity	Number of COVID-19 daily new cases	High absolute humidity (decrease)	[161]
Zhu <i>et al.</i> (2021)	China	Ambient temperature	Number of COVID-19 daily new death	High temperature (decrease)	[162]

LAC: Latin America and the Caribbean, GCC: Gulf Cooperation Council, RH: Relative humidity, UV: Ultraviolet, UVI: UV index, US: United States, UK: United Kingdom, COVID-19: Coronavirus disease 2019

and individually [Figure 2]. Most studies reported the inverse effects of temperature with death^[35,67,159] and cases related to COVID-19^[85,134,142,159] in the US. In addition, the studies by Ficaretola and Rubolini and Pan *et al.* indicated that no correlation between climatic variables such as temperature, wind speed, and relative humidity with COVID-19 daily cases in the US.^[41,126] However, Bashir *et al.* and Bilal *et al.* proved the interaction of temperature, humidity, and precipitation with COVID-19 growth and death rate in the US.^[65,68]

Results of studies performed in China showed inverse effect of temperature and humidity on COVID-19 cases and death.^[12,17,23,24,71,77,78,83,104,113,127,139,162] However, some studies indicated a positive correlation between temperature with number of COVID-19 cases and death. Moreover, the positive relationship between humidity and COVID-19 cases and death was proved in China.^[24,102,111] Lin *et al.*'s study indicated that the high air pressure, wind speed, and humidity can cause an increase in number of COVID-19 cases.^[23] However, Huang *et al.* showed no correlation between wind speed, humidity, and precipitation with the recovery rate of COVID-19 cases in China.^[93] Chowdhury *et al.* reported the influence of temperature, UV index, and relative humidity on the number of COVID-19 cases.^[75] In addition, the study by Wei *et al.* proved the interaction between meteorological variables and number of COVID-19 daily cases in China. According to this study, low temperature, high wind speed, and average precipitation can cause a high risk of COVID-19 incidence in warm areas.^[155]

Several studies showed that temperature (minimum, maximum, average, and dew point), wind speed, and relative and absolute humidity had positive correlations with COVID-19 cases and death in India.^[18,38,64,119,135,141] Goswami *et al.* explained that there was an interaction between average temperature and relative humidity with the number of COVID-19–positive cases in India.^[82] While Gupta *et al.* proved no influence of climate variables on COVID-19 incidence,^[84] Kulkarni *et al.* and Pahuja *et al.* reported inverse effect of temperature and wind speed on COVID-19 cases.^[106,124] Moreover, Singh *et al.* stated inverse correlation between minimum, average, and maximum temperature, evaporation, relative humidity, and wind speed with COVID-19 incidence, but there was no correlation between sunshine and rainfall with COVID-19 disease in India.^[144] Sahoo reported that the number of COVID-19 cases had a positive correlation with temperature and a negative association by humidity in India, as well.^[136]

High temperature increased COVID-19–positive cases in Italy.^[72,79] However, Ceylan's study specified an opposite correlation between relative humidity and COVID-19–positive cases.^[72] They reported an opposite effect of temperature with COVID-19 cases by Hassan *et al.*^[87] On the other hand, Pirouz *et al.* described a link between weather factors and positive cases of COVID-19 in Italy.^[129]

Many studies verified the positive influence of temperature, UV index, heat index, and wind speed and the negative effect of precipitation and humidity on cases and death related to

COVID-19 in Pakistan.^[16,40,56,60,66] The study by Aslam *et al.* indicated the effect of climatic variables on COVID-19.^[61] However, the study by Rehman and Rehman showed no relationship between temperature, humidity, sunshine, and wind speed with COVID-19 incidence, recovery, and death in Pakistan.^[132]

Studies were done in Bangladesh represented a positive association between minimum and mean temperature, wind speed, and relative and absolute humidity with the number of COVID-19 cases.^[91,97] In addition, the study by Haque and Rahman indicated that high temperature and humidity parameters decreased COVID-19 cases in Bangladesh.^[86] Hassan *et al.* evidenced that rainfall, wind speed, and wind pressure can influence COVID-19 cases.^[88] Furthermore, Islam *et al.* reported that 26.6°C mean temperature, 64% relative humidity, and 3 mm rainfall increased COVID-19 cases in Bangladesh.^[98]

Auler *et al.* reported that high mean temperature and relative humidity can increase COVID-19 cases.^[62] However, the study by Pequeno *et al.* showed a reverse effect of temperature on COVID-19 cumulative cases in Brazil.^[128]

