Effects of temperature and relative humidity on the COVID-19 pandemic in different climates: a study across some regions in Algeria (North Africa)

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Abstract

After more than a year from the first confirmed cases of coronavirus (COVID-19) disease, the role of meteorological factors in the transmission of the virus still needs to be correctly determined. In this scenario of deep uncertainty, the present study aims to investigate the effects of temperature and relative humidity on daily new cases of COVID-19. For this purpose, the COVID-19's development of infection in fourteen Algerian cities characterized by different climatic conditions, during the period from April 1, 2020, to August 31, 2020, has been investigated. A detailed time series analysis along with linear regression was used to state a possible correlation among some climate's factor variability (temperature and relative humidity) and daily new confirmed cases of COVID-19. The results showed a weak correlation between daily new cases of COVID-19 and meteorological factors throughout the selected regions. In addition, we concluded that the COVID-19 could fit to high or low values of temperature and relative humidity, and other factors not climates could affect the spreading of the virus like demography and human contact. So, after the discovery of the vaccine and before vaccination of 70% of the world's population, living with the virus has become an inevitable reality, and it is mandatory to apply the sanitary procedures to slow down the COVID-19 transmission.

Keywords COVID-19 · Temperature · Relative humidity · Climatic conditions

Introduction

During December of 2019, several and anomalous cases of a novel coronavirus disease (COVID-19), classified and now known as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (Gorbalenya 2020; Wu et al. 2020), were registered in Wuhan (China). Starting from March, the number of cases drastically increased also outside China, and the virus still today continues to spread across the whole planet. Specifically, on March 10, 2020, several regions were strongly affected from this new and worried disease: China registered 80,778 total confirmed cases and 3,158 deaths, followed by Italy with 10,156 total cases and 631 deaths, Iran with 8,042 total reported cases and 291 deaths, and finally South Korea where the total cases of COVID-19 were 7,513 with 60 deaths. Forced by this dramatic situation, on March 11, 2020, in sight of the over one hundred thousand (118,319) confirmed cases and with more than 4,000 deaths around the world (World Health Organization (WHO) 2020) the WHO declared the novel coronavirus (COVID-19) outbreak a global pandemic. On November 03, 2020,

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Fig. 1 Location of the Algerian studied cities, in different climates

the total infected, in the world, almost reached forty million (47,277,834) with a death toll of over one million peoples (1,210,328). Furthermore, in the middle of April 2021, the total infected exceeds 140 million cases with more than 3,000,000 deaths around the world.

Table 1 Geographic location of cities studied

Bioclimatic zone	City name	Latitude (°)	Longitude (°)
Humid to sub-humid	Algiers	36.75 N	3.03 E
	Annaba	36.90 N	7.75 E
	Jijel	36.81 N	5.76 E
	Oran	35.71 N	0.64 W
	Blida	36.47 N	2.82 E
Semi-arid	Setif	36.15 N	5.43 E
	Batna	35.55 N	6.16 E
	Djelfa	34.67 N	3.25 E
	Tiaret	35.38 N	1.31 E
	Naâma	33.26 N	0.39 W
Arid	Ouargla	31.97 N	5.38 E
	Bechar	31.61 N	2.21 W
Hyper-arid	Tamanrasset	22.78 N	5.52 E
	Adrar	27.86 N	0.28 W

In Algeria, North Africa, the first case of COVID-19 was observed on February 25, 2020, while the number of infected today (middle of April 2021) reached almost 120,000 peoples with a number of death equal to 3,148. Currently, the number of new cases rapidly increased in all the five continents, and unfortunately, there are still no effective therapies (drugs) approved by research committee to successfully treat and fight COVID-19 disease. To make matters worse, several researchers have confirmed its transmissibility among peoples (human-to-human) (Wang et al. 2020a, b) raising the threshold of attention all over the world. Compared to other types of coronaviruses such as the 2002/2003 SARS-CoV and the 2012/2014 MERS-CoV (Middle East respiratory syndrome-related coronavirus), the COVID-19 has proven to spread faster. For example, while the MERS-CoV and SARS-CoV took almost 2.5 years, respectively, to infect 1,000 people, the novel SARS-CoV-2 has exceeded this number in only 1 day. Recently, numerous authors have described how the COVID-19 spread can depend on a large number of factors, among which the climatic conditions (Qi et al. 2020; Tosepu et al. 2020). Further, the results of Tian et al. (2021) suggest that COVID-19 patients living in regions with high adverse environmental and climatic factors may be more vulnerable to complications from the virus, specifically higher risk for death.

Table 2 Weather stations of the study area

Bioclimatic zone	City name	Weather station name	Latitude (°)	Longitude (°)	Altitude (m)
Humid to sub-humid	Algiers	Dar El Baida airport	36.72° N	3.25° E	25
	Annaba	El Mellah airport	36.83° N	7.82° E	4
	Jijel	Achouat airport	36.88° N	5.82° E	2
	Oran	Es Senia airport	35.63° N	0.60 W	90
	Blida	Dar El Baida airport	36.72° N	3.25° E	25
Semi-arid	Setif	Ain-Arnat airport	36.18° N	5.31° E	1040
	Batna	Batna airport	35.55° N	6.18° E	1052
	Djelfa	Djelfa	34.68° N	3.25° E	1144
	Tiaret	Tiaret airport	35.25° N	1.43° E	978
	Naâma	Naâma	33.72° N	0.30° W	1166
Arid hyper-arid	Ouargla	Ouargla airport	31.92° N	5.40° E	141
	Bechar	Bechar airport	31.62° N	2.23° W	773
	Tamanrasset	Tamanrasset	22.78° N	5.52° E	1364
	Adrar	Adrar airport	27.88° N	0.28° W	283

