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Low temperature, high relative humidity and higher precipitation are associated with a higher number of deaths from COVID-19

Baixa temperatura, alta umidade relativa e maior precipitação estão associadas a um maior número de mortes por COVID-19

Las bajas temperaturas, la alta humedad relativa y las mayores precipitaciones se asocian a un mayor número de muertes por COVID-19

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Sérgio André de Souza Júnior
ORCID: https://orcid.org/0000-0001-9248-0061
Federal University of Ceará, Brazil
E-mail: sergioandre@edu.unifor.br
Pedro Victor Cabral de Freitas
ORCID: https://orcid.org/0000-0001-6589-420X
Federal University of Ceará, Brazil
E-mail: pedrocabralv@alu.ufc.br
Yohanna do Valle Hamberger
ORCID: https://orcid.org/0000-0002-3468-4370
Federal University of Ceará, Brazil
Email: yohamberger@gmail.com
Luisa Weber Bisol
ORCID: https://orcid.org/0000-0002-8657-8801
Federal University of Ceará, Brazil
Email: lwbisol@gmail.com
Fábio Gomes de Matos e Souza
ORCID: https://orcid.org/0000-0001-5804-053X
Federal University of Ceará, Brazil
Email: fgmsouza@yahoo.com.br

Abstract
Background: Meteorological variables play a major role in the transmission of infectious diseases such as coronavirus disease 2019 (COVID-19). Objective: To analyze the correlation between climatic variables and COVID-19 deaths/cases. Methods: An exploratory-descriptive study based on secondary data on deaths, cases of COVID-19 and climatic variables from March 2020-May 2021 in Fortaleza, Brazil. Data from the COVID-19 surveillance system of the Ministry of Health were used. The climatic indicators were extracted from the National Institute of Meteorology. The variables under study were temperature (minimum, mean and maximum in °C), relative air humidity (%), total precipitation (mm) and total daily insolation (h). Pearson's correlation and the linear regression model were used for statistical analysis. Correlations were considered significant when $P \leq 0.05$ and a 95% confidence interval was adopted. Results: All meteorologic variables were correlated with deaths from COVID-19, temperature minimum ($r = -0,126$; $P < 0,01$), mean temperature ($r = -0,146$; $P < 0,05$), maximum temperature ($r = -0,190$; $P < 0,001$), insolation ($r = -0,214$; $P < 0,001$), precipitation ($r = 0,216$; $P < 0,001$) and relative humidity ($r = 0,348$; $P < 0,001$). In relation to the new cases of COVID-19, only maximum temperature ($r = -0,116$; $P < 0,05$), insolation ($r = -0,141$; $P < 0,01$) and relative humidity ($r = 0,231$; $P < 0,001$) were correlated are significantly. Conclusion: There were significant correlations between meteorological variables and COVID-19 deaths/cases. It was found that meteorologic variables had the most influence on COVID-19 deaths.
Keywords: Coronavirus; Meteorology; Pandemics; SARS-CoV-2; Climate.

Resumo
Introdução: As variáveis meteorológicas desempenham um papel importante na transmissão de doenças infecciosas como a doença pelo coronavírus 2019 (COVID-19). Objetivo: Analisar a correlação entre as variáveis climáticas e os óbitos/casos diários da COVID-19. Metodologia: Um estudo exploratório-descritivo baseado em dados secundários sobre óbitos, casos de COVID-19 e variáveis climáticas de março de 2020 a maio de 2021 em Fortaleza, Brasil. Foram utilizados dados do sistema de vigilância da COVID-19 do Ministério da Saúde. Os indicadores climáticos foram extraídos do Instituto Nacional de Meteorologia. As variáveis em estudo foram temperatura (mínima, média e máxima em °C), umidade relativa do ar (%), precipitação total (mm) e insolação total diária (h). A correlação de Pearson e o modelo de regressão linear foram utilizados para análise estatística. As correlações foram consideradas

significativas quando P ≤ 0,05 e um intervalo de confiança de 95% foi adotado. Resultados: Todas as variáveis meteorológicas foram correlacionadas com óbitos por COVID-19, temperatura mínima (r = -0,126; P < 0,01), temperatura média (r = -0,146; P < 0,05), temperatura máxima (r = -0,190; P < 0,001), insolação (r = -0,214; P < 0,001), precipitação (r = 0,216; P < 0,001) e umidade relativa do ar (r = 0,348; P < 0,001). Em relação aos novos casos de COVID-19, apenas a temperatura máxima (r = -0,116; P < 0,05), insolação (r = -0,141; P < 0,01) e umidade relativa do ar (r = 0,231; P < 0,001) foram correlacionadas de forma significativa. Conclusão: Houve correlações significativas entre as variáveis meteorológicas e os casos de óbitos/casos diários de COVID-19. Verificou-se que as variáveis meteorológicas tiveram a maior influência nos óbitos decorrentes da COVID-19.
Palavras-chave: Coronavirus; Meteorologia; Pandemias; SARS-CoV-2; Clima.

