Original Article

Detecting the Seasonal and Spatial Patterns of COVID-19 Hospitalization and Deaths in Iran: Insights from a Spatiotemporal and Hotspot Analysis

Leila Mounesan[1], Ebrahim Farhadi[2,3], Sana Eybpoosh[1], Ali Hosseini[2], Mahboubeh Parsaeian[4], Safoora Gharibzadeh[1], Mozhgan Ahmadinezhad[1], Farideh Bahari[5], Mohammad Mehdi Gouya[6], Aliakbar Haghdoost[7], Ehsan Mostafavi[1]

[1]Department of Epidemiology and Biostatistics, Research Centre for Emerging and Reemerging Infectious Diseases, Pasteur Institute of Iran, Tehran, Iran, [5]Department of Nanobiotechnology, New Technologies Research Group, Pasteur Institute of Iran, Tehran, Iran, [2]Department of Human Geography and Planning, University of Tehran, Tehran, Iran, [3]Department of Architecture, Bologna University, Italy, [4]Department of Epidemiology and Biostatistics, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran, [6]School of Medicine, Iran University of Medical Sciences, Tehran, Iran, [7]HIV/STI Surveillance Research Center and WHO Collaborating Centre for HIV Surveillance, Institute for Futures Studies in Health, Kerman University of Medical Sciences, Kerman, Iran

Abstract

Background: Understanding the seasonal and spatial patterns of COVID-19 hospitalization and deaths is crucial for effective hospital management, resource allocation, and public health interventions. The current study conducts a spatiotemporal hotspot analysis that explores the seasonal and geographical patterns of high-risk areas of COVID-19 hospitalizations and deaths in Iran. **Methods:** Provincial-level data on laboratory-confirmed COVID-19 cases with acute respiratory symptoms in Iran (February 2019–March 30, 2022) were collected. Hotspot analyses mapped seasonal incidence risks, and Global Moran's spatial autocorrelation analysis identified COVID-19 clusters. **Results:** Over the 2 years, 26 hotspots and 11 cold spots were identified ($P < 0.05$). Western and central provinces showed the highest hospitalization hotspots, while the west and north had the most death hotspots. South and southeast provinces exhibited low incidence and the highest number of cold spots. High-risk areas were prevalent in spring and autumn, mainly in the west, north, and central regions. **Conclusions:** This research unveils the clustering patterns of COVID-19 hospitalizations and fatalities in Iran during the most severe pandemic. Spatial clusters and dynamic hotspots varied across regions and time. Prioritizing high-risk areas during critical epidemic waves, devising seasonal care strategies, and implementing preventive measures can significantly improve health outcomes.

Keywords: *Covid-19, hospitalization, incidence, Iran, spatiotemporal analysis*

Introduction

The COVID-19 pandemic has posed unprecedented challenges to public health systems globally. In January 2020, the World Health Organization (WHO) initially declared COVID-19 as a public health emergency of international concern.[1] With the decreasing trend in COVID-19 deaths and related hospitalizations, on May 5, 2023, the WHO officially declared that the COVID-19 pandemic is no longer a global health emergency, but it remains a significant threat to public health worldwide, and countries should remain vigilant through long-term management of COVID-19.[2]

COVID-19 is susceptible to mutations, resulting in new strains that differ in their genetic sequences and the number of mutations. As a result, even with intervention, they are not entirely effective in preventing the virus, and a portion of the vaccinated population may still become infected with varying degrees of severity.[3-5]

During the first 2 years of the pandemic, Iran experienced more pressure with the most burden of COVID-19 hospitalization and deaths,[6-10] as well as major COVID-19 variants and six epidemic waves.[11]

Health geography and spatial epidemiology examine disease patterns over time, providing insights into epidemic behavior and essential guidance for addressing future pandemics in vulnerable areas.[12-15] One popular spatial approach is the Getis-Ord Gi* analysis, which identifies hotspots or clusters of high values. Another commonly used technique is the global Moran's I index, which assesses the overall spatial autocorrelation and distribution of disease cases.[16,17]

In Iran, despite the existence of several spatial studies conducted at the national or provincial levels during the COVID-19 pandemic, these studies were predominantly carried out during the initial phases of the outbreak, characterized by limited duration[13,18-21] and a lack of consideration for seasonal patterns of COVID-19

How to cite this article: Mounesan L, Farhadi E, Eybpoosh S, Hosseini A, Parsaeian M, Gharibzadeh S, *et al.* Detecting the seasonal and spatial patterns of COVID-19 hospitalization and deaths in Iran: Insights from a spatiotemporal and hotspot analysis. Int J Prev Med 2025;16:20.

