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REVIEW ARTICLE

COVID-19 Influencing Factors on Transmission and Incidence Rates-Validation Analysis

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INTRODUCTION

Coronavirus disease has caused devasting effect so far which has put every nation in difficult situations in multiple ways. The pandemic has affected every business globally right from small, medium to large establishments collapsing the world economy. The major impact COVID has caused is restricting movement and travel that has heavily affected the international business and tourism showing predicted revenue loss of -810.7 bn USD in 2020 [1]. While the global COVID cases are increasing at an exceptional rate, normal life has got disrupted with many businesses have totally shut down in many cities and most countries are likely to experience economic recession [2,3].

The pandemic is caused by coronavirus group of RNA virus which is a novel strain (nCoV-2) of SARS-CoV-2 causing severe respiratory diseases in humans [4,5]. There were many epidemics and pandemics reported from 1918 to 2009 causing millions of deaths globally which most of them belong to virus origin (Figures 1 & 2). In December 2019 nCoV-2 was identified causing a global crisis spreading the disease outbreak globally, hence WHO has announced the COVID-19 as pandemic in March 2020.

COVID-19 PANDEMIC

Coronavirus diseases has reached to pandemic levels in a short period of time after it was first reported in December 2019 as an epidemic initially, though every epidemic does not necessarily reach to pandemic situation. The conditions that lead to pandemic levels depends on the disease transmission features, environmental factors favoring the growth, multiplication and spread of disease agent, therefore under such dependable factors it is not possible to predict any pandemics that might occur in the future. In addition, rapid industrialization, globalization and migration of people are also other factors possibly escalating the risk of disease incidence among vulnerable population as observed in Ebola outbreak [4].

Although number of epidemic outbreaks in the past have reached pandemic levels the time period taken from epidemic outbreak to reach pandemic conditions are not analysed extensively to know the pandemic occurrence scenarios. In addition, examining the rapid increase of disease intensity across the world, it is also very important to understand the factors that are influencing the SARS-CoV-2 in sustaining and facilitating the transmission in the population. Further the phenomena of the disease transmission need investigation from both urban

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and rural perspective to comprehend the phenomena of transmission that can provide some clues to the pandemic spread [6]. Have claimed that society and economic conditions of people living in a particular environment shows effect on the disease transmission though [6-9] have emphasized on various environmental and urban factors specifically population density influencing the transmission and increase of incidence rates in many cities around the world. However, despite the findings of high incidence rates the coronavirus disease can also be result of other factors which are not extensively studied to enable us to understand how the disease transmission takes place in different geographical and climatic regions which is key to formulate customized preventive measures.

Hence considering the information available from existing studies, this article will attempt to critically review and study the factors widely influencing the transmission phenomena and disease spread with reference to GCC and mixed group of countries having different climatic conditions and compare the results of the study to validate the proposition outcomes in conjunction with the literature.

LITERATURE REVIEW

Most investigation to deal with any pandemic or epidemic outbreak is the mechanism of disease transmission and the factors that favor the growth and spread of infection. Extensive studies reported by various researchers have observed the transmission and phenomena in different geographical settings and most of the results reveal that the diffusion of the coronavirus disease is associated with pollution levels and PM concentration in the air [10].

Transportation and industrial emissions containing particulate matter in urban cities facilitates the spread of virus in the atmosphere [11]. Reported that particulate matter due to high pollution in urban environments has shown increased rates of disease incidence, while [12] and [13] observed significant relationship of air pollution combining with meteorological parameters with COVID incidence [11-13,14]. Reported the presence of particulate matter in air can influence the fatality rates from COVID-19. Meteorological and weather parameters were extensively studied by [10, 14-17] on the relationship stating $PM_{2.5}$, PM_{10}, CO, NO_X, O_3 shows different degrees of association to COVID-19 transmission and incidence depending on other contribution factors such as population density and prevailing climatic conditions, while [8] stated air pollutants SO_2, CO, CO_2, NO_X, PM, VOC at high concentrations in urban environments show an adverse effect on the respiratory system escalating the risk of airborne transmission of virus [18,19]. Confirms the transmission of COVID is more at high temperatures observed in urban environments, however [20] reported that temperature increase will deter the growth of SARS-CoV-2 but has affinity to propagate in enclosed environments. Infection through aerosol droplets increases the risk of transmission in confined spaces like flight cabins, passenger vehicles and healthcare centers [21,22] states meteorological factors plays an independent role in transmission of the disease and the prevailing local weather condition likely favors the transmission within the region, confirming with [23] who observed correlation exists between weather conditions and incidence rate of COVID-19 in Oslo Norway. Though there are several studies done on transmission much of them have conflicting opinions.

Investigations on the disease transmission, environmental factors and weather conditions are detrimental to the transmission rates and spread of infection were studied on two spatial data by [24], although weather alone cannot facilitate the transmission process independently [7]. Also confirms meteorological factors temperature and humidity influence the transmission and spread of the COVID-19 though not consistent over spatial and temporal changes within a geographical region. Temperature and humidity influence on COVID-19 incidence are principally studied by all researchers with majority published from China mainland [25,26]. Observed temperature is correlated with the disease transmission and incidence rate [27-30]. Studied on temperature association and influence on the daily new confirmed cases COVID-19 in different cities globally specifying temperature has a major imprint on the transmission and incidence rate at city level regardless of prevailing climatic conditions. Few research studies stated factors referring to climatic, weather, meteorological factors, some of the parameters common to the three categories overlapping between them [31-37] where all reported different meteorological parameters independently show variable degrees of association and influence on the COVID transmission and incidence rate [16].

