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Investigation of effective climatology parameters on COVID-19 outbreak in Iran

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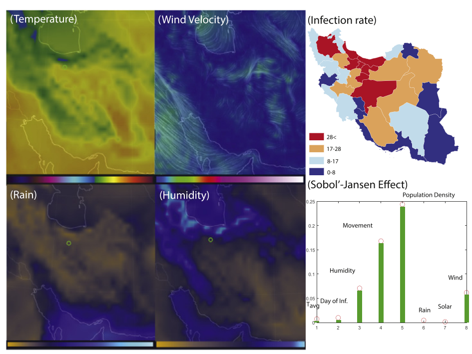
HIGHLIGHTS

- Geographical and Climatological parameter is assessed to study COVID-19 outbreak.
- Population density, intra-provincial movement have a direct relationship with the infection rate.
- Humidity has a reverse relationship within the virus outbreak speed.
- The outbreak at low speed of the wind is remarkable.
- Solar radiation threats the virus's survival.

GRAPHICAL ABSTRACT



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ABSTRACT

SARS CoV-2 (COVID-19) Coronavirus cases are confirmed throughout the world and millions of people are being put into quarantine. A better understanding of the effective parameters in infection spreading can bring about a logical measurement toward COVID-19. The effect of climatic factors on spreading of COVID-19 can play an important role in the new Coronavirus outbreak. In this study, the main parameters, including the number of infected people with COVID-19, population density, intra-provincial movement, and infection days to end of the study period, average temperature, average precipitation, humidity, wind speed, and average solar radiation investigated to understand how can these parameters effects on COVID-19 spreading in Iran? The Partial correlation coefficient (PCC) and Sobol'-Jansen methods are used for analyzing the effect and correlation of variables with the COVID-19 spreading rate. The result of sensitivity analysis shows that the population density, intra-provincial movement have a direct relationship with the infection outbreak. Conversely, areas with low values of wind speed, humidity, and solar radiation exposure to a high rate of infection that support the virus's survival. The provinces such as Tehran, Mazandaran, Alborz, Gilan, and Qom are more susceptible to infection because of high population density, intra-provincial movements and high humidity rate in comparison with Southern provinces.

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1. Introduction

Since late December 2019, patients presenting with viral pneumonia due to an unidentified microbial agent were reported in Wuhan, China. It was an outbreak of the novel Coronavirus disease named 2019 novel coronavirus (COVID-19; previously known as 2019-nCoV). The disease has rapidly spread from Wuhan to other areas and affected 196 countries worldwide by March 25, 2020, which raised intense attention internationally (Chen et al., 2020; Lu et al., 2020; Phan et al., 2020; Xu et al., 2020). It is really important to find out all the factors that play a role in COVID-19 spreading in Urban. The transmission of viruses can be affected by many factors, including climate conditions (such as temperature and humidity), population density and medical care quality (Wang et al., 2020). Therefore, understanding the relationship between the geographical features of a country and the transmission of COVID-19 is key to making the best decision to control and prevent the pandemic. In other words, the discipline of geography is playing in the fight against the virus SARS-CoV-2, which causes coronavirus disease (COVID-19). Therefore, urban geography can be very helpful in that the spatial organization of the city determines the spatial pattern of the spread of the disease (Boulos and Geraghty, 2020; Wang et al., 2020). While a set of health experts are banking on warmer weather conditions to slow down, if not completely halt, the Coronavirus, it is yet not clear whether the coming months will bring any respite to the world. Based on recent research, which has yet to be peer-reviewed, indicated that two factors include high temperature and humidity, directly correlated with the spreading of COVID-19 in a region (Wang et al., 2020).

Based on the research conducted in Massachusetts Institute of Technology the spreading of coronavirus frequently accrue in regions with low annual average temperatures, between about 37 ° and 63 °F (~3–17 °C). The total number of cases in countries with an average temperature above about 64 °F (~18 °C) is <6%, according to the online post of Massachusetts Institute of Technology on March, 19. Based on two recently published papers, the same result concluded. In mid-March, Chinese researchers indicated that there is a correlation between temperature, humidity, and Coronavirus outbreak. They approved that in warm and humid regions of China, the COVID-19 spreading was lower (Wang et al., 2020). Moreover, other researchers from Spain and Finland, found that 95% of infections globally have so far occurred at temperatures between about 28 ° and 50 °F (~2–10 °C), and in dry climates (Araujo and Naimi, 2020). However, the spreading of COVID-19 virus in hot and humid conditions will not stop entirely. Malaysia has confirmed >1500 cases of the virus; >500 people are infected in Indonesia; and in Singapore, where the average temperature is around 80 °F (~27 °C) year-round, despite rigorous detection methods and strict quarantine rules. The results of the research show that longer-term dramatic change of solar flux of ionizing radiation leads to provide an opportunity to create nono-metrical viruses like SARS and MERS (Qu and Wickramasinghe, 2017). Also, high solar radiation prevents an outbreak with inactivating (or semi-infectious) coronaviruses (Gupta et al., 2015; Qu and Wickramasinghe, 2017). Based on the results of (Qu and Wickramasinghe, 2017) if a double peak in the sunspot cycle causes pandemics in the world. Two double peaks are occurred in solar radiation first in 2002 with SARS and in 2012 with MERS. Therefore, the novel coronavirus COVID-19 also probably is created because of the third double peaks.

