Original Article
http://mjiri.iums.ac.ir
Medical Journal of the Islamic Republic of Iran (MJIRI)

Med J Islam Repub Iran. 2021(4 Oct);35.128. https://doi.org/10.47176/mjiri.35.128

A description of spatial-temporal patterns of the novel COVID-19 outbreak in the neighbourhoods' scale in Tehran, Iran

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Received: 6 Mar 2021 Published: 4 Oct 2021

Abstract

Background: Analyzing and monitoring the spatial-temporal patterns of the new coronavirus disease (COVID-19) pandemic can assist local authorities and researchers in detecting disease outbreaks in the early stages. Because of different socioeconomic profiles in Tehran's areas, we will provide a clear picture of the pandemic distribution in Tehran's neighbourhoods during the first months of its spread from February to July 2020, employing a spatial-temporal analysis applying the geographical information system (GIS). Disease rates were estimated by location during the 5 months, and hot spots and cold spots were highlighted.

Methods: This study was performed using the COVID-19 incident cases and deaths recorded in the Medical Care Monitoring Centre from February 20, to July 20, 2020. The local Getis-Ord Gi* method was applied to identify the hotspots where the infectious disease distribution had significantly clustered spatially. A statistical analysis for incidence and mortality rates and hot spots was conducted using ArcGIS 10.7 software.

Results: The addresses of 43,000 Tehrani patients (15,514 confirmed COVID-19 cases and 27,486 diagnosed as probable cases) were changed in its Geo-codes in the GIS. The highest incidence rate from February to July 2020 was 48 per 10,000 and the highest 5-month incidence rate belonged to central and eastern neighbourhoods. According to the Cumulative Population density of patients, the higher number is estimated by more than 2500 people in the area; however, the lower number is highlighted by about 500 people in the neighborhood. Also, the results from the local Getis-Ord Gi* method indicate that COVID-19 has formed a hotspot in the eastern, southeast, and central districts in Tehran since February. We also observed a death rate hot spot in eastern areas.

Conclusion: Because of the spread of COVID-19 disease throughout Tehran's neighborhoods with different socioeconomic status, it seems essential to pay attention to health behaviors to prevent the next waves of the disease. The findings suggest that disease distribution has formed a hot spot in Tehran's eastern and central regions.

Keywords: Spatial-temporal analysis, COVID-19 outbreak, Hotspot cases, GIS, Tehran, Iran

Conflicts of Interest: *None declared*
Funding: *None*

Cite this article as: Lak A, Maher A, Zali A, Badr S, Mostafavi E, Baradaran HR, Hanani Kh, Toomanian A, Khalili D. A description of spatial-temporal patterns of the novel COVID-19 outbreak in the neighbourhoods' scale in Tehran, Iran /. *Med J Islam Repub Iran.* 2021 (4 Oct);35:128. https://doi.org/10.47176/mjiri.35.128

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↑What is "already known" in this topic:
Risk maps as the primary step to take for managing and controlling COVID-19 has been identified in Iran and its provinces. Because of the large population and a relatively high prevalence of socioeconomic problems, Iran's metropolitan cities confronted the outbreak with more significant stress.

→What this article adds:
We provided a clear picture of the pandemic distribution in Tehran's neighbourhoods, as the largest metropolitan city in Iran, during the first months of its spread from February to July 2020. A spatial-temporal analysis suggested hot spots in Tehran's eastern and central regions.

Introduction

Involving all 6 continents, the outbreaks of the new coronavirus disease (COVID-19) are still raging and have become a global public health concern(1–3). It is considered urgent for the countries to implement effective strategies for containing this increasingly severe pandemic as quickly as possibl e, especially in urban areas with crowded neighborhoods. Epidemiological and clinical studies have pointed out that a person-to-person transmission characterizes the infection during its incubation period, especially in communities in the affected geographical areas (4–7). Currently, the only effective prevention and control strategy is to block person-to-person transmission and prevent exposure to the virus because there is no vaccine or specific therapeutic drug against the disease as yet (8).

Numerous reports have tried to estimate the location of potential COVID-19 transmission spots in different countries and use various models to support effective preventive measures and control strategies (5). Identification of potentially high-risk zones is equally significant for health authorities to precisely implement effective prevention and control measures on a fine-scale (9). However, this issue has hardly been addressed in previous investigations (5).