Resumen
Introducción: Las variables meteorológicas desempeñan un papel importante en la transmisión de enfermedades infecciosas como la enfermedad por coronavirus 2019 (COVID-19). Objetivo: Analizar la correlación entre las variables meteorológicas y las muertes/casos diarios de COVID-19. Metodología: Estudio exploratorio-descriptivo basado en datos secundarios sobre muertes, casos de COVID-19 y variables climáticas de marzo de 2020 a mayo de 2021 en Fortaleza, Brasil. Se utilizaron datos del sistema de vigilancia COVID-19 del Ministerio de Sanidad. Los indicadores climáticos se extrajeron del Instituto Nacional de Meteorología. Las variables estudiadas fueron la temperatura (mínima, media y máxima en °C), la humedad relativa (%), la precipitación total (mm) y la insolación diaria total (h). Para el análisis estadístico se utilizaron la correlación de Pearson y el modelo de regresión lineal. Las correlaciones se consideraron significativas cuando P ≤ 0,05 y se adoptó un intervalo de confianza del 95%. Resultados: Todas las variables meteorológicas estaban correlacionadas con las muertes por COVID-19, la temperatura mínima (r = -0,126; P < 0,01), la temperatura media (r = -0,146; P < 0,05), la temperatura máxima (r = -0,190; P < 0,001), la insolación (r = -0,214; P < 0,001), las precipitaciones (r = 0,216; P < 0,001) y la humedad relativa (r = 0,348; P < 0,001). En cuanto a los nuevos casos de COVID-19, sólo la temperatura máxima (r = -0,116; P < 0,05), la insolación (r = -0,141; P < 0,01) y la humedad relativa (r = 0,231; P < 0,001) estaban significativamente correlacionadas. Conclusión: Hubo correlaciones significativas entre las variables meteorológicas y las muertes/casos diarios de COVID-19. Se comprobó que las variables meteorológicas fueron las que más influyeron en las muertes por COVID-19.
Palabras clave: Coronavirus; Meteorología; Pandemias; SARS-CoV-2; Clima.

1. Introduction

An outbreak of pneumonia was initially reported in the Chinese province of Wuhan in late December 2019. The pathogen was identified as a new enveloped ribonucleic acid (RNA) betacoronavirus 2 called severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which has a similar phylogenetic with SARS-CoV and Middle Eastern respiratory syndrome coronavirus (MERS-CoV) (Alves et al., 2021; Cucinotta & Vanelli, 2020; Guan et al., 2020; Wang et al., 2020). The SARS-CoV-2 is the coronavirus family member that affects humans. It shares with SARS-CoV and MERS-CoV the ability to infect the lower respiratory tract. The SARS-Cov-2 infection that causes coronavirus disease 2019 (COVID-19) can be transmitted through aerosols, droplets and/or direct contact with secretions from the pulmonary tract (Benseñor & Lotufo, 2020; Guan et al., 2020; Wang et al., 2020). The symptoms of COVID-19 are similar to what occurs in SARS and MERS including fever, dry cough, myalgia, fatigue, dyspnea, among others. Complications such as pneumonia, septic shock, acute kidney injury and acute respiratory distress syndrome may occur (Alves et al., 2021; Cucinotta & Vanelli, 2020; Guan et al., 2020; Wang et al., 2020).

Due to the high degree of contagion, COVID-19 quickly spread across the planet. On March 11, 2020, it was designated a pandemic by the World Health Organization (WHO) and became a global public health crisis (Benseñor & Lotufo, 2020; Cucinotta & Vanelli, 2020). On February 26, the first case of COVID-19 was confirmed in Brazilian territory. In the following weeks, Brazil showed an exponential growth in the number of cases (Alves et al., 2021). The city of Fortaleza became the fifth city with the highest number of accumulated deaths in Brazil (Secretarias Estaduais de Saúde, 2020).