Access this article online

Website: www.ijpvmjournal.net/www.ijpm.ir

DOI: 10.4103/ijpvm.ijpvm_146_24

Quick Response Code:

Address for correspondence:
Dr. Ehsan Mostafavi,
Pasteur Institute of Iran (IPI), No. 69,Pasteur Ave, Tehran, Iran.
E-mail: mostafaviehsan@gmail.com

hospitalizations and deaths. In this paper, we conducted a spatiotemporal hotspot analysis focused on the spatial distribution of COVID-19 hospitalizations and deaths in Iran, encompassing a comprehensive 2-year period during the acute phase of the pandemic when the country experienced a significant impact from the disease.

Methods

Data collection and preparation

Data were sourced from the Medical Care Monitoring Center (MCMC), covering daily reports of COVID-19 hospitalizations and deaths at the provincial level from February 19, 2020, to March 30, 2022. The MCMC, a national center overseeing healthcare service delivery, compiles data from 1066 hospitals nationwide, including public, private, insurance, and charity hospitals. Inclusion criteria involved patients exhibiting acute respiratory symptoms, admitted for COVID-19, and testing positive for SARS-CoV-2 via reverse transcription-polymerase chain reaction (RT-PCR) within the initial 24 hours of hospitalization. Following the cleaning and verification of the data, the seasonal incidence rates were calculated based on the number of hospitalizations and deaths per 100,000 population.

Statistical analysis

To investigate the relationship between the risk of death and hospitalization with a 1-week time lag (the average lag between hospitalization and deaths) based on time and place (separated by 31 provinces), Pearson's correlation coefficient was performed (using STATA 14 software (StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP)).

Hotspot analysis and Global Moran's spatial autocorrelation analysis were used to identify spatial autocorrelation and areas that have high, low, or average occurrences of hospitalizations and deaths. Seasonal classification was used to study the changes in hotspots over time. Data were analyzed and reported seasonally, except for the first month, which was the beginning of the epidemic in the country. ArcGIS 10.7 (ESRI, 2018) software was used for spatial analysis.

Hotspot analysis and Moran's spatial autocorrelation analysis: Hotspot analysis was used to identify clustering patterns of the COVID-19 hospitalized cases and deaths, and hot and cold spots were identified using the Getis Ord's Gi test and fixed distance weighting method. Calculations are influenced only by neighbors within the designated distance, with equal weight given to each. Any features beyond this distance have no impact on the calculations and are assigned a weight of zero. The cold spot and hotspot features are further classified according to confidence intervals of 99%, 95%, and 90%.[22]

The global Moran's test with the inverse distance weighting method was examined to measure the tendency of events to cluster and the degree to which nearby areas had similar values compared to those that were far apart. According to this, a weighted matrix was defined by considering the spatial adjacency or distance between spatial units. The range of values for Moran's is between −1.0 and +1.0, where a value of 0 can be interpreted as random spatial ordering. A value greater than 0 indicates positive spatial autocorrelation and a tendency toward clustering, while a value less than 0 indicates negative spatial autocorrelation and a tendency toward dispersion.[13,14]

This study was reviewed and approved by the Research Ethics Committee at the Pasteur Institute of Iran (Approval code: IR.PII.REC.1399.081). The dataset utilized in this study consisted of daily aggregated data on hospitalizations and deaths reported at the provincial level. The process of acquiring data and conducting data analysis was approved by the Ethics Review Board at the Pasteur Institute of Iran.

Results

The geographical distribution of hospitals in Iran, as illustrated in Figure 1, provides insight into the distribution of hospitals per 100,000 population across different provinces in the country. The province-wise population, area, number of hospitals, and number of hospitals per 100,000 population are shown in Appendix 1.

The provinces of South Khorasan, Ilam, Fars, Kohgiluyeh and Boyer-Ahmad, and Semnan showed the highest number of hospitals per 100,000 population, while Sistan and Baluchestan, Alborz, Qom, and West Azerbaijan had the lowest number of hospitals per 100,000 population.