Because of the large population and a relatively high prevalence of socioeconomic problems, Iran's metropolitan cities confronted the outbreak with more significant stress (10). Therefore, our study emphasizes COVID-19 patients to identify the potential risk zones of the infection based on hot spots of confirmed and probable patients and deaths from February 20, to July 20, 2020 in Tehran. This study would supply useful clues for local health authorities to prioritize effective interventions to implement mitigation measures, especially the local scale (meso and micro scales) (11). Given the strategic role of Tehran in Iran and its diverse typogeographical neighbourhoods with varying socioeconomic and environmental characteristics, the geographical information system (GIS) is a suitable method for the study of the COVID-19 outbreak (12).

Given the importance of the future waves of COVID-19 and its massive death toll, identifying the hot spot cases can help to provide for epidemic prevention measures. The present study was conducted between 2 disease waves (2 peaks on March 23 and 24 and July 14 and 15) in Tehran based on the address of the patients in the municipality neighbourhoods. Accordingly, we provide a map of the distribution of the pandemic in Tehran's districts during the first months of the outbreak from February to July 2020 through a GIS-based spatial-temporal analysis. Patients' locations and time estimate disease rates during the 5 months, and hot spots and cold spots were distinguished.

Methods

Study Design and Participants

The scale of the study is single patients' location and municipal districts in Tehran, the capital city of Iran, a mega city located in the central plateau of Iran, 1500 kilometers north of the Persian Gulf, with an area of more than 700 km^2, 354 official neighbourhoods in 22 municipality regions (Fig. 1). Tehran's population density varies from 10 to 580 persons per hectare (in this analysis, areas with population density below 40 are omitted). According to Tehran municipality's 2018 statistics, Tehran's neigh-

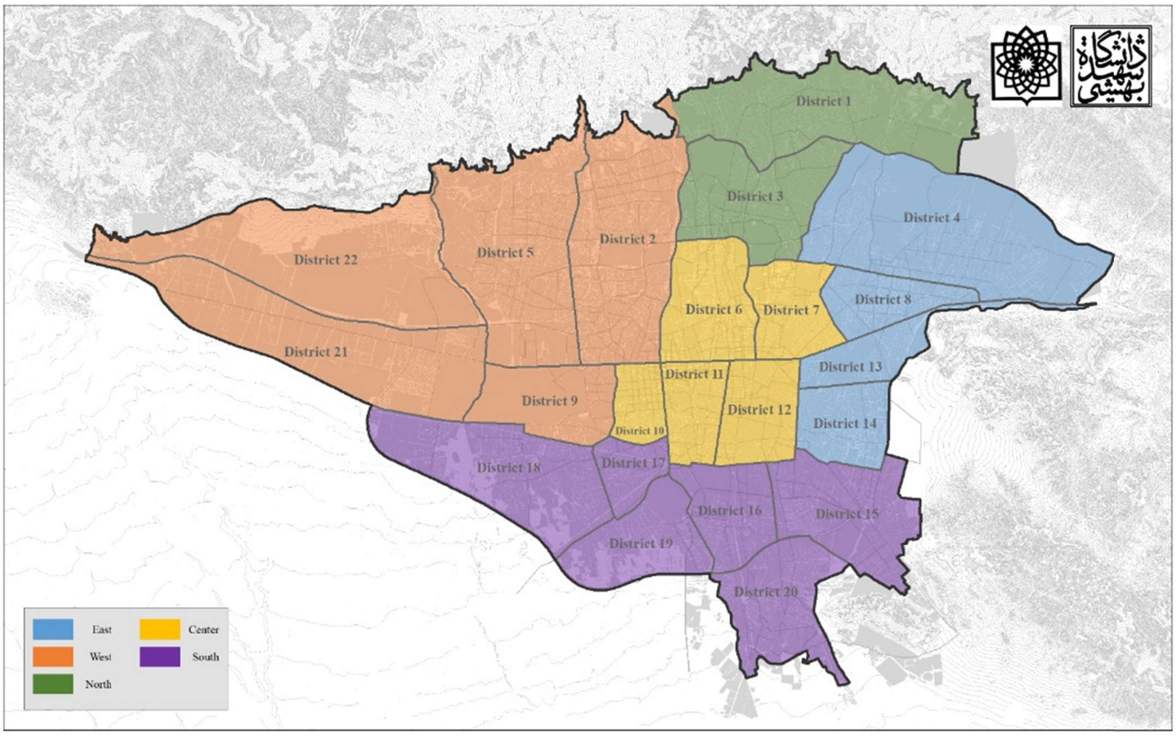

Fig.1. The 22 districts of the city of Tehran dived to five region of north, south, east, weat and center (Redraw from (21))

bourhoods' population is 8,938,686 (4,466,825 malesand 4,472,268 females), form 3,041,133 households with a mean of 2.9 individuals per family. The population density in regions 1 to 7 is generally of higher socioeconomic status compared to the other regions (13).