It has been shown that the spread of diseases caused by beta-coronaviruses, such as severe acute respiratory syndrome (SARS) and Middle Eastern respiratory syndrome (MERS), is impacted by climatic conditions (Kaplin et al., 2021; Mecenas et

al., 2020). Hot and humid climates showed a reduction in the viability of these viruses, while in places with low temperature and humidity there was greater viral stability (Mecenas et al., 2020; Yang et al., 2021).

Different variables affect the speed of contamination such as social behavior, level of socioeconomic development and climatic parameters. Meteorological factors can influence the transmission of infectious diseases, including influenza and other respiratory system diseases. The effects of environmental components on the incidence of COVID-19 have been studied. These meteorological factors, such as humidity, temperature, insolation and precipitation, can affect the stability of the droplets in the environment or affect the survival of viruses such as air temperature, thus impacting epidemic transmission (Chen et al., 2020; Kaplin et al., 2021).

Recent studies demonstrate the possibility that certain meteorological conditions favor the transmission of COVID-19, but its influence varies between different regions. (Coelho et al., 2020) show that average annual temperature and rainfall does not significantly relate to the growth of cases COVID-19 globally. However, (Auler et al., 2020) analyzed the relationship between weather variables with the spread of COVID-19 in five Brazilian cities, including Fortaleza, finding a correlation between cases with increased temperature around 27.5 ºC and relative humidity of 80%, but with no statistical significance and with a short study period. The present study aims to analyze the possible influence of weather conditions on the COVID-19 pandemic according to the evolution of cases and daily deaths for fourteen consecutive months in the Brazilian city, Fortaleza.

2. Methodology

Type of study

An exploratory-descriptive study, based on secondary data on deaths, cases of COVID-19 and climatic variables from March 2020 to May 2021 in Fortaleza, Brazil.

Study location

Fortaleza is the fifth-largest city in Brazil and is located in the Northeast region, with an estimated population of 2,686.612 inhabitants in 2020. It is located at latitude 3°43' 02" S and longitude 38° 32'35" Wgr. It has an area of approximately 312.4 km² (Instituto Brasileiro de Geografia e Estatística (IBGE), 2020; Instituto de Pesquisa e Estratégia Econômica do Ceará (IPECE), 2018). According to the classification by Köppen,(Alvares et al., 2013), the climate is tropical with dry summer, characterized by average temperatures between 26 and 28 °C and an average rainfall of 1338 mm, with a greater concentration between January and May (Instituto de Pesquisa e Estratégia Econômica do Ceará (IPECE), 2018).

Variables

Cases and daily deaths of COVID-19 occurred between March 27, 2020 (first recorded case in the city) and May 31, 2021, were selected through the Coronavirus Panel of the Health Surveillance Secretariat, an agency linked to the Ministry of Health (https: //covid.saude.gov.br). The climatic indicators were extracted from the National Institute of Meteorology (INMET) (https://portal.inmet.gov.br). The variables under study were temperature (minimum, average and maximum), relative air humidity, total precipitation and total daily insolation.

Statistical analysis

We used the descriptive statistics and inferential, applying the Pearson correlation, after the normality test Shapiro-Wilk, and the linear regression model to investigate the relationship between climate variables and daily cases and deaths from COVID-19. Correlations were considered significant when $P \leq 0.05$ and a 95% confidence interval was adopted. All analyses were performed using the Statistical Package for the Social Sciences (SPSS) software, version 26.0.

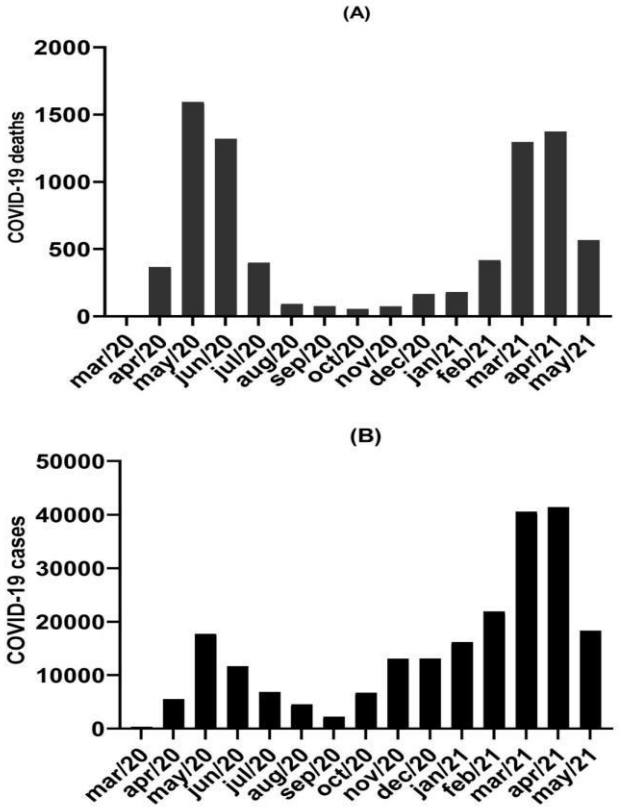
Ethical aspects

The study used data from secondary sources. Therefore, the opinion of the ethics committee is not required.

3. Results

Figure 1 shows the evolution of the cases and deaths daily COVID-19 that occurred in Fortaleza, Brazil. The first records took place in March/2020, with notification of 371 accumulated cases and six deaths. The peak of accumulated cases occurred in April/2021, totaling 41,412 cases, and the maximum number of deaths occurred in May/2020, totaling 1,594 deaths.

Figure 1. The evolution of the deaths (A) and cases (B) of daily coronavirus disease 2019 (COVID-19) occurred in Fortaleza, Brazil.



Source: Secretarias Estaduais de Saúde (2021).

Table 1 summarizes the descriptive statistics for confirmed daily cases/deaths of COVID-19 and climate variables. The average number of confirmed cases and deaths were 532.03 (± 831.38) and 19.29 (± 29.01), respectively. Climatic data show mean minimum temperature of 24.35 °C ± 1.12, mean temperature of 27.29 °C ± 0.91, mean maximum temperature of 31.39 °C ± 1.27, mean relative humidity equal to 79 .38% ± 8.52, mean total precipitation of 5.073 mm ± 12.08 and mean total insolation of 7.117h ± 3.21.

Table 1. Monthly distribution of deaths, daily coronavirus disease 2019 (COVID-19) cases and climatic variables in Fortaleza, Brazil.

Month/year	Daily deaths	Daily cases	Minimum temperature (°C)	Average temperature (°C)	Maximum temperature (°C)	Relative humidity (%)	Precipitation (mm)	Insolation (h)
March/2020	1.20 (±1.64)	74.20 (±129.08)	24.85 (±0.19)	27.46 (±0.90)	30.95 (±1.79)	87.50 (±7.32)	9.075 (±9.99)	3.675 (±3.92)
April/2020	12.23 (±9.26)	183.47 (±120.37)	24.37 (±0.91)	27.31 (±1.07)	31.54 (±1.90)	87.26 (±6.49)	15.134 (±19.48)	4.428 (±3.07)
May/2020	51.42 (±33.72)	572.19 (±393.92)	24.37 (±0.46)	27.29 (±0.78)	31.31 (±1.43)	84.11 (±4.17)	9.003 (±17.49)	6.292 (±3.44)
June/2020	44.03 (±41.52)	390.00 (±234.18)	23.87 (±0.54)	26.75 (±0.67)	30.74 (±0.89)	82.65 (±5.45)	2.850 (±4.96)	5.862 (±2.76)
July/2020	12.94 (±13.27)	221.39 (±179.97)	23.09 (±0.82)	26.34 (±0.64)	30.78 (±0.98)	76.50 (±5.43)	2.251 (±6.63)	7.756 (±2.71)
August/2020	2.97 (±4.40)	147.74 (±179.42)	23.31 (±1.00)	26.78 (±0.37)	31.54 (±0.72)	72.44 (±3.61)	0.015 (±0.07)	9.036 (±0.64)
September/2020	2.53 (±4.60)	74.57 (±668.24)	24.23 (±0.75)	27.22 (±0.34)	31.66 (±0.59)	68.65 (±13.12)	0.203 (±0.6)	9.235 (±0.86)
October/2020	1.81 (±3.85)	216.65 (±429.29)	24.88 (±0.85)	27.86 (±0.27)	32.15 (±0.4)	72.63 (±3.76)	0.588 (±1.57)	9.693 (±1.26)
November/2020	2.47 (±4.82)	435.17 (±479.10)	25.57 (0.79)	28.31 (±0.43)	32.27 (±0.5)	74.83 (±3.01)	0.644 (±1.8)	8.987 (±2.25)
December/2020	5.35 (±7.99)	423.52 (±481.03)	25.30*	28.50*	32.10*	70.00*	0.000*	10.500*
January/2021	5.84 (±5.26)	522.55 (±375.42)	25.41 (0.91)	27.81 (±0.85)	31.65 (1.31)	78.88 (±6.54)	4.266 (±7.3)	6.976 (±3.38)
February/2021	14.93 (±19.16)	782.21 (±892.39)	25.24 (±0.83)	27.78 (0.74)	31.42 (±0.99)	81.20 (±5.11)	1.982 (±3.31)	6.867 (±3.38)
March/2021	41.77 (±31.48)	1.308,61 (±1.395,08)	23.96 (±1.18)	26.94 (±0.99)	30.56 (±1.59)	86.22 (±5.84)	12.451 (±21.15)	4.856 (±3.63)
April/2021	45.77 (±42.28)	1.380,40 (±1.600, 04)	24.44 (±0.87)	27.70 (±0.61)	31.89 (±0.51)	82.29 (±4.59)	4.545 (±9.29)	7.304 (±1.93)
May/2021	40.50 (±33.65)	1.306,29 (±999.83)	23.24 (±0.45)	25.88 (±0.96)	29.61 (±1.98)	89.00 (±6.11)	20.640 (±17.59)	3.420 (±3.87)
Total	19.29 (±29.01)	532.03 (±831.38)	24.35 (±1.12)	27.29 (±0.91)	31.39 (±1.27)	79.38 (±8.52)	5.073 (±12.08)	7.117 (±3.21)

*data referring to December 01, 2020. Source: INMET (2021).

Table 2 shows the correlation of climatic variables with COVID-19 daily cases and deaths. Maximum temperature ($r = -0.116$; $P < 0.05$), relative air humidity ($r = 0.231$; $P < 0.001$) and total insolation ($r = -0.141$; $P < 0.01$) were significantly correlated with confirmed daily cases. There was no correlation with precipitation and minimum and average

temperatures. However, the correlation with daily deaths was statistically significant with all climatic variables, highlighting the relative humidity of the air (r = 0.348; P < 0.001).

Table 2. Pearson correlation between climatic variables, deaths and daily cases of coronavirus disease 2019 (COVID-19) in Fortaleza, Brazil.

	Climate variables	Daily deaths	Daily cases
Pearson correlation	Minimum temperature	-0.126*	0.041
	Average temperature	-0.146**	-0.005
	Maximum temperature	-0.190***	-0.116**
	Relative humidity	0.348***	0.231***
	Total precipitation	0.216***	0.64
	Total insolation	-0,.14***	-0.141*

*P < 0.01; **P < 0.05; ***P < 0.001. Source: Prepared by the authors (2021).

Table 3 shows the regression analyses between the climatic variables with deaths and daily cases by COVID-19. Mean temperature showed a statistically significant relationship with daily deaths (β = 0.403; P = 0.012; 95% confidence interval, CI = 2.961 | 24.006). Minimum temperature (β = -0.310; P = 0.002; 95% CI = -13.963 | -3.114) and relative air humidity (β = 0.362; P = 0.00; 95% CI = 0.768 | 1.840) also had a significant relationship with deaths. Average temperature (β = 0.447; P = 0.008; 95% CI = 116.263 | 764.940), maximum temperature (β = -0.294; P = 0.015; 95% CI = -380.848 | -40.868) and relative humidity (β = 0.205; P = 0.01; 95% CI = 5.135 | 38.183) showed also had a significant relationship a statistically significant relationship with confirmed daily cases.

Table 3. Linear regression model of the association between climatic variables and coronavirus disease 2019 (COVID-19), Fortaleza, Brazil.

Climate variable	Regression coefficient (β)	T-value	P-value	CI 95%
Deaths				
Minimum temperature	-0.310	-3.097	0.002	-13.963 | -3.114
Average temperature	0.403	2.521	0.012	2.961 | 24.006
Maximum temperature	-0.209	-1.816	0.07	-10.606 | 0.424
Relative humidity	0.362	4.786	0.000	0.768 | 1.840
Total precipitation	0.085	1.328	0.185	-0.115 | 0.592
Total insolation	0.047	0.527	0.599	-1.221 | 2.113
Cases				
Minimum temperature	-0.162	-1.544	0.124	-298.377 | 36.008
Average temperature	0.447	2.673	0.008	116.263 | 764.940
Maximum temperature	-0.294	-2.441	0.015	-380.848 | -40.868
Relative humidity	0.205	2.579	0.01	5.135 | 38.183
Total precipitation	-0.026	-0.389	0.698	-13.040 | 8.736
Total insolation	-0.041	-0.443	0.658	-62.937 | 39.814

CI = confidence interval. Source: Prepared by the authors (2021).

4. Discussion

The main findings of this paper are: a) all independent meteorological variables were significantly associated with daily COVID-19 deaths; b) insolation, relative humidity and temperature were also related to daily COVID-19 cases.

Daily Deaths

Minimum, mean and maximum temperatures and total insolation were negatively associated with COVID-19 deaths. Total precipitation and relative air humidity, on the other hand, were positively correlated.

Temperature and daily deaths

The present study from Fortaleza shows a weak negative correlation ($r = -0.146$) between daily deaths and mean temperature. In an analysis of 16 African countries, (Meo et al., 2020) found a similar correlation ($r = -0.180$) between the same variables describing an average temperature of 26.16 °C for the period in the countries where the study took place. Beside the average temperature, also minimum and maximum temperature are showed a significant negative correlation with daily deaths ($r = -0.190$) and ($r = -0.126$), respectively.

Total Insolation and Daily Deaths

This study also identified a decrease in the occurrence of daily deaths in periods of greater total insolation ($P < 0.001$). A similar finding was found in an evaluation of European countries by logistic regression, with a negative correlation between the COVID-19 mortality rate and total monthly heat stroke (Omer et al., 2021).

Precipitation and daily deaths

The increase in precipitation was positively correlated with daily deaths ($P = 0.348$). Unfortunately, we did not find data in the literature to compare with our findings.

Humidity and Daily Deaths

It was found in this study that the greater the relative humidity of the air, the greater the number of daily deaths ($r = 0.348$). In opposition to our study, (Yueling Ma et al., 2020) found that the increase in relative humidity is negatively correlated with the increase in deaths.

New Cases

Concerning daily new cases, both the mean temperature and the total insolation showed a negative correlation, while the relative humidity showed a positive correlation.

Temperature and new cases

The only maximum temperature was negatively correlated with daily new cases ($r = -0.116$). A study conducted in 14 cities in Japan, (Kodera et al., 2020) found an inverse correlation with the maximum temperature and the occurrence of new cases of COVID-19. However, a polynomial regression performed with data from 27 Brazilian capitals, found that each increase of 1 degree in the mean temperature was associated with a 4.89% decrease in the number of confirmed cases, reaching the value of 25.8 °C (Prata et al., 2020). Furthermore, an analysis carried out with data from 127 countries identified an inverse correlation between mean temperature and new cases for values below 20 ºC and a direct correlation for higher totals (Yuan et al., 2021).

Total Insolation and new cases

A negative correlation was found between total heat stroke and daily new cases ($P < 0.01$). (Karapiperis et al., 2021) used pairs of countries with similar socioeconomic indicators, as models for the analysis of climate variables through Machine Learning, finding the incidence of ultraviolet (UV) rays as the main indicator of variation in the incidence of new cases.

Current literature presents conflicting results about the mechanism of action of UV radiation in the course of COVID-19. (Ratnesar-Shumate et al., 2020) points to the action of radiation in the sterilization of surfaces, indicating a modulating effect on non-air contamination. (Walrand, 2021) affirms that low serum concentrations of vitamin D contribute to the severity of COVID-19 infection, combining the reduced blood levels of vitamin seasonal decline in the sunshine. (Yiqun Ma et al., 2021) points out that weather factors have more impact on the course of COVID-19 in places with colder climates, dry and less sunshine.

Precipitation and new cases

No significant findings were found in this correlation.

Relative air humidity and new cases

The new daily cases are related to the relative humidity of the air, observing a positive correlation ($r = 0.231$). As well as about daily deaths, we found disagreement in the literature, in which a study negatively correlates relative humidity and new cases (Wu et al., 2020).

5. Final Considerations

In conclusion, it was observed that all meteorologic variables, temperature, insolation, rainfall and relative humidity were related to deaths caused by COVID-19. For new cases, only maximum temperature, insolation and relative humidity were correlated are significant. Therefore, it can be concluded that deaths are more affected than new cases climate variables.

Among the limitations, the work was carried out with secondary data from a single city, which may not reproduce compatible results in other locations. Another limitation is that the weather data for December/2020 were partially computed, with data only for the first day of the month being recorded. Further longitudinal studies are needed to characterize the interaction of climatic factors with COVID-19 and to verify other factors that may interfere with the evolution and prognosis of the disease.

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