Many studies had different results in Spain. Briz-Redón *et al.* demonstrated that there was no correlation between minimum, maximum, and mean temperature on the growth of COVID-19 cumulative cases.^[31] However, some studies indicated a link between climatic factors, especially temperature and absolute humidity by COVID-19 cases.^[44,149] Shahzad *et al.* detailed the inverse effect of temperature on COVID-19 cases,^[140] while Paez *et al.* stated that COVID-19 cases increased in high sunshine and temperature cause increase COVID-19 cases.^[123] Tobías *et al.* showed that warm and wet conditions can decrease COVID-19 incidence in Spain.^[149]

Fallahzadeh *et al.* reported an inverse correlation between temperature and COVID-19 cases in Iran.^[47] Ahmadi *et al.* stated that low humidity, wind speed, and UV index amplified COVID-19 incidence in Iran, as well.^[13] It was accepted that COVID-19 cases in warm weather were not lower than moderate and cold weather. As a result, the temperature did not influence COVID-19 incidence in Iran.^[99]

Most studies had various results in Australia. Ward *et al.* presented no correlation between temperature, rainfall, and wind speed with COVID-19 cases. However, there was a negative correlation with relative humidity.^[153] On the other hand, Ward *et al.* showed a positive correlation between COVID-19 cases and relative humidity.^[154]

The study by Şahin indicated a high effect of temperature and wind speed on COVID-19 cases.^[30] In contrast, Ince *et al.* exhibited a converse effect of high temperature on COVID-19 positive cases and relative humidity and a positive association of air pressure with COVID-19 positive cases in Turkey.^[94]

Some studies specified that high temperature could rise COVID-19 cases in Singapore.^[37,114] There was a positive connection between relative and absolute humidity and water

vapor with COVID-19 cases. However, there was a negative correlation between wind speed and COVID-19 cases.^[37] Likewise, there was an inverse effect of relative humidity and rainfall on daily cases of COVID-19 in Singapore.^[114]

Ghosh *et al.*'s study implemented in the UK did not show a correlation between the minimum and maximum temperature, wind speed, and humidity with COVID-19.^[81] Ujii *et al.* stated that low temperature intensified COVID-19 cases in Japan.^[152] Moreover, Méndez-Arriaga verified the opposite effect of temperature on COVID-19-positive cases in Mexico.^[34] There was no correlation between temperature and COVID-19 in Canada.^[148] However, Bolaño-Ortiz *et al.* showed that all the meteorological factors including temperature, rainfall, wind speed, and relative humidity had influence on COVID-19 spread in Argentina.^[69] There was no association between temperature and COVID-19 incidence, and relative humidity had an inverse effect on COVID-19 incidence in Finland.^[89] Aidoo *et al.* stated that COVID-19 daily cases increased with increasing in wind speed and atmospheric pressure and decreasing in relative humidity in Ghana.^[59] There was a negative association between temperature, wind speed, and sunshine, as well. However, there was no correlation seen between rainfall and humidity with COVID-19 cases in Indonesia.^[133] Menebo reported that high maximum and minimum temperature increased but high precipitation decreased COVID-19 incidence in Norway.^[118] In addition, Hoang and Tran verified a positive relationship between temperature and COVID-19 cases in Korea.^[90] Abdelhafez *et al.* reported the effect of maximum temperature, wind speed, wind pressure, and average daily solar on COVID-19 daily cases increasing in Jordan.^[54] There was a positive correlation between relative humidity but a negative correlation between temperature with COVID-19 daily cases in Malaysia.^[147] Furthermore, daily cases of COVID-19 increased due to high temperature, relative and absolute humidity, and wind speed in Thailand.^[20]

According to Briz-Redón *et al.*'s survey, the results of single-country studies about the effect of climate variables on the disease are more accurate.^[7] Based on the review of studies, the significant climatic factors that were in association with COVID-19 cases and death consist of temperature, humidity, wind speed, rainfall, precipitation, UV/heat index, solar radiation, and air pressure.

CONCLUSIONS

According to the results of this review, all climate variables such as temperature, humidity, rainfall, precipitation, solar radiation, UV index, and wind speed can play a possible role in the transmission of COVID-19; however, most of the studies had contradictory results. Thus, we recommend that future studies are surveying the role of all meteorological variables and interaction between them on COVID-19 spread in specific small areas such as cities of each country and comparison between them.

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Conflicts of interest

There are no conflicts of interest.

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