Throughout the period, the provinces of Sistan and Baluchestan, Fars, Khorasan-Razavi, Alborz, Qazvin, Isfahan, West Azerbaijan, Gilan, and Qom reported the highest percentages of deaths among hospitalized cases, ranging from approximately 15% to 23% [Appendix 1]. In contrast, Kohgiluyeh and Boyer-Ahmad, South Khorasan, and Ilam had the lowest percentages of deaths among hospitalized patients.

The Pearson correlation between the risk of COVID-19 hospitalization and hospital rate was 0.46 (P = 0.008), indicating a moderate positive correlation. However, there was no correlation between the risk of death cases and hospital rates (r = −0.14, $P = 0.437$).

In addition, the study found that there was no statistically significant correlation between hospital rates and the number of hospitalization and death hotspots of provinces (r = 0.28 and −0.12; $P = 0.123$ and $P = 0.506$, respectively). However, there was a positive correlation between cold spots of death and hospital rates (r = 0.36, $P = 0.042$), while no significant association was observed between cold spots of hospitalization and hospital rates (r = −0.11, $P = 0.574$). These findings suggest that there is no clear relationship between hospital rates and the number of hospitalization and death hotspots of provinces, but there may be a positive relationship between cold spots of death and hospital rates.

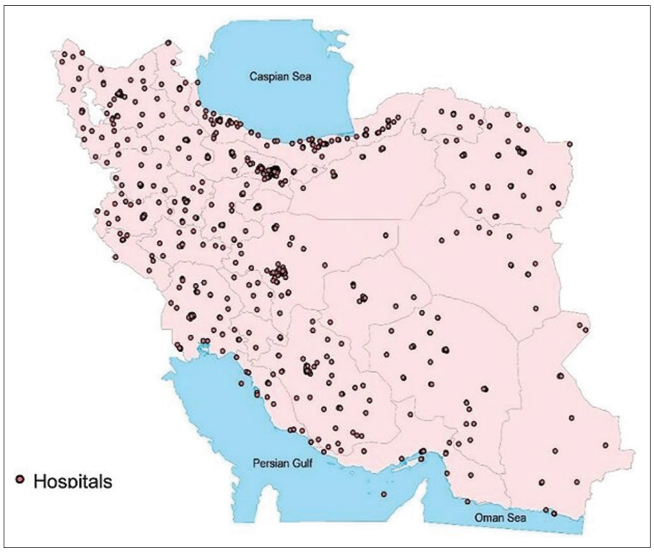

Figure 1: The geographical distribution of hospitals across different provinces in Iran

The Pearson correlation coefficient of the risk of death and hospitalization during the time and also at the level of the 31 provinces was 0.87 and 0.42 ($P < 0.001$ and $P = 0.017$ respectively). In this regard, the risk of death and hospitalization was strongly correlated over time, but this correlation was moderate at the provincial level.

The map of the hotspot analysis of COVID-19 hospitalization and deaths at the provincial level over 2 years is shown in Figure 2. According to the results of Getis-Ord's Gi test, two hotspots (Ilam and Chaharmahal and Bakhtiari) and one cold spot (Sistan and Baluchistan) for hospitalized cases, as well as one hotspot (Gilan) (with a confidence level of 90%) and two cold spots (Sistan and Baluchistan and Kerman), were identified at the 95% confidence level for deaths.

The findings of the study on COVID-19 hospitalizations [Figure 3] in the first month of the epidemic (20 February–20 March 2020) revealed that 11 provinces in the north and central regions of the country were hotspots; six provinces, namely Qom, Tehran, Alborz, Mazandaran, Semnan, and Isfahan were classified as highly significant hotspots, and Gilan, Qazvin and Zanjan, Hamadan, and Markazi provinces were identified as relatively significant hotspots (with confidence levels of 99% and 90%, respectively). During this month, only one relatively cold spot was detected in the south of Iran (with a confidence level of 90%). In the first year of the epidemic, four provinces were identified as hotspots and two provinces as cold spots (with confidence levels of 90%–99%). During the spring of 2020, two provinces in the west (Kermanshah and Kurdistan) were relatively