In this study, the correlation between statistical and climatology parameters role in Coronavirus spreading analyzed. The climatology data are based on information between February 19 to March 22 in Iran. The sensitivity analysis between variables evaluated based on the Partial correlation coefficient (PCC) and Sobol'-Janson methods and all results approved by geographical maps. Besides, the main parameters which can result in infection prevalence in Iran cities introduced and the provinces are more in the exposure to COVID-19 identified. Finally, the discussion and conclusion presented.

Table 1
The descriptive statistics of the indicators.

Variables	Mean	StDev	Min	Max
Number of infected	660	906	55	4849
Population density	94.6	139.9	5.1	704.8
Movement	5389	5027	1242	20,664
Days of infection	25.129	3.557	17.0	32.00
Average temperature	8.323	4.550	2.000	21.00
Average rain	20.03	8.37	6.00	47.50
Humidity	0.5755	0.1272	0.3700	0.8700
Wind speed	12.727	2.304	8.300	17.800
Solar radiation	5.1484	0.5397	4.1000	6.7000
Infection rate	24.17	30.04	2.92	161.63

2. Methods and materials

The main variables in this study include geographical indicators with averaged data from February 19 to March 22 from Weather Spark online web service (Anon, n.d.). Variables including the number of infected people with COVID-19 reported by (WHO | World Health Organization, n.d.), population density, intra-provincial movement, infection days to end of the study period, average temperature (°C) (Yuan et al., 2006), average precipitation (mm) (Araujo and Naimi, 2020), humidity (%) (Wang et al., 2020), wind speed (km/h) (Yuan et al., 2006) and average solar radiation (kWh/m^2) (Qu and Wickramasinghe, 2017) in the study period. The infection rate as a dependent variable defined as Eq. (1).

$$Inf.Rate = \frac{Number\ of\ Infected}{Days\ of\ Infection} \tag{1}$$

This variable indicates the rate of infection or speed of the COVID-19 spreading. Table 1 shows the descriptive statistical and meteorological data of Iran from February 19 to March 22.

The categorical variable of this study is the classification of provinces based on the De Martonne method, which is used in most climatology projects is defined as Eq. (2) (Zareiee, 2014).

$$I = \frac{P}{T + 10} \tag{2}$$

where P is average annual precipitation (mm), T is the average annual temperature (°C) and I is De Martonne aridity coefficient. In this equation, the evaporation is indirectly considered. This method is more widely used in Iran for two reasons. The first availability of the factors and second the classification of this method can define diverse climates (Zareiee, 2014). The De Martonne classification is shown in Table 2.

3. Results

3.1. Statistical analysis

Iran can be divided into at least four different climate zones. Different clustering current climate regions in Iran shown in Fig. 1a. More than half of Iran's area is Arid and consists of lands with high average

Table 2
The De Martonne classification table.

Classes	I value
Hyper-Arid	$I < 5$
Arid	$5 < I < 10$
Semi-Arid	$10 < I < 20$
Mediterranean	$20 < I < 24$
Semi-wet	$24 < I < 28$
Wet	$28 < I < 35$
Very wet	$35 < I < 55$
Extremely wet	>55

