Investigating the effects of regional characteristics on the spatial distribution of COVID-19 pandemic: a case of Turkey

Cem Kırancıoğlu¹

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Abstract

Today, the COVID-19 pandemic continues to threaten all humanity worldwide. Turkey, one of the countries severely affected by the disease, has 81 provinces showing regionally different incidence rate patterns. This study explores the effect of social, economic, demographic, climatic, and geographic characteristics of different regions on the COVID-19 spread in Turkey. Geographic Information System (GIS)-based spatial interpolation techniques and multiple linear regression analysis have been conducted to examine the relationship between provincial incidence rates and eighteen explanatory variables determined by an in-depth literature survey. Results show that five of eighteen predictors have a statistically significant impact and can explain 57% of the regional variability of the COVID-19 incidence rates. Urbanization level, education index, and wind speed positively associate with the virus spread, but the sunshine duration and average temperature negatively correlate. On the other hand, 43% of the variation is due to other factors not included in this study. Therefore, an interdisciplinary study should be carried out by participating in all the related fields such as natural sciences, engineering and technology, medical and health sciences, social sciences, and humanities to understand the dynamics of the disease.

Keywords COVID-19 · GIS · Regression analysis · Turkey

Introduction

After the first case in China in December 2019, COVID-19 pandemic now threatens all humanity. Currently, there are 393,502,787 confirmed cases and 5,735,289 deaths on the global scale (JHU 2022). Until now, many scientific studies have been carried out, and a vast amount of scientific articles has been published worldwide to understand the effects of social, demographic, economic, physical, biological, geographic, and environmental factors on COVID-19 incidence rates. The literature survey proffers that few researchers have addressed the issue of principal reasons of the virus spread in Turkey. In addition, previous works have been limited to specific parts of the problem. This study investigates the relationship between possible causes and COVID-19 incidence rates in Turkey with a comprehensive and holistic

approach by Geographic Information System (GIS)-based spatial modeling techniques and advanced statistics.

Hays (2009) claims that physically inadequate living spaces and environments played an essential role in spreading epidemic and pandemic diseases throughout history and the spread of diseases to enormous masses occurred because of people living together more intensely in line with the development of urbanization. Alirol et al. (2011) state high-density cities as the breeding ground for pandemics. People live together in cities, come together in public spaces, use public transportation, and consciously or unconsciously violate the social distance necessary to protect themselves. An increasing number of studies have found that population density has a strong positive correlation with the COVID-19 spread (Sarkar et al. 2021; Arif and Sengupta 2021; Coşkun et al. 2021; Mehmood et al. 2021; Mishra et al. 2020; Mansour et al. 2021; Hamidi et al. 2020; Almagro and Orane-Hutchinson 2020; Rocklöv and Sjödin 2020; Wheaton and Thompson 2020). More recent evidence reveals that transmission of the virus increases with the social and spatial interaction between people, so urbanized areas are favorable environments for the spread of outbreaks because of their building and population density. Conversely, Carozzi

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✉ Cem Kırancıoğlu
kirlangicoglu@sakarya.edu.tr

¹ Faculty of Art, Design and Architecture, Sakarya University, Sakarya, Turkey

et al. (2020) have found no association between population density and COVID-19 incidence rates in urban counties of the USA. On the other hand, Bhadra et al. (2021) have found a moderate association between population density and COVID-19 spread in India through deep regression and correlation analyses based on case numbers and mortality rates. Gavi (2020) argues that urbanization rate and climate change are effective on the virus spread, too. Since COVID-19 is an airborne disease, meteorological conditions such as daily sunshine duration, temperature, wind, humidity, and air quality may influence the spread of the virus (Iqbal et al. 2020; Qi et al. 2020; Xie and Zhu 2020; Wu et al. 2020). Gupta et al. (2020), Xie and Zhu (2020), Tosepu et al. (2020), Bashir et al. (2020), Chen et al. (2020), and Şahin (2020) affirm that there is a linear correlation with average air temperature and COVID-19 cases in different countries such as India, Indonesia, Turkey, and the USA. Humidity is accepted as another influential factor in virus spread by some researchers, such as Ahmadi et al. (2020), Ali and Alharbi (2020), Auler et al. (2020), and Wu et al. (2020). Thangariyal et al. (2020) point out a negative and substantial correlation between daily sunshine duration and COVID-19 cases after examining 138 countries worldwide. In addition, Zhu et al. (2020), Frontera et al. (2020), and Wang et al. (2020) consider that the wind has an indirect effect on virus spread by affecting air quality. Alternatively, Coşkun et al. (2021) report the direct effect of wind speed on virus spread by increasing air circulation in Turkey. Correspondingly, air quality may be another comprehensive indicator of the spread of many airborne viruses like COVID-19 (Zhang et al. 2020a). Firstly, where air pollution is high, the virus can stay in the air longer, travel further distances, spread over larger areas, and penetrate deeper into the lungs (Andree 2020; Zhu et al. 2020; Doremalen et al. 2020). Secondly, air pollution may negatively affect the normal functions of the lungs and make some people more vulnerable than others to the virus (Ali and Alharbi 2020; Korber 2020; Helen 2020; Fattorini and Regoli 2020). Saadat et al. (2020) found that different socioeconomic groups react differently to the virus spread, especially that household size may positively affect the incident rates. The household-based studies highlight the virus's secondary attack rate for household contacts, which is much higher than that for non-household close contacts (Jing et al. 2020). That means if infected people are not isolated, the disease risk increases for their household. In their overview, Zhang et al. (2021) underline that cities with higher GDP values are more at risk than others because of the virus spread due to higher trade and commercial activities among people. Likewise, Zhang et al. (2020b) investigated a robust positive correlation between case numbers and GDP in Chinese cities. Mansour et al. (2021) explored sociodemographic and health factors such as age structure, population density, hospital

beds, and nursing practitioners to explain and predict the spatial transmission of the incidence rates in Oman. They maintain that the incidence rate increases as parallel to an increase in age, especially that people older than 65 years are more at risk than the others. Age may be a crucial factor for the incident rates because younger and older people have different susceptibility levels. Reniers (2020) outlines several reasons that young people take more risks against social distancing and other precautions. Zhang et al. (2021) draw our attention to the inverse correlation between the health indicators such as the number of health institutions, health personnel, hospital beds, and the case numbers after examining 342 cities of China. In their review, Sands et al. (2016) affirm that health infrastructure, health surveillance, and response measures directly affect any virus spread; thus, each province's physician number and hospital bed capacity are crucial factors to fight against these types of viruses. In a study conducted in Oman, COVID-19 incidence rates have been found to be negatively associated with hospital bed numbers (Mansour et al. 2021).

Understanding the principal variables and the main characteristics of the virus will help us propose a new way of urbanism for post-pandemic cities (Megahed and Ghoneim 2020). There may be hundreds of factors affecting the virus spread in different regions under divergent physical and social conditions. In line with the official data available, this study focuses on eighteen possibly explanatory variables, which are population density, urbanization level, median age, household size, GDP per capita, average air temperature, humidity, daily sunshine duration, average wind speed, air quality index, health index, income and wealth index, education index, environment index, social life index, life satisfaction ratio, number of hospital beds, and total physician number in the cities.

Area of the study

The study area, Turkey, is mathematically positioned between approximately 26°–45° eastern meridians and 36°–42° northern parallels given in Fig. 1 (Doğanay and Orhan 2019). The population of Turkey is reported as 83,614,362 by the Turkish Statistical Institute (Turkstat 2020), and the total surface area is 777,971 km². According to the Turkish Republic Ministry of Environment and Urbanization (MoEU 2011), 97% of the country is in Asia, and the rest is in Europe. Database of Coordination of Information on the Environment (CORINE), a prototype project working on many different environmental issues, is serviced by the Ministry of Agriculture and Forestry in Turkey (MoAF 2019). It shows that 1.94% of the country is an artificial area, 42.26% is an agricultural area, 50.31% is forest and semi-natural area, 0.51% is wetland, and 4.98% is water body.

Fig. 1 Location of the study area (Turkey)

In Turkey, the first COVID-19 case was notified on March 11, 2020. As of July 9, 2021, the confirmed total case number is 5,514,373 and the death number is 50,450, as maintained by the Republic of Turkey Ministry of Health (MoH 2021). This paper will focus on 81 provinces of Turkey to determine the influential factors and reasons for regional differences in confirmed incidence rates.

Data and method

The Republic of Turkey Ministry of Health releases weekly situation reports about COVID-19 statistics, including provincial incidence rates and case numbers since February 8, 2021. This study has been conducted by 5 months of provincial data published until July 9, 2021. Table 1 enumerates the COVID-19 numbers for each province based on the official data published between February 8, 2021, and July 9, 2021.

Statistical studies are usually carried out on numbers, but numbers visualized on maps are much more effective for understanding the spatial distribution of statistics. So, inverse distance weighted (IDW) interpolation tool of ArcGIS, a commercially available software package, has been used to produce spatial distribution maps related to all the variables. The dataset is based on point data of 81 city centers, including spatial and non-spatial data about the provinces, acquired from Turkey's Ministry of Environment and

Urban Planning. Figure 2 illustrates the distribution of confirmed case numbers in Turkey.

Istanbul has 924,793 cases, the highest COVID-19 case number among Turkish cities. Ankara, İzmir, and Konya provinces follow it. A distribution map of case numbers is not enough to understand the reasons and regional differences of the virus spread. While the population of İstanbul is 15,519,267, the population of Tunceli Province is just 84,660 (Turkstat 2020). Naturally, the case counts are much higher in İstanbul, which has a 183 times greater population size. For this reason, the case distribution has been normalized for all provinces. Figure 3 depicts the spatial distribution of confirmed COVID-19 incidence rates (case number per 100,000 people) in Turkey.

Figure 3 demonstrates that the Marmara, Mid-Black Sea, and Eastern Black Sea regions have the highest incidence rates while Southeast Anatolia and the south part of Eastern Anatolia regions have the lowest rates. As the figures reveal the regional differences, this study will use correlation and regression analyses to determine the reasons and the association between possible factors and COVID-19 incidence rates. While correlation is a model that defines the relationship between two or more variables through their covariance (Demir 2019), a regression model gives the relationship's mathematical function among variables. That function may estimate the value of a variable based on other variables. Regression analysis explains a variation on the dependent variable (Y) with independent variables ($X_1, X_2, X_3, \dots, X_n$). The dependent variable is

Table 1 Confirmed COVID-19 case numbers and incidence rates for 81 provinces of Turkey

Province	Case no	Incidence rate
İstanbul	924,793	5959
Ankara	215,582	3823
İzmir	110,710	2535
Konya	99,385	4452
Bursa	98,988	3239
Kocaeli	90,543	4636
Samsun	79,159	5870
Antalya	61,712	2457
Kayseri	56,845	4039
Balıkesir	54,133	4406
Tekirdağ	50,333	4769
Gaziantep	43,788	2116
Ordu	38,766	5140
Eskişehir	36,750	4141
Sakarya	34,359	3337
Mersin	34,140	1855
Trabzon	33,847	4184
Manisa	30,613	2125
Adana	30,324	1355
Malatya	30,222	3777
Erzurum	28,654	3760
Çanakkale	28,371	5233
Tokat	26,973	4402
Hatay	24,955	1532
Giresun	24,918	5557
Diyarbakır	22,797	1298
Zonguldak	20,367	3417
Kütahya	20,094	3469
Aydın	19,742	1777
Muğla	19,653	1999
Kırklareli	18,949	5237
Denizli	18,846	1817
Çorum	18,623	3508
Afyonkarahisar	18,573	2546
Sivas	18,485	2893
Şanlıurfa	18,414	888
K. Maraş	18,246	1581
Kastamonu	17,305	4561
Edirne	16,660	4025
Rize	16,337	4760
Ağrı	16,102	3003
Osmaniye	15,613	2898
Adıyaman	14,684	2344
Düzce	13,534	3451
Aksaray	13,532	3250
Yalova	13,370	4934
Elâzığ	13,235	2239
Van	12,857	1131
Yozgat	12,804	3040

Table 1 (continued)

Province	Case no	Incidence rate
Amasya	12,664	3749
Isparta	12,453	2799
Bolu	11,858	3751
Niğde	10,871	2996
Erzincan	9282	3954
Nevşehir	9021	2977
Kırıkkale	8986	3175
Sinop	8747	4008
Bilecik	8362	3811
Mardin	7994	953
Batman	7900	1298
Kars	7255	2542
Karaman	6877	2715
Karabük	6572	2645
Bartın	6423	3240
Burdur	6239	2304
Bitlis	6141	1764
Kirşehir	6137	2526
Çankırı	6089	3110
Uşak	5676	1532
Gümüşhane	5066	3079
Kilis	5061	3552
Bingöl	5053	1806
Muş	5045	1234
Iğdır	4645	2329
Siirt	4178	1265
Artvin	4033	2360
Hakkâri	3147	1120
Bayburt	2921	3443
Şırnak	2759	521
Ardahan	2595	2667
Tunceli	1694	2001

explained or predicted in the regression model (Ersöz and Ersöz 2019). This variable is assumed to be associated with the independent variables, also called explanatory variables in the regression model (Karataş 2014). The linear equation between Y_i and X_i variables is obtained as follows:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \dots \beta_n X_{in} + \epsilon_i^- \quad (1)$$

where Y is the expected value of the dependent variable, X is the independent variable, β is the regression coefficient, ϵ is the residual, and n is the number of independent variables.

Table 2 lists the variables used in this study in line with the literature survey and available official data.

The data about all the variables have been ensured from the local and central government agencies.

Fig. 2 Distribution of confirmed COVID-19 case numbers in Turkey

Fig. 3 Distribution of COVID-19 incidence rates in Turkey

Population density shows the population size in the areas where people live. It can be calculated by proportioning the population size with the province's total surface area. Population numbers and case counts have an obvious positive relationship, but the relationship of incidence and population density differs. Figure 4 portrays the population density distribution in different regions of Turkey.

The population density of Turkey is 107.45 people per km² all over the country. Marmara region is the most

densely populated region, including İstanbul (2842 p/km²) and Kocaeli (575 p/km²) cities. On the other hand, Erzincan (20 p/km²), Ardahan (19.7 p/km²), and Tunceli (11 p/km²) have the lowest population density in the country. In Turkey, while people living in urban areas are 93% of the citizens, 7% of residents live in rural areas (MoH 2018). The median age is 32.4 (Turkstat 2020), the average household size is 3.35 (Turkstat 2019), and according to Turkstat (2018b), the average GDP per capita is 9693 USD. Figure 5 illustrates the

Table 2 Dependent and independent variables of the study

Dependent variable	Independent variables
COVID-19 incidence rate (case number per 100,000 people)	Population density (p/km ²) Urbanization level (%) Median age Average household size Gross domestic product (USD) Annual average temperature (°C) Humidity (%) Annual sunshine duration (h/year) Annual average wind speed (m/s) Air quality index (AQI) Health index Income and wealth index Education index Environment index Social life index Life satisfaction ratio (%) Number of hospital beds Physician no. (per 1000 people)

Fig. 4 Population density distribution in Turkey

distribution maps of urban population ratio, household size, median age, and GDP per capita values.

The spatial distribution maps of the meteorological factors in Turkey based on official annual data are given in Fig. 6. While heat is a sum of the kinetic energy of particles that make up a substance, temperature refers to the reflection of this energy to the outside. Temperature is measured by a thermometer and expressed in °C (Doğrusöz 2018). The annual average temperature of Turkey is 13.2 °C. Air quality

index (AQI) classifies air pollution to characterize the air quality in particular regions, and it is based on five basic contaminative which are particulate matters (PM10), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), ozone (O₃), and carbon monoxide (CO) emissions (WAQI 2020). AQI data for Turkey has been gathered from IQAir (2020) and MoEU (2021). The average AQI for Turkey is 45.60, which means air pollution poses a minor threat except for some regions with polluted and unhealthy air conditions. The amount of

Fig. 5 Spatial distribution maps. **a** Urban population ratio. **b** Household size. **c** Median age. **d** GDP per capita

Fig. 6 Annual distribution maps of meteorological conditions in Turkey. **a** Average temperature. **b** Air quality index. **c** Average humidity. **d** Total sunshine duration in a year

water vapor in the atmosphere is called humidity. A hygrometer is used to measure the humidity of the air. Turkish State Meteorological Service (TSMS 2020a) reported the average relative humidity in Turkey as 63.7%. The length of time that shows how much of the day is sunny is called daily sunshine duration, and it is measured by heliograph. In Turkey, the average daily sunshine duration is 6.6 h by the measurements between 2011 and 2018 (TSMS 2020b).

The wind is another meteorological factor that may allow the virus to spread in the air and travel longer distances. The average wind speed of Turkey is 2 m/s at 10 m above ground (TSMS 2020b). Figure 7 shows the spatial distribution of wind speed in different regions of Turkey. Çanakkale has the highest wind speed, which is 6.6 m/s, followed by İzmir (5 m/s), Mardin (4.9 m/s), and İstanbul (4.5 m/s). Provinces with the lowest wind speed

Fig. 7 Annual average wind speed distribution map of Turkey (Süzek 2007; World Bank Group, 2021)

are Gaziantep (1.4 m/s), Çankırı (1.3 m/s), and Düzce (1.24 m/s).

Hospital beds are placed in patient rooms or units where patients are provided with a minimum of 24 h of medical care (MoH 2018). According to reports of Turkstat (2018a), the average hospital bed number is 2.76, and the average physician number is 1.5 per 1000 residents in Turkey (Fig. 8).

Life index, produced by the Turkish Statistical Institute based on the OECD Better Life Index, is a study for monitoring and comparing people's living conditions under objective and subjective criteria at a local level. This composite index includes 11 leading indicators and 41 sub-indicators at province-based statistics (Turkstat 2015). However, the primary indicators are housing, career, income and wealth, education, health, safety, environment, civil engagement, social life, access to infrastructure services, and life satisfaction; just five of these indicators have been used in this study

to investigate their relationship with COVID-19 patient density. *Health index* is calculated by some fundamental factors such as satisfaction rate about health infrastructure and public health services available in the cities. The average health index is 0.59 for Turkey. *Income and wealth index* is calculated by average daily earnings, savings deposit per capita, job satisfaction rate, and percentage of households in the lower-, middle-, and higher-income levels. The average income and wealth index is 0.40 for Turkey. *Education index* includes the percentage of higher education graduates, schooling ratio of kindergartens, and average points of necessary examinations like the transition to secondary and higher education. The average education index is 0.53 for Turkey. *Environment index* includes active green area per km², percentage of the population receiving waste services, satisfaction rate with municipal cleaning services, and infrastructure. The average environment index is 0.59 for Turkey. *Social life index* is another leading indicator,

Fig. 8 Spatial distribution of health infrastructure. **a** Number of hospital beds. **b** Physician number per 1000 people in Turkey

including cinema and theater audience ratio, satisfaction rate with social life and social relations, and shopping mall area per thousand people. The average social life index is 0.42 for Turkey. *Life satisfaction ratio* shows residents' happiness level about their living standards in the provinces where they live. The average life satisfaction ratio is 61.2% for Turkey (Turkstat 2016). Figure 9 depicts the spatial distribution maps of these indexes in Turkey.

After defining, visualizing, and understanding all the variables, a multiple linear regression analysis will be performed to explore relationships between dependent and independent variables to understand the factors behind observed spatial patterns of COVID-19. However, firstly, it is required to understand the characteristics of the data for further steps. For this purpose, descriptive statistics of all the variables have been prepared in SPSS software and are given in Table 3.

Descriptive statistics are essential to understand that the data is normally distributed or not. For a normal distribution, the central tendency measures like mean and median values must be close to each other as much as possible. Also, smaller standard deviation values mean less spread

out of the observations. In addition, if kurtosis and skewness values are between -1 and $+1$, that means distribution is inside the range of normality. The degree and direction of asymmetry in the dataset are measured by skewness. If the skewness value is zero, that means a perfectly normal distribution. If the skewness value is positive, the mean value is more than the median in the dataset, and vice versa. By kurtosis value, which is a measure of tail extremity, it is possible to see there are outliers in a distribution or not. Positive and negative kurtosis values show the occurrence of outliers in the dataset (UCLA 2021). Table 3 presents that, although the datasets of the dependent variable and most of the other variables are trustworthy, some independent variables such as household size, population density, and GDP are not entirely reliable due to lack of data. Some scatterplot diagrams have been prepared to understand the relationship between dependent and independent variables; to detect the outliers, if any; and to determine whether a relationship is linear or not (Fig. 10).

The scatterplots in Fig. 10 reveal that there may be a positive association between the incidence rate and population density, median age, GDP, humidity, different types

Fig. 9 Life index distribution in Turkey. **a** Health. **b** Income and wealth. **c** Education. **d** Environment. **e** Social life. **f** Life satisfaction ratio

Table 3 Descriptive statistics of variables

Variables	Mean	SD	Median	Min	Max	Kurtosis	Skewness
COVID-19 incidence rate	3037	1268	3003	521	5959	−0.55	0.22
Population density	130.2	318.7	63	11.2	2842	67.5	7.93
Urbanization level	68.4	23.75	63.40	22.40	100	−1.30	−0.01
Median age	10.16	3.46	10.90	3.20	18.3	−0.57	−0.18
Household size	3.45	0.75	3.18	2.63	6.11	1.99	1.60
GDP	7250	2571	6745	3204	16,791	2.79	1.32
Avg. temperature	13.03	3.25	13.10	3.60	19.1	0.43	−0.41
Humidity	66	6.75	65	48	81	−0.28	0.24
Annual sunshine duration	2688	283.6	2690	2124	3508	−0.31	0.12
Avg. wind speed (m/s)	2.70	0.93	2.56	1.24	6.56	2.76	1.23
Air quality index	45.6	21.4	41	2	116	1.07	0.63
Health index	0.59	0.11	0.62	0.30	0.84	0.24	−0.61
Income and wealth index	0.40	0.17	0.44	0.02	0.88	−0.03	−0.22
Education index	0.53	0.14	0.57	0.10	0.75	0.89	−1.12
Environment index	0.59	0.12	0.61	0.20	0.81	1.17	−1.03
Social life index	0.42	0.12	0.41	0.19	0.67	−0.72	0.15
Life satisfaction ratio	61	7.53	60.4	42	77.7	−0.27	0.15
No. of hospital beds	2.76	0.82	2.60	1.20	5.02	0.39	0.76
Physician no	1.5	0.57	1	1	3	−0.63	0.59

of well-being indexes, and number of hospital beds. There may be moderate or almost no relationship between the dependent variable and urbanization level, wind speed, air quality index, life satisfaction ratio, and physician number. On the other hand, sunshine duration, average temperature, and household size show a negative linear relationship with the incidence rates. For a better understanding, the Pearson correlation coefficient of each independent variable has been calculated to measure the statistical relationship, summarized in Table 4.

The Pearson correlation coefficient changes between -1 and $+1$, where -1 indicates a perfect negative correlation while $+1$ means a perfect positive correlation, and 0 indicates no relationship between the variables. A coefficient value between ± 0.5 and ± 1 states a strong correlation, a value between ± 0.3 and ± 0.49 means moderate correlation, and a value under ± 0.29 indicates small correlation (Statistics Solutions 2021). Table 4 presents that sunshine duration and household size have the strongest correlation with the incidence rates. Income level, education index, and median age variables seem like the other strongly correlated factors. Moreover, correlation is significant for all these variables at the 0.01 level. GDP, humidity, health index, environment, social life, and number of hospital beds show a moderate correlation while the other variables have small or no correlation with COVID-19 incidence rates. Descriptive statistics, scatterplot diagrams, and correlation coefficients suggest that model estimates are not biased and have been conducive to understand the data's characteristics and associations between dependent and

independent variables. In addition, the data seems well founded for the robustness and accuracy of the regression model. This study has only one dependent variable and eighteen predictors, so a multiple linear regression analysis has been conducted in SPSS software. Table 5 summarizes the model.

In Table 5, R is the multiple correlation coefficient, and its value (0.827) indicates a good level of prediction for the dependent variable. R^2 value (0.685) means that our exploratory variables explain 68.5% of the variability of COVID-19 incidence rates, while 31.5% of the variation occurs due to other factors not included in this model. Nevertheless, the model is effective enough to determine the relationship. The adjusted R^2 value (0.593) means the predictors explain true 59.3% of the variation in the outcome variable in the model. The standard error of the estimate value ($808,666$), also called the root mean square error, seems higher than average, but it is acceptable due to the lack of data and sample size used in the study.

To sum up, the model summary table is satisfactory, and the database used in the study is plausible. Therefore, as the next step, the analysis of variance (ANOVA) tool has been used to test whether there is a statistically significant difference between the means of independent groups or not. Table 6 lists the ANOVA results.

In Table 6, the Sig. value (p value) is less than 0.05 . That means the results are significant and trustworthy. The F ratio is important to see if the overall regression model is a good fit for the data or not. Here, the F ratio value (7.48) is greater than 1 and shows that the exploratory variables statistically

Fig. 10 Scatterplots showing the association between dependent and independent variables

significantly predict the COVID-19 incidence rates. Table 7 summarizes the analysis results for coefficients.

The constant value (732.25) is the predicted value for the dependent variable. That means we can expect the COVID-19 incidence rate to be 732.25 anywhere in Turkey. The *B* column includes the values for predicting the dependent variable from the exploratory variables in the regression equation. In the *B* column, a 1-unit increase in any positive variable causes an increase in the COVID-19 incidence rate, but each negative value in the column causes a reduction in the dependent variable. The beta weight (beta column) values are the standardized coefficients, and they measure how much the outcome variable changes in standard deviations when the exploratory variable is changed by 1 standard deviation

(Dhakal 2018). Hence, the education index (0.39), median age (0.39), and urbanization level (0.38) seem like the highest contributing predictors to explain COVID-19 incident rates. Zero-order correlation values show the bivariate correlation between the dependent and independent variables. The highest values in this column, sunshine duration value (-0.61) and household size value (-0.60), are the direct effect of these variables on COVID-19 incidence rates. Multicollinearity check is also substantial for a well-specified regression model. Dhakal (2018) says that if the VIF value is higher than 10 or the tolerance value is lower than 0.1, there is a multicollinearity problem. That means just median age and household size seem as the problematical predictors in the model in terms of multicollinearity, which means

Table 4 Correlation between dependent and independent variables

Independent variables	COVID 19 incidence rate (dependent variable)	
	Pearson correlation	Sig. (2-tailed)
Population density	0.279*	0.012
Urbanization level	− 0.014	0.903
Median age	0.529**	0.000
Household size	− 0.602**	0.000
GDP	0.471**	0.000
Average temperature	− 0.16	0.144
Humidity	0.430**	0.000
Sunshine duration	− 0.609**	0.000
Average wind speed	0.14	0.211
Air quality index	0.2	0.074
Health index	0.442**	0.000
Income and wealth index	0.564**	0.000
Education index	0.534**	0.000
Environment index	0.383**	0.000
Social life index	0.413**	0.000
Life satisfaction ratio	0.144	0.200
No. of hospital beds	0.302**	0.006
Physician no	0.21	0.061

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5 Multiple regression analysis model summary

Model	<i>R</i>	<i>R</i> ²	Adjusted <i>R</i> ²	Std. error of the estimate
1	0.827	0.685	0.593	808,666

Table 6 ANOVA results

Model	ANOVA				
	Sum of squares	<i>df</i>	Mean square	<i>F</i>	Sig
1					
Regression	88,045,400.1	18	4,891,411.117	7.480	0.000
Residual	40,544,315.45	62	653,940.572		
Total	128,589,715.6	80			

there is a very high relationship between these two variables. Therefore, the median age has been excluded from the final regression model. In the most important column, significance values show that urbanization level ($p(0.006) < 0.05$), average temperature ($p(0.01) < 0.05$), sunshine duration ($p(0.029) < 0.05$), wind speed ($p(0.038) < 0.05$), and education index ($p(0.036) < 0.05$) are statistically significant to be used in the model while the others are not more useful in the model. The analyses show that the regression model is not specified well enough, and there is multicollinearity among

some of the variables. Thus, a final regression model has been tested by using only the statistically significant exploratory predictors. Table 8 gives the model summary of the final regression analysis.

R value (0.755) indicates a good level of prediction for the dependent variable. *R*² value (0.570) indicates that these five variables explain 57% of the variability of COVID-19 incidence rates, while 43% of the variation is because of other factors not included in this study. Adjusted *R*² value (0.542) means true 54.2% of the variation in the COVID-19 incidence rate is explained by the predictors in the final model. As an additional and final analysis, spatial dependency among the COVID-19 incidence rate observations was tested using the ArcGIS Spatial Autocorrelation (Global Moran's *I*) tool, and a statistically significant spatial cluster pattern was found (Fig. 11).

In Fig. 11, the *z*-score is + 7.20, which means the analyzed attributes are not randomly distributed among the features in the area, and COVID-19 incident rates are clustered in some regions in Turkey. Also, the *p* value (significance level) in the analysis is less than 0.01 and seems statistically significant, and the regression model used in this study has a confidence level of 99%. That means the model is genuinely specified, and results can be trusted.

Discussion

The distribution of COVID-19 incidence rates was examined for Turkey to understand how a province's spatial and non-spatial structure can regulate the overall pattern, and the results were found to be heterogeneous across Turkey. While some regions have higher incidence rates than usual, some regions have lower rates than expected. This clustered distribution could be attributed to many corresponding factors such as geographical, physical, environmental, sociocultural, socioeconomic, demographic, and meteorological differences among the provinces. A multiple linear regression analysis has been conducted to determine the relationship between COVID-19 incidence rates and the chosen explanatory variables. Based on the COVID-19 incidence rate distribution map and spatial autocorrelation results, it seems that Marmara, Mid-Black Sea, and Eastern Black Sea regions have the highest incidence rates while Southeast Anatolia and south part of Eastern Anatolia regions have the lowest rates as clustered. For instance, the incidence rate (cases per 100,000 people) was found maximum in İstanbul, Kırklareli, Çanakkale, Yalova, Tekirdağ, Kocaeli (Marmara Region), and Samsun, Giresun, Ordu, and Rize (Middle and Eastern Black Sea), while the incidence rate was found minimum in Mardin, Şanlıurfa, Siirt (Southeast Anatolia Region), and Şırnak, Hakkâri, and Van (south part of Eastern Anatolia Region) provinces. Sunshine duration, urbanization ratio,

Table 7 Coefficients

	Coefficients						
	Unstandardized coefficients		Std. coefficients	<i>t</i>	Sig	Correlation	Collinearity statistics
	<i>B</i>	Std. error					
Constant	732.25	3590.74		0.20	0.839		
Population density	0.63	0.39	0.16	1.62	0.110	0.28	0.53
Urbanization level	20.38	7.23	0.38	2.82	0.006	−0.01	0.27
Median age	142.36	85.59	0.39	1.66	0.101	0.53	0.09
Household size	−61.94	447.35	−0.04	−0.14	0.890	−0.60	0.07
GDP	0.14	0.08	0.29	1.85	0.069	0.47	0.20
Average temperature	−124.32	46.98	−0.32	−2.65	0.010	−0.16	0.34
Humidity	28.01	15.93	0.15	1.76	0.084	0.43	0.68
Sunshine duration	−1.16	0.52	−0.26	−2.24	0.029	−0.61	0.36
Wind speed	218.83	103.26	0.16	2.12	0.038	0.14	0.84
Air quality index	3.42	5.23	0.06	0.65	0.515	0.20	0.63
Health index	−2808.09	1571.06	−0.25	−1.79	0.079	0.44	0.25
Income and wealth index	339.54	1234.84	0.05	0.27	0.784	0.56	0.17
Education index	3631.78	1693.58	0.39	2.14	0.036	0.53	0.14
Environment index	−3004.62	1533.00	−0.29	−1.96	0.0545	0.38	0.23
Social life index	−1089.11	1495.66	−0.10	−0.73	0.470	0.41	0.24
Life satisfaction ratio	30.58	17.13	0.18	1.79	0.079	0.14	0.47
No. of hospital beds	207.48	174.55	0.13	1.19	0.239	0.30	0.38
Physician no	−280.18	226.30	−0.13	−1.24	0.220	0.21	0.47

Table 8 Final regression analysis model summary

Model	Model summary			
	<i>R</i>	<i>R</i> ²	Adjusted <i>R</i> ²	Std. error of the estimate
1	0.755 ^a	0.570	0.542	858.171

^aPredictors: constant, urbanization ratio, sunshine duration, average temperature, wind speed, and education index.

wind speed, education index, and average temperature maps have similar spatial distribution by their correlation values. These statistical results indicate that the rate of COVID-19 incidences must be considered for unbiased estimation and compelling interpretation of the results.

Statistical results of this study show that:

- As the urbanization ratio of cities increases, the COVID-19 incidence rate increases.
- As the education index increases, the COVID-19 incidence rate increases, too.
- As the sunshine duration increases, the COVID-19 incidence rate decreases.
- As the average temperature increases, the COVID-19 incidence rate decreases.
- As the wind speed increases, the COVID-19 incidence rate increases.

Transmission of the virus increases with the social and spatial interaction between people, so urbanized areas are favorable environments for the spread of outbreaks because of their higher building and population density. So, the positive association between the urbanization ratio and the incidence rates is reasonable and acceptable. Furthermore, educated people generally live in bigger cities such as İstanbul, İzmir, and Ankara, which are significant attraction points. The percentage of higher education graduates, schooling ratio of kindergartens, university number, and average points of necessary examinations like the transition to secondary and higher education are higher in these cities, too. Thus, the positive correlation between the education index and the incidence rate makes sense since educated people prefer to live in urbanized areas. Many recent studies report that daily sunshine duration and average air temperature negatively correlate with COVID-19 incident rates. In addition, many kinds of research in different parts of the world show that wind increases virus spread directly by increasing air circulation among people, cities, and regions.

Conclusion

In conclusion, this study has tested eighteen potential factors on the COVID-19 incidence rate. Five of them (urbanization ratio, education index, sunshine duration,

Fig. 11 Spatial autocorrelation (Moran's I) results for COVID-19 incident rates

average temperature, and wind speed) have been found statistically significant due to the multiple linear regression analysis processes. As a result, it is recognized that these five factors can explain 57% of the variability of COVID-19 incidence rates in Turkey, while 43% of the variation is due to other factors not included in this study. That means after this study and thousands of other related studies, COVID-19 still stands as a complex phenomenon that is not fully understood, and its causes have not been entirely resolved. Today, billions of people continue living together in cities without knowing the fundamental dynamics of this virus, but we have to find out all the reasons and solutions as soon as possible to finish this outbreak. We have to comprehend that an alternative lifestyle emerging toward the COVID-19 pandemic is not a location-independent phenomenon. All human beings and most of their activities are related to space, so all occupational groups dealing with space, especially urban planners, must think about the effects of social and spatial urban life on the disease's spread. However, the study's model and the results are trustworthy; the eighteen factors examined in this study do not explain all reasons for different spread rates of COVID-19 in different regions. This complex phenomenon cannot be explained by a single discipline such as medicine, sociology, urban planning, or

psychology. All human-related disciplines must combine their data, experience, and knowledge to identify a collectively exhaustive list of significant factors affecting the spread rates. Governments and non-governmental organizations, public and private sectors, universities, and all kinds of actors must unite their forces against COVID-19 disease to solve the current problems and to design the post-pandemic cities of the near future.

Author contribution I made all the contributions for the conceptual framework of the study and collected, processed, analyzed, and interpreted all the data, maps, and tables. In addition, I approve that the work is ready for publication, and I accept the responsibility for all of the work.

Data availability Materials presented in this manuscript are available upon request from the author.

Code availability Not applicable.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The author declares no competing interests.

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