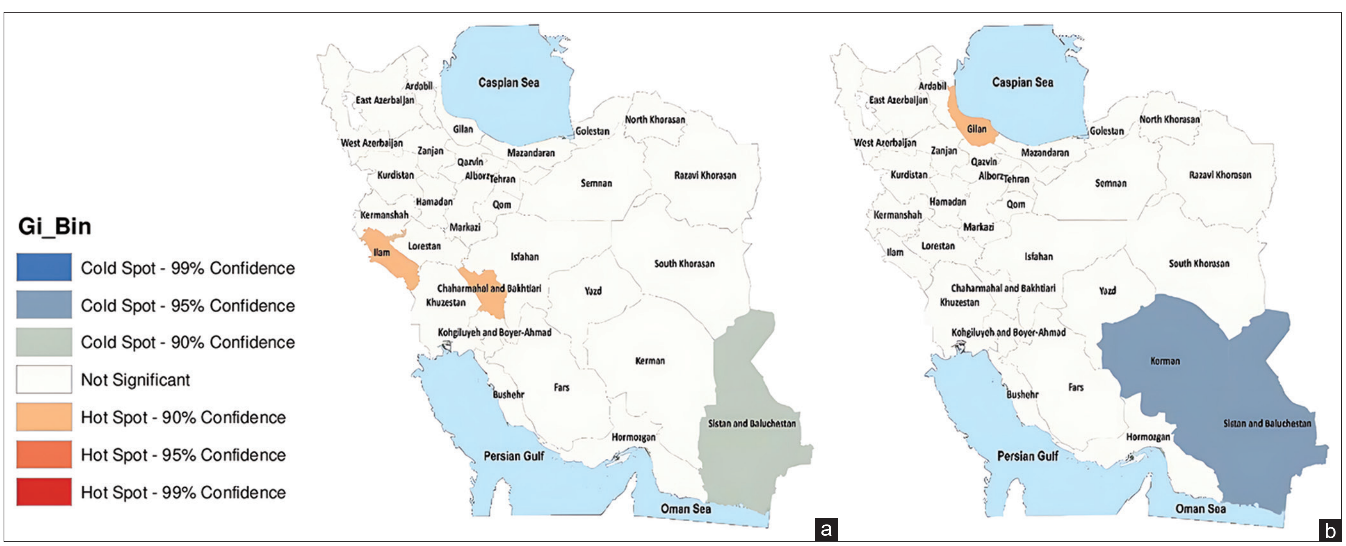

Figure 2: The map displays the provincial-level geography of Iran and highlights the COVID-19 hospitalization (a) and death (b) hot and cold spots from 2020 to 2022. The map uses a color-coded system to indicate the level of clustering, with seven confidence levels ranging from red for high-incidence hotspots to blue for low-incidence hotspots (cold spots). Two relatively hot spots (west) and one relatively cold spot (southeast) were identified for hospitalizations, while one relatively hot spot (north) and two cold spots (southeast) were identified for deaths