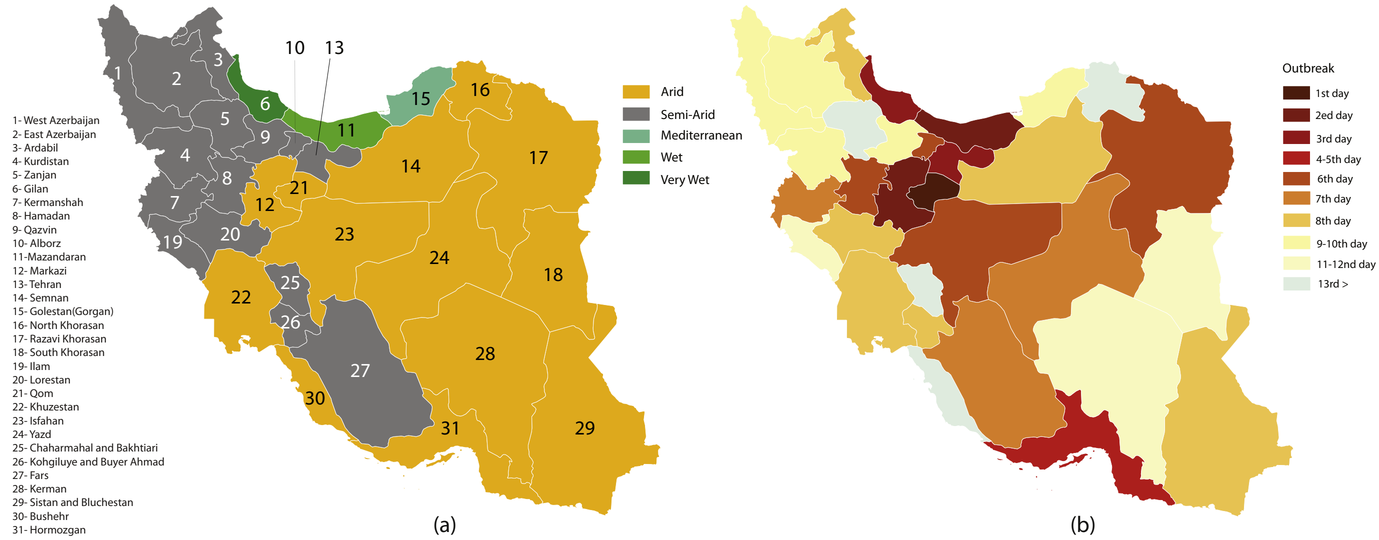

Fig. 1. (a): Classification of Iran climates, (b): Outbreak of COVID-19 based on first observation.

temperature shown in orange color. However, the semi-arid area includes high mountain and agricultural lands. This area is gray in Fig. 1a. Also, three provinces of Iran have the Mediterranean, wet and very wetlands consisting of jangles and grasslands.

The outbreak of COVID-19 based on the first case of observation is shown in the geographical map (Fig. 1b). The first case of COVID-19 infection occurred in Qom and then spread to all provinces over the 13-days period. Regarding the figure, Qom and Tehran can be described as the center of outbreaks that have spread throughout the south and north. In some provinces, this outbreak has occurred earlier, which has been spectacularly significant in terms of intra-provincial movement. In some provinces, this outbreak has occurred after 13 days, which can be attributed to a lack of awareness of the people. In order to get a better understanding of the COVID-19 outbreak in the Iranian provinces and the study of geographical factors, the meteorological data recorded in the study period are referred. The results of Pearson correlation analysis between the variables are shown in Table 3. In this study, the infection rate was defined as the independent variable and its correlation with geographical variables analyzed. Do these results show whether the rate of disease outbreaks in the provinces depends on geographical factors or not? Using these results, we can infer the meteorological impact scenario on the outbreak of COVID-19. According to Table 3, there is a significant and direct relationship between the number of infected people, population density, movement, and days of infection with the Infection rate.

Based on correlation analysis results, areas with high internal movement such as city transportation, high-ways, taxis, etc. results in a high rate of disease spreading. Population density also has a direct relationship with movement. Consequently, these two factors have a remarkable effect on increasing of COVID-19 outbreak. Some indicators such as Humidity and Solar radiation have an inverse relationship with infection rate however the correlations are not significant according to Pearson's method low percent of relative humidity supports the survival of viruses on the contaminated area. However, the humid area causes the coronavirus to be inactive (Chan et al., 2011). Among the meteorological variables, Wind speed has a significant and inverse relationship with the rate of COVID-19 infection rate. Therefore, in the lower speed of the wind, the infection rate is higher. Iran's average wind speed in the study period is 12.727, so based on provinces with a high infection rate, Mazandaran, Golestan, Tehran have lower average wind speed as 8.3, 9.2 and 9.7 km/h. In the following, the sensitivity and importance of variables effecting on the outbreak of the virus are discussed.

