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SARS-CoV-2 and the Weather: Correlation between COVID-19 and Meteorological Variables in 3 Cities in Mexico

Hermes Ulises Ramirez-Sanchez[1*], Alma Delia Ortiz-Bañuelos[1] and Aida Lucia Fajardo-Montiel[2]

[1]Institute of Astronomy and Meteorology CUCEI, University of Guadalajara, Av. Vallarta 2602. Col. Arcos Vallarta, CP 44130, Guadalajara, Jalisco, Mexico.
[2]University Center of Tonalá. University of Guadalajara. Av. Nuevo Periférico No. 555 Ejido San José Tateposco, C.P. 45425, Tonalá Jalisco, México.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Meteorological factors such as temperature, humidity, atmospheric pressure, wind speed and direction are associated with the dispersion of the SARS-CoV-2 virus through aerosols, particles <5μm are suspended in the air being infective at least three hours and dispersing from eight to ten meters. It has been shown that a 10-minute conversation, an infected person produces up to 6000 aerosol particles, which remain in the air from minutes to hours, depending on the prevailing weather conditions.
Objective: To establish the correlation between meteorological variables, confirmed cases and deaths from COVID-19 in the 3 most important cities of Mexico.
Methodology: A retrospective ecological study was conducted to evaluate the correlation of meteorological factors with COVID-19 cases and deaths in three Mexican cities.

*Corresponding author: E-mail: ramirez@astro.iam.udg.mx;

Results: The correlations between health and meteorological variables show that in the CDMX the meteorological variables that best correlate with the health variables are Temperature (T), Dew Point (DP), Wind speed (WS), Atmospheric Pressure (AP) and Relative Humidity (RH) in that order. In the ZMG are T, WS, RH, DP and AP; and in the ZMM are RH, WS, DP, T and AP.
Conclusions In the 3 Metropolitan Areas showed that the meteorological factors that best correlate with the confirmed cases and deaths from COVID-19 are the T, RH; however, the correlation coefficients are low, so their association with health variables is less than other factors such as social distancing, hand washing, use of antibacterial gel and use of masks.

Keywords: Correlation; weather; confirmed cases and deaths; SARS-CoV-2; Mexico.

1. INTRODUCTION

The COVID-19 disease caused by the SARS-CoV-2 virus was detected in December 2019 in Wuhan (China) [1-2], which was confined by the authorities when the outbreak became an epidemic [3]. On March 11, 2020, the World Health Organization declared COVID-19 a global pandemic [4]. Currently, the virus is distributed around the world [5] and does not follow a pattern of geographical distribution [6]. The pandemic has affected 216 countries causing a public health problem. In Mexico the first case of COVID-19 was detected on 27/02/2020 and the first death on 18/03/2020.

Knowledge of the virus, dispersal and spread in different climates, weather conditions and ability to cause disease has been the subject of recent research [7-18]; however, much is still unknown. Knowledge of the potential transmission routes of SARS-CoV-2 (respiratory/droplet, indirect, fecal-oral, vertical, sexual and ocular) are important in the application of preventive measures to mitigate the spread of SARS-CoV-2, associated with weather conditions.

Some factors such as temperature (T), relative humidity (RH), atmospheric pressure (AP), wind speed (WS) and wind direction (WD) are associated with dispersion, through the aerosol transmission mechanism: particles <5μm that are suspended in the air being infective for at least three hours, and moving from eight to ten meters [19]. Experimental models have shown that in a 10-minute conversation, an infected person produces up to 6000 aerosol particles, which remain in the environment and can remain in the air from minutes to hours, depending on the prevailing weather [7-8].

Some authors have suggested the relationship between weather conditions and the spread of SARS-CoV-2; and presence of the COVID-19 disease [19,7,8], so an ecological study was conducted to describe the correlation between meteorological variables (T, RH, AP, and WS) and confirmed cases and deaths from COVID-19 in Mexico City (CDMX), Guadalajara Metropolitan Area (ZMG) and Monterrey Metropolitan Area (ZMM).

SARS-CoV-2 belongs to the family of β-coronavirus, single-stranded ribonucleic acid (RNA) virus, positive polarity, envelope, not segmented, genome from 27 to 32 kb and size from 80-160 nm. Of the RNA viruses they are the largest and belong to group IV of the Baltimore classification [9]. Four distinct genera are known: α-coronavirus: mammals, β-coronavirus: mammals, γ-coronavirus: birds, fish, and δ-coronavirus: birds. The coronaviruses that affect humans with high pathogenicity are: Severe Acute Respiratory Syndrome-1 (SARS-CoV-1), Middle East Respiratory Syndrome (MERSCoV) and Severe Acute Respiratory Syndrome-2 (SARS-CoV-2), which are associated with severe illness [10].

The SARS-CoV-2 genome has 96% homology with the β-coronavirus of bats and 91% that of the pangolin; considered definitive and intermediate host respectively; has homology of 80% with SARS-CoV-1 and 55% with MERS-CoV [11-13]. 103 strains of SARS-CoV-2 and two haplotypes have been identified: type L (70%) and type S (30%); type L predominated in the early stage in China, with hypovirulence and increased transmission [12]. A recent analysis detected 160 SARS-CoV-2 genomes, identifying three strains: A, B and C by mutations.

The basic reproduction number (R0) of SARS-CoV-2 is variable according to the stage of the pandemic, the R0 calculated by the World Health Organization (WHO) was 1.94 and that of Wuhan was 2.2. However, R0 of up to 10 have been reported in "super transmitter" patients [14]. The rapid increase in cases suggests "super transmitters", individuals with the ability to transmit the virus >percentile 95, generating a higher number of cases than expected by common transmitters [15]. "Super transmission" responds to multiple virus, host, environmental, and human behavioral factors [16]. Children have been shown to have a higher prevalence of mild, unnoticed disease, making them potential "super transmitters," in closed, crowded places [13].

The transmission of SARS-CoV-2 has been described by direct and indirect mechanisms:

1. Direct: by respiratory secretions (main transmission mechanism): a) Transmission by droplets that have a size >5-10μm; are produced by talking, coughing, sneezing, singing, or breathing. Distances of one meter are traveled when talking and four meters when coughing or sneezing; b) Aerosol transmission: particles <5μm suspended in the air being infective for at least three hours, with higher concentration in the initial phase of the disease and displacement of eight to ten meters [19]. It has been shown that in a 10-minute conversation, an infected person produces up to 6000 aerosol particles that will remain with viral load according to the prevailing weather conditions [7-8].
2. Indirect: Another route of transmission is by contact; the virus is deposited on surfaces in droplets or aerosols of an infected individual and remains viable in the material where it was deposited. Thus, the approach with this surface and subsequent contact with some mucosa (oral, nasal or conjunctival) causes the infection. In experiments with SARS-CoV, MERS-CoV and other coronaviruses, average SARS-CoV-2 viability times were estimated in aluminum (two to eight hours), copper (four hours), latex (eight hours), plastic (72-96 hours), cardboard (24-96 hours), stainless steel (48-72 hours), paper (four to five days), glass and wood (four days) [7-8].
3. Other mechanisms: a) Fecal-oral: this mechanism is given by the ability to infection the cells of the intestinal epithelium, prolonged viral excretion in fecal matter has been reported in asymptomatic patients. The virus was detected in bowel movements for up to 42 days, while the nasopharyngeal swab was negative. Prolonged viral excretion occurs in pediatric patients in bowel movements more than 10 days after remission of symptoms: b) Vertical: Cases of newborn mothers with COVID-19 have been reported. However, more studies are needed to determine whether SARS-CoV-2 crosses the placental membrane; (c) Sexual: Positivity has been documented in the early stages of infection; more research is needed to demonstrate this route of transmission [19]; d) Ocular: There are few reports of conjunctivitis by SARS-CoV-2, the incidence is 0.8-4.8%. SARS-CoV-2 has been detected in tears and conjunctival secretions in patients with and without conjunctivitis. The incidence is low and is considered a potential route of infection [17]; and e) Blood: there is no evidence to suggest transfusion transmission of blood products [18].

Both asymptomatic and presymptomatic individuals are important in the transmission of the virus. Asymptomatic: Carriers are able to transmit the virus and develop lung injury despite not presenting any clinical manifestations. Presymptomatic transmission: it is possible during incubation and is a key factor for transmission by high viral excretion in the upper respiratory tract [7]. The prevalence of patients with SARS-CoV-2 positive CRP in this phase is 30-60%.

The COVID-19 pandemic shows the importance of adequate infection control by identifying the different routes of transmission of the virus and determining the role played by meteorological variables in them. It has been described that the respiratory tract and contact are the main routes of transmission, however, it has not been accurately evidenced how T, RH, AP and WS intervene.

Most of the research that relates atmospheric conditions with the distribution of SARS-CoV-2 concludes that a cool and dry environment in a mesothermal climate is the most suitable for its expansion. However, depending on the research design are the results, which makes it difficult to establish the effect of atmospheric conditions on the spread of the virus and disease, compared to other variables.

Traditionally, studies of the geographical distribution of diseases are carried out from the perspective of medical geography (environmental factors that influence their spread and the effects of the environment on people's health, [20]. Biometeorology and bioclimatology have been extended to medical practice, where the impact of atmospheric conditions on the human body is studied [21]. As for environmental factors, pathogens are subject to climatic and seasonal variations. However, bioclimatic studies are complex, time-consuming, systematic and controversial.

In 2002, during a SARS outbreak in the province of Guangzhou, it was evidenced that the optimal ambient temperature associated with SARS cases is 16 to 28°C and that the increase in cases is associated with cold waves and suggested a higher probability of occurrence with similar environmental conditions [21-23].

For their part, Chan et al. [24] evaluated the stability of the virus at different temperatures and relative humidity on solid surfaces. They showed that the virus maintains its viability more than five days at T between 22-25 ºC and RH between 40-50%, (T and RH of air conditioners). They also conclude that the higher the T and RH, the viability of the virus is rapidly lost and that the ideal environmental conditions for the preservation of SARS-CoV are low T and RH, which would facilitate its transmission in subtropical areas in the spring and in air-conditioned environments. They suggest that in tropical areas, with high T and RH environments, there were no large outbreaks of SARS-CoV.

Based on the above, the objective of this study is to determine the correlation of meteorological variables (T, RH, DP, WS and AP) with the number of confirmed cases and deaths from COVID-19 in the three most important cities in Mexico.

1.1 Study Area

The study includes the three most important metropolitan areas of Mexico CDMX, ZMG and ZMM (Fig. 1).

Mexico City (CDMX) is the capital of the United Mexican States. It is located in the Valley of Mexico and is administratively divided into 16 delegations: Álvaro Obregón, Azcapotzalco, Benito Juárez, Coyoacán, Cuajimalpa, Cuauhtémoc, Gustavo A. Madero, Iztacalco, Iztapalapa, Magdalena Contreras, Miguel Hidalgo, Milpa Alta, Tláhuac, Tlalpan, Venustiano Carranza and Xochimilco. The first confirmed case of COVID-19 occurred on 27/02/2020 and the first death on 18/03/2020.

The Metropolitan Area of Guadalajara (ZMG), is located in the central part of the state of Jalisco and is made up of ten municipalities, six with continuous conurbation: Guadalajara, Zapopan, San Pedro Tlaquepaque, Tonalá, El Salto and Tlajomulco de Zúñiga, the other four municipalities are: Juanacatlán, Ixtlahuacán de los Membrillos, Acatlán de Juárez and Zapotlanejo. The first case of COVID-19 occurred in Guadalajara on 14/03/2020 and the first death on 23/03/2020.

Fig. 1. Location of the CDMX, ZMG and ZMM
Source: https://www.turismomexico.es/estados-de-mexico/(modified by Ramírez, 2020)

The Metropolitan Area of Monterrey (ZMM) is the metropolitan area made up of 18 municipalities in the state of Nuevo León: Monterrey, Abasolo, Apodaca, Benito Juárez, Cadereyta Jiménez, Ciénega de Flores, El Carmen, García, Hidalgo, San Pedro Garza García, General Escobedo, General Zuazua, Guadalupe, Pesquería, Salinas Victoria, San Nicolás de los Garza, Santa Catarina and Santiago. The first case of COVID-19 was registered in Monterrey on 11/03/2020 and the first death on 03/04/2020.

2. MATERIALS AND METHODS

A retrospective ecological study was designed to establish the correlation of meteorological factors (T, RH, DP, WS and AP) with confirmed cases and deaths from COVID-19. in the 3 most important metropolitan areas of Mexico (CDMX, ZMG and ZMM) that presented the highest number of COVID-19 cases (Fig. 1).

Data on confirmed cases and deaths from COVID-19 were obtained from the repository of the National Council of Science and Technology (CONACYT) (https://datos.covid-19.conacyt.mx/). The repository gathers COVID-19 cases from official sources, counts of confirmed cases and deaths from 01/01/2020 to 27/02/2021 were transformed into records and time series were created.

The meteorological data were obtained from the meteorological stations that are located within the Metropolitan Areas studied (Sources: CONAGUA and Wunderground). Daily temperature (T), relative humidity (%), wind speed (WS), dew point (DP) and atmospheric pressure (AP) were obtained by season as a daily average. Subsequently, all stations were averaged to have a single daily value for each Metropolitan Area and correlate them with the confirmed cases and deaths from COVID-19 daily average by metropolitan area.

The data was processed and fed into the JMP 15.2.1 statistical analysis software (https://www.jmp.com/es_mx/home.html) to perform simple linear correlations between health variables and meteorological parameters. Subsequently, a group line adjustment was made, associating all meteorological variables with health variables. Likewise, a multivariate and principal component analysis was carried out, to end with an analysis of partial least squares, with the aim of confirming that meteorological factors had significant weight in the correlation. With these analyses, it was possible to show between which variables there are significant correlations and which are the meteorological factors that have the greatest association on the number of confirmed cases and deaths from COVID-19. Likewise, the association between temperature and humidity was evaluated since they are apparently the most significant variables. The contribution of T and RH to the viability and transmission of COVID-19 in the afore mentioned Mexican metropolises was examined, under the assumption that T followed by RH would have a predominant relationship, as reported in the literature [25-28].

3. RESULTS

The COVID-19 analysis included a total of 693372 confirmed cases and 40649 deaths in the 3 Metropolitan Areas between 01/01/2020 and 17/02/2021. In CDMX, 396 days were analyzed, in ZMM 344 days and in ZMG 343 days since the first case appeared. The highest number of confirmed cases occurred in CDMX, with 1344.6±1369.5 average daily cases and maximum of 7130; followed by the ZMM with 301.6±241.7 daily average cases and maximum of 1077; and the ZMG with 164.4±136.0 average daily cases and maximum of 714. The average daily deaths in CDMX were 65.1±52.6 and a maximum of 222; in the ZMM of 21.7±15.0 daily average and maximum of 64; and in the ZMG of 21.3±19.0 daily average and maximum of 85 (Table 1, Figs. 2-4).

The analysis of the meteorological variables included maximum, average and minimum of T, RH, DP, WS and AP of the 3 Metropolitan Areas for the same period analyzed of confirmed cases and deaths from COVID-19. As for the average temperatures, the CDMX presented the coolest values between 11.7 and 24.6 °C with an average of 18.1 °C, followed by the ZMG with values between 12.1 and 27.9 °C and an average of 19.8 °C, while the ZMM presented the warmest values between 16.4 and 28.2 °C with an average of 21.8 °C.

With respect $T_{maximum}$ the behavior is similar to the $T_{average}$ the CDMX had the coolest, while the ZMM presented the warmest and the intermediate ZMG. For the $T_{minimum}$ the behavior was inverse to that of the $T_{average}$ and $T_{maximum}$, the ZMM presented the coolest minimums, while the CDMX presented the warmest (Table 2).

Table 1. Total of confirmed cases and deaths by COVID-19 with their arithmetic average, standard deviations, maximum and minimum in the CDMX, ZMG and ZMM (Own authorship)

		Average	Dev. Standard	Maximum	Minimal	TOTAL
CONFIRMED COVID	CDMX	1344.6	1639.5	7130.0	0.0	533806
	ZMG	161.4	136.0	714.0	0.0	55509
	ZMM	301.6	241.7	1077.0	0.0	104058
COVID DEATHS	CDMX	65.1	52.6	222.0	0.0	25833
	ZMG	21.3	19.0	85.0	0.0	7339
	ZMM	21.7	15.0	64.0	0.0	7477

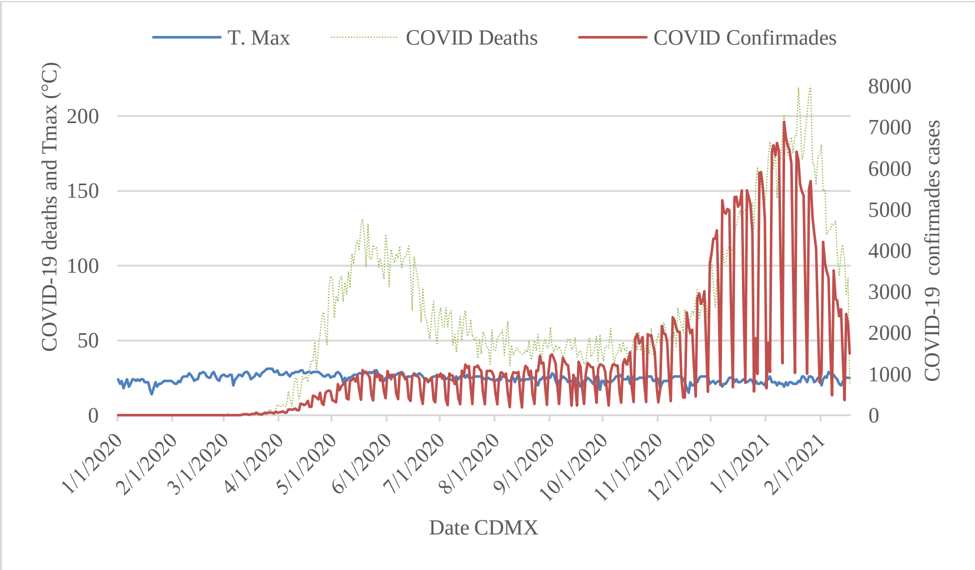

Fig. 2. Maximum temperature behavior, confirmed cases and deaths from COVID-19 during the period from 01/01/2020 to 17/02/2021 in Mexico City (Own authorship)

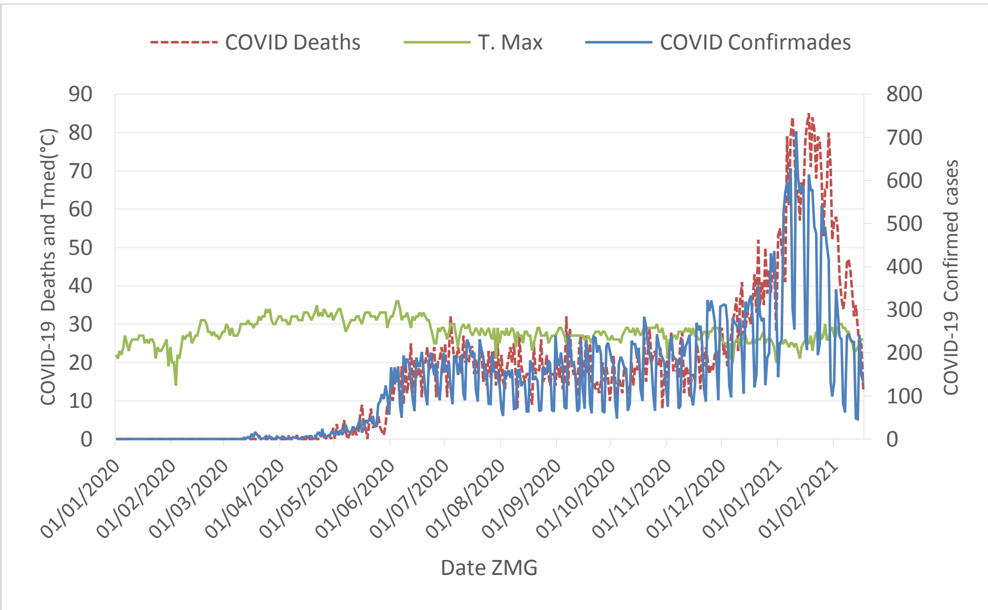

Fig. 3. Maximum temperature behavior, confirmed cases and deaths from COVID-19 during the period from 01/01/2020 to 17/02/2021 in the ZMG (Own authorship)

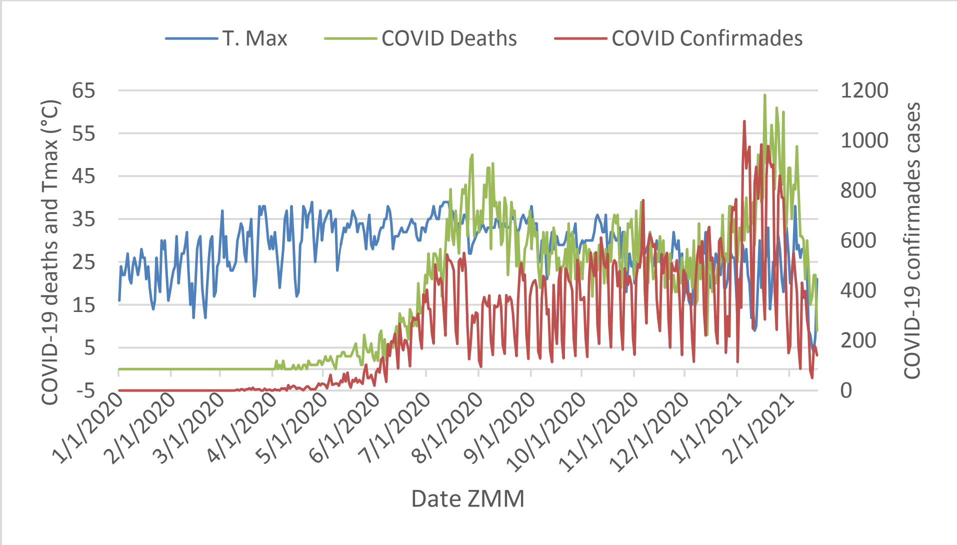

Fig. 4. Maximum temperature behavior, confirmed cases and deaths from COVID-19 during the period from 01/01/2020 to 17/02/2021 in the ZMM (Own authorship)

The relative humidity is intimately linked to the dew point so the behavior of both variables is almost identical. Thus, the $RH_{average}$ in the CDMX presented the lowest values between 24.7 to 73.5% with an average of 48.4%, followed by the ZMG with values between 24.3 to 78.8% and an average of 50.6%, while the ZMM presented the highest values ranging from 40.7 to 88.7% with an average of 65.3%. With respect to the $RH_{maximum}$ and $RH_{minimum}$ the behavior is similar to that of $RH_{average}$, the CDMX had the lowest, while the ZMM presented the highest and the intermediate ZMG. The dew point had the same behavior as the RH (Table 2).

The $WS_{average}$ wind speeds in Mexico City presented the highest values between 0.7 to 27.0 m/s with an average of 11.1 m/s, followed by the ZMM with values between 0.6 to 25.0 m/s and an average of 10.6 m/s, while the ZMG presented the lowest values between 0 to 22.1 m/s with an average of 6.4 m/s. The $WS_{maximum}$ presented different behavior to the $WS_{average}$, the highest maximums corresponded to the ZMM, followed by the ZMG and the lowest to the CDMX. With respect to the $WS_{minimum}$ presents a behavior similar to that of the $WS_{average}$, the CDMX had the highest minimums, while the ZMG presented the lowest and the intermediate ZMM (Table 2).

The atmospheric pressures $AP_{average}$, $AP_{maximum}$ and $AP_{minimum}$ had the same behavior being the highest in the ZMM, followed by the ZMG and the CDMX, linked to the height of each Metropolitan Area, being the ZMM the lowest height with 540 masl, followed by the ZMG with 1560 masl and at the end the CDMX with 2240 masl (Table 2).

The simple linear correlations and multivariate analysis between health and meteorological variables (average, maximum and minimum values) show that in the CDMX for confirmed cases of COVID-19 the most important meteorological factors of the maximums and averages are in descending order T, WS, DP, RH, AP and for the minimums T, DP, WS, RH and AP. For deaths from COVID-19 the meteorological factors that are most associated in descending order are; for maximums and minimums are T, DP, WS, AP and RH; and for average T, WS, DP, AP and RH. In summary, in CDMX the factors that best correlate with the health variables are T, DP, WS, AP and RH in that order (Table 3 and Fig. 5).

In the case of the ZMG for confirmed cases of COVID-19 the most representative meteorological factors with maximum values are T, RH, WS, AP and DP while for the averages they are T, WS, RH, AP and DP; and for the minimums are T, RH, AP, DP and WS. For deaths from COVID-19, the meteorological factors that are most associated in descending order; for maximum and average values are T, WS, RH, DP and AP, while for minimums T, AP, RH, DP and WS. In summary, in the ZMG the factors that best correlate with the health variables are T, WS, RH, DP and AP (Table 4 and Fig. 6).

Table 2. Descriptive statistics of the meteorological variables (Own authorship)

		Temperature (°C)			Relative Humidity (%)			Dew Point			Wind Speed (m/s)			Atmospheric pressure		
		Max	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**
Average	CDMX	24.6	18.1	11.7	73.5	48.4	24.7	8.7	5.5	0.9	27.0	11.1	0.7	784.3	782.4	780.0
	ZMG	27.9	19.8	12.1	78.8	50.6	24.3	10.6	7.1	2.6	22.1	6.4	0.0	851.4	849.3	846.8
	ZMM	28.2	21.8	16.4	88.7	65.3	40.7	16.5	13.9	10.7	25.0	10.2	0.6	972.7	969.8	967.1
Dev. standard	CDMX	2.8	2.4	3.1	14.6	12.7	11.1	3.9	4.5	6.3	7.2	2.8	2.1	1.7	1.6	1.7
	ZMG	3.1	3.2	4.5	13.5	15.0	13.0	5.0	5.9	7.4	10.5	2.6	0.0	1.8	1.6	1.8
	ZMM	6.6	6.1	6.5	12.6	15.2	17.3	6.9	7.6	8.6	13.8	3.3	2.1	5.5	5.1	5.2
Maximum	CDMX	31.0	23.5	18.0	100.0	79.1	60.0	15.0	12.8	12.0	59.0	21.7	13.0	789.6	787.6	785.8
	ZMG	36.0	28.3	21.0	100.0	84.2	68.0	18.0	16.3	15.0	143.0	16.2	0.0	858.8	855.6	852.6
	ZMM	39.0	32.8	28.0	100.0	97.6	88.0	30.0	23.0	22.0	144.0	22.3	11.0	996.0	987.5	984.7
Minimal	CDMX	14.0	11.6	2.0	28.0	14.8	4.0	-8.0	-12.7	-23.0	11.0	4.5	0.0	778.5	776.8	770.8
	ZMG	14.0	11.0	0.0	26.0	12.3	3.0	-4.0	-9.7	-20.0	9.0	1.2	0.0	846.4	844.7	840.7
	ZMM	4.0	-1.8	-5.0	33.0	22.4	5.0	-10.0	-12.5	-17.0	9.0	2.0	0.0	961.7	958.4	955.6

Table 3. Correlation between meteorological variables with number of confirmed cases and deaths due to COVID-19 in Mexico City (Own authorship)

CDMX	T. Max	DP Max	RH Max	WS Max	AP Max	COVID Conf.	COVID Deaths
T. Max	1	0.0556	-0.303	0.2977	-0.295	-0.3182	-0.1629
DP Max		1	0.7297	0.2549	0.0631	-0.2087	-0.125
RH Max			1	0.0904	0.2731	-0.0576	-0.0441
WS Max				1	-0.148	-0.2791	-0.1231
AP Max					1	-0.0243	-0.0922
COVID Conf.					-	1	0.7329
COVID Deaths							1
	T. Avg	**DP Avg**	**RH Avg**	**WS Avg**	**AP Avg**	**COVID Conf.**	**COVID Deaths**
T. Med	1	0.2393	-0.261	0.0972	-0.37	-0.3514	-0.1945
DP Med		1	0.8552	0.2161	0.1223	-0.1683	-0.1132
RH Med			1	0.1623	0.2933	-0.0244	-0.0415
WS Med				1	-0.037	-0.2676	-0.1618
AP Med					1	-0.0203	-0.0913
COVID Conf.						1	0.7329
COVID Deaths							1
	T Min	**DP Min**	**RH Min**	**WS Min**	**AP Min**	**COVID Conf.**	**COVID Deaths**
T Min	1	0.5536	0.3297	0.1153	-0.164	-0.326	-0.1715
DP Min		1	0.8605	0.1073	0.1917	-0.0798	-0.0809
RH Min			1	0.2079	0.3337	0.0321	-0.0374
WS Min				1	0.1217	-0.0691	-0.0628
AP Min					1	-0.0008	-0.0559
COVID Conf.						1	0.7329
COVID Deaths							1

Table 4. Correlations between meteorological variables with number of confirmed cases and deaths from COVID-19 in the ZMG (Own authorship)

ZMG	T.Max	DP Max	RH Max	WS Max	AP Max	COVID Conf.	COVID Deaths
T. Max	1	-0.0176	-0.484	0.2082	-0.2205	-0.2873	-0.309
DP Max		1	0.6407	0.012	-0.1193	0.0088	-0.0745
RH Max			1	-0.122	0.06	0.1563	0.107
WS Max				1	-0.2014	-0.1078	-0.1298
AP Max					1	0.0605	0.0408
COVID Conf.						1	0.8099
COVID Deaths							1
	T. Avg	**DP Avg**	**RH Avg**	**WS Avg**	**AP Avg**	**COVID Conf.**	**COVID Deaths**
T. Med	1	0.3306	-0.1597	0.4327	-0.2575	-0.3126	-0.3655
DP Med		1	0.8621	-0.104	0.0193	0.0292	-0.0591
RH Med			1	-0.343	0.1022	0.1641	0.0988
WS Med				1	-0.2054	-0.2866	-0.2888
AP Med					1	0.0569	0.0259
COVID Conf.						1	0.8099
COVID Deaths							1
	T. Min	**DP Min**	**RH Min**	**WS Min**	**AP Min**	**COVID Conf.**	**COVID Deaths**
T. Min	1	0.6929	0.5523	0	-0.1699	-0.1584	-0.2295
DP Min		1	0.8931	0	0.1391	0.0533	-0.0267
RH Min			1	0	0.1993	0.106	0.0522
WS Min				1	0	0	0
AP Min					1	0.1028	0.0724
COVID Conf.						1	0.8099
COVID Deaths							1

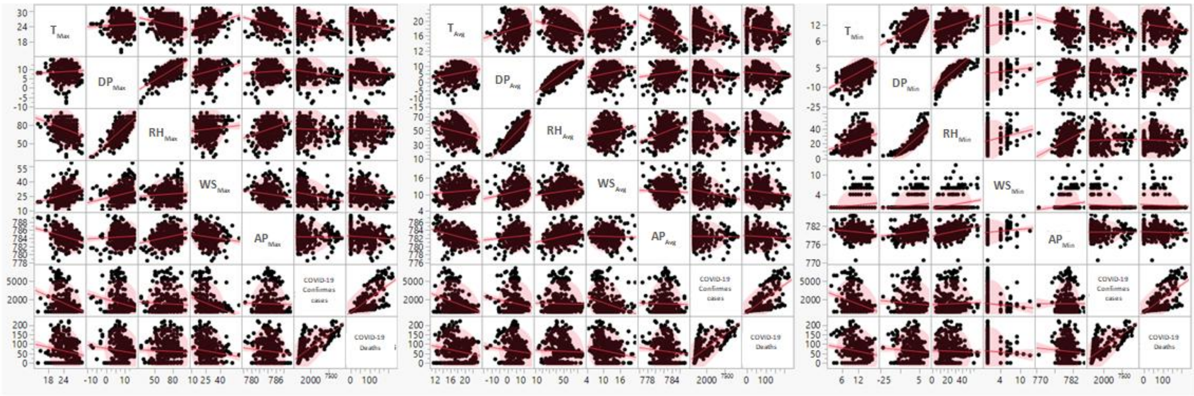

Fig. 5. Correlations between meteorological variables with number of confirmed cases and deaths due to COVID-19 in Mexico City (Own authorship)

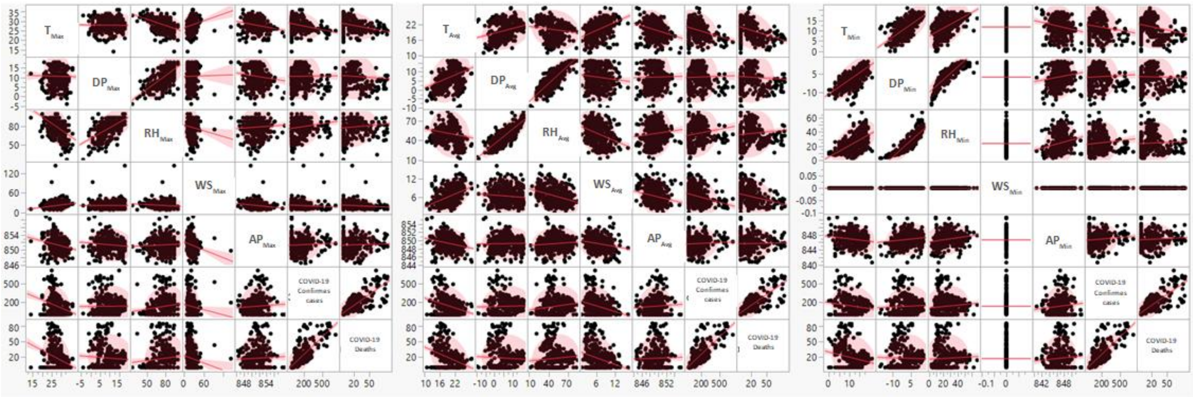

Fig. 6. Correlations between meteorological variables with number of confirmed cases and deaths due to COVID-19 in the ZMG (Own authorship)

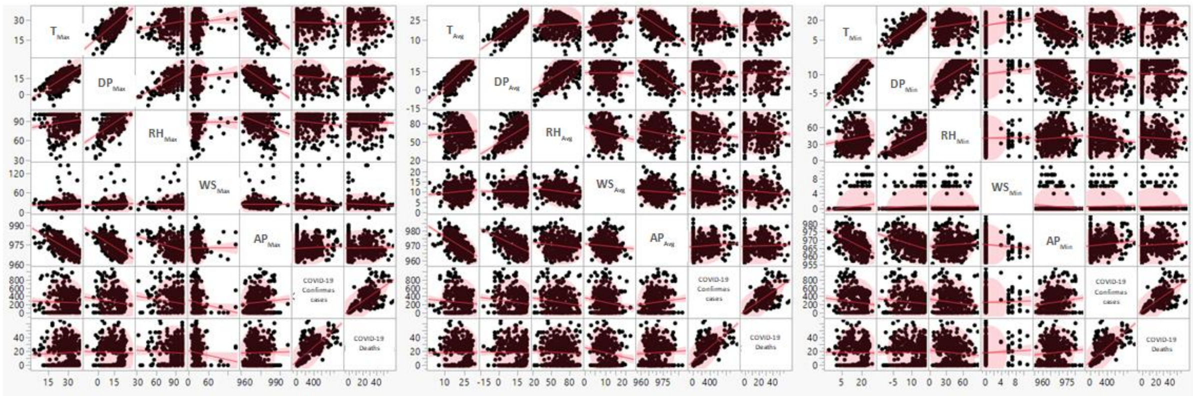

Fig. 7. Correlations between meteorological variables with number of confirmed cases and deaths due to COVID-19 in the ZMM (Own authorship)

In the case of the ZMM of the confirmed cases of COVID-19, the most representative meteorological factors with maximum values are AP, RH, T, DP and WS while for the averages they are RH, WS, DP, AP and T; and for the minimums are RH, DP, WS, AP and T. For deaths from COVID-19, the meteorological factors that are most associated in descending order; for maximum values are RH, AP, WS, DP and T, for the averages WS, RH, AP, DP and T; and for the minimum WS, RH, T, DP and AP. In summary, in the ZMM the factors that best correlate with the health variables are RH, WS, DP, T and AP (Table 5 and Fig. 7).

Table 5. Correlations between meteorological variables with number of confirmed cases and deaths from COVID-19 in the ZMM (Own authorship)

ZMM	T Min	DP Min	RH Min	WS Min	AP Min	COVID Conf.	COVID Deaths
T Min	1	0.831	0.169	0.1387	-0.508	-0.1144	-0.0169
DP Min		1	0.5431	0.0854	-0.392	-0.1077	-0.0178
RH Min			1	0.0048	0.0772	-0.1325	-0.0888
WS Min				1	-0.084	0.0245	0.0408
AP Min					1	0.1328	0.083
COVID Conf.						1	0.7681
COVID Deaths							1
	T. Avg	**DP Avg**	**RH Avg**	**WS Avg**	**AP Avg**	**COVID Conf.**	**COVID Deaths**
T. Med	1	0.8235	0.0727	0.1214	-0.639	-0.0782	0.0059
DP Med		1	0.6136	-0.007	-0.573	-0.1319	-0.0232
RH Med			1	-0.183	-0.16	-0.1472	-0.0588
WS Med				1	-0.087	-0.1446	-0.1463
AP Med					1	0.1069	0.0451
COVID Conf.						1	0.768
COVID Deaths							1
	T. Max	**DP Max**	**RH Max**	**WS Max**	**AP Max**	**COVID Conf.**	**COVID Deaths**
T. Max	1	0.7308	0.1741	0.0705	-0.693	-0.0328	0.0418
DP Max		1	0.6102	0.0671	-0.648	-0.1291	-0.0279
RH Max			1	-0.005	-0.339	-0.1336	-0.0465
WS Max				1	0.0022	-0.1151	-0.0912
AP Max					1	0.08	0.0172
COVID Conf.						1	0.7681
COVID Deaths							1

The analysis of principal components and partial least squares in the 3 Metropolitan Areas showed that the meteorological factors that best correlate with the confirmed cases and deaths from COVID-19 are the T, RH; however, the simple and multivariate correlation coefficients are low, so their association with health variables is less than other factors such as social distancing, hand washing, use of antibacterial gel and use of masks.

4. DISCUSSION

Based on the results obtained, it is evident that atmospheric variables can be associated on the viability and spread of the SARS-CoV-2 virus in outdoor spaces.

Several observational studies are based on statistical records of COVID-19 follow-up (accumulated cases, basic reproduction number, time intervals, transmission rates, mortality, among others) used as a response variable, when related to atmospheric variables used as independent variables, including temperatures (mean, minimum, maximum, amplitude), humidity (absolute and relative), solar radiation, wind and air quality; in some cases, supplemented by precipitation and/or evapotranspiration. This study used confirmed cases and deaths from COVID-19 vs T, RH, DP, AP and WS (maximum, medium and minimum).

Many studies argue that variables such as temperature and humidity are associated with the viability of SARS-CoV-2, others manifest discrepancies when explaining the geographical spread of COVID-19 related to atmospheric conditions. Some works extrapolate their results into the future, such as research based on epidemiological simulations or models of bioclimatic envelopes, which is dangerous without having a robust and long-term database.
Chin et al. [29] analyzed the stability of SARS-CoV-2 at different environmental conditions and conclude that at 4ºC the virus is highly stable (prolonged periods), at 22°C reduced stability after 7 days and not present at 14 days, at 37°C they did not detect viruses after the first day and at 56°C they did not detect viruses after 30

minutes. Al-Rousan & Al-Najjar [30] analyzed meteorological variables with an autoregressive model and found a significant effect of solar radiation and temperature on the spread of COVID-19 in many Chinese provinces and showed that as in the SARS outbreak (2003), the favorable environmental conditions for survival and spread of the virus are T between 13 and 24°C, RH between 50 and 80% and monthly rainfall <30 mm. In the present research the results in the three Metropolitan Areas showed that the $T_{average}$ are in the range conducive to the spread of the virus (12-28°C), the $T_{maximum}$ are above the range of viability of the virus (18-39°C), expecting reduction of cases and deaths (which did not happen) and the $T_{minimum}$ are in a range considered of high viability for the conservation and spread of the virus (-1.8-14°C). With respect to the $RH_{average}$ (25-89%) and $RH_{maximum}$ (60-100%), they are at limits considered viable for virus conservation, while the $RH_{minimum}$ (4-33%) are out of the range of virus conservation.

Wang et al. [27] investigated the effect of T and RH on COVID-19 transmission in Chinese cities using daily values of the effective reproduction number and conclude that high temperature and humidity significantly reduce the transmission of the virus, and suggest that the arrival of summer and rains in the northern hemisphere could significantly reduce the transmission of COVID-19, as with the flu virus. Bannister-Tyrrell et al. [31] studied the effect of seasonal variation on COVID-19 incidence and found that higher $T_{average}$ are associated with lower incidence of the disease. However, they mention that the T explained a modest amount of the total variation in the incidence of COVID-19, which coincides with what was reported in this study where the T modestly associated with the spread of the virus, although in a differentiated way between CDMX and ZMG versus the ZMM.

Sajadi et al. [32] analyzed meteorological data with the significant spread of COVID-19, using ERA-5 reanalysis data and contrasted the results with unaffected areas or no spread of the virus. They found that the distribution of the outbreaks was restricted to the latitude range (30°-50°N), temperature (5-11°C) and absolute humidity (4-7 g/m^3) consistent with the behavior of seasonal respiratory viruses. Ficetola & Rubolini [33] evaluated the effects of environmental factors on the dynamics of the early COVID-19 outbreak; finding that climate variables were the best explanatory factors for the global variation in the growth of COVID-19 cases; peaking in temperate regions of the Northern Hemisphere with $T_{average}$ around 5°C and specific humidity of 4-6 g/m^3, and decreased in warmer and cooler regions. In the present study, after analyzing more than a year of data, it was evident that this does not apply, since the growth of cases and deaths grew throughout the analyzed period regardless of seasonality or spatiality.

In some studies, meteorological data corresponding to the same time interval as epidemiological data were used, however, other authors used climatic parameters from past times, sizing the evaluation of correlations between these variables and COVID-19 cases [34]. Chen et al. [35] developed a global weather model where T, WS and RH combined were the best environmental predictors of virus transmission on a global scale. Holtmann et al. [36] show that low temperatures are associated with the faster spread of COVID-19 in early stages of the epidemic outbreak. While Álvarez-Ramírez&Meraz [37] found that T and RH influence the spread of SARS-CoV-2. Xie & Zhu [38] assessed daily COVID-19 cases and weather factors in 122 cities, with a generalized additive model to relate $T_{average}$ and confirmed COVID-19 cases through exposure-response curves. The results show that the $T_{average}$ has a "linear positive" relationship with the number of cases up to 3°C, and report that there is no evidence that the incidence of COVID-19 will increase when the T increases above this threshold. In the present study, like the authors mentioned, T and RH were the meteorological variables that best correlated with the viability of SARS-CoV-2, although in a modest way.

Shi et al. [25] evidenced that the highest incidence of COVID-19 occurred at T around 10°C and AH of $7g/m^3$, Ma et al. [39] correlated daily data on COVID-19 deaths, meteorological parameters and air pollution, with a generalized additive model and found that daily mortality is positively associated with thermal amplitude and negatively with AH. Gupta [40] concludes the opposite, every 1°C increase of T above 5°C translates into a 10% decrease in the rate of transmission of COVID-19 and showed that the doubling time of the number of cases correlates positively with T and inversely with RH which would suggest a decrease in the progression of COVID-19 as spring/summer arrives in the Northern Hemisphere. In the present research, the increase in T and RH did not discourage the spread of the virus.

Bashir et al. [41] analyzed the association between COVID-19 and meteorological variables, with non-parametric correlation techniques, showing that the $T_{average}$, $T_{minimum}$ and air quality presented a significant relationship with the incidence of COVID-19. The present research points in the same direction, however, its weighting is low compared to social factors (distancing, hand washing, use of gel, etc.).

Other authors indicate that there is no evidence that warm weather slows the COVID-19 epidemic. Harbert et al. [42] reported that in the United States there are more cases in cold areas and conclude that climate is not the main factor in the spread of COVID-19, since it occurs anywhere in the country, driven more by factors of human geography than by environmental factors, coinciding the present study with the authors.

Oto-Peralías [43] analyzed the correlation between confirmed cases of COVID-19 and geographical and meteorological variables; found a negative relationship between $T_{average}$ and COVID-19 cases. The T and the population density together, would explain 66% of the variation of confirmed cases of COVID-19, however, they do not distinguish the weighting of each variable. The Carlos III Health Institute and the State Meteorological Agency [44] related the number of new daily infections with the $T_{average}$, reporting negative correlation adjusting to an exponential model.

Briz-Redón&Serrano-Aroca [45] analyzed the relationship between the incidence of COVID-19 and environmental factors, using space-time modeling techniques with fixed and random effects, concluding that there is no evidence that higher T reduces COVID-19 cases. It was analyzed if the arrival of summer could reduce the pandemic, showing that 90% of COVID-19 transmissions occurred with T between 3-17°C and RH between 4-9 g/m^3. The total number of cases decreased to 6% with $T_{average}$ >18°C and HA >9 g/m^3. Thus, if humidity influences the transmission of the virus, its ability to limit transmission would be negligible in North America and Europe (RH <9g/m^3), unlike In Asian countries, where the monsoon could experience a decrease in transmission (AH >10g/m^3) during that time. Bhattacharjee [46] (2020), analyzed the relationship between COVID-19 and environmental factors in China and Italy, and found that the influence is not very significant, and concludes that there is no evidence that SARS-CoV-2 can be inactivated in the summer. Results that coincide with those presented in CDMX, ZMG and ZMM, where despite having high T and RH, the cases did not decrease.

Notari [28] reported a relationship between the rate of transmission of COVID-19 and decrease in T and concludes that for the northern hemisphere, the transmission rate should decrease with the increase in T, but mainly due to the effect of strong containment and monitoring policies. Baker et al. [47], used a climate-dependent epidemic model to simulate the pandemic, finding that RH variations can influence endemic infections; in the pandemic stage of an emerging pathogen (SARS-CoV-2) the climate would modestly influence the size and duration of the pandemic; and in the absence of effective control measures, significant cases would occur in the future, even in hot and humid climates, regardless of the influence of climate on the transmission of the virus.

Brassey et al. [48] point out that cold and dry conditions can influence the spread of SARS-CoV-2 through two mechanisms: the stability of the virus and the effect on the host. They conclude that the effect of climate may be minimal, hence the need to implement effective public health measures. Jüni et al. [49] suggest that as environmental factors will not reduce the spread of COVID-19 during spring-summer in the Northern Hemisphere, effective public health measures should be implemented in all seasonal scenarios to curb transmission, as it has been shown that public health measures to reduce the increase in the epidemic.

Pacheco et al. [50] analyzed the effect of socioeconomic, climatic, and transportation factors on the daily rate of increase of COVID-19. They found that the global connections of the global air transport network constitute the best predictor of the growth rate of COVID-19 in the affected countries; and that climate, geographical distance and socio-economic factors were not relevant. They conclude that the global air transport network caused the global pandemic as no containment measures were taken. Thus, they recommend an effective social isolation policy to avoid an increase in mortality rates resulting from the collapse of health systems. All this was confirmed since the existence of SARS-CoV-2 transmission has been recorded in 216 countries, covering all climatic zones of the world [51].

Although the viability of SARS-CoV-2 outside the human body depends on environmental conditions, as with other viruses such as SARS-CoV, MERS-CoV and influenza. Under experimental conditions, SARS-CoV-2 is viable in aerosols for a few hours and for days on solid surfaces [52-53, 7].

It is the viability of the virus in indoor and outdoor spaces that facilitates the mechanisms of contagion and what justifies continuing to carry out research where the relationship with meteorological variables is analyzed. The importance of the results of environmental research is confirmed by the correlation of T and RH on the viability of SARS-CoV-2, both indoors and outdoors.

Chin et al. [29], mentions that the viability of the virus in temperate climates is greater than in cool and dry environments. Coronaviruses belong to the family of enveloped (lipophilic) viruses, that is, they are covered by a fatty layer where proteins protrude like "spikes" that crown the envelope [54]. The investigation of other enveloped viruses suggests that their fatty layer makes them more susceptible to heat than those that do not, which would explain the seasonality of the outbreaks of enveloped viruses [55], which in the case of SARS-CoV-2 in Mexico has not been met, since it did not present seasonality throughout the period studied or in the CDMX, ZMG and ZMM.

An important aspect in the geographical distribution of COVID-19 is caused by humans, who as a host have mobilized the virus around the world, through direct and indirect infections. Thus, two aspects stand out, the means of transport as a mechanism of long-distance propagation; and the population density in short-distance infections, which puts mobility as the decisive vector for the moment.

On the other hand, from the ecological-environmental perspective, indirect contagion in certain environments and/or surfaces contaminated by the virus is important. Thus, the virus can persist on surfaces and be affected by T and RH; mainly in indoor spaces, such as hospitals (where surfaces are important vectors of transmission), hence the relevance of disinfection.

A very important element when considering the association of atmospheric conditions on SARS-CoV-2 is that space- and time-restricted data sets are used, from studies based on data from a few weeks, to wide-ranging studies where robust and long-term databases were ignored. Regression methods are to interpolate between known points, so extrapolation is risky when studying the influence of environmental factors on the geographical distribution of epidemics [44, 56].

Considering that mobility is a preponderant factor in the spread of SARS-CoV-2. Under this perspective, the meteorological factors involved in the geography of SARS-CoV-2 would not be the determining factor in the conservation and spread of the virus. It is also compatible to think that mobility and atmospheric conditions can operate together and no matter how small the magnitude of the effect of meteorological weather, these must be taken into account.

Another factor to consider in the association of atmospheric conditions in confirmed cases and deaths from COVID-19 are the cases detected, since the records are not the result of a systematic sampling of SARS-CoV-2 in outdoor spaces and therefore related to atmospheric conditions. The number of cases is only an approximation (distant or biased) of the prevalence of COVID-19 within a population and from there the presence of SARS-CoV-2 in the environment is inferred. This is conditioned by the level of development and effectiveness of public health services in each country. Even in countries with the best health systems, the epidemic curves of reported cases do not always reflect the true rate of epidemic growth, due to the number and nature of screening tests [57].

5. CONCLUSION

1. The highest average daily number of cases was for Mexico City with 1344.6±1369.5; followed by the ZMM with 301.6±241.7; and ZMG 164.4±136.0.
2. Regarding the number of average daily deaths, the CDMX was the highest with 65.1±52.6; followed by the ZMM with 21.7±15.0; and ZMG 21.3±19.0.
3. The correlation between health and meteorological variables show that for Mexico City the factors that correlate the number of confirmed cases and deaths from COVID-19 in order of importance are T, DP, WS, AP and RH. While for the ZMG they are T, WS, RH, DP and AP. And in the ZMM they are RH, WS, DP, T and AP. However, the correlation coefficients are

low, while there are other factors that could be more important such as mobility, social distancing, hand washing, use of antibacterial gel and masks.

4. The analysis of principal components and partial least squares in the 3 Metropolitan Areas shows that the meteorological factors that best correlate with confirmed cases and deaths from COVID-19 are T, RH, DP and WS.
5. The results show that it can be considered that atmospheric conditions can associated with the distribution of the SARS-CoV-2 virus and the COVID-19 disease, although it has not been possible to determine the actual weighting of each of them.
6. It is proposing that the relationship of COVID-19 cases and deaths with atmospheric conditions should be evaluated under controlled conditions of its main variables (T, RH) and their importance in the context of the mechanisms of contagion that produce the spread of the virus and the disease.
7 Finally, research with a biogeographic perspective is suggested, assembling components that interact and associate in bioclimatic and epidemiological models.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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