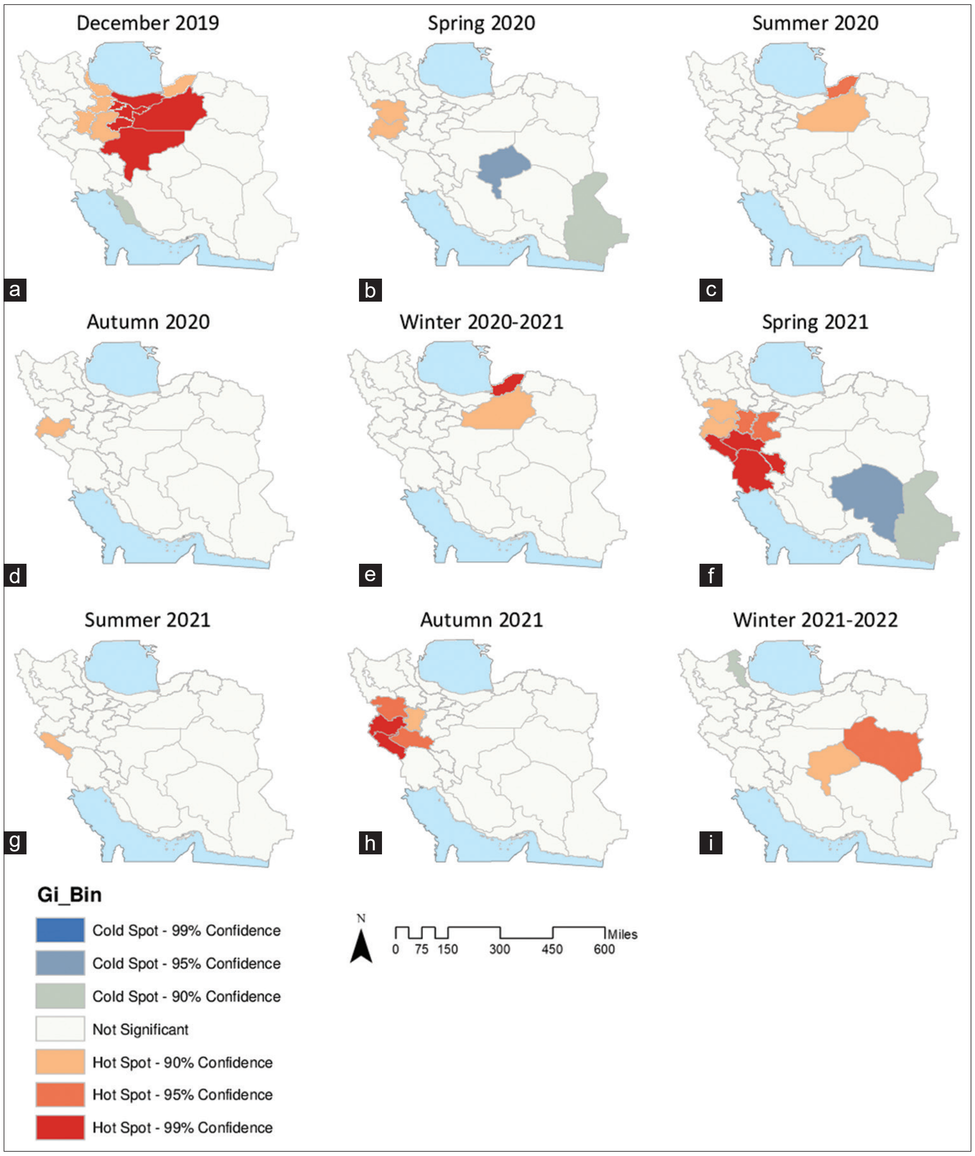

Figure 3: (a–i): Hotspot analysis of COVID-19 hospitalizations by season from epidemic onset to March 20, 2022. The first figure (a) relates to the first month of the epidemic, and the other figures (b–i) show for the eight seasons during 2 years The map is color-coded to represent the level of clustering (with 7 confidence levels), with red indicating high-incidence hotspots and blue indicating low-incidence hotspots (cold spots)

significant hotspots, and Yazd and Sistan and Baluchestan were cold and relatively cold spots. In the summer and winter, Golestan and Semnan, and in autumn, Kermanshah were significant hotspots. In total, in the second year, ten provinces were classified as hotspots, and there were cold spots (with confidence levels of 90%–99%). In the spring, there were very hot to relatively hot spots in eight provinces in the western regions of the country (9 provinces). Kerman and Sistan and Baluchestan provinces were cold and relatively cold spots during this season. In the summer, only Ilam province was a relatively significant hotspot. In the autumn, once again, five western provinces, namely Ilam, Kermanshah, Kurdistan, Lorestan, and Hamedan, were very hot to relatively hot spots; the dominant variants of COVID-19 in the country during these three seasons were alpha and delta. In the winter, the hotspot clusters moved to the central and eastern regions of the country, with the South Khorasan and Yazd provinces being hot and relatively hot spots. Ardabil province was also a relatively cold spot.

The accumulation of the hotspots of COVID-19 deaths [Figure 4] in the first month of the epidemic was quite similar to the hotspots of hospitalized cases. Thus, the nine provinces of Qom, Tehran, Alborz, Mazandaran, Gilan, Semnan, Isfahan, Qazvin, and Zanjan in the northern and central parts were from very hot to relatively hot spots (with confidence levels of 90%–99%). As the epidemic progressed, during the first year, nine provinces were identified as hotspots and five provinces as cold spots (with confidence levels of 90%–99%). In the spring, clustering of deaths emerged in the north and west of the

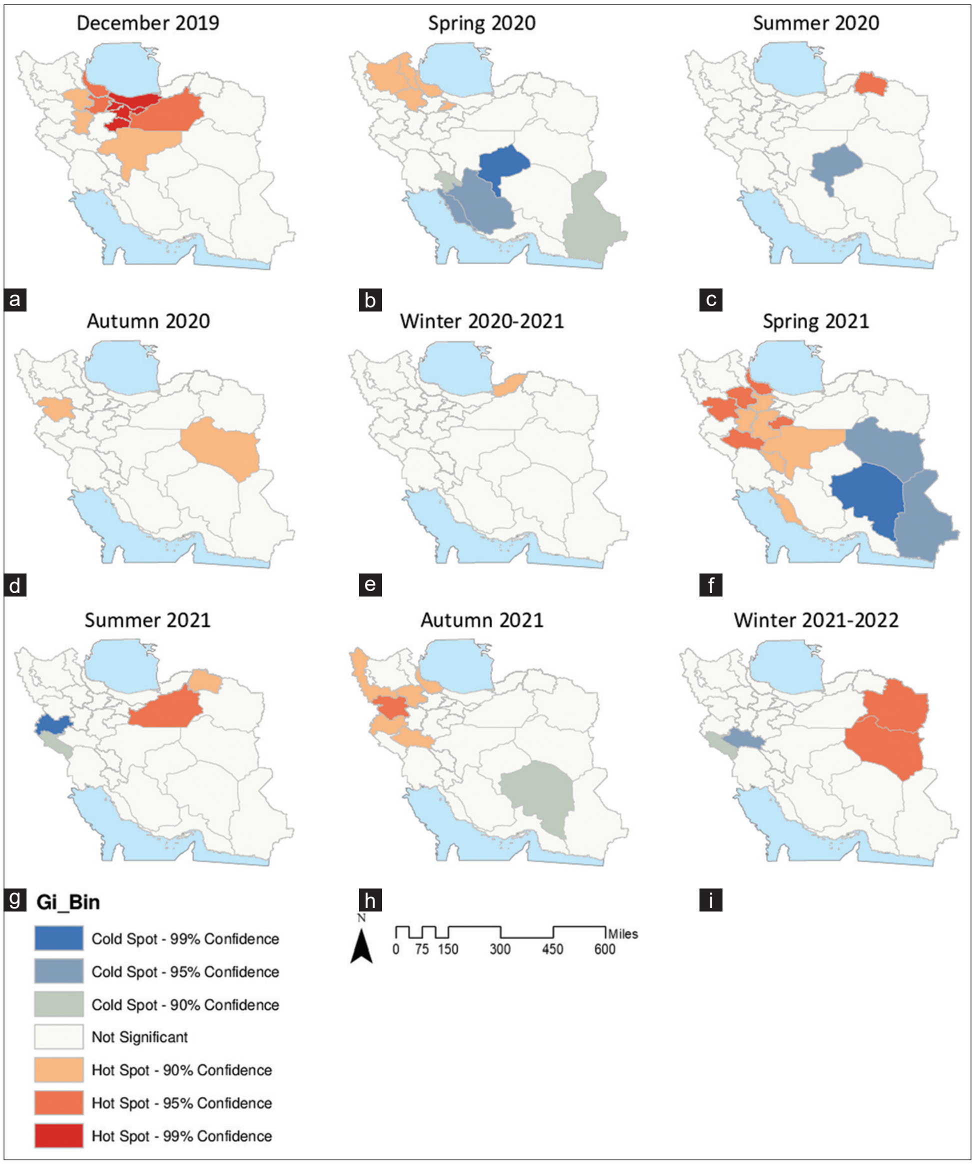

Figure 4*:* (a–i): Hotspot analysis of COVID-19 deaths by season from epidemic onset to March 20, 2022. The first figure (a) relates to the first month of the epidemic, and the other figures (b–i) show for the eight seasons during 2 years. The map is color-coded to represent the level of clustering (with 7 confidence levels), with red indicating high-incidence hotspots and blue indicating low-incidence hotspots (cold spots)

country, with Gilan, Ardabil, East Azerbaijan, Zanjan, and Alborz provinces experiencing relatively hot spots. During this period, Yazd, Fars, Bushehr, Sistan and Baluchestan, and Kohgiluyeh and Boyer-Ahmad provinces were cold spots. In the remaining three seasons of the year, the number of hot or cold spots in the country decreased, and there was no significant difference in the occurrence of deaths between other provinces. During summer, North Khorasan was a hotspot, while Yazd was a cold spot. In autumn, two provinces of South Khorasan and Kurdistan, and in winter, Golestan experienced relatively hot spots in the country.

During the second year, 17 provinces were identified as hotspots and seven provinces as cold spots (with confidence levels of 90%–99%). In the spring, hot and relatively hot spots in 11 provinces of Gilan, Zanjan, Kurdistan, Qom, Qazvin, Hamadan, Markazi, Lorestan, Chaharmahal and Bakhtiari, Isