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Original Research

The Effect of Seasonal Factors on the Spread and Mortality of COVID-19: Retrospective Multicenter Study

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Abstract

Objectives: The impact of seasonal factors on the spread of Coronavirus-19 disease (COVID-19) is not yet clear. The aim of this study is to determine the effect of seasonal factors on the spread of COVID-19.
Methods: This multicenter retrospective study was performed by collecting 284-day COVID-19 data from two university hospitals in a metropolitan center. Correlations between the seasonal parameters of temperature, humidity, wind, and rainfall and the spread of COVID-19 and its clinical outcomes were evaluated using Spearman's correlation test. Since no linear relationship was determined between variables exhibiting correlation, all models were tested using non-linear curve estimation regression models. The most powerful of the curve estimation regression models, capable of explaining more than 20% of the changes in COVID-19 parameters, was formulated to explain the expected number of events.
Results: A total of 24 225 patients were included in the study. The most powerful correlation was between mean daily temperature and daily case numbers (r:-0.643, p<0.00), with case numbers being highest on days when the mean temperature was 7-18°C. Mean temperate was capable of explaining 57% of COVID-19 case numbers (R-Square:0.571, p<0.00), the relationship between them being best explained in the 'S' curve regression model. The formula ''Y=exp(2.07+31.34/x)'' was obtained for the number of patients expected from the model according to mean temperature.
Conclusions: Temperature may be the most effective factor in the spread of COVID-19 and the number of cases may be predicted based on temperature.

Keywords: *SARS-CoV-2, Pandemic, Temperature, Humidity, Fatality Rate*

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Introduction

Coronavirus-19 disease (COVID-19) caused by Severe Acute Respiratory Syndrome Corona Virus-2 (SARS-CoV-2) spread rapidly across the world, causing a pandemic (Scafetta, 2020). According to the World Health Organization (WHO) data, 756 411 740 people were infected from its first appearance to the beginning of 2023, and 6 842 462 of them died (*WHO Coronavirus (COVID-19) Dashboard | WHO Coronavirus (COVID-19) Dashboard With Vaccination Data*, 2023.). As with several infectious diseases, quarantine measures were some of the first precautionary initiatives introduced worldwide to prevent the spread of the virus, due to the severity of the disease. Optimizing quarantine conditions by predicting conditions that increase the spread of the disease is of considerable importance in terms of preparing health institutions for epidemics, and of minimizing the adverse effects of such measures on society.

During the global SARS-CoV-2 pandemic, it has been suggested that several factors can affect the rate of spread of the disease and its attendant mortality, such as interaction between individuals, living in large, busy cities, population density, the age of the population, and air pollution (Alzahrani et al., 2022; Scafetta, 2020). A limited number of studies have also suggested that seasonal factors may be one of the principal factors affecting the rate of dissemination of SARS-CoV-2 (Ma et al., 2020; Scafetta, 2020; Tosepu et al., 2020). However, no consensus has been achieved concerning the effect on the spread of the disease of seasonal factors such as temperature humidity, and wind. (Alzahrani et al., 2022; Harmooshi et al.., 2020; J. Liu et al.., 2020; Meo et al., 2020; Scafetta, 2020) One of the principal limitations of these studies investigating the relationship between weather and COVID-19 is that they are generally performed in areas as large as continents, cities, or regions (Alzahrani et al., 2022; Bolaño-Ortiz et al., 2020; J. Liu et al., 2020; Meo et al., 2020; Raza et al., 2021; Scafetta, 2020). However, population density, air pollution, health system, sociocultural factors, and meteorological factors are not homogeneous in the large areas in which such studies have been conducted, and this has been described as a limitation in them.

The aim of this study is to determine the relationship between the rate of transmission of COVID-19, admission rates to intensive care, mortality rates and climatic conditions more successfully, by monitoring for a long time in a region with homogeneous seasonal conditions.

Material and Methods

This retrospective, observational, multicenter study was performed by examining 284-day (from the day the first Covid-19 case was seen in the city until the end of 2020) COVID-19 data from pandemic clinics in two university hospitals in the north and south of the city of Turkey in İzmir. Turkey, where the study was conducted, lies at the 38-39th northern and 26-28th eastern meridians. İzmir is third largest city, with a total population of approximately 4.4 million in 2020. The population density is 366/km2, and the mean age is 37.2 (*TÜİK Kurumsal*, 2020). The ethical approval was obtained from local ethical committee of İzmir Katip Çelebi University in İzmir with approval number of 713 on the date of 12.05.2020 and by the Ministry of Health of Turkey clinical trials committee were registered with the registration number 2020-05-04 T09_17_13.

Patients with positive polymerase chain reaction (PCR) tests and patients diagnosed with COVID-19 as a result of imaging and clinical findings were included in the study. Patients aged under 18 were excluded. The study data were obtained from a retrospective examination of hospital records of patients presenting to the COVID-19 clinics. The North American Radiology Society expert consensus report was used in the interpretation of the pulmonary computed tomography images of PCR-negative patients in terms of COVID-19 (Simpson et al., 2020). These patients' hospital records were examined, and those whose diagnoses changed in the light of repeated PCR tests, swab tests for other viral agents, repeat imaging, or laboratory results were excluded from the study. Clinical outcomes were followed up one month after first admission and until discharge or death in case of hospitalized patients. The daily numbers of patients included in the study in this manner, their sex and age, and clinical outcomes due to COVID-19 were recorded, together with outpatient treatment, admitted to the ward, admitted to intensive care, or exitus status. The rate of admission to the intensive care unit (ICU) was calculated using the formula ''Number of patients admitted to the intensive care unit per day-/-number of patients diagnosed with COVID-19 per day'', while the fatality rate was calculated with the formula ''Number of exitus patients per day-/-number of patients diagnosed with COVID-19 per day''. Meteorological data were obtained following official application to the Meteorology General Directorate and included daily maximum temperature during the study period (°C), average temperature (°C), minimum temperature (°C), humidity (%), wind speed (m/sec), and rainfall (kg/m^2).

The primary outcome of this study was the COVID-19 case number, while the secondary outcomes were the rate of admission to intensive care and fatality. The effects of temperature, humidity, wind, and rainfall on the spread of COVID-19 and its clinical outcomes were investigated.

A professional biostatistics expert in our study team took part in the planning, processing and statistical analysis of the study. Data are presented as number of observations (n, %), mean ± standard deviation, and range (IQR). Homogeneity (Levene's test) and normality (Shapiro-Wilk test) results were used to select the statistical methods used to compare the study groups. Among normally distributed groups with homogeneous variances, dependent groups were compared using Student's t-test. According to the test results, parametric test assumptions were not met for some variables and independent groups were therefore compared using the Mann Whitney-U test. Relationships between two continuous variables were assessed using Pearson's correlation coefficient, or Spearman's correlation coefficient when parametric test conditions were not met. One-way analysis of variance was used to compare differences between three or more groups when parametric test conditions were fulfilled, and the Kruskal Wallis test when these were not met. The Bonferroni correction method, a multiple comparison test, was used to evaluate significant results concerning three and more groups. Univariate parametric and nonparametric regression methods were used to determine relationships between dependent and independent variables. SPSS 25 (IBM Corp., SPSS Statistics for Windows, version 25.0. Armonk, NY, USA) software was used to evaluate the data. The significance levels of the tests were assumed to be $p < 0.05$ and $p < 0.01$.

Results

A total of 121 738 patients presented to the pandemic clinics of the two centers with suspected COVID-19 during the 284 days study period. COVID-19 was diagnosed in 24 225 of these patients, ranging in age between 18 and 102, 57% of whom were men. A flow chart is shown in Figure-1. Analysis showed that 20.5% (n=4.969) of patients were admitted to the ward and 4.6% (n=1.108) to intensive care, while the remaining 74.9% were followed-up on an outpatient basis. Death occurred in 4.5% of patients (n=1.086) due to COVID-19 and its complications.

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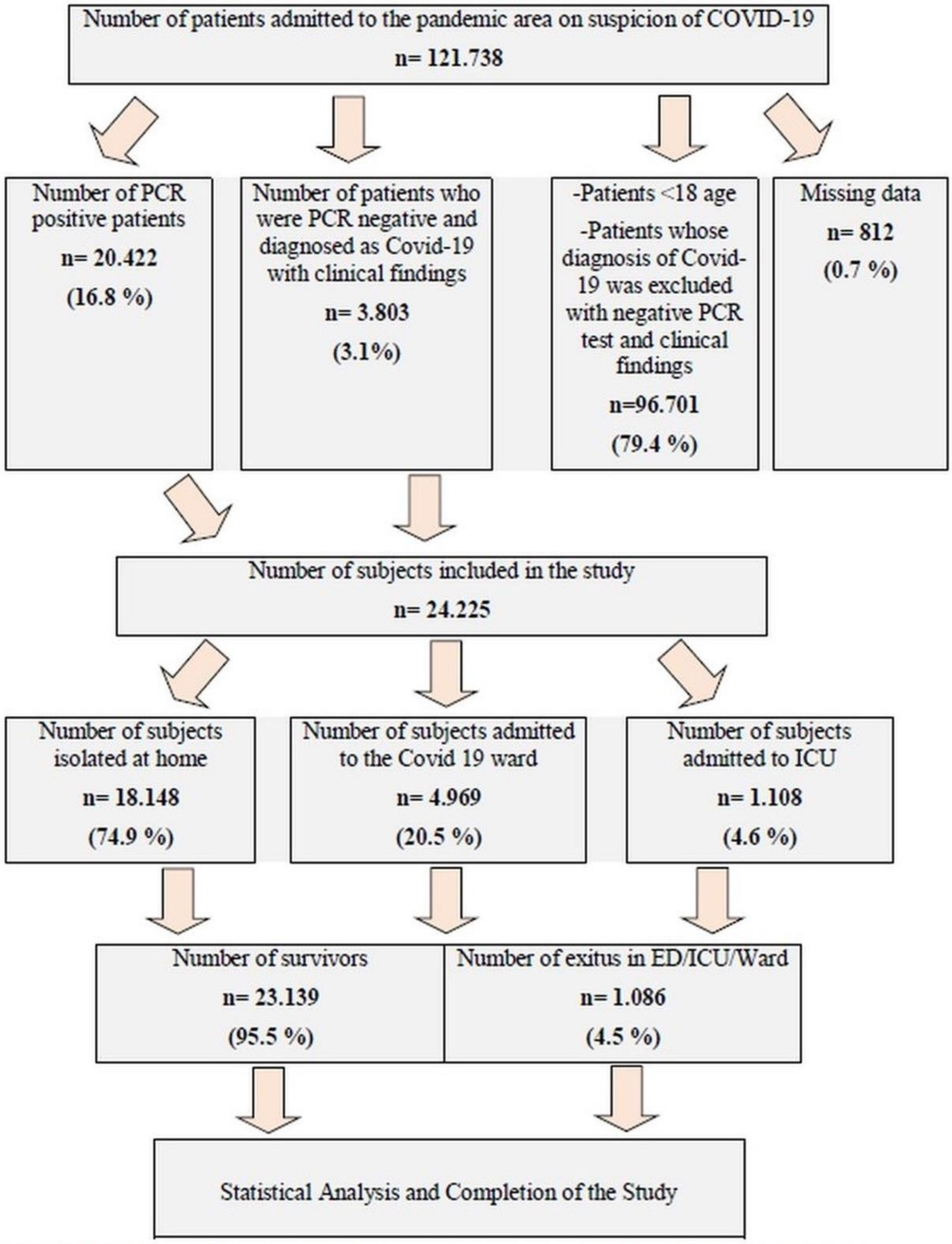

PCR: Polymerase Chain Reaction, **ICU:** Intensive Care Unit, **ED:** Emergency Department

Figure 1. Workflow chart.

The minimum temperature in the city where the study was conducted during the research period was -1-℃, and the maximum temperature was 39.2-℃. The daily number of COVID-19 patients, ICU admission rate, fatality rate and seasonal parameters in the province are shown in Table-1. Distribution showing the relationship between daily case numbers and seasonal parameters is shown in Figure-2a. Correlations between seasonal parameters and COVID-19 patient numbers, intensive care admission rates, and fatality rates are shown in Table-2. Examination of the relationship between daily COVID-19 case numbers and seasonal parameters revealed that the highest correlation was with mean temperature with inverse correlation being observed between them (r: -0.643, Table-2). When focusing on the graph of mean number of cases per day and mean temperature with the highest correlation coefficient, there were three different distributions of cases. The mean number of cases on days when the mean temperature was 18 °C or below was 162-±-160, the mean number of cases on days when the mean temperature was 19–25 °C was 27-±-12, and the mean number of cases on days when the mean temperature was 25-°C or higher was 30-±-11. Comparison of the three groups showed that the number of cases on days when the mean temperature was 18-°C or below differed significantly from those on days in the other two temperature groups (p<-0.001 for both at post hoc analysis). There was no difference in case numbers between days with temperatures of 18-25-°C and those with temperatures of 25-°C or more (p<-0.972).

Table 1. Monthly number of patients and seasonal variables.

	Daily Mean Covid-19 Cases (Mean±SD*)	ICU† Admission Rate (Mean±SD)	Fatality Rate (Mean±SD)	Minimum Temperature °C (Mean±SD)	Mean Temperature °C (Mean±SD)	Maximum Temperature °C (Mean±SD)	Humidity % (Mean±SD)	Wind Speed m/sn (Mean±SD)	Rainfall mm/m² (Mean±SD)
March	51 ± 13	0.10 ± 0.06	0.11 ± 0.08	7 ± 2	13 ± 1	18 ± 2	68 ± 9	6.7 ± 1.2	2.4 ± 5.3
April	68 ± 17	0.06 ± 0.04	0.07 ± 0.04	8 ± 3	15 ± 2	22 ± 3	55 ± 11	7.9 ± 1.7	1.7 ± 3.9
May	34 ± 12	0.09 ± 0.06	0.09 ± 0.07	13 ± 3	20 ± 4	27 ± 5	54 ± 12	7.9 ± 1.9	2.5 ± 5.2
June	29 ± 7	0.10 ± 0.05	0.09 ± 0.06	16 ± 3	23 ± 3	30 ± 3	53 ± 10	8.1 ± 1.5	1.3 ± 6.2
July	23 ± 6	0.08 ± 0.05	0.07 ± 0.06	22 ± 2	28 ± 2	34 ± 2	47 ± 8	9.2 ± 0.9	0
August	38 ± 11	0.08 ± 0.04	0.07 ± 0.04	22 ± 2	28 ± 2	34 ± 2	45 ± 9	8.8 ± 1.3	0
September	24 ± 8	0.11 ± 0.08	0.10 ± 0.08	19 ± 3	25 ± 2	32 ± 2	51 ± 7	8.6 ± 1.8	0
October	22 ± 8	0.14 ± 0.10	0.14 ± 0.10	13 ± 2	20 ± 3	27 ± 4	60 ± 11	6.8 ± 2.1	1.9 ± 6.3
Novemder	208 ± 162	0.05 ± 0.04	0.06 ± 0.04	7 ± 4	13 ± 3	19 ± 2	55 ± 8	7.2 ± 2.3	0.1 ± 0.6
December	330 ± 142	0.02 ± 0.01	0.02 ± 0.01	6 ± 4	11 ± 3	16 ± 2	72 ± 8	7.0 ± 1.9	7.8 ± 17.1

*SD: Standard Deviation, †ICU: Intensive Care Unit

Table 2. Correlation of seasonal parameters and number of Covid-19 patients, fatality rate and intensive care unit admission rate.

Variable	**cc‡ and p value**	**Number of Covid-19 cases**	**Fatality Rate**	**ICU§ Admission Rate**
Min °C|:	ρ†	-0.612***	0.185**	0.257***
	p	**<0.001**	**0.002**	**<0.001**
Mean °C¶:	ρ	-0.643***	0.221***	0.295***
	p	**<0.001**	**<0.001**	**<0.001**
Max °C††:	ρ	-0.642***	0.247***	0.316***
	p	**<0.001**	**<0.001**	**<0.001**
Humidity	ρ	0.309***	-0.151*	-0.160**
	p	**<0.001**	**0.011**	**0.007**
Wind Speed	ρ	-0.181**	0.057	0.069
	p	**0.002**	0.338	0.247
Rainfall	ρ	0.240***	-0.032	-0.070
	p	**<0.001**	0.589	0.239

Correlation is significant at the; * $p < .05$, ** $p < .01$, *** $p < .001$.
†:Spearman's rho, ‡: Correlation Coefficient, §: Intensive Care Unit, |: Minimum Temperature, ¶: Mean Temperature, ††: Maxiumum Temperature.

The seasonal parameter exhibiting the highest correlation with daily case numbers, after temperature, was relative humidity (Table-2). The case number and relative humidity graph (Figure-2a) shows that the mean case number on days when relative humidity was 40–80% (mean 92-±-130) was lower than that on days with a relative humidity below 40% (mean 33-±-12) (p:-0.032).

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When the distribution of COVID-19 fatality rate according to seasonal parameters is analyzed, it is seen that the relationship between them is weaker than the number of daily cases (Figure-2b). In the correlation analysis, a weak positive correlation was found between fatality rate and temperature, and a very weak negative correlation was found between fatality rate and humidity (Table-2). The distributions between COVID-19 ICU admission and seasonal parameters are shown in Figure-2c, correlation values between seasonal parameters and ICU admissions are similar to that of fatality rate.

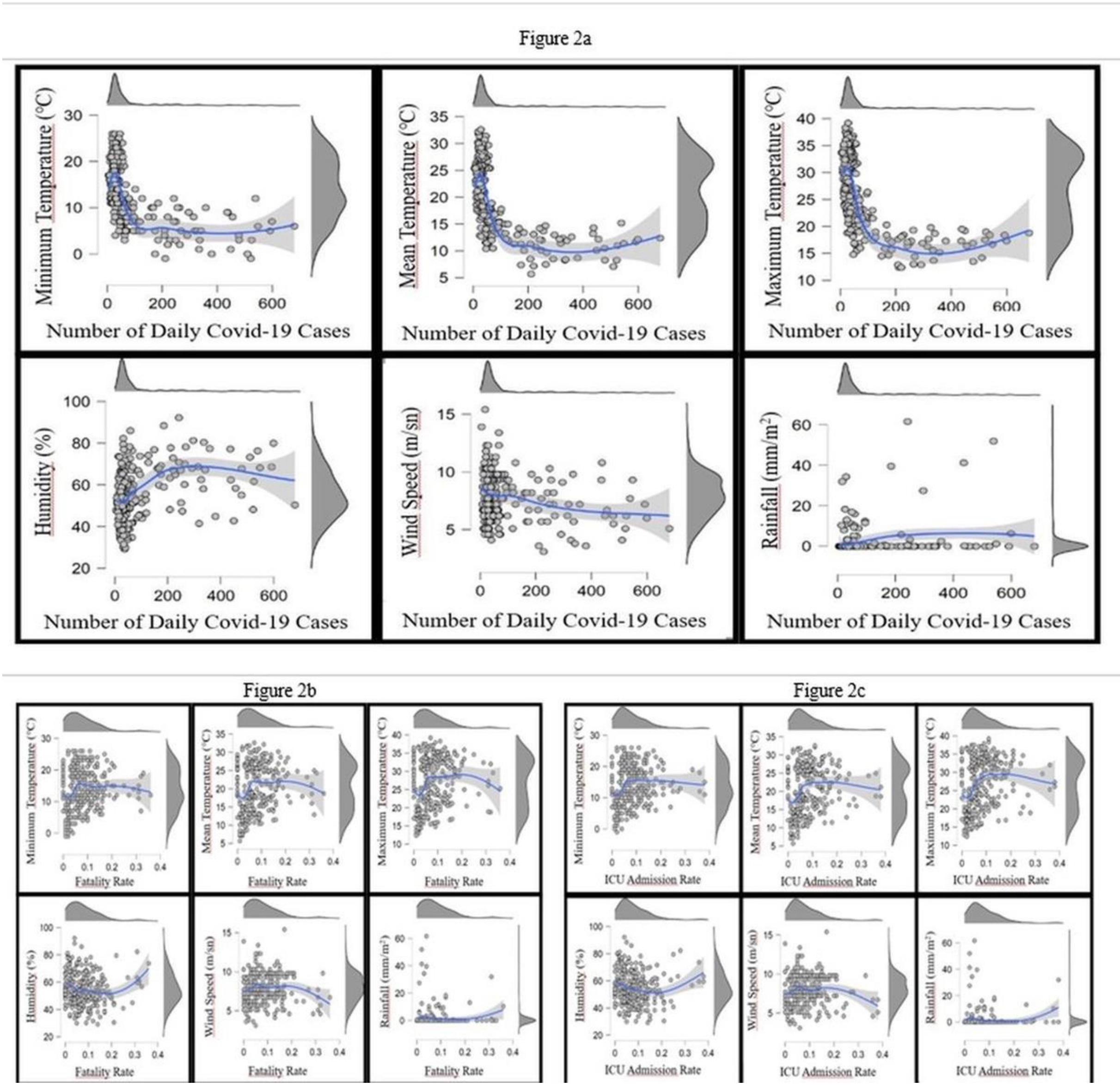

Figure 2. Scatter Plot showing the relationship between daily COVID-19 cases (2a), fatality rate (2b), intensive care unit admission rate (2c) and seasonal parameters.

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In the regression analyzes to test the strength of the relationship between seasonal variables and COVID-19 data; Correlations between daily patient numbers and seasonal factors (Suppl.-1), the fatality rate and seasonal factors (Suppl.-2), and the rate of admission to intensive care and seasonal factors (Suppl.-3) were measured on 10 regression curves (Linear, Logarithmic, Inverse, Quadratic, Cubic, Compound, Power, S, Growth, and Exponential). The most successful regression curves showing the relationship between seasonal parameters and Covid-19 patient data are presented in Table-3. The most powerful relationship was between mean temperature and daily patient numbers, which was obtained from the ''S'' curve regression model (Figure-3). The mean temperature parameter was found to explain 57% of the change in daily patient numbers in the model (R-Square:-0.571, p<-0.001). The number of patients anticipated depending on the mean temperature was calculated using the formula 'Y=-exp (2.0694-+-31.338 x)'. None of the other seasonal parameters was by itself able to explain more than 20% of the events and made no addition to the power when added to any model.

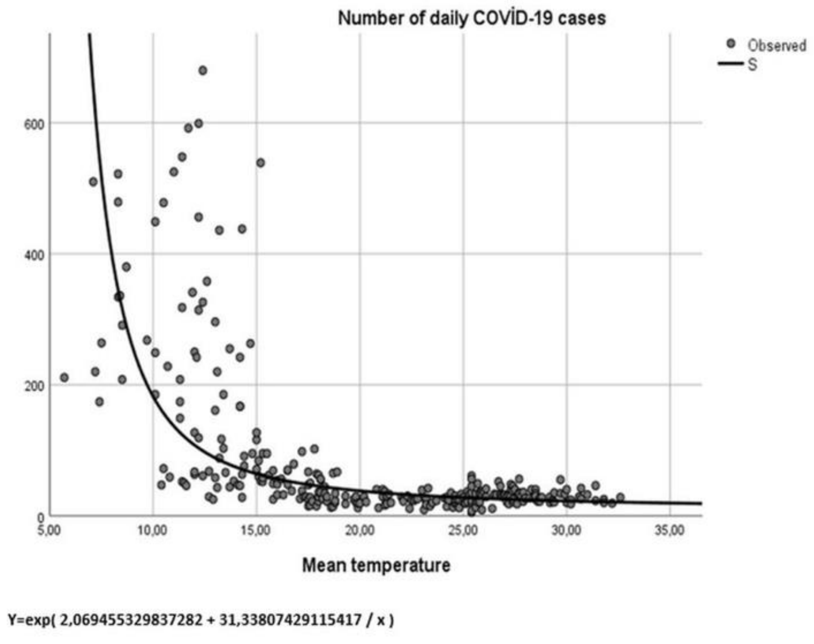

Figure 3. 'S'' regression curve offering the strongest relationship between daily COVID-19 cases and mean temperature.

Table 3. The most successful regression curves showing the relationship between seasonal parameters and Covid-19 patient data.

	Number of Daily Covid-19 Patients			Fatality Rate			ICU* Admission Rate		
	Equation	R Square	p value	Equation	R Square	p value	Equation	R Square	p value
Mean Temperature	S Curve	**0.571**	**<0.001**	Cubic Curve	0.105	**<0.001**	Cubic Curve	0.117	**<0.001**
Humidity	Compound Curve	0.144	**<0.001**	Cubic Curve	0.009	=0.493	Cubic Curve	0.009	=0.489
Wind Speed	Cubic Curve	0.081	**<0.001**	Cubic Curve	0.002	=0.906	Cubic Curve	0.002	=0.910
Rainfall	Quadratic Curve	0.051	**=0.001**	Cubic Curve	0.011	=0.395	Quadratic Curve	0.010	=0.242

*: Intensive Care Unit

Discussion

Knowing the factors affecting the rate of transmission and mortality during the ongoing worldwide COVID-19 pandemic will make it possible to predict patient numbers beforehand, and to take the requisite precautions in the health system, thus facilitating effective allocation of resources. Unlike other studies conducted for the same purpose (Bolaño-Ortiz et al., 2020; J. Liu et al., 2020; Meo et al., 2020; Scafetta, 2020; Çınaroğlu,O.S et al.,2022), this study was conducted in a more homogeneous region in terms of seasonal and social variables. In addition, COVID-19 patients were included in the study not solely on the basis of PCR tests, but also of clinical findings. In this study, with its entirely original design, the strongest and most appropriate relationship was between mean temperature and the number of daily COVID-19 cases. The highest correlation between mean daily temperature and daily case numbers was obtained in the 'S' curve regression model, and alone was powerful enough to explain 57% of daily case numbers. The relationship between mean temperature and daily case numbers is expressed with the formula 'Y=-exp (2.0694-+-31.338 x)'. The mean temperature range causing the highest rise in case numbers in our population was 7-18°C. Although correlation was also determined between daily case numbers and wind speed, rainfall, and relative humidity, none of these was powerful enough to contribute to the model. Correlation, albeit weak, was observed between patients' admission to intensive care and mortality rates and heat parameters and relative humidity but it was not strong enough to form a model.

Similarly to the results of the present study, moderately cool weather has been reported to encourage the spread of the virus in several previous studies (Bolaño-Ortiz et al., 2020; Harmooshi et al., 2020; J. Liu et al., 2020; Scafetta, 2020). Liu et al. reported that 40–60% of COVID-19 case numbers can be explained through changes in temperature, a figure highly compatible with our finding of 57% (X. Liu et al., 2021). Salcido et al. also reported moderate-powerful correlation between temperature and COVID-19 case numbers (mean-r:-0.50), also very similar to the correlation determined in the present study (r:-0.643) (Salcido & Castro, 2022). However there are also studies reporting weak or very weak correlation between temperature and case numbers (r:-0.062) (Menebo, 2020; Meo et al., 2020;; Tosepu et al., 2020). The second parameter affecting case numbers in the present study was humidity, with weak positive correlation being observed between the two, with humidity exceeding 40% being associated with increased case numbers. However, relative humidity was only sufficiently powerful to explain a very small part of case numbers (Table-3), and its contribution to the regression model was low. Consistent with the present research, some previous studies have also linked increased humidity to increased case numbers (Bolaño-Ortiz et al., 2020; Harmooshi et al., 2020; Scafetta, 2020), although others have associated low humidity with rising case numbers (Alzahrani et al., 2022; Bolaño-Ortiz et al., 2020; Endeshaw et al., 2022; J. Liu et al., 2020). Others again have suggested that there is no significant association between the two (Salcido & Castro, 2022; Tosepu et al., 2020). Studies reporting positive correlation between humidity and case numbers, similarly to the present research, predict that high temperatures and dry air will reduce transmission by preventing the formation of small condensation droplets that permit the virus to remain viable in the air for extended periods (Scafetta, 2020). It has therefore been suggested that remaining in enclosed areas for long periods in cold seasons in particular can facilitate the transmission of the virüs (Fuhrmann, 2010; Harmooshi et al., 2020). Another parameter exhibiting significant correlation with case numbers in the present study was wind speed, with very weak, negative correlation being observed between them. Our results are consistent with those of studies reporting that wind speed is linked to a decrease in COVID-19 case numbers by removing from the air particles associated with the transmission dynamics of viral infection (Bolaño-Ortiz et al., 2020; Coccia, 2020). The final parameter associated with case numbers in this study was the amount of rainfall, with weak positive correlation being observed between the two. However, in contrast to our findings, Menebo et al. reported a weak negative correlation between rain and case numbers (r:-−0.285) (Menebo, 2020). Nonetheless, inconsistent findings have been obtained on this subject (Raza et al., 2021; Tosepu et al., 2020). The city where this study was conducted has a temperate climate, and rain is generally seen only in the winter. We therefore think that the increase in case numbers of cases in line with the amount of rainfall is actually related to the decrease in temperature and increase in humidity,

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which are stronger parameters. The amount of rainfall as also identified as a confusing factor in the regression models applied and made no contribution to the model.

As shown above, there is inconsistency between studies regarding seasonal factors that may affect case numbers. However, the most important limitations of previous studies are that they have been performed within a short period and in very large and non-homogeneous areas. They have also been based on declared PCR results, rather than being conducted in the field (Menebo, 2020; Meo et al., 2020;; Salcido & Castro, 2022; Tosepu et al., 2020). Unlike the others, in two studies that were conducted for a longer period of time, the distribution of temperature values during the working period is quite different from our region, and this difference may have affected the results of the studies. (Alzahrani et al., 2022; Endeshaw et al., 2022.) The present study was therefore carried out in a city that is homogeneous in terms of many characteristics, and we endeavored to avoid these limitations observed in other studies by examining data for 284 days.

The parameters exhibiting correlation with admission to ICU and mortality rates in this study were temperature and humidity. Case numbers decreased as temperature increased, resulting in increased admission to intensive care and mortality rates. Consistent with the present study, both Ma et al. (Ma et al., 2020) and Meo et al. (Meo et al., 2020;) reported positive, very weak correlation between temperature and mortality (r: 0.118). But the effect of temperature on mortality was in any case weak and was able to explain only a very few of the fatalities (Table-3). Another seasonal factor with an effect on patient mortality in this study was relative humidity, which exhibited negative and very weak correlation. This finding was similar to the negative correlation reported by both Ma et al. (Ma et al., 2020) and Meo et al. et al., 2020;) This suggests that consistent with several other studies, relative humidity is correlated with mortality, albeit weakly. However, relative humidity was only able to explain a very few fatalities, and it made no powerful contribution to the regression models (Table-3).

Conclusion

In this study, which examined the relationship between seasonal parameters and COVID-19 data, it was found that the mean temperature was the most effective factor on the number of daily cases. Mean temperature alone was found to be the main factor that could explain more than half of the number of daily COVID-19 cases. In the fight against this epidemic, the temperature parameter should be closely monitored, and necessary precautions

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should be taken by anticipating that the number of cases will increase in days and seasons when the temperature is expected to be low.

Limitations

Although this study was conducted in the emergency department, the study also links environmental medicine issues. The most important limitation of this study is that it involves missing data, associated with their being obtained retrospectively. A second important limitation is that the centers where the study was conducted are advanced university hospitals to which patients in severe conditions are referred from external centers. These patients' severe clinical conditions may have led to an increase in fatality and admission to ICU rates.

Conflict of Interest

Author declare no conflinct of interest.

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