3.2. Sensitivity analysis

In this part of the research, sensitivity analysis between variables is discussed. Therefore, we use two methods of Partial correlation coefficient (PCC) and Sobol'-Jansen method to examine the importance of variables and prioritize it. In the PCC method, a linear regression must be made between the independent variables of the problem and the infection rate. On this basis, the basic geographical data should first be standardized. Linear regression is created after changing data range between −1 and 1. Regression coefficients are of particular importance in this section because the value of these coefficients can measure the importance and sensitivity of each variable. The results show that the variables of population density and movement are the most important factors in the outbreak of the COVID-19 virus. Also among the meteorological variables, humidity is a more important variable. Regarding Table 4 absolute values of PCC shows the importance of each variable. Based on these results, Population density, movement, humidity, solar radiation, days of infection, average rain, and average temperature are

Table 3
The results of correlation test (* shows the higher and significant correlation (P-value<0.05)).

	Infected	P. density	Movement	Days of Inf.	Average temp.	Average rain	Humidity	Wind	Solar
P. density	0.822*								
Movement	0.626*	0.419							
Day of inf.	0.539*	0.371	0.267						
Average temp.	0.028	−0.022	−0.002	0.133					
Average rain	0.029	0.157	−0.020	0.180	−0.09				
Humidity	−0.133	−0.001	−0.031	−0.017	−0.110	0.447			
Wind	−0.358*	−0.401	−0.138	−0.369	−0.192	−0.447	−0.430		
Solar	−0.210	−0.238	−0.118	−0.097	0.473	−0.277	−0.512	0.239	
Inf. rate	0.997*	0.816*	0.636*	0.507*	0.009	0.009	−0.147	−0.347*	−0.221

Table 4
Results of sensitivity analysis using PCC method.

Term	Coefficient	T-value	P-value
P. density	0.523	5.17	0.000
Movement	0.2312	3.35	0.003
Day of infection	0.1372	1.77	0.091
Average temp.	0.0134	0.16	0.872
Average rain	−0.0917	−0.97	0.345
Humidity	−0.1604	−1.83	0.081
Wind	−0.0895	−0.97	0.342
Solar	−0.140	−1.29	0.210
Constant	0.309	−3.01	0.006

respectively important. However, variables of population density and movement are significantly effective on the infection rate (see Table 4). We are not satisfied with linear regression, to investigate these variables more consistently, we will continue to use one of the most powerful methods for identifying influential variables in this research. The Sobol'-Jansen method is one of the most important methods in identifying and prioritizing medical variables (or sensitivity analysis) (Dorosti et al., 2019; Saltelli et al., 2010). To analyze the sensitivity of independent variables to the dependent variable (rate of infection), a relationship between the variables must first be formalized.

In this paper, we used the multi-layer perceptron (MLP) technique with 10 hidden neurons to create a more accurate model. We used 70% of the data for training, 15% testing, and 15% model validation, to obtain the best model with the highest accuracy ($R = 92\%$). The results were recorded as shown in Fig. 2.

By applying the MLP model on Sobol'-Jansen method, results are depicted in Fig. 3d. Fig. 3d illustrates the significance and sensitivity analysis of the Sobol'-Jansen method. The vertical axis indicates the degree of importance of the variables or the first-order effect of sensitivity. The results show that population density and movement are the most important variables in the COVID-19 virus infection rate. Then, the more important variables are humidity and wind speed. The rest of the indicators are less important. In the following, the results of this section of the study are discussed in terms of geographical maps. Fig. 3 shows the contour infection rate of COVID-19 disease concerning geographic variables (population density and movement). The higher value of the population density and intra-provincial movement leads to a higher value of infection rate so that in high-density provinces, the rate of disease growth reaches 150 people per day. Fig. 3b also shows the bubble plot of the average

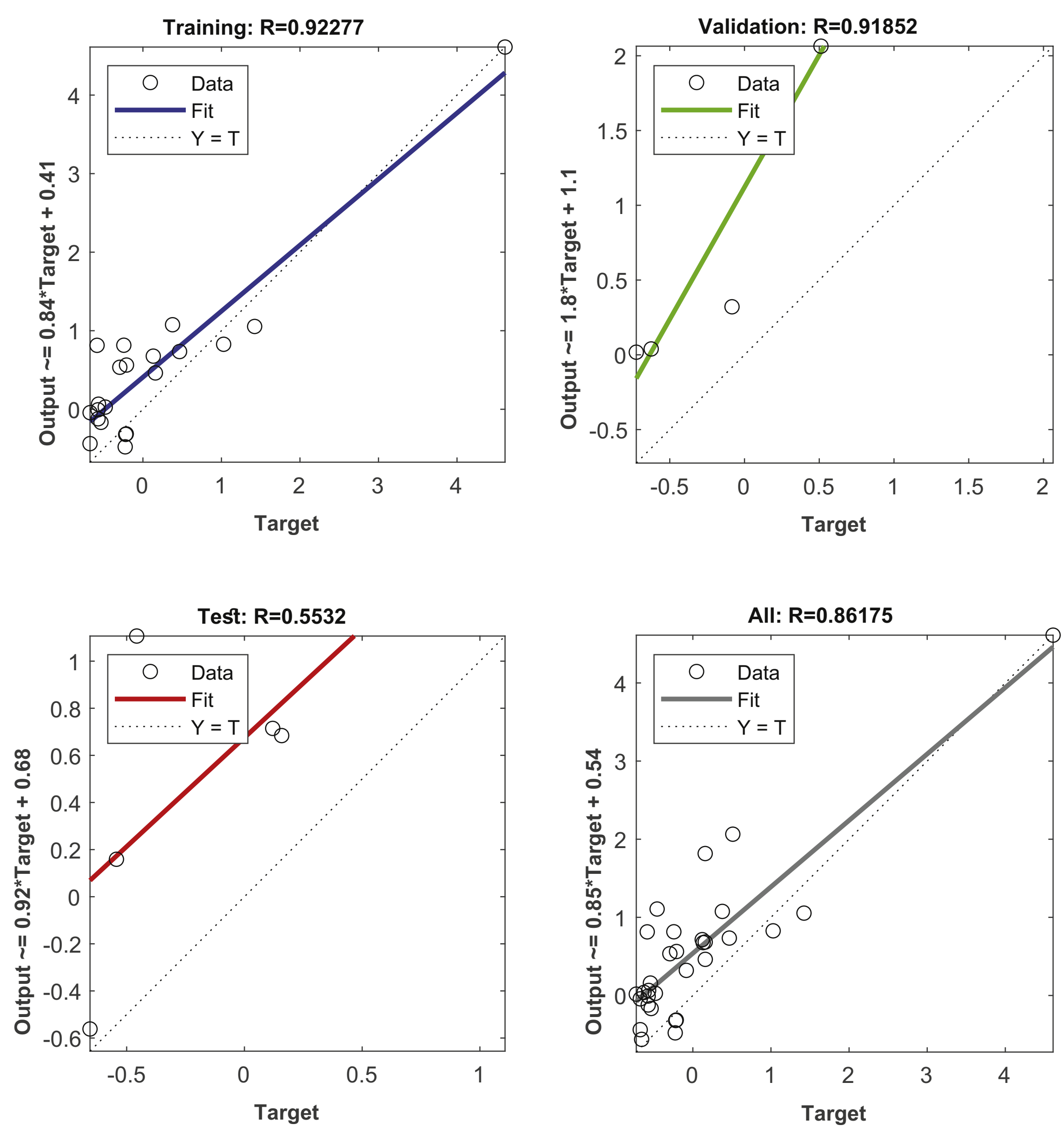

Fig. 2. The scatter plots of the MLP model.

temperature and relative humidity over the study period. The size of bubbles also indicates the rate of infection, and the bubbles have different colors for different climates from Iran. Results show that in arid and semi-arid regions, disease rates are higher in areas with low humidity than in areas with high humidity. However, two wetlands of Mazandaran and Gilan are places with a high rate of infection. Because these provinces are areas with very high population density. With the classification of the area to different climates, the average rate of disease spread in wetlands is higher than in other areas of Iran (Fig. 3 c). Fig. 4 illustrates the governing variables involved in the change of Coronavirus COVID-19 spreading rate. The maps are depicted and colored based on data quartiles. Fig. 4 i shows the COVID-19 infection rate over the study period. Observations show that the infection rate in the provinces of central Iran is higher than in the border regions, and these provinces are both high in population density and movement. A comparison of the virus infection rate charts and meteorological maps can justify the results obtained in the aforementioned methods.

According to Fig. 4f, it can be seen that the humid area includes north, west, and northwest of Iran. However, the main part of the outbreak is in humid, very humid, and semi-arid (or mountainous) areas. The wind direction in most parts of Iran is from the west and in the northeast to west. Wind speeds are low in most parts of the country. Based on Fig. 4 h solar radiation in central Iran is lower than southeast with a low infection rate. We can conclude that where the infection rate is high, the population density and movement are high. Also, in this area humidity, wind speed and solar radiation have a reverse relationship with the rate of the disease spreading.

4. Discussion

The results of geographical surveys of COVID-19 outbreaks in Iran show that the most important variables affecting the outbreak rate in the provinces are population density, which is higher in Tehran, Alborz, Gilan, Mazandaran, and Qom. The disease growth rates in these provinces are (161.63, 41.37, 38.43, 53.67 and 36.28, respectively), which are significant compared to other cities with low population densities. There are also areas with the highest infection rates with high intra-provincial movement, such as Tehran, Khorasan Razavi, Isfahan, and Fars, with disease growth rates of 161.33, 24.48, 70.074 and 18.42, respectively. According to the results of this article, these provinces should prevent intra-provincial movements as much as possible and prevent the incidence of the disease to reduce the infection rate. Meanwhile, Tehran is in a more critical situation. Based on our results using the influential meteorological variables, the scenario of the impact of weather conditions on the rate COVID-19 outbreak can be put forward. In provinces where the relative humidity is low, the outbreak is higher than elsewhere. Despite, the provinces of Mazandaran and Gilan are wetland (based on the De Martonne technique) with higher infection rates. An example can explain the above result. The population density of Alborz province (from arid regions) is 465 and that of Mazandaran (from wetlands) is 138.22 which is approximately 3.3 times more than that of Mazandaran. While the infection rate is 41.37, in Mazandaran it is 53.68 (more than Alborz). Another influential parameter is the wind speed. In provinces with low wind speeds such as Mazandaran, Golestan, Tehran, and Gilan the outbreak rate is much higher. The wind speed can cause the spreading of suspended particles in the air. The particle density can have a significant role in the outbreak of the

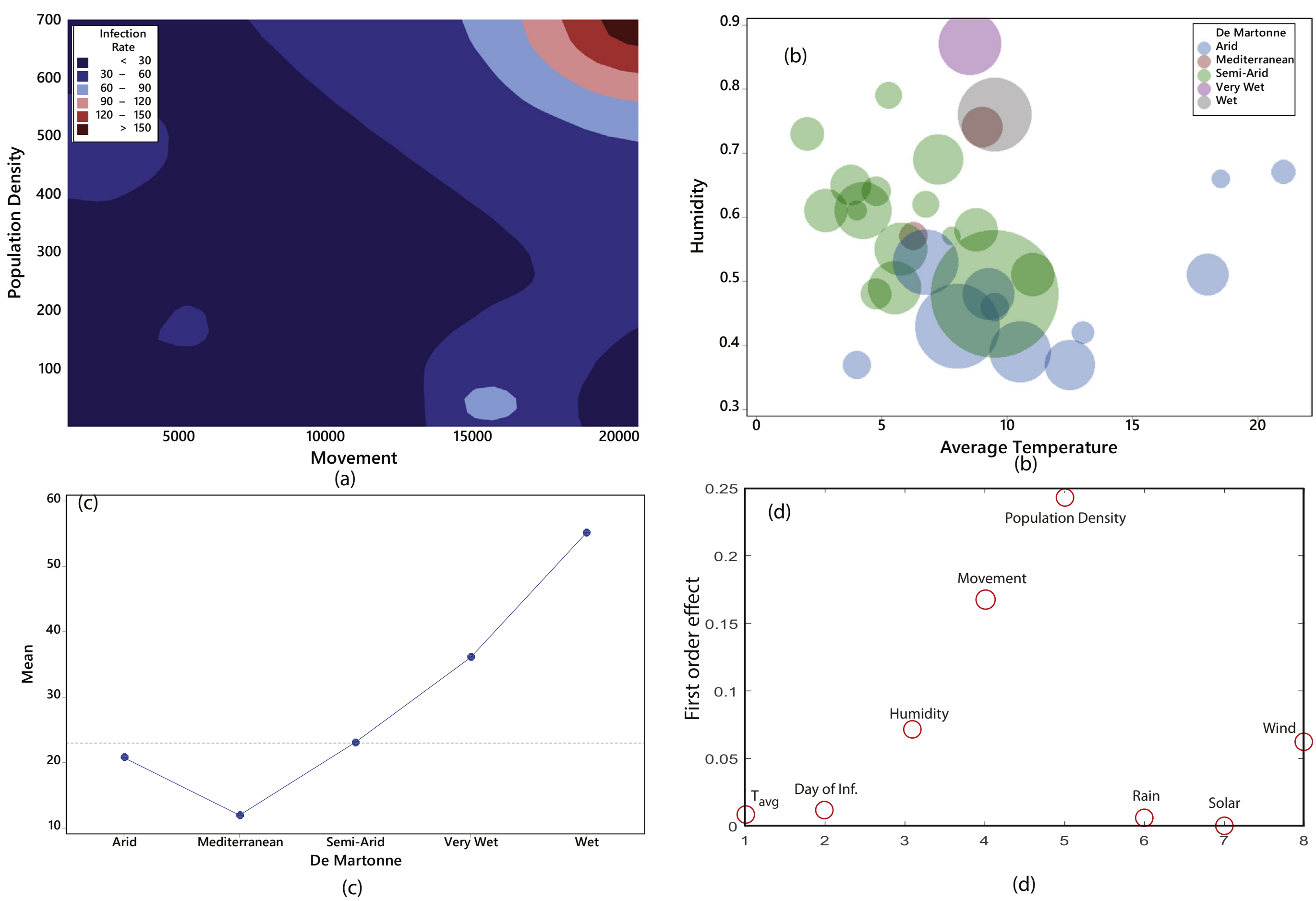

Fig. 3. (a): Contour plot of movement-Population density and infection rate, (b): Bubble scatter plot of average temperature-humidity and infection rate in different climates, (c): Infection rate in different climates, (d): First order effect of Sobol'-Jansen Method.

virus in cities like Tehran. Therefore, the prevention of particle density increment can be an effective way to reduce the infection rate in cities. The measurements like minimizing the use of vehicles and limitation of work hours of urban factories can be taken. According to the results, in the southeastern provinces of Iran with high solar radiation, the infection rate is lower than elsewhere. For example, Sistan and Baluchestan, Kerman, Hormozgan and Bushehr are among the provinces with high radiation and low infection rate. Other variables such as precipitation and air temperature up to this point in the study were not significantly correlated with the COVID-19 outbreak. That requires more experimental study and observations.

5. Conclusion

The new Coronavirus (COVID-19) is a widespread infectious disease that has affected millions of people around the world since late December in 2019. The COVID-19 origin is Wuhan, China. The disease has spread across the world, affecting over 400,000 (report of March 16) people. Conducting any research in this epidemic can result in better understanding and taking appropriate measurements. Lately, considerable studies have conducted to provide information about COVID-19. However, understanding how different variables geographical can affect the spreading of infectious is vital. In other words, urban geography can be very helpful in that the spatial organization of the city determines the spatial pattern of the spread of the disease.

Iran is one of the countries with different types of climate. The infection rate in provinces is different; therefore, understanding the main variables that play an important role in this various spreading rate is crucial. In this study, the correlation of nine main variables includes the number of infected people, population density, intra-provincial movement, days of infection, average temperature, average rain, humidity, wind speed, and solar radiation with infection rate analyzed. The sensitivity analysis between variables determined by two methods Partial Correlation Coefficient (PCC) and Sobol'-Jansen to examine the importance of variables and prioritize it. Based on the PCC method, the population density, intra-provincial movement, day of infection have a direct relation with infection outbreak. Conversely, wind speed, humidity, and solar radiation have an indirect correlation with the infection rate. However, in two humid regions of Iran, the rate of virus spreading is high. The Sobol'- Jansen method also approved the aforementioned results and confirmed that the main variables that play an important role in the COVID-19 outbreak are population density, intra-provincial movement, wind speed, and humidity. Consequently, based on the geographical maps, the average rate of disease spread in humid provinces is higher than in other areas of Iran, however in arid areas humidity has a reverse relationship with the disease infection rate; the central provinces of Iran are approximately higher than in non-central and southern regions.

The effective parameters in the COVID-19 outbreak show that Tehran, Mazandaran, Alborz, Gilan, and Qom people are more exposed to virus spreading because of the high population. Moreover,