Soon after detecting the first several confirmed cases of COVID-19 in Iran, the National Committee on COVID-19 Epidemiology was formed in the Ministry of Health and Medical Education. This Committee is the official source of gathering, analyzing, and reporting the COVID-19 data in Iran. The data used in this study include medical care monitoring centre (MCMC) and Hospitals' Information Management (HIM) based on the factsheets contain daily situation reports on COVID-19 in Iran.

All patients with a positive polymerase chain reaction (PCR) test admitted and hospitalized in Tehran, as confirmed COVID-19 cases between February 20, and July 20, 2020, were studied. In addition to these laboratory-confirmed cases, we also included patients with clinical symptoms and signs, including computed tomography (CT) scan findings of the chest, but initially negative PCR test results, who were diagnosed as probable COVID-19 and hospitalized. After retrieving the data from the databases mentioned above, the data were reviewed based on the patients' national identification card, date of admission and discharge, personal data, the date on which symptoms had begun, and the patients' address for patients living Tehran. Finally, after screening the data and removing duplicates, we analyzed the individual's address in those with cinfirmed or probable COVID-19 diagnosis since February 2020. The address of all patients was coded to Geo-Codes on the GIS map and analyzed. The Research Ethics Committee of Shahid Beheshti University of Medical Sciences, Tehran, Iran, approved the study (IR.SBMU.RETECH.REC.1399.070).

Data Preparation and Statistical Analyses

First, the information of 47,489 confirmed and probable cases of COVID-19 was reviewed. After eliminating duplicated and incomplete data, the information of 43,000 patients with complete information for COVID-19 diagnosis was finally decided to be converted into Geo-Codes using available addressing systems (Table 1). The level of precision in this process was estimated at 10%. Using a localized system for processing Persian addresses, we could also identify and correct some linguistic errors. Next, we turned the residence addresses into coordinates that could be converted to spots using ArcGIS-10.7 (as the closest streets to the patients' home).

Incidence of the COVID-19 confirmed/probable cases and the incidence of related deaths are reported as absolute numbers for total incident cases/deaths in Tehran and incidence rate per 10,000 individulas for different districts with different reference population sizes. The incidences are cumulative monthly values or values for February 20, to July 20, 2020. The reference populations were considered according to the Tehran municipality's 2018 statistics. To consider both the size of the population and the size of the area, we also calculated the cumulative population density of COVID-19 confirmed/probable patients adjusted with the population density of Tehran's neighborhoods (in 1000 people per square kilometer).

Spatial Pattern

To identify affected areas and clusters, local Getis-Ord Gi* was used as a local indicator of spatial autocorrelation (LISA). Clusters are defined as points where the rate of COVID-19 is considerably high (HH) or much low (LL) in terms of geostatistics. Outlier data include regions with a high COVID-19 speed but surrounded by areas with low rates, or areas with a low COVID-19 rate, which are surrounded by areas with high COVID-19 rates (14, 15).

In the local Getis-Ord Gi* method, weight is calculated by taking the neighbourhoods into account. Settings can be regarded as distance or adjacency. Also, factors such as land use, daily travel rate, and population density can be defined as the neighbourhood's weight. We use the fixed distance band to determine the values so that the regions outside a set, the specific distance will not impact the internal areas (16, 17). Statistical analysis was conducted through ArcGIS 10.3 software.

Detection of Hot and Cold Spot Areas

To highlight areas as to hot or cold spots is made using the Getis-Ord Gi* statistic based on the Z score (Formula 1). Taking into account the number of confirmed cases within a radius of 100 m, regions with a positive Z-score and values ≥ 1.96 indicate a higher rate and considered hot spots. Likewise, areas with a negative Z-score and values ≤ -1.96 have a lower rate and are taken as cold spots. Based on the formula, x_j denotes the rate for the $j_{\text{-th}}$ area. $W_{i,j}$ is the spatial weight between the $i_{\text{-th}}$ and $j_{\text{-th}}$ areas, and n equals the total number of areas. $\bar{X}$ and S are the arithmetic mean and the standard deviation of the COVID-19 rate in Tehran's neighbourhoods, respectively.

Formula 1 =

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}\, x_j - \bar{x}\sum_{j=1}^{n} W_{i,j}}{s\sqrt{\frac{\left[n\sum_{j=1}^{n} W_{i,j}^2 - \left(\sum_{j=1}^{n} W_{i.j}\right)^2\right]}{n-1}}}$$

Results

From February 20, 2020 to July 20, 2020, the addresses of 43,000 Tehrani patients (15,514 confirmed COVID-19 cases and 27,486 diagnosed as probable cases) referred to hospitals affiliated to Tehran's Medical universities were changed in its Geo-codes in the GIS. The data show that about 38,091 (91.80%) of the confirmed cases and 26,977 (89.83%) of the probable cases had been hospitalized, and the rest had received outpatient health care services. Table 1 lists the data of the cases during the study period. The mean age of confirmed COVID-19 patients who died was 67.54 (±15.81) years, while this value was 49.17 (±17.43) years for recovered cases. Probable cases who died with COVID-19 had a mean age of 66.65 (±19.52), whereas the mean age of probable cases who survived was 47.65

Table 1. The COVID-19 patients and dead information referring to health-care centres in Tehran

	Total	Percentage
Confirmed/Probable Cases	43000	-
Death from COVID_19 cases	3354	8%
Men	22080	56%
Women	18920	44%
Below 60	24510	57%
Above 60	18940	43%
Inpatient	34400	80%
Outpatient	8600	20%
With PCR test	38700	88%
PCR result -	19380	57%
PCR result+	13330	31%

(±18.99) years. In our study, most new cases (57.2% of confirmed cases and 56.9% of probable cases) and patients who died from COVID-19 (63.4% of confirmed cases and 59.5% of probable cases) were men.

The analysis of mapping suggests that the prevalence of COVID-19 varied greatly across different neighbourhoods in Tehran, with a substantially higher concentration in central and eastern areas in comparison with peripheral areas. The temporal and spatial distribution of COVID-19 cases is depicted during the 5 months in Figure 2 and the 22 municipally regions in Figure 3, respectively.

The disease's duration is taken as 1 month, consisting of 2 weeks of incubation and 2 weeks of physical manifestation. The following results were extracted from our data of locales of 43,000 confirmed/probable patients in the 5 months of the study in Tehran's neighbourhoods emphasizing urban blocks. The lowest number of cases belongs to the period from May 20, to June 20, with 5068 cases (13% of total cases), and the highest number occurred in the period between March 20, and April 20, with 9320

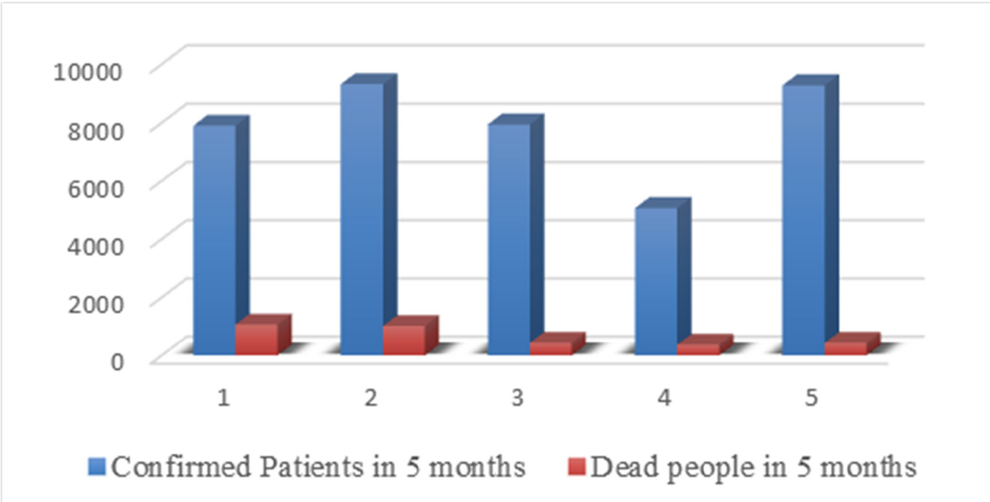

Fig. 2. Incident cases(confirmed /probable) of The COVID-19 Outbreak in Tehran, Iran from 20 February to 20 July

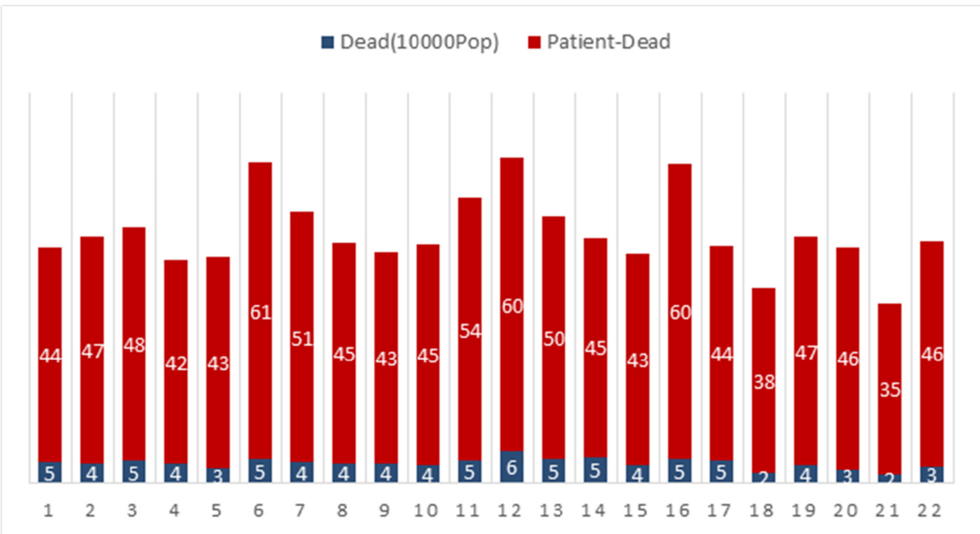

Fig. 3. Total incidence rates(per 100000 people) of Patients and dead people of COVID-19 in Tehran(20 February to 20 July)

Fig. 4. The spatial trend of COVID-19 Incidence Rate in selected regions of Tehran per month according to Fig.1 (20 February to 20 July)

cases (24%). The lowest number of death was in the period between May 20 to June 20, 2020, with 373 deaths (11% of total deaths), and the highest number of death belongs to the period between February 20, to March 20, 2020, with 1073 deaths (32%) in Tehran's neighbourhoods.

The analysis of the spatial trend in varied regions of Tehran (north, east, west, south and center) in Figure 4 shows that at the outbreak of the COVID-19, the northern regions were more involved with confirmed/probable patient; however, over time, the number of cases in the central and southern areas has increased in camparision with other regions.

The results of our spatial-temporal analysis show that, within 5 months of the beginning of the epidemic in Tehran's neighbourhoods, remarkable geographical changes have taken place. Within 1 month from February 20, when the epidemic was officially declared in Iran (18), the neighbourhoods in eastern and northern Tehran became involved. The disease spread had an east-west direction. In the second month, central areas became involved, and the infectious disease began to spread along the north-south axis of the city. In the third and fourth months, the spread rate in neighbourhoods was reduced. However, from June 20, to July 20, the disease rate began to increase dramatically in the entire city, especially in central communities. Studies suggest that the disease rate has been highest in central Tehran's historical fabric (region 12), which contains Tehran Bazaar (Fig. 5).

To specify disease clusters and hot spots, we used the local Getis- Ord Gi* method for both patients and dead people (Fig. 6). Taking into account the number of cases within a radius of 100 m, it can be stated that the hot spot of cases in the period between February 20, and March 20, can be seen in east and central areas (regions 4, 8, 10, 13, 14, 17, and 19). One month later, the hot spot is reduced down to neighborhoods in regions 10 and 11. In the third month, the settings involved 2 months ago become severely affected by the disease, and patients' concentrations are observed in all eastern, southeastern, northeastern, and central neighborhoods. In the fourth month, the number of patients decreases, but in the fifth month, the situation aggravates again in regions 10, 11, 16, and 17.

Concerning the death rate hot spot, the eastern neighbourhoods of regions 13 and 14 had the highest concentration in the first month. In the second month, the number of deaths decreased, and the only hot spot was in region 10 in central Tehran. With the continuous reduction in Tehran's death toll in the third and fourth months, the death rate hot spots became more limited. The only hotspot in the fourth month was observed in southern neighbourhoods in region 16 (Fig. 6). We have also represented the maps of hotspots of patients and the maps of patients' population density adjusted with a population density of Tehran's' neighborhoods (Figs. 7 and 8). These figures show that adgusted for size of population and area, northern disctricts of Tehran had a more density of COVID-19 cases compared to the other districts.

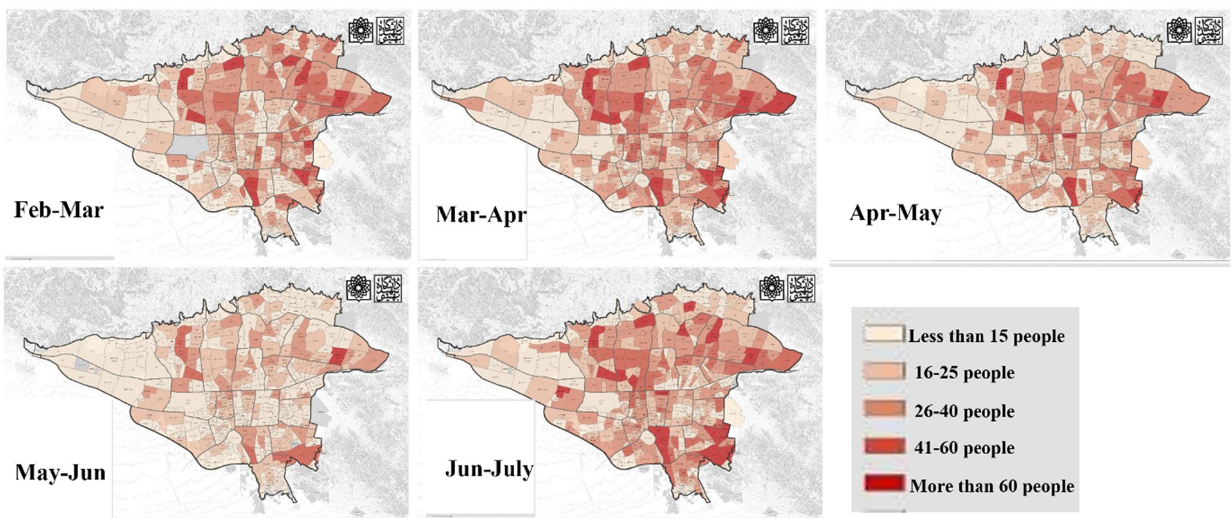

Fig. 5. For the Cumulative incidence mean of COVID-19 confirmed/probable patients in Tehrans' neighborhoods from 20 February to 20 July

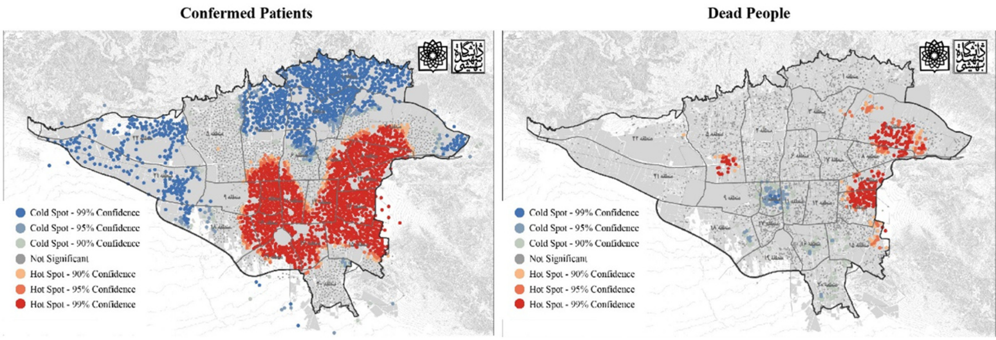

Fig. 6. Hot-Spot map of COVID-19 confirmed/probable cases by local Getis from 20 February to 20 July

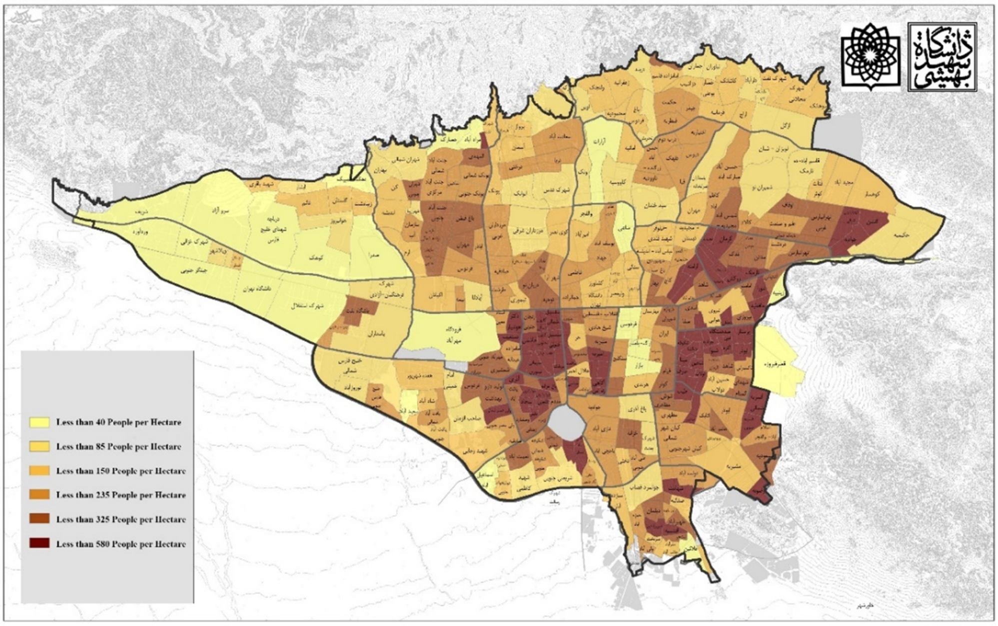

Fig. 7. The population density in Tehran's neighborhoods (20)

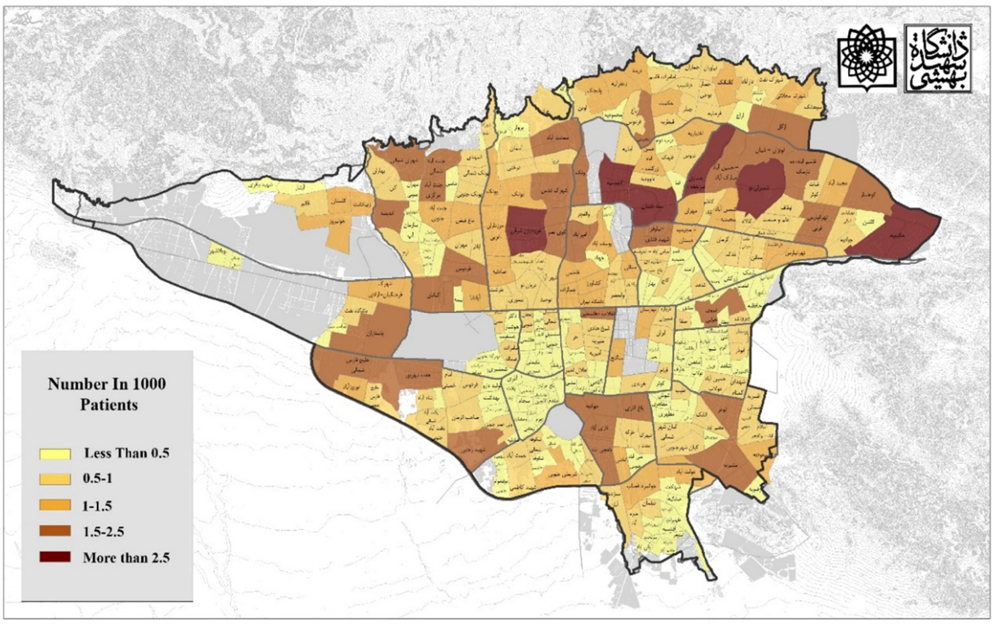

Fig. 8. The cumulative population density of COVID-19 confirmed/probable patients adjusted with the population density of Tehran's neighborhoods (number in 10000 people)

Discussion

Our findings suggest that the spread of COVID-19 in Tehran from February 20, to July 20, 2020, followed various neighbourhoods patterns, with central areas experienc-

[DOI: 10.47176/mjiri.35.128]

ing a more difficult situation. What is noticeable is the involvement of communities with high levels of socioeconomic status (SES) in northern parts of the city (19) and the higher disease rate in central neighbourhoods compared with peripheral ones. Surprisingly, access to health care services in the northern communities is more increased. Health care services and centers are concentrated mainly in the central and north of Tehran, and the population is also concentrated in this part of the city (19). Because of the unprecedented aspects of the COVID-19 pandemic, it is difficult to compare our results with previous infectious diseases in Tehran, Iran, or even with global studies on neighbourhood-scale in terms of spatial analysis.

Analysis of patients' spatial mappings in Tehran's neighbourhoods was conducted based on the 2 waves of the disease, 1 peaking in mid-March and the other peaking in mid-July because of the peaks of patients' number in 5 months. Analysis of the cumulative spatial-temporal distribution of the absolute number of patients in Tehran neighbourhoods shows that, in order of significance, the residents of regions 2,3,5, southeastern areas of Tehran, and central Tehran have had the highest infection rates, which can be explained by the high population of these areas. Concerning the discovering of infection, the residents in region 2,3, and 5 as the northern neighborhoods had the highest number of referral to health care centers, which may be because of more numbers of urban parks and more interactions as well as the high rate of urban trips in these areas (20, 21).

According to Pishgar et al (2020), the spread of the disease in the neighbourhoods in districts 3, 4, and 5 can be because of the following factors concerning the urban statistics of Tehran municipality in 2018 as Larger public parks in these areas that are visited and used by people from all over the city More remarkable presence of people in public places. Higher travel rates are indicative of increased destination activities and socialization in these areas.

In the analysis of spatial-temporal distribution maps of patients according to population density in the first wave of the disease (first 2 months), the areas in regions 2,3, and 5, around one of the main east-west highway in the north of Tehran called Hemmat Expressway, were involved in an east-west direction, whereas in the second wave (in fourth and fifth months), the disease had also spread to southern and southwestern neighbourhoods. The cumulative population density map also shows that the densely populated areas are located along the Hemmat Highway in the north of Tehran. The distribution differences of patients in terms of population density in Tehran's' neighborhoods (regions 2, 3, 4, and 5) and the hotspots of patients in the eastern and central areas of Tehran (regions 8, 13, 14, 10, 11, 16, and 17) might show that in Northern Districts, the distribution of COVID-19 patients have occurred in throughout neighborhoods (Fig. 8). In contrast, the accumulation of patients in hotspot maps in the east and center areas might be related to high population density and high building density (20) and increased social interactions in the eastern and central communities.

In addition to the more heightened awareness and hygiene levels in areas with higher socioeconomic status (northern part of the city), higher death toll in eastern neighbourhoods (Fig. 6) can be associated with the lower socioeconomic status, which might cause people to refer to health care services only if their conditions have deteriorated.

This study shows that after adjusting the results of the absolute number of confirmed /probable patients in Tehran's neighborhoods based on population density, the northern regions of the city had a higher incidence of COVID-19 cases. This could confirm that in the southern and central parts of Tehran, the incidence rate increased because of the population density; however, in northern parts it did because of the further commuter and social contacts of the disease.

Our analysis shows that the hot spot of disease rate lies in eastern and southeastern neighbourhoods in the first and second waves. In the first month of pandemics, the death rate hot spot corresponds to the disease rate hot spot and is located in the east and southeastern areas. According to the population density map of Tehran (Fig. 7), it can be claimed that the probability of infection and death rises in areas with higher population density. After the moderation of the results, however, it is revealed that northern parts of the city, which enjoy a higher socioeconomic status as well as high population density in the northern regions of Tehran (19, 20), have also been affected with a remarkable incidence of the disease, despite their lower population density. Despite the higher incidence in proportion to the population in northern areas of the city, the hotspots map of incidences is highlighted in Tehran's' districts' east and centre. This aggravated situation can be explained by factors such as population density, malnutrition, a delayed visit to medical centres, lack of sufficient rest, and inadequate health care in these neighborhoods. Analysis of the hot spot cases during the 5 months indicates that they have remained almost unchanged.

In general, it can be concluded that the disease has started from areas with a higher population in Tehran and gradually transmitted to less populated areas. COVID-19 has affected all social classes, even the affluent areas in northern parts of the city. This confirms that observing hygiene is necessary for all people. Still, after being infected, the deprived social groups suffer the highest death toll in the deprived southern area of Tehran (20). Thus, the most important preventive measure is a lifestyle, hygienic behavior, and health education (22, 23). The slower progress of the disease in March and April was because of effective interventions by limiting commercial and recreational activities, restricting intercity travels, and employees' distance-working. However, with the total elimination of the lockdown, the disease spread more quickly in June and July.

Conclusion

Given our findings, which indicate that the hot spots of COVID-19 have recently centred on the eastern and central neighbourhoods in Tehran, disease control authorities

[DOI: 10.47176/mjiri.35.128]

can focus on appropriate prevention and control measures in these areas. Thus, it is recommended that the control and research programs for COVID-19 in these neighbourhoods be prioritized over other regions.

Ethics approval and consent to participate

This article reports a study at Shahid Beheshti University of Medical Sciences with ethics code IR.SBMU.RETECH.REC.1399.070. The study did not involve human participants and animals; therefore, no informed consent was needed.

Acknowledgement

Not applicable.

Conflict of Interests

The authors declare that they have no competing interests.

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[DOI: 10.47176/mjiri.35.128]