Today, several studies stated a clear relationship between climate characteristics and different types of coronaviruses (MERS-CoV, SARS-CoV-1, SARS-CoV-2). In fact, the latter seems to spread faster under certain weather conditions in terms of temperature and humidity (Marr et al. 2019; Peci et al. 2019; Moriyama and Ichinohe 2019; Shahzad et al. 2021). Generally, all these studies reported a decrease of new observed case accordingly with the temperature increasing, while in opposite, the temperature decrease may increase the virus transmission's risk (Oliveiros et al. 2020; Moriyama et al. 2020; Yao et al. 2020). Furthermore, also a significant correlation with coronaviruses and relative humidity was observed regarding transmission rate (Metz and Finn 2015; Doğan et al. 2020). Zhu and Xie (2020) stated how the absolute humidity is negatively correlated to the COVID-19 spread especially in those regions with a wide humidity range. However, correlation of the spread of COVID-19 with climate is not yet clearly stated since none of the mentioned studies states with strong scientific evidence that temperature and humidity could have significant effect on the virus spread. The main limitation of this study was to not proper consider the effects of climate's factor (temperature and relative humidity) in different regions characterized by different climatic conditions to make a proper assertion. Considering such scenario, the aim of this study is to deeply investigate the correlation among COVID-19 spread and local meteorological factors within fourteen cities of Algeria (studies region), with different climates (humid, sub-humid, semi-arid, arid, and hyper-arid) and geographic position to provide useful clarifications for policymakers and the public audience on this possible correlation. A brief literature summary review on recent findings of previous studies has been done to be able to juxtapose our findings in the context of other studies and present a conclusive recommendation.

Materials and methods

Study area

The Algeria region is in North African continent, and it is classified as the largest African country covering an area of approximately 2,381,741 km² (Fig. 1). It extends from the Mediterranean coast in the North until the Sahara Desert in the South. It is bordered to the East by Tunisia and Libya, to the southeast by Niger, to the southwest by Mali, and to the West by Mauritania, Western Sahara, and Morocco. The nation holds a very special spot in the Mediterranean Basin with its geostrategic position and its demographic and economic weight. According with National Office of Statistic (Algeria), more than 43 million of habitants were estimated in 2018 with the higher density mainly concentrated in the North of the country along the Mediterranean coastline. The climatic conditions of the nation could vary considerably from North to South. Specifically, the coastal area has characterized by a Mediterranean climate, while the high plateaus are characterized by hot summers and cold low rainy winters. The Sahara Desert, in the South of the region, instead, represents a true example of extreme climate with very rare rain and strong differences in temperature between day and night. The rainfall regime can be classified as abundant along the coastal zone (North), ranging from 400 to 700 mm for year, with a substantial increasing precipitation pattern moving from West to East. Precipitations become even more abundant in the northern part of East Algeria, reaching 1200 mm in some years. The average temperature and humidity during summer range between 21 and 36 °C and 70 and 90%, respectively. In winter, instead the average temperature and humidity range from 8 to 12 °C and from 50 to 80%, respectively. Winters are so characterized by not too rigid temperatures but by very high relative

Table 3 Descriptive statistics for the daily new cases of COVID-19 in 14 cities (In different climates) and the meteorological variables

Variable	<i>N</i>	Mean	Std dev	Minimum	Maximum
Humid to sub-humid region: Algiers					
TMAX (°C)	153	29.30	5.01	16.5	41.8
TMIN (°C)	153	16.42	4.34	6.2	26.0
RHD (%)	153	70.36	9.63	44.0	91.0
Daily new cases (<i>N</i>)	153	30.02	24.06	0.0	116.0
Humid to sub-humid region: Annaba					
TMAX (°C)	153	27.82	5.01	16.1	42.3
TMIN (°C)	153	16.19	4.10	4.0	25.2
RHD (%)	153	75.71	8.23	52.0	92.0
Daily new cases (<i>N</i>)	153	7.65	12.00	0.0	75.0
Humid to sub-humid region: Jijel					
TMAX (°C)	153	27.52	4.38	17.7	38.4
TMIN (°C)	153	17.05	4.04	6.0	25.9
RHD (%)	153	69.50	8.97	42.0	89.0
Daily new cases (<i>N</i>)	153	4.51	7.21	0.0	45.0
Humid to sub-humid region: Oran					
TMAX(°C)	153	28.56	5.03	17.7	38.3
TMIN (°C)	153	17.95	4.25	6.8	26.0
RHD (%)	153	67.69	11.17	36.0	91.0
Daily new cases (<i>N</i>)	153	22.76	22.46	0.0	110.0
Humid to sub-humid region: Blida					
TMAX (°C)	153	29.30	5.01	16.5	41.8
TMIN (°C)	153	16.42	4.34	6.2	26.0
RHD (%)	153	70.36	9.63	44.0	91.0
Daily new cases (<i>N</i>)	153	20.64	12.92	0.0	70.0
Semi-arid region: Setif					
TMAX (°C)	153	28.95	6.72	11.2	40.8
TMIN (°C)	153	14.51	5.19	2.2	23.9
RHD (%)	153	43.78	18.03	17.0	94.0
Daily new cases (<i>N</i>)	153	19.33	18.46	0.0	102.0
Semi-arid region: Batna					
TMAX (°C)	153	31.77	6.69	14.3	43.0
TMIN (°C)	153	14.11	4.81	1.8	28.4
RHD (%)	153	45.55	14.90	20.0	80.0
Daily new cases (<i>N</i>)	153	9.88	14.20	0.0	70.0
Semi-arid region: Djelfa					
TMAX (°C)	153	28.53	6.98	9.8	38.7
TMIN (°C)	153	15.71	5.25	1.8	25.7
RHD (%)	153	36.38	17.57	14.0	91.0
Daily new cases (<i>N</i>)	153	7.26	11.25	0.0	94.0
Semi-arid region: Tiaret					
TMAX (°C)	153	30.25	7.42	10.5	41.2
TMIN (°C)	153	13.93	5.20	1.2	23.8

Table 3 (continued)

Variable	N	Mean	Std dev	Minimum	Maximum
RHD (%)	153	45.91	22.32	16.0	99.0
Daily new cases (N)	153	5.97	7.82	0.0	53.0
Semi-arid region: Naâma					
TMAX (°C)	153	31.73	6.47	14.9	40.5
TMIN (°C)	153	17.39	5.77	3.3	28.3
RHD (%)	153	33.13	13.27	14.0	76.0
Daily new cases (N)	153	1.66	2.86	0.0	16.0
Arid region: Ouargla					
TMAX (°C)	153	39.26	5.69	23.7	48.7
TMIN (°C)	153	24.07	5.09	9.6	33.7
RHD (%)	153	22.39	8.65	10.0	56.0
Daily new cases (N)	153	7.97	9.87	0.0	53.0
Arid region: Bechar					
TMAX (°C)	153	35.82	5.95	21.7	43.2
TMIN (°C)	153	23.59	5.91	10.8	35.4
RHD (%)	153	18.74	8.61	9.0	58.0
Daily new cases (N)	153	2.27	4.62	0.0	28.0
Hyper-arid region: Tamanrasset					
TMAX (°C)	153	35.83	1.86	29.4	40.7
TMIN (°C)	153	22.29	3.30	12.0	29.4
RHD (%)	153	17.54	10.00	8.0	68.0
Daily new cases (N)	153	1.29	3.13	0.0	18.0
Hyper-arid region: Adrar					
TMAX (°C)	153	41.69	5.40	22.0	48.4
TMIN (°C)	153	25.36	5.48	8.0	35.0
RHD (%)	153	16.38	8.04	8.0	69.0
Daily new cases (N)	153	4.07	6.30	0.0	34.0

humidity. In the high plateaus, the yearly rainfall substantially decreases ranging among 100 m and 400 mm, mainly occurring during the months of October and December. The average maximum and minimum temperatures in winter are 16 °C and − 2 °C, respectively, with sporadic snowfall on the highest peaks, while during summer, they are 42 °C and 10 °C, respectively. The relative humidity is moderate, varying from 30 to 60% in summer and from 60 to 80% in winter. In the Algerian Sahara's desert, the climate is classified as extremely arid to hyper-arid with the almost entirely absence of rainfall during the year, except for torrential rains. In this area, a significant difference in temperature between the day and the night also occurs. In winter, during the day, the temperature ranges from 20 to 30 °C with cold nights (− 5 to 10 °C). In summer, instead the temperature can reach 47 °C during the day and 30 °C at the night. The relative humidity

is low during all the year (less than 40%). Fourteen Algerian cities have been selected in different climatic regimes for this study, including (i) Algiers, Annaba, Jijel, Oran, and Blida in humid to sub-humid climate; (ii) Setif, Batna, Djelfa, Tiaret, and Naâma in semi-arid climate, (iii) Ouargla and Bechar in arid climate; and (iv) Tamanrasset and Adrar in hyper-arid climate (Fig. 1). The location of all cities center is reported in Table 1.

Data collection

Data of COVID-19 daily new cases were collected considering the fourteen Algerian cities from April 1, 2020, to August 31, 2020. The data was made available from the Algerian Ministry of Health (http://covid19.sante.gov.dz/carte/#pll_switcher).

Fig. 2 Variation of daily TMIN, TMAX, and new cases of COVID-19 in the humid to sub-humid regions (5 Algerian cities) (period: April 1, 2020, to August 31, 2020). Green, daily new cases of COVID-19; blue, TMAX; red, TMIN

To correlate the COVID-19 case with meteorological condition, a representative weather station was chosen for each city. The geographic characteristics of all the weather stations are reported in Table 2. The daily meteorological data, including maximum temperature (TMAX) (°C), minimum temperature (TMIN) (°C), and relative humidity (RHD) (%), were obtained from the National Weather Center (ONM) (<https://www.meteo.dz/previsions/carte>).

Data analysis

The effect of meteorological factors such as wind speed, temperature, sunshine hours, rainfall, and humidity on COVID-19 cases was usually examined using the Spearman correlation test (Rendana 2020), Pearson correlation, Kendall's rank correlation (Doğan et al. 2020; Shahzad et al. 2021), autoregressive distributed lag (ARDL) (Doğan et al. 2020), and linear regression method. Specifically, in this study, a linear regression method was utilized to investigate the interconnection among new cases of COVID-19 and the available factors.

First, a descriptive statistical of epidemiological data (daily new cases of COVID-19) along with daily meteorological factors during the period April 1, 2020–August 31, 2020, in the fourteen Algerian cities was also performed. Secondly, given the spatial and temporal variability of climate characteristics, the linear regression method was used to explore the relationship among daily meteorological factors and correspondent new cases of COVID-19. The number of daily new cases was chosen as dependent variables, while the daily meteorological factors were selected as independent variables. The formula used was as follows:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n$$

where Y is the linear function indicating a set of predictor variables, α indicates a numerical constant that represents an intercept, n is the number of predictor variables, X represents those meteorological factors that are significantly associated with epidemiological data, and finally β is the regression coefficients of X . Each β reflects how Y will change with the X , which is associated with the β , when all other X variables are constant (Jaccard et al. 2006). This analysis was performed in Origin Pro 2019b software.

Based on the statement of the World Health Organization (WHO) which reported an incubation period for COVID-19 between 2 and 10 days with a mean incubation period of 5.2 days (WHO 2020), 5 days lag time to assess the correlation between the new cases of COVID-19 and climate's factor variability has been considered (temperature and relative humidity).

Results

Description analysis

The descriptive statistics computed for the daily new cases of COVID-19 along with climate characteristics of temperature and humidity during the study period (April 1, 2020, to August 31, 2020) is shown in Table 3. According to the data, in humid to sub-humid regions, the daily new cases of COVID-19 ranged from a minimum of 0 in all cities to a maximum of 116 registered in the city of Algiers. The daily TMIN and TMAX vary from 4.0 °C in Annaba to 26.0 °C in Algiers and Blida and 16.1 °C in Algiers to 42.3 °C in Annaba, respectively. The RHD ranged between 36% in Oran to 92% in Annaba. In the semi-arid regions, the daily new cases of COVID-19 ranged from 0 (in all cities) to 102 (Setif). The daily TMIN and TMAX ranged from 1.2 °C in Tiaret to 28.4 °C in Batna and 9.8 °C in Djelfa to 43.0 °C in Batna, respectively. The daily RHD varies between 14% in Djelfa and 99% in Tiaret. In the arid regions, instead, the daily new cases of COVID-19 ranged from 0 to 53 (Ouargla). Here the TMIN and TMAX vary from 9.6 °C in Ouargla to 35.4 °C in Bechar and 21.7 °C in Bechar to 48.7 °C in Ouargla, respectively. The daily RHD ranged from 9 to 58% in Bechar. Finally, in the hyper-arid regions, the daily new cases of COVID-19 varied between 0 and 34 in Adrar. In this climatic zone, the TMIN and TMAX ranged from 8.0 to 35.0 °C and 22.0 to 48.4 °C, respectively, in Adrar. The daily RHD ranged from 8 to 69% in Adrar.

Effects of daily minimum and maximum temperatures and daily relative humidity on daily new cases of COVID-19

As previously described, the selected fourteen Algerian cities are characterized by different climatic conditions. The figures below show the effect of temperature on daily new cases of COVID-19, in these different cities and climates, during the 5-month period (April 1, 2020, to August 31, 2020).

In the humid to sub-humid regions (Figs. 2 and 3), the number of daily new cases ranged between 0 and 116.

- In Algiers the daily new cases of COVID-19 ranged between 0 and 116 for 3,615,149 inhabitants. The minimum number of daily new cases (0 cases) was observed on April 20, 2020, where the daily TMIN and TMAX were 14.4 °C and 24.4 °C, respectively, with a RHD of the 83%. However, the highest number of daily cases (116 cases) was observed on July 23, 2020, with a TMIN, TMAX, and RHD of 23.7 °C, 32.1 °C, and 70%, respectively.

◀ **Fig. 3** Variation of daily RHD and daily new cases of COVID-19 in the humid to sub-humid regions (5 Algerian cities) (period: April 1, 2020, to August 31, 2020). Green, daily new cases of COVID-19; pink, RHD

- In Annaba the daily new cases of COVID-19 ranged from 0 to 75 for 695,003 inhabitants. This city registered several days (55) with no confirmed cases of COVID-19. In this period, the daily TMIN and TMAX ranged from 4.3 to 23.2 °C and from 17.6 to 33.7 °C, respectively. The daily RHD ranged from 55 to 92%. The highest report of daily new cases instead (75 confirmed cases) was observed on August 24, 2020, when TMIN and TMAX were 20.7 °C and 30.6 °C, respectively with a daily RHD of 68%.
 - In Jijel the daily new cases of COVID-19 varied from 0 to 45 for 726,303 inhabitants. Also in these cases, several days (54) during the studied period registered no cases of COVID-19. The range of daily TMIN and TMAX was from 6.0 to 21.7 °C and 18.6 to 34.6 °C, respectively, while the daily RHD varied from 54 to 84%, whereas the number of maximum daily new cases (45 cases) was observed on August 29, 2020, with a daily TMIN and TMAX of 20.7 °C and 36.4 °C, respectively. In addition, the daily RHD was 42%.
 - In Oran the daily new cases of COVID-19 ranged from 0 to 111 for 1,822,544 inhabitants. The minimum value of daily new cases (0 cases) was observed in some days of April and May. In these 2 months, the daily TMIN and TMAX varied from 11.8 to 15.0 °C and 17.7 to 24.0 °C, respectively, while the daily RHD ranged from 64 to 91%. However, the maximum number (111 cases) was observed on July 17, 2020, where the daily TMIN and TMAX were 20.4 °C and 29.0 °C, respectively, with a daily RHD of 70%.
 - In Blida the daily new recorded cases of COVID-19 varied between 0 and 70 considering 1,348,839 inhabitants. The minimum report of daily new cases (0 cases) was observed in only 1 day of April 26, 2020, where the daily TMIN and TMAX were 15.4 °C and 20.6 °C, respectively, with a RHD of 86%. In addition, the higher number of daily new cases (70 cases) was reported on August 30, 2020, where the daily TMIN, TMAX, and RHD were 23.9 °C, 35.1 °C, and 68%, respectively.
- In the semi-arid regions (Figs. 4 and 5), the number of daily new cases ranged from 0 to 102.
- In Setif the daily new infected of COVID-19 ranged among 0 and 102 for 1,531,274 inhabitants. The lowest value of daily new cases (0 cases) was observed in a few days (6) of April and May. The daily TMIN and TMAX varied from 9.4 to 22.3 °C and 17.8 to 35.0 °C, respectively, with a RHD ranging from 21 to 82%. However, the maximum number of daily new cases

(102 cases) was observed on July 16, 2020, when the daily TMIN and TMAX were 17.7 °C and 31.2 °C, respectively, with a RHD of 63%.

- In Batna the daily new cases of COVID-19 ranged from 0 to 70 for about 1,354,757 inhabitants. The lowest value of daily new cases (0 cases) was observed in some few days (34) during the analyzed period. Accordingly, the daily TMIN and TMAX ranged from 1.8 to 21.9 °C and 14.3 to 40.3 °C, respectively, with a daily RHD ranging from 21 to 80%. The maximum number of daily new cases (70 cases) instead was observed on July 11, 2020, with daily TMIN and TMAX of 17.2 °C and 40.3 °C, respectively. The daily RHD for the same day was 25%.
 - In Djelfa the daily new cases of COVID-19 ranged between 0 and 94 for 1,434,840 inhabitants. The lower number of daily new cases (0 cases) was observed in some days (24), with a daily TMIN, TMAX, and RHD ranging from 1.8 to 23.7 °C, 12.5 to 35.8 °C, and 19 to 91%, respectively, whereas the higher number of new cases (94 cases) was observed on July 21, 2020, with a daily TMIN and TMAX of 19.7 °C and 32.6 °C, respectively. The daily RHD was 94%.
 - In Tiaret the daily report of COVID-19 ranged from 0 to 53 for 1,024,512 inhabitants. The minimum number of daily new cases (0 cases) was observed during several days (37) in the 5 months. The daily TMIN and TMAX in those days varied from 1.2 to 22.8 °C and 14.0 to 36.7 °C, respectively, while the daily RHD ranged from 23 to 98%. However, the maximum report of daily new cases (53 cases) was observed on July 21, 2020, where the daily TMIN and TMAX were 21.0 °C and 36.7 °C respectively, with a daily RHD of 23%.
 - In Naâma the daily new cases of COVID-19 ranged between 0 and 16 for about 319,686 inhabitants. The minimum number of daily new cases (0 cases) was observed during several days (81) of the study period (5 months), where the daily TMIN and TMAX ranged from 3.3 to 25.4 °C and 17.4 to 39.7 °C, respectively, and the daily RHD varied from 17 to 76%. The maximum number of daily new cases instead (16 cases) was registered on July 20, 2020, where the daily TMIN, TMAX, and RHD were 21.8 °C, 35.1 °C, and 37%, respectively.
- In the arid and hyper-arid regions (Figs. 6, 7, 8, and 9), the number of daily new cases varies between 0 and 53.
- In Ouargla the daily new cases of COVID-19 ranged from 0 to 53 for 733,797 inhabitants. The minimum report of daily new cases (0 cases) was observed during several days (32) of the study period (5 months). The daily TMIN, TMAX, and RHD in this period ranged from 9.6 to 31.6 °C and 23.7 to 47.9 °C and 11 to 48%, respectively. The highest number of daily new infected (53 cases) was observed on August 1, 2020, where the

Fig. 4 Variation of daily TMIN, TMAX, and new cases of COVID-19 in the semi-arid regions (5 Algerian cities) (period: April 1, 2020, to August 31, 2020). Green, daily new cases of COVID-19; blue, TMAX; red, TMIN

daily TMIN and TMAX were 22.6 °C and 43.1 °C, respectively, with a RHD of 17%.

- In Bechar the daily new cases of COVID-19 ranged between 0 and 28 for 338,495 inhabitants. The minimum number of daily new cases (0 cases) was observed during several days (90) of the study period (5 months), with a daily TMIN, TMAX, and RHD ranging from 10.8 to 33.6 °C, 22.6 to 43.1 °C, and 10 to 50%, respectively, whereas the maximum daily new infected (28 cases) was observed on May 26, 2020, with a daily TMIN and TMAX of 25.0 °C and 35.3 °C, respectively. In addition, the daily RHD was 17%.
- In Tamanrasset the daily new cases of COVID-19 ranged from 0 to 18 for 240,353 inhabitants. The minimum number of daily new cases (0 cases) was observed during several days (110) of the study period (5 months). The daily TMIN and TMAX in those days varied from 12.0 to 26.6 °C and 30.0 to 39.2 °C, respectively, while the daily RHD ranged from 8 to 61%. However, the higher number of daily new cases (18 cases) was observed on July 25, 2020, where the daily TMIN and TMAX were 25.7 °C and 34.9 °C with a daily RHD of 43%.
- In Adrar the daily new cases of COVID-19 ranged between 0 and 34 for 543,898 inhabitants. The minimum daily new cases (0 cases) were observed during several days (61) of the study period (5 months), where the daily TMIN and TMAX ranged from 12.1 and 33.9 °C and between 30.0 and 46.3 °C respectively, while the daily RHD varied from 9 to 60%. The higher number of daily new cases (34 cases) was observed on August 9, 2020, where the daily TMIN, TMAX, and RHD were 28.0 °C, 42.4 °C, and 18%, respectively.

After a first preliminary analysis, the results, considering the reported case in the investigated city, showed a very weak effect of temperature and relative humidity on daily new cases of COVID-19 that are not dependent from these climatic parameters.

Correlations between daily TMIN, TMAX, RHD, and daily new cases of COVID-19

Several scatter diagrams were realized to highlight the absence/presence of linear correlation among the considered meteorological factors and daily new cases of COVID-19 in the fourteen Algerian cities, during a study period of 5 months (April 1, 2020, to August 31, 2020). They are shown in Fig. 10 for sub-humid to humid regions (5 Algerian cities), Fig. 11 for semi-arid regions (5 Algerian cities), Fig. 12 for arid regions (2 Algerian cities), and Fig. 13 for hyper-arid regions (2 Algerian cities). From a first analysis of these diagrams, an inconsistent correlation between daily new cases of COVID-19 and meteorological data (TMIN, TMAX, and RHD) was found in the 14 Algerian cities (the correlation was extremely weak). Figures 12, 15, 18, and 21 show a decreasing linear trend of daily relative humidity (RHD) as a function of new cases of COVID-19 but with a weak negative correlation. Conversely, the temperature parameter representation (Figs. 10, 11, 13, 14, 16, 17, 19, and 20) show an increasing linear trend as a function of new cases of COVID-19 but always with a weak positive correlation. However, the linear regression equations and the correlation coefficients (R) for each parameter are presented in Table 4. In the humid to sub-humid regions (Figs. 10, 11, 12, and Table 4), the correlation coefficients (R) among daily TMIN, TMAX, and RHD with the number of daily new cases of COVID-19 ranged from 0.391 to 0.498, 0.332 to 0.490, and 0.105 to 0.324, respectively. In the semi-arid regions instead (Figs. 13, 14, 15, and Table 4), the correlation coefficients (R) among daily TMIN, TMAX, and RHD with the number of daily new cases of COVID-19 varied between 0.212 to 0.447, 0.274 to 0.423, and 0.167 to 0.316, respectively. Analyzing the arid regions (Figs. 16, 17, 18, and Table 4), the correlation coefficients (R) between daily TMIN, TMAX, and RHD with the number of daily new cases of COVID-19 ranged from 0.100 to 0.356, 0.173 to 0.351, and 0.032 to 0.272, respectively. Finally, in the hyper-arid regions (Figs. 19, 20, 21, and Table 4), the correlation coefficients (R) between daily TMIN, TMAX, and RHD with the number of daily new cases of COVID-19 ranged from 0.161 to 0.182, 0.182 to 0.217, and 0.100 to 0.110, respectively. Therefore, the results of the linear regression model further confirmed the weak correlation between meteorological data (weak negative correlation for RHD and weak positive correlation for temperature) and daily new cases of COVID-19 for the 14 considered Algerian cities.

Fig. 5 Variation of daily RHD and daily new cases of COVID-19 in the semi-arid regions (5 Algerian cities) (period: April 1, 2020, to August 31, 2020). Green, daily new cases of COVID-19; pink, RHD

Discussions

Today, the COVID-19 pandemic is the definitive global health crisis of our time and the greatest challenge facing by the world community (United Nations Development Program 2020). In this study, the relationship among few meteorological factors (TMIN, TMAX, and RHD) and daily new cases of COVID-19 in different climates across some regions in Algeria (North Africa) has been estimated and discussed. The obtained results stated a weak correlation among COVID-19's new cases and meteorological factors (temperature and relative humidity). The results also agree with the previous study investigation conducted by Prata et al. (2020) who showed how COVID-19 may not vanish at high temperatures, for example, during the period from 15 to 31 July 2020. Conversely, other studies (Zhu and Xie 2020; Wang et al. 2020a, b; Yongjiana et al. 2020; Núñez-Delgado 2020; Liu et al. 2020; Moriyama and Ichinohe 2019; Xu et al. 2020) observed how high temperatures could be beneficial to the disappearance of COVID-19, while low humidity environments could favor the transmission of COVID-19 (Sun et al. 2020; Kudo et al. 2019; Wu et al. 2020). For example, Auler et al. (2020) highlighted how the COVID-19 transmission rate in Brazil was initially favored by the high mean temperatures (27.5 °C) and intermediate relative humidity (near 80%). Generally, the infectious diseases such as the Severe Acute Respiratory Syndrome (SARS) and the influenza are strongly influenced by the low values of temperature and high values of humidity (Davis et al. 2016a, b) and how the transmission of pandemic influenza virus is favored under cold, dry conditions (Steel et al. 2011) this seems not be the cases of COVID-19. Summarizing in this study, we concluded that the COVID-19 could fit to both high or low temperatures and how it seems to not significantly vanish if the climate is wet or dry (high or low humidity). Despite this assumption, it is worth to mention that the higher R , especially for TMIN ($R=0.498$) and TMAX ($R=0.490$), correlations were observed in humid-sub humid and semi-arid regions. These regions are characterized by the higher population amount and density (in Algiers, Oran, and Setif cities where the density is 3,037; 862 and 385 people per square kilometer, respectively) that probably could affect more than climate characteristics of COVID-19 spread.

Accordingly, with this assumption, here two more examples in two cities with different climates around the world are reported (from October 1 to 10, 2020). In the city of Moscow (Russia), the daily new cases of COVID-19 ranged

from 2,424 to 4,082 where the daily TMIN and TMAX vary from 4.9 to 13.6 °C and 12.6 to 18.7 °C, respectively, and the RHD ranged from 42 to 84%. In Texas (USA), instead, the daily new cases of COVID-19 varied between 2,199 and 4,577. In the city, the daily TMIN and TMAX ranged from 11.9 to 20.2 °C and 27.3 to 37.9 °C, respectively, and the RHD ranged from 42 to 69%.

A further investigation focusing on the fluctuations in environmental pollutants and air quality before, during, and after each COVID-19 wave along with the study of the development trend in the same cities after vaccination of 70% of the country's inhabitants (according to the WHO recommendations) could give new insight to the research.

Conclusion

To determine the correct position on the current debate on impact of temperature and humidity on the viral spread of COVID-19, this study aimed to investigate the effects of these two parameters on the daily new cases of COVID-19 in 14 Algerian cities (North Africa) characterized by different climatic conditions (humid to sub-humid, semi-arid, arid to hyper-arid) from April to August 2020.

The findings showed that the daily new cases of COVID-19 pandemic, in cities with different climates, were not influenced by the increase or decrease in temperature or humidity, i.e., the effects of temperature and humidity on COVID-19 transmission are weak. The linear regression equations and the correlation coefficients (R) show a weak correlation between meteorological factors (temperature and relative humidity) and daily new cases of COVID-19. The correlation coefficients (R) between daily TMIN, TMAX, and RHD with the number of daily new cases of COVID-19 ranged from 0.100 to 0.498, 0.173 to 0.490, and 0.032 to 0.324, respectively. It should be noted that the higher R , especially for TMIN ($R=0.498$) and TMAX ($R=0.490$) correlations were observed in humid-sub humid and semi-arid regions. These regions are characterized by the higher population amount and density that probably could affect more than climate characteristics of COVID-19 spread.

Today, COVID-19 continues to spread globally, and the fourth wave of COVID-19 has been observed. The World Health Organization says that the COVID-19 pandemic is one big wave, not seasonal. It is now clear that this virus did not behave like influenza which tended to follow seasonal trends. The world was waiting for COVID-19 to fade with the rise in temperature or the decrease in humidity, but the latter adapted to the environment due to its genetic components "A.A.R.N," which made it difficult to detect a vaccine quickly.

Fig. 6 Variation of daily TMIN, TMAX, and new cases of COVID-19 in the arid regions (2 Algerian cities) (period: April 1, 2020, to August 31, 2020). Green, daily new cases of COVID-19; blue, TMAX; red, TMIN

Fig. 7 Variation of daily RHD and daily new cases of COVID-19 in the arid regions (2 Algerian cities) (period: April 1, 2020, to August 31, 2020). Green, daily new cases of COVID-19; pink, RHD

Fig. 8 Variation of daily TMIN, TMAX, and new cases of COVID-19 in the hyper-arid regions (2 Algerian cities) (period: April 1, 2020, to August 31, 2020). Green, daily new cases of COVID-19; blue, TMAX; red, TMIN

Fig. 9 Variation of RHD and daily new cases of COVID-19 in the hyper-arid regions (2 Algerian cities) (period: April 1, 2020, to August 31, 2020). Green, daily new cases of COVID-19; pink, RHD

Fig. 10 Scatter diagrams for correlation between daily TMIN and new cases of COVID-19 in the sub-humid to humid regions (5 Algerian cities) (period: April 1, 2020, to August 31, 2020). Red diamond, daily new cases of COVID-19; blue line, line of the best fit

After the discovery of the vaccine by some laboratories and before vaccination of 70% of the world's population, living with the virus has become an inevitable reality. The containment measures must be followed to stop other epidemic wave that is plaguing the world. Furthermore, it is necessary to apply the sanitary procedures to slow down the COVID-19 transmission such as wearing masks. We can think that the mask, by reducing the viral load, would allow its wearer to develop less symptomatic forms of the disease

and, at the same time, to acquire protection against COVID-19. Moreover, several in-home measures such as liquid chlorine, alcohol, and sanitizer to prevent the spread of infection have been adopted from community (Das et al. 2021). Also, the physical distancing among with an establishment a field monitoring to observe the extent of compliance with the health protocol is mandatory. This immunization, on a global population scale, could then prove to be a valuable weapon against the pandemic.

Fig. 11 Scatter diagrams for correlation between daily TMAX and new cases of COVID-19 in the sub-humid to humid regions (5 Algerian cities) (period: April 1, 2020, to August 31, 2020). Red diamond, daily new cases of COVID-19; blue line, line of the best fit

Fig. 12 Scatter diagrams for correlation between daily RHD and new cases of COVID-19 in the sub-humid to humid regions (5 Algerian cities) (period: April 1, 2020, to August 31, 2020). Red diamond, daily new cases of COVID-19; blue line, line of the best fit

Fig. 13 Scatter diagrams for correlation between daily TMIN and new cases of COVID-19 in the semi-arid regions (5 Algerian cities) (period: April 1, 2020, to August 31, 2020). Red diamond, daily new cases of COVID-19; blue line, line of the best fit

Fig. 14 Scatter diagrams for correlation between daily TMAX and new cases of COVID-19 in the semi-arid regions (5 Algerian cities) (period: April 1, 2020, to August 31, 2020). Red diamond, daily new cases of COVID-19; blue line, line of the best fit

Fig. 15 Scatter diagrams for correlation between daily RHD and new cases of COVID-19 in the semi-arid regions (5 Algerian cities) (period: April 1, 2020, to August 31, 2020). Red diamond, daily new cases of COVID-19; blue line, line of the best fit

Table 4 Results of the linear regression performed between daily TMIN, TMAX, RHD, and daily new cases of COVID-19

Region climate	Cities	Model formula	R^2	R
Correlation between daily TMIN and new cases of COVID-19				
Sub-humid to humid	Algiers	$y = 2.820x - 16.300$	0.238	0.488
	Annaba	$y = 1.164x - 11.300$	0.158	0.398
	Jijel	$y = 0.949x - 11.680$	0.222	0.471
	Oran	$y = 3.165x - 34.050$	0.248	0.498
	Blida	$y = 1.165x - 1.501$	0.153	0.391
Semi-arid	Setif	$y = 1.237x - 1.361$	0.121	0.348
	Batna	$y = 1.322x - 7.645$	0.200	0.447
	Djelfa	$y = 0.742x - 4.403$	0.119	0.345
	Tiaret	$y = 0.573x - 2.026$	0.145	0.381
	Naâma	$y = 0.105x - 0.171$	0.045	0.212
Arid	Ouargla	$y = 0.694x - 8.745$	0.128	0.356
	Bechar	$y = 0.023x + 1.718$	0.001	0.100
Hyper-arid	Tamanrasset	$y = 0.154x - 2.150$	0.026	0.161
	Adrar	$y = 0.218x - 1.502$	0.033	0.182
Correlation between daily TMAX and new cases of COVID-19				
Sub-humid to humid	Algiers	$y = 2.619x - 46.730$	0.237	0.487
	Annaba	$y = 1.136x - 23.970$	0.224	0.473
	Jijel	$y = 0.779x - 16.940$	0.223	0.472
	Oran	$y = 2.262x - 41.860$	0.240	0.490
	Blida	$y = 0.857x - 4.478$	0.110	0.332
Semi-arid	Setif	$y = 1.081x - 11.670$	0.155	0.394
	Batna	$y = 0.899x - 18.690$	0.179	0.423
	Djelfa	$y = 0.560x - 8.715$	0.120	0.346
	Tiaret	$y = 0.394x - 5.979$	0.140	0.374
	Naâma	$y = 0.121x - 2.194$	0.075	0.274
Arid	Ouargla	$y = 0.609x - 15.940$	0.123	0.351
	Bechar	$y = 0.045x + 0.655$	0.030	0.173
Hyper-arid	Tamanrasset	$y = 0.247x - 7.572$	0.033	0.182
	Adrar	$y = 0.254x - 6.511$	0.047	0.217
Correlation between daily RHD and new cases of COVID-19				
Sub-humid to humid	Algiers	$y = -0.323x + 52.750$	0.016	0.126
	Annaba	$y = -0.338x + 33.240$	0.053	0.230
	Jijel	$y = -0.260x + 22.640$	0.105	0.324
	Oran	$y = -0.109x + 30.160$	0.030	0.173
	Blida	$y = -0.141x + 30.580$	0.011	0.105
Semi-arid	Setif	$y = -0.274x + 31.340$	0.072	0.268
	Batna	$y = -0.289x + 23.060$	0.092	0.303
	Djelfa	$y = -0.185x + 14.020$	0.084	0.290
	Tiaret	$y = -0.100x + 11.050$	0.100	0.316
	Naâma	$y = -0.036x + 2.861$	0.028	0.167
Arid	Ouargla	$y = -0.311x + 14.950$	0.074	0.272
	Bechar	$y = -0.018x + 2.612$	0.001	0.032
Hyper-arid	Tamanrasset	$y = -0.004x + 1.213$	0.001	0.100
	Adrar	$y = -0.089x + 5.538$	0.012	0.110

Fig. 16 Scatter diagrams for correlation between daily TMIN and new cases of COVID-19 in the arid regions (2 Algerian cities) (period: April 1, 2020, to August 31, 2020). Red diamond, daily new cases of COVID-19; blue line, line of the best fit

Fig. 17 Scatter diagrams for correlation between daily TMAX and new cases of COVID-19 in the arid regions (2 Algerian cities) (period: April 1, 2020, to August 31, 2020). Red diamond, daily new cases of COVID-19; blue line, line of the best fit

Fig. 18 Scatter diagrams for correlation between daily RHD and new cases of COVID-19 in the arid regions (2 Algerian cities) (period: April 1, 2020, to August 31, 2020). Red diamond, daily new cases of COVID-19; blue line, line of the best fit

Fig. 19 Scatter diagrams for correlation between daily TMIN and new cases of COVID-19 in the hyper-arid regions (2 Algerian cities) (period: April 1, 2020, to August 31, 2020). Red diamond, daily new cases of COVID-19; blue line, line of the best fit

Fig. 20 Scatter diagrams for correlation between daily TMAX and new cases of COVID-19 in the hyper-arid regions (2 Algerian cities) (period: April 1, 2020, to August 31, 2020). Red diamond, daily new cases of COVID-19; blue line, line of the best fit

Fig. 21 Scatter diagrams for correlation between daily RHD and new cases of COVID-19 in the hyper-arid regions (2 Algerian cities) (period: April 1, 2020, to August 31, 2020). Red diamond, daily new cases of COVID-19; blue line, line of the best fit

Author contribution Abdelmadjid Boufekane conducted the literature review, prepared the datasets, interpreted the results, and drafted and finalized the manuscript; Gianluigi Busico contributed to the conception of the meta-analysis, interpreted the findings, and assisted in finalizing the manuscript; Djamel Maizi contributed to the literature review and dataset preparation. All authors have read and approved the manuscript.

Data availability The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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