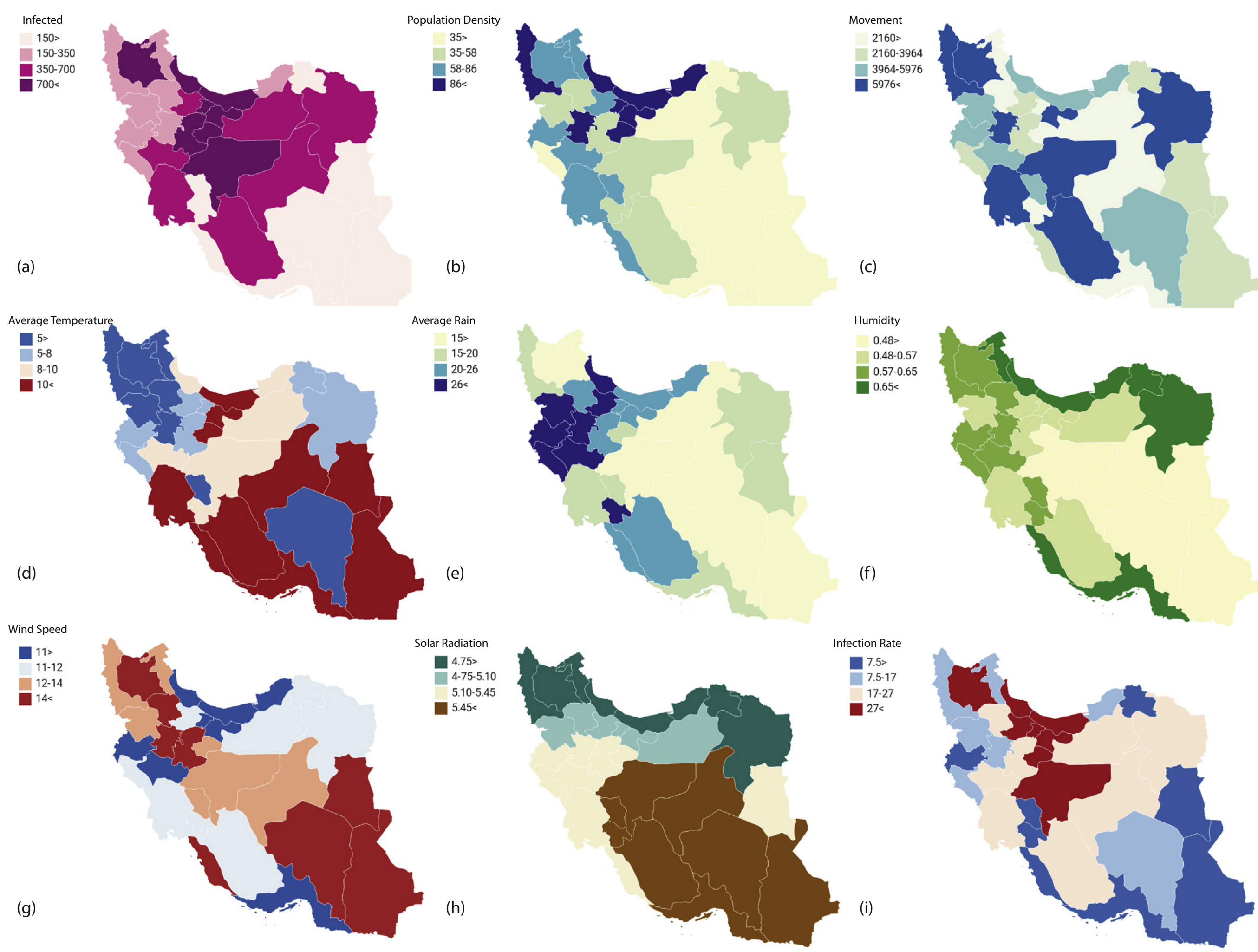

Fig. 4. (a) Number of confirmed, (b) Population density, (c) Movement, (d) Average temperature, (e) Average rain, (f) Humidity, (g) Wind speed, (h) Solar radiation and (i) COVID-19 infection rate.

in provinces as a destination of intra-provincial movements, Tehran, Isfahan, Khorasan Razavi, and Fars population are more susceptible to the COVID-19 virus. The Gilan and Mazandaran provinces have wet weather; therefore, the high infection rate; besides, the wind speed is low in these cities plus Tehran and Gorgan. The southern region of Iran includes Sistan and Baluchestan, Kerman, Hormozgan, and Boushehr have lower infection rate because of high solar radiation. Based on literature results the coronavirus is created because of dramatic solar activity when in a period of years (~10) appearance of two peaks in sunspots creates coronavirus. Therefore, we should expect these types of pandemics once every 10 years. Future studies should pay more attention to provide results based on experimental and observational studies and considering how the factors can affect COVID-19 spreading. Also, long term studies of world climates can anticipate other possible pandemics.

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CRediT authorship contribution statement

Mohsen Ahmadi: Formal analysis, Writing - review & editing. **Abbas Sharifi:** Data curation, Methodology, Conceptualization, Software, Writing - review & editing. **Shadi Dorosti:** Writing - original draft. **Saeid Jafarzadeh Ghoushchi:** Supervision, Project administration, Investigation. **Negar Ghanbari:** Validation, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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