Stated all the meteorological parameters showed positive correlation with COVID-19 cases studied in Singapore [38]. Also measured sunshine hours, besides [13,22,31,39] all considered daylight hours as potential factor to study influence on the disease incidence and transmission pattern while increase in the average daylight hours has affinity to promote the disease transmission in both hot and cool climatic regions. Further few researchers emphasized temperature, humidity and precipitation under meteorological factors and studied their relationship [40]. Reported the meteorological factors influenced the disease transmission only up to certain variable levels beyond that show significant negative association with the COVID-19 incidence.

There are mixed reports disregarding the temperature effect on incidence rate by other researchers, leading to inconsistent and deficient understanding on the environmental parameters role in transmission and spread of disease as [41] claims temperature and number of cases show negative correlation but is influenced by precipitation [42]. Reported humidity as consistent factor for limiting the incidence rate along with [43] indicating short term exposure to humidity have increased transmission in cities, while wind speed, temperature and precipitation show no substantial influence. Meteorological parameters are also studied in different geographical context on the viability and potency of the virus strain survival in adverse conditions. Report high temperature and humidity levels reduce the viability, stability and survival potential while low temperature, humidity, dew point, wind speed and precipitation extends the disease incidence by activating the virus strain [39]. Observed mortality rates from COVID-19 are governed by temperature but humidity factor deterred the mortality rate showing negative relation with the pandemic.

Some research studies focused on single factors to understand the level and degree of correlation with disease transmission and incidence rate, where temperature and humidity are two general parameters that are widely observed to ascertain the influence on COVID-19 [45]. Concluded the incidence rates are regulated by the weather factors predominantly from the prevailing temperature conditions [46]. Stated long term exposure to air pollutant NO_X would contribute to the increased fatality from the COVID-19 either in urban or rural environments. However very limited studies were done towards understanding the population size and density per sq. km on the disease transmission while [47] confirms urban environments characterized with high population density, high ambient temperatures and humidity levels influences the daily new confirmed cases as observed in urban settings [48]. Reports transmission rate shows very little effect towards variation in temperature but has high sensitivity towards variation in population size confirming that COVID-19 is more specifically an urban subject of investigation.

In conclusion, the current studies by various researchers on the transmission and environmental factors are contradicting obtained through different studies. The incidence rates, phenomena of disease transmission and spread is not studied specifically from urban and rural context which is fundamental in understanding the SARS-CoV-2 causing global crisis and pandemic condition. From the analysis of the background studies on coronavirus disease and inconsistency in the findings, the authors have arrived at two propositions to validate the outcomes through this study.

P_1: COVID-19 is principally urban phenomenon

$P_{2:}$ The viability and transmission of the virus is dependent of environmental factors with different incidence rates in city and rural settings

These propositions will be investigated from the available information validating the presumptions on the disease spread and transmission and verified based on the phenomena SARS-CoV-2 has caused COVID-19 in different geographical settings.

METHODOLOGY

Study area and data

The study focused on 24 countries classified in two data sets. Data set 1 comprises of mixed group of countries and data set 2 includes GCC countries/cities (Table 1). Different parameters are examined for each data set countries to validate the propositions on the COVID-19. Temperature, humidity, population size and density per sq. km, city fraction, cases per million are considered for evaluation. Monthly new confirmed cases were collected from January to August 2020 which is calculated based on the absolute change over previous monthly cases to arrive at cumulative confirmed cases for the 8-month duration in data set 2. For data set 1 cumulative confirmed case were recorded from May to July. Monthly averages of temperature and relative humidity levels for each country and city for data set 2 are collected from January to August. For data set 1, the parameters for each city are recorded from May to July 2020. Data pertaining to the parameters for each of the data set are collected from [49-59].

Literature collection

Literature on COVID-19 were collected from secondary sources using institutional supported research portal [60,61]. More than 50 research articles were reviewed critically to understand the relationship of environmental parameters on the COVID transmission, viability and spread of infection. Only peer reviewed published articles are considered for the study and based on the analysis, authors have proposed two propositions to validate them by comparing with observations from the three data sets and to evaluate whether the two propositions agree with the published research studies.

Statistical analysis

Spearman correlation test is conducted to examine the association between the environmental parameters and COVID-19. The correlation is estimated by using the following equation [16].

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)}$$

d_i within the equation denotes the difference among the ranks of two variables while n denotes number of substitutes. R_s value ranges from 1.0 (indicates + ve correlation) and -1.0 (indicates -ve correlation). A R_s of 0 indicates no relationship among variables. Spearman rank correlation analysis is used

Table 1: Countries considered for study in the two data sets.

Data set	Countries
1	Oman, New Zealand, Spain, Ireland, Ecuador, Belarus, Latvia, Kazakhstan, France, Switzerland, Belgium, Italy, Georgia, Egypt, Somalia and Tunisia
2	Kuwait, Qatar, Bahrain, Riyadh, Jeddah, Dubai, Abu Dhabi and Muscat

as the Pearson correlation assumptions are not satisfied. The tests are performed using SPSS *Ver*. 26 software applying bivariate, two-tailed analysis. The values are considered significant at 0.05 and 0.01 level.

RESULTS

More than 10 pandemics were known to have effected humanity so far (Figures 1 & 2). Some of those were epidemics and reached pandemic conditions spreading globally. Oddly, COVID-19 does not share much similarity with other pandemics in the nature, transmission and the factors that govern viability and spread of disease except with SARS-CoV and MERS-CoV. COVID-19 though in comparison with other pandemics, has less significant fatalities against SARS-CoV and MERS-CoV, but is highly infectious disease spreading very easily among people causing rapid disease incidence globally. Thus, despite the lower fatality rate, the overall number of deaths from COVID-19 are exceedingly higher than SARS and MERS. The season of disease onset is also important to know the viability and further spread of the infection apart from the localized factors that harbor the pathogens. In case of COVID-19 the infections were first reported during December end 2019 in winter, but the past pandemics have not emerged during winter. This indicates clearly that temperature is likely influencing factor for the survival of SAR-CoV-2 pathogens. The disease outbreaks that occurred in majority of the countries, the incidence rates were higher over urban regions than rural regions that have

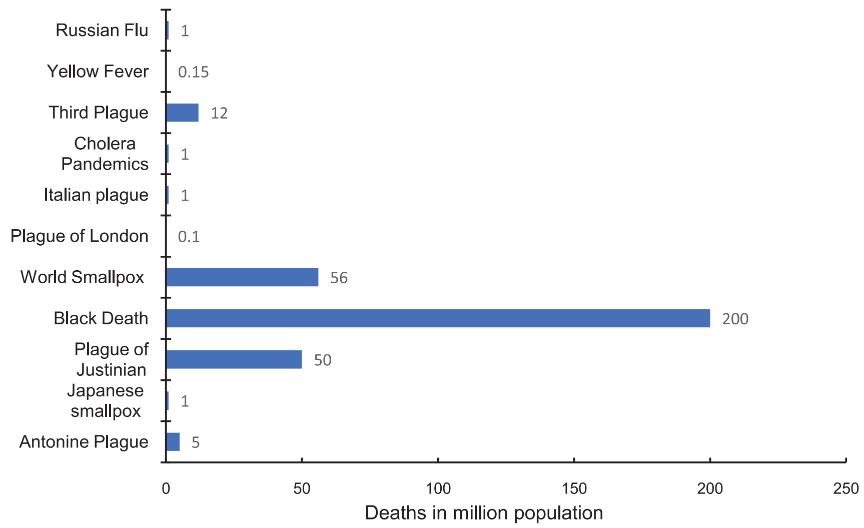


Figure 1 History of diseases post 1900 era and their death toll. Source: [5].

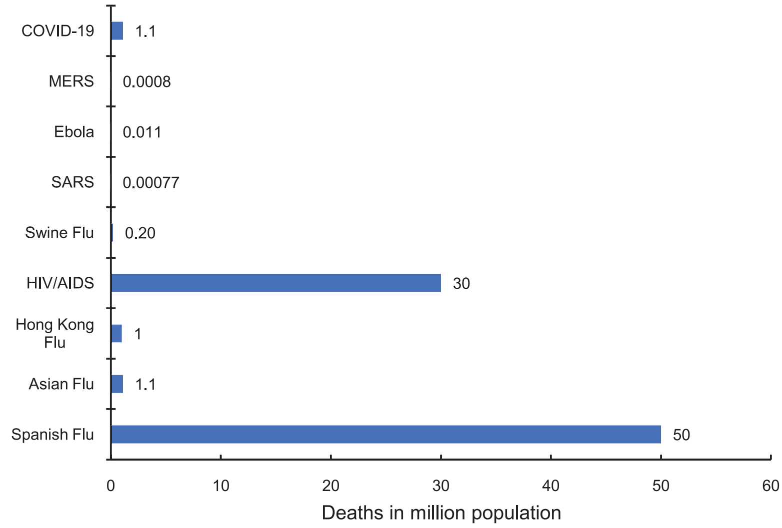


Figure 2 History of diseases post 1900 era and their death toll. Source: [5].

same temperature bands over certain periods with limited changes in weather. On the contrary, the daily reported cases in different cities are not similar because of the varying population density to city population in each region.

More than 15 parameters were analysed from the literature review to understand the relationship between the sets of variables in different cities and countries. Most of the studies were focused towards temperature and humidity on COVID-19 transmission and incidence rate to greater extent and other parameters to lesser extent. The most common parameters examined are temperature and humidity with 35 reported studies on temperature and 25 on humidity followed by precipitation from the 43 literatures studies analyzed (Table 3). From the factor associations analyzed, temperature has 24 reported studies showing positive significant relationship and 9 reported studies showing negative significant relationship with COVID transmission and incidence rates and the factor association agrees to with the two propositions variably (Table 2). The two propositions inconsistently tally with the key findings of 18 research studies on association of environmental parameters with COVID transmission.

Humidity has less reports of negative association with COVID incidence rates than temperature from the data analyzed implying both the parameters are paramount to understand the disease transmission and incidence phenomena. The other environmental parameters known to influence the incidence rates to lesser extent were windspeed, solar radiation, population density, air quality parameters and Particulate Matter (PM) that have significant contribution in the disease transmission and incidence rates depending on geographical locations and regional climatic conditions in urban and rural settings.

Data set # 1- mixed group of countries

To understand the environmental factors that are predominantly influencing the SARS-CoV-2 transmission and spread, the two data sets are statistically analysed to ascertain any close resemblance between any two subjects. Spearman rank correlation analysis (Table 4) of data set 1 between the temperature and the incidence rates shows very weak association between temperature and confirmed cases indicating that temperature as environmental factor does not show considerable effect on the disease incidence and spread, $r_s = .201$, $p = 0.456$, M= 19.87 ± 6.20. However, within

Table 2: Summary of the key research findings and association of environmental factors on COVID transmission and incidence rate relative to the current proposition outcomes.

Author/s	Study area	Factors/data analysed	Findings	Level of Factor association with Covid incidence			
				P	N	N	D
Qi, et al. [7]	China	• Temperature • Humidity • Daily cases- COVID	• No correlation of temperature and humidity on new confirmed cases. • Relationship between the two parameters is not consistent to daily new cases.		Y		
Auler, et al. [19]	Brazil	• Cumulative cases • Daily new cases • Contamination rate • Temperature • Humidity	• Temperature and humidity favor spread of CoVID in tropical countries	Y			
Babu, et al. [15]	India	• Temperature • Rainfall • Humidity • Windspeed • PM_{10}, $PM_{2.5}$, CO, O_3, NO_X	• Temperature and windspeed significant influence on CoVID cases.	Y			
			• Rainfall, humidity not associated with CoVID cases		Y		
			• PM_{10}, $PM_{2.5}$, CO, NO_X shows weak influence on the CoVID cases			Y	
			• O_3, has significant influence and association with CoVID cases.	Y			
Coccia [10]	Italy	• PM_{10} • O_3 • Number of days • CoVID	• High pollution accelerates the diffusion rate of CoVID. • Greater number of days having high average PM_{10} is associated with high infection rate	Y			
Eslami and Jalili [20]	Global	• Temperature • Humidity • Windspeed • Water, sewage, air, insects, inanimate surface.	• Temperature and sunlight lead to destruction of virus.	Y			
			• Sewer transmission is not confirmed.				Y
			• Inanimate surfaces are more significant sources of infection and risk of contact.	Y			
Iqbal, et al. [13]	Global	• Climatic parameters • Meteorological parameters • Temperature • Daylight hours • CoVID cases	• Lower temperature influence increase of CoVID cases	Y			
			• Meteorological parameters have significant association with CoVID cases	Y			
			• Daylight hours and temperature show significant correlation with transmission,	Y			

Jayaweera, et al. [21]	Global	• Droplets • Aerosols • Confined spaces	• Airborne transmission is more possible in confined spaces with droplets combining aerosol particles	Y			
Lin, et al. [18]	China, Singapore	• Temperature • Humidity • CoVID cases	• High temperature limits the transmission of disease • Humidity promotes transmission but changes under fluctuating temperatures	Y	Y		
Liu, et al. [22]	China	• Ambient temperature • Diurnal temperature • Humidity, Migration scale index • Confirmed cases • Meteorological factors	• Ambient and diurnal temperature reduces the transmission and decreases the confirmed cases • Humidity shows significant influence with confirmed case • Meteorological factors are independent to the transmission and confirmed cases.	Y	Y	Y	
Menebo [23]	Norway	• Temperature • Windspeed • Precipitation	• Temperature and precipitation show significant influence on CoVID • Windspeed influence on the CoVID transmission is not described.	Y			Y
Pani, et al. [16]	Singapore	• Temperature • Humidity • Dew point • Windspeed • Surface pressure • Ventilation coefficient • CoVID transmission	• Temperature, dew point, humidity, water vapor shows significant influence on CoVID transmission. • Windspeed and ventilation coefficient does not show any influence on CoVID transmission	Y	Y		
Poirier, et al. [24]	China	• Humidity • Temperature • CoVID transmission	• Temperature and humidity would influence CoVID transmission.	Y			
Prata, et al. [25]	Brazil	• Temperature • CoVID infection	• Temperature on CoVID infection rate and cases shows not influence between the variables		Y		
Runkle, et al. [43]	USA	• Temperature • Humidity • CoVID cases	• Reported new cases are due to exposure to humidity for short intervals. • Temperature and solar radiation not correlated with CoVID incidence	Y	Y		
Wu, et al. [28]	Global	• Temperature • Humidity • Daily new cases	• Temperature and relative humidity both show no significant association with new cases.		Y		
Yao, et al. [14]	China	• Particulate matter • PM 2.5 • PM 10 • Case fatality rate	• Particulate matter shows significant influence on CoVID case fatality rate.	Y			
Ahmadi, et al. [35]	Iran	• Temperature • Humidity • Windspeed • Solar radiation • Precipitation • Population density • CoVID cases	• Population density shows association with CoVID cases • Low levels of windspeed, humidity, solar radiation show high rate of infection	Y Y			
Pramanik, et al. [31]	Russia	• Temperature • Humidity • Windspeed • Day light hours • Diurnal temperature	• Temperature, humidity, windspeed, diurnal temperature shows significant influence on transmission.	Y			
Azuma, et al. [38]	Japan	• Ambient air pollution • CoVID infection	• Temperature and sunshine shows association and influences transmission. • Short term exposure in ambient polluted environment increase infection rate	Y Y			
Bashir, et al. [37]	USA	• Temperature • Humidity • Windspeed • Air quality • CoVID cases	• Temperature, windspeed, air quality and humidity show association and influences CoVID incidence	Y			
Gupta, et al. [36]	India	• Temperature • Humidity	• Temperature and humidity similar to the weather conditions of India can used to predict CoVID cases in USA.	Y			
Jahangiri, et al. [48]	Iran	• Population size • Temperature	• Temperature shows little effect to CoVID cases • Population size has high effect on CoVID cases	Y	Y		

Ma, et al. [39]	China	• Death cases • Daytime temperature • Meteorological factors • PM_{10}, $PM_{2.5}$, SO_2, CO, O_3, NO_2.	• Diurnal temperature is related to daily mortality rate	Y			
			• Humidity and PM_{10} are not associated with mortality rate by CoVID		Y		
			• Meteorological parameters show mixed influence on the mortality rate of disease			Y	
Ogen [46]	Europe	• NO_2 • CoVID fatality	• Long term exposure to NO_2 increases CoVID fatality	Y			
Quilodran, et al. [30]	Global	• Mortality rate • Temperature • Humidity	• Air temperature shows no significant relation to mortality rate		Y		
			• Humidity shows positive relation with mortality rate	Y			
Redon and Aroca [32]	Global	• Climate • CoVID expansion	• Climatic factors temperature, precipitation, humidity, windspeed and radiation influences the CoVID expansion secondarily.			Y	
Rosario, et al. [33]	Brazil	• Temperature • Humidity • Solar radiation • Windspeed • Precipitation • CoVID infection	• Solar radiation shows no significant relation to incidence		Y		
			• Temperature and windspeed no influence on incidence		Y		
			• Precipitation relation with incidence is not critically assessed				Y
Sahin 2020	Turkey	• Temperature • Humidity • Dew point • Windspeed	• Temperature, humidity, dewpoint windspeed show high association with CoVID infection in differential days.	Y			
Sarkodie and Owusu [44]	Global	• Temperature • Dewpoint • Humidity • Precipitation • Surface pressure • Confirmed CoVID cases	• Temperature and humidity show reduction in the survival, viability and transmission of disease.	Y			
			• Windspeed, precipitation, surface pressure prolongs the activity of virus.	Y			
Shi, et al. [26]	China	• Temperature • Confirmed cases	• Confirmed cases show association with varying levels of temperature conditions between 3°C to 10°C.	Y			
Sobral, et al. [41]	Global	• Temperature • Precipitation • CoVID mortality	• Temperature and CoVID mortality and number of cases are not associated		Y		
			• Precipitation shows strong association influencing disease transmission.	Y			
Tosepu, et al. [45]	Indonesia	• Temperature • Humidity • Precipitation • CoVID daily cases	• Average temperature shows correlation to some extent on disease transmissions.	Y			
			• Humidity and precipitation show no influence on CoVID transmission.		Y		
Ward, et al. [42]	Australia	• Temperature • Humidity • Precipitation • Windspeed • CoVID transmission	• Humidity shows no association with CoVID transmission		Y		
			• No relationship of temperature, windspeed and precipitation on CoVID cases.		Y		
Xie and Zhu [27]	China	• Temperature • CoVID cases	• Temperature has significant relation and associate with CoVID cases	Y			
Zhu, et al. [12]	China	• $PM_{2.5}$ • PM_{10} • SO_2 • CO, NO_2, O_3	• Positive relationship between $PM_{2.5}$, PM_{10}, NO_2, O_3 and CO COVID-19 transmissions	Y			
			• No correlation with SO_2 and disease transmission.		Y		
Zoran, et al. [11]	Italy	• $PM_{2.5}$ • PM_{10} • Temperature • Humidity • Windspeed • Atmospheric pressure	• Temperature, windspeed, atmospheric pressure, particulate matter shows association and influences CoVID outbreak	Y			
			• Humidity shows no significant influence on CoVID outbreak.		Y		
Pirouz, et al. [47]	Italy	• Temperature • Humidity • Windspeed • Population density • Confirmed cases	• The effect of the weather parameters on the confirmed cases shows time delay from 3-5 days.	Y			
			• Population density and weather conditions show influence on the confirmed cases	Y			
Wei, et al. [29]	China	• Attack rate • Temperature • Windspeed • Precipitation	• Temperature, windspeed and precipitation shows association and influences the attack rate of the disease.	Y			

Chien and Chen [40]	USA	• Daily CoVID cases • Temperature • Humidity • Precipitation	• Temperature, humidity and precipitation showed inconsistent association with daily CoVID cases.			Y	
Comunian, et al. [17]	Global	• CoVID cases • Particulate matter	• Particulate matter shows association and influences transmission of CoVID	Y			
Domingo, et al. [8]	Global	• Air pollutants- SO_x, NO_x, CO, CO_2, PM, O_3, VOC	• Air pollutants concentrations shows association with covid and causes lethal concentration of virus proliferation in environment.	Y			
Tosepu, et al. [45]	Indonesia	• Temperature • Humidity • Rainfall	• Temperature shows significant association with CoVID	Y			
Pirouz, et al. [47]	Italy	• Temperature • Humidity • Windspeed • Population density • Daily confirmed cases	• Population density and weather conditions shows significant association the daily confirmed cases	Y			

P: Positive; N: Negative; N: Neutral; D: Deficient; NA: No Agreement.

Table 3: Research findings on environmental factor association with COVID transmission and incidence rate (positive, negative, neutral and deficient).

	AT	RH	WS	PM	SR	DP	PD	Pp	O_3	CO	NO_x	As	SO_2	CO_2
Qi et al. 2020														
Auler et al. 2020														
Babu et al. 2020														
Coccia 2020														
Eslami & Jalili 2020														
Iqbal et al. 2020														
Jayaweera et al. 2020														
Lin et al. 2020														
Liu et al. 2020														
Menebo 2020														
Pani et al. 2020														
Poirier et al. 2020														
Prata et al. 2020														
Runkle et al. 2020														
Wu et al. 2020														
Yao et al. 2020														
Ahmadi et al. 2020														
Pramanik et al. 2020														
Azuma et al. 2020														
Bashir et al. 2020														
Gupta et al. 2020														
Jahangiri et al. 2020														
Ma et al. 2020														
Ogen 2020														
Quilodran et al. 2020														
Redon & Aroca 2020														
Rosario et al. 2020														
Sahin 2020														
Sarkodie & Owusu 2020														
Shi et al. 2020														
Sobral et al. 2020														
Tosepu et al. 2020														

Ward et al. 2020	Negative	Negative	Negative					Negative						
Xie & Zhu 2020	Positive													
Zhu et al. 2020				Positive				Positive	Positive	Positive			Negative	Negative
Zoran et al. 2020	Positive	Negative	Positive	Positive										
Pirouz et al. 2020	Positive	Positive	Positive				Positive	Positive						
Wei et al. 2020	Positive		Positive					Positive						
Chien & Chen 2020	Neutral	Neutral						Neutral						
Comunian et al. 2020				Positive										
Domingo et al. 2020				Positive					Positive	Positive	Positive		Positive	Positive
Tosepu et al. 2020	Positive													
Pirouz et al. 2020	Positive	Positive	Positive				Positive							

Positive Negative Neutral Deficient

AT: Average Temperature; RH: Relative Humidity; WS: Wind Speed; PM: Particulate Matter; SR: Solar Radiation; DP: Dewpoint: PD: Population Density; Pp: Precipitation; As: Aerosols; SO_2: Sulphur Dioxide.

Table 4: Correlation analysis of environmental parameters in data set #1 (*n* = 16).

Factor/parameter	AT˚C	No. of confirmed cases	Population density	City population
AT˚C	1.0			
No. of confirmed cases	r_s = .201 (*p* = .456; *p* > .01)	1.0		
Population density	r_s = -.064 (*p* = .815; *p* > .01)	r_s= .335 (*p* = .204; *p* > .01)	1.0	
City population	r_s = -.297 (*p* = .264; *p* > .01)	r_s = .815 (*p* = .000; p < .001)	r_s = .418 (*p* = .107; *p* > .01)	1.0

*Significance at 0.01 level.

the same data cluster the disease incidence rates have strong correlation (r_s = .815, *p* < .001) to the population levels of each city while the same has weak significant correlation (r_s= .335, *p* = .204) with the population density/km² of each country.

Data set # 2-GCC countries

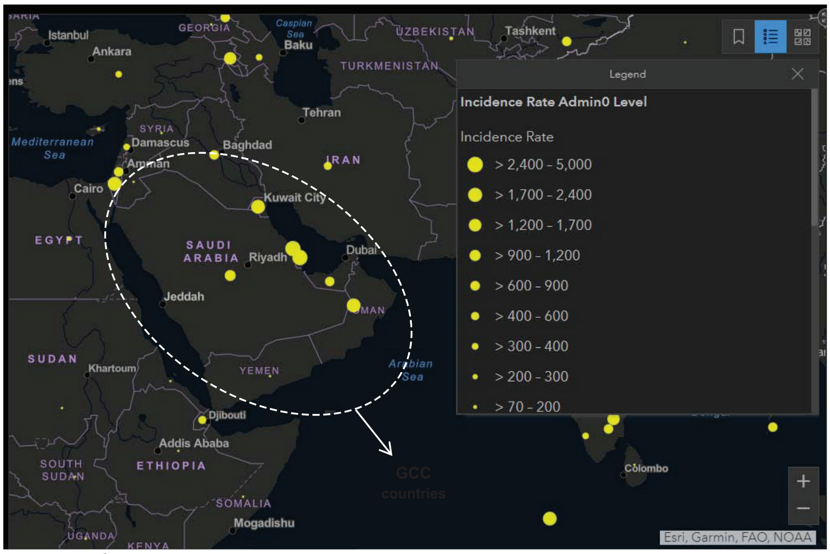
The significance of the environmental factors on the incidence rates of COVID -9 and the factors that govern the viability, transmission and spread are statistically analysed in the six GCC countries (Figure 3). The average difference in temperature among the eight cities (6 countries) studied between the two (first and second quadrimester) were 13.0˚C ± 3.80. The average temperatures in the first quadrimester is 27.1˚C ± 2.39 while the second quadrimester is 40.2˚C ± 2.58 (Figure 4). Analysis of the environmental factors shows prevalence of high temperatures during the second quadrimester over the first quadrimester in the year, while the temperature difference of 13.0˚C between the two quadrimester shows weak significant negative correlation (r_s = .314, *p* = .554; M = 13.0˚C ± 3.80, N= 6) on the incidence rates of COVID-19 between the two quadrimesters, implying the disease outbreak is not influenced from the temperature differences that occur within two consecutive months in a given period, however gradual temperature increase over successive months or periods would result in high disease outbreaks adding daily new confirmed cases.

Notwithstanding, the COVID-19 incidence rates gradually increased during the second quadrimester and are higher than the first quadrimester reciprocating to the changes recorded in the average temperatures of both the periods.

Statistical analysis on month wise data shows moderate significant correlation (r_s = .536, *p* = .215, M = 33.35 ± 1.83) between temperature parameter and the incidence levels of disease which implies the transmission and spread in the population is mediated to certain level from prevailing temperatures in the region, additionally in each of the 6 countries the number of disease outbreak cases reported has weak association with population density/km² and the total population signifying the incidence rates are not governed by population size and density within the region (Table 5). However, correlation analysis in individual countries shows strong significant relationship between temperature and disease incidence rates in Kuwait, Bahrain, Kingdom of Saudi Arabia (KSA) and Oman while there is moderate significant association between the two subjects in Qatar and UAE (Table 6).

DISCUSSION

Disease causing organism are susceptible to environmental factors primarily temperature and humidity.



Source: www.jhu.in

Figure 3 Covid -19 incidence rates in GCC countries reported until mid of September 2020.

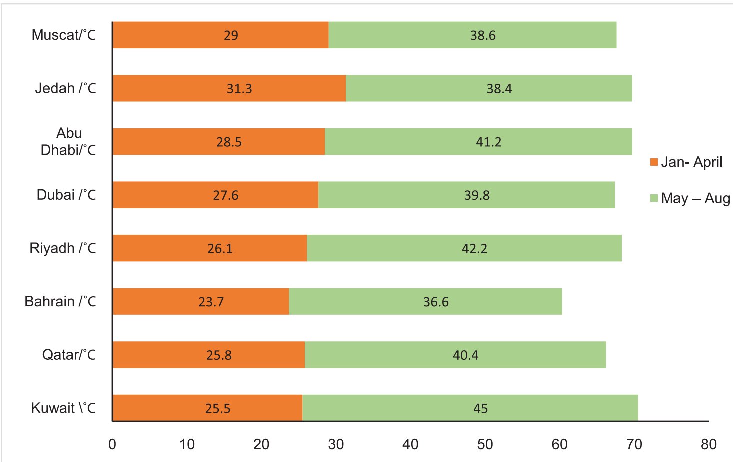


Figure 4 Average temperature difference between the two quadrimesters among subjects of data set 2.sss.

Table 5: Correlation analysis of environmental parameters in data set # 2, (*n* = 8).

Factor/parameter	AT˚C	No. of confirmed cases	Population density	City population
AT˚C	1.0			
No. of confirmed cases	r_s = .536 (p = .215; p > .01)	1.0		
Population density	r_s = -.144 (p = .758; p > .01)	r_s= .072 (p = .878; p > .01)	1.0	
City population	r_s = -.071 (p = .867; p > .01)	r_s = .263 (p = .528; p > .01)	r_s = .133 (p = .754; p > .01)	1.0

*Significance at 0.01 level.

The presence of those parameters at different levels will cause or deter the infection and transmission of disease within the population [62]. High levels of aerosol concentration from industrial and vehicular emissions especially in urban environments can cause wider transmissions through airborne media spreading the disease [63].

Another area causing high incidence rates of infection are enclosed environments that have limited ventilation and air circulation in confined spaces such as shopping malls, hospitals, offices etc. Poor ventilated workspaces and enclosed environments often leads to ambient temperature rise providing favorable conditions for sustaining the

Table 6: Correlation analysis of environmental parameters in individual countries of data set #2, (n = 8).

City/Country	Spearman rank correlation		Parameters	
			AT °C	ARH %
Kuwait	No. of confirmed cases	r_s	.786	-.766
		p	.021	.27
Qatar	No. of confirmed cases	r_s	.779	-.95
		p	.023	.000
Bahrain	No. of confirmed cases	r_s	.904	-.838
		p	.002	.009
KSA	No. of confirmed cases	r_s	.874	-.785
		p	.005	.021
UAE	No. of confirmed cases	r_s	.667	-.922
		p	.071	.001
Muscat	No. of confirmed cases	r_s	.929	-.357
		p	.001	.385

*Significance at 0.05 and 0.01 level.

virus. Observations also indicate the phenomenon of COVID-19 spread and transmission between urban and rural environments must not be generalized as both of these habitats vary in meteorological conditions and environmental factors air quality, temperature and humidity effects the transmission rates to humans [43].

Transmission factors and incidence

Temperature differ between urban and rural environment because of fluctuations on daily basis due to other influencing meteorological factors such as wind intensity, humidity, atmospheric pressure and solar intensity [64]. The transmission scenario and viability of the virus is conditional on ambient temperature and humidity levels but would also depend on the air conditioning and refrigeration conditions in enclosed environment in hot climatic regions such as GCC and some middle east countries. Under such conditions, infected population would escalate the transmission even under low density of population per km² leading to two possible premises (a) the number of confirmed cases differ between enclosed and non-enclosed environments varying between urban and rural settings and (b) shows difference of incidence rates in both regions that are not characterized as hot climates on the contrary proves that density of population is critical to the rapid transmission and spread of virus within communities and population where countries with high density of population per sq. km have recorded highest daily confirmed cases. Factors contributing COVID-19 incidence rate and transmission were widely studied across meteorological, weather, climatic, air pollution parameters but in absence of sufficient studies in urban and rural context either are more prone or susceptible to further infections.

Both the environmental parameters temperature and relative humidity studied critically relative to the two propositions does not reveal significant relationship overall and association of environmental factors to the incidence rates observed in the transmission of the COVID-19 are inconsistent between the data sets countries. While temperature factor association with the number of cumulative confirmed COVID cases in the overall data has weak to moderate positive correlation similar to findings reported by [25]. Generally daily temperature and humidity levels changes over a region but when the average levels over a period are consistent then the parameters tend to influence the transmission and incidence rates in individual countries, though it alone cannot be ruled as the prime factor. The effect of the environmental parameters is also partly due to the physical dynamics of each geographical location, meteorological factors, ambient pollution levels in each country which explains the varying association of incidence rates that shows dissimilarity of disease transmission trend between countries. Temperature and daily new cases at city and country level association changes according to spatiotemporal patterns of geographical location stated by [22].

In GCC countries the average temperatures during the second quadrimester (May to August) is considerably higher in comparison to data set 1 (Figure 5), causing the increase in incidence rates of COVID-19 moderately during summer months, nevertheless the degree of preventive measures, person hygiene and environmental protection measures enforced within each region are also important factors that will determine the transmission ratio and spread in the population (Table 7). In enclosed environments where air conditioning and refrigerator systems are used it will be more favorable for the virus to remain viable for longer time which can lead to increase in infection rates [18] but then high temperatures can potentially cause more infection transmission [7]. Enclosed environments are areas more susceptible to cause infections regardless of population density per km² and high temperatures especially where

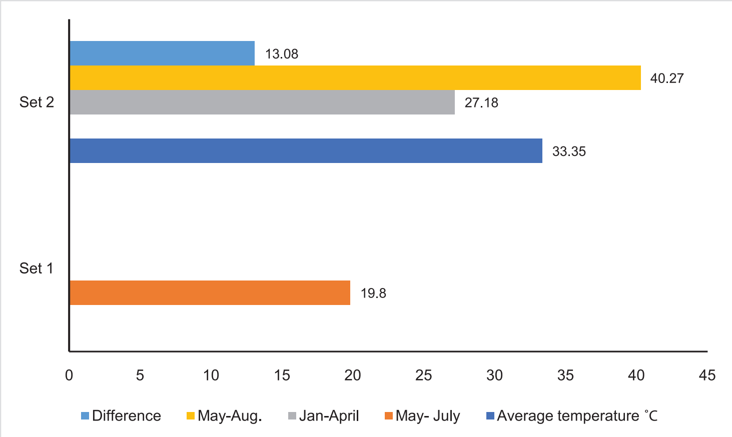


Figure 5 Average temperatures of three data sets in the two quadrimesters- 2020.

Table 7: Average temperatures of two data sets in the two quadrimesters-2020.

Data set	Duration	Average Temp. ˚C
I	May-July	19.8 ± 6.20
II	Jan-Aug	33.35 ±1.83
	1st Quad. (Jan-April)	27.18 ± 2.39
	2nd Quad. (May-Aug.)	40.27 ± 2.58
	Difference (1st and 2nd quad.)	13.08 ± 3.80

large population work in indoor environments [13]. However, high pollution levels from particulate matter in both urban and rural environments either in outdoor or enclosed environments can boost infection rates and increasing disease incidence rate can lead to secondary transmission [10].

The study significantly proves that the transmission of the virus strain and the incidence of COVID-19 is influenced mainly by temperature and humidity primarily to a major extent and when these are combined with high population density, increased pollution levels, concentration of aerosols particles basically observed in industrialized environments, then the incidence rates would rapidly increase the intensity of disease outbreak [14,15,65].

Finally, COVID-19 is noticeably a city phenomenon, transmission normally favored through environmental factors which are temperature, humidity and air pollution levels mostly in moderate to high industrialized cities. The viability and transmission are dependent on the combination of workplace conditions such as human to human transmission within urban and rural settings. Frequent migration of population from rural to urban environments is also significant reason for high incidence rates among cities perceived through the study.

CONCLUSION

The current study is a critical review on the transmission and environmental factors that contribute to the COVID-19 on a global scale. The authors have approached to study the incidence rates through the daily new confirmed cases and the cumulative confirmed cases reported in each country and further analyzed them to understand the transmission phenomena and the underlying environmental factors contributing to the incidence of the pandemic. The outcomes of the study provide substantial contribution to the literature on published data and gives a detail account of the COVID-19 in light of the global crisis.

The SARS-CoV-2 behaves differently in different climatic and weather conditions showing any consistent uniformity in transmission and incidence rates across the different countries studied in temperate and tropical climatic regions. However, the incidence rate and new daily confirmed cases appear to be intensive in all the countries studied spanning high and low annual average temperature regions signifying both the type of climatic conditions favor the transmission and incidence of the disease with different intensities.

The study has revealed some significant findings from city and country specific analysis.

- The pandemic COVID-19 is principally a city phenomenon justifying the propositions completely through the study, but temperature and humidity analyzed does not show consistent significant correlation with COVID transmission across all the data sets.
- Majority of the studies done on environmental factors association with COVID incidence rate have considered temperature and humidity parameters for analysis.
- From the assumption perceived in the study, the disease spread widely occurs through community transmission by two interfaces, human to human and air pollution to human through aerosols/airborne particles.
- The pattern of disease incidence, transmission and spread observed in different countries does not share

any resemblance or is generalized to a particular or entire geographical region.

- The literature review analysis shows positive, negative, mixed and deficient results regarding the factors principally temperature towards the transmission and spread of COVID-19.
- The SARS-CoV-2 virus strain does not behave similarly in different environmental conditions and there is no uniformity observed in incidence rates occurring in tropical or temperate regions as both the climatic conditions are known to favor the spread of the disease with different intensities in urban and rural settings.
- Given the similar type of weather conditions, average temperatures within city, country or geographical region, the incidence rates observed are different, indicating the phenomena are more correlated towards city dynamics.
- The virus strain SARS-CoV-2 is highly mutant type, though the maximum viability is for four days, the disease transmission can be more effective under high pollution levels in any environment.
- Temperature and humidity are not the limiting factors for the transmission, but other environmental factors such as wind velocity, regional climatic and local weather variations, precipitation levels, ambient pollution levels, population density per sq. km, average day length, aerosols concentration together determines the effectivity of disease transmission.

The observations are taken from beginning of the first confirmed case reported in each of the country from January up till the end of August, hence the data collected is very comprehensive to make the conclusions. however the study was confined to few of the environmental parameters due to the lack of accurate information available on other meteorological parameters in all the countries, therefore the role and contribution of those factors are also substantial to understand the transmission and incidence rates at global level. Further studies are needed to investigate extensively on the influence and role of other environmental factors such as wind velocity, humidity, dew point, precipitation, population density per sq. km, average length of day, ambient air pollution levels during different seasons, aerosol concentrations etc. as the virus strain is known to behave differently in different physical and climatic conditions at local, regional and global level. Critical studies are urgently needed in this perspective to understand how the virus transmission happen with reference to the every single factor which gives better understanding to take further control of sporadic outbreaks in different physical and geographical settings which is probably the only feasible option to gradually eliminate the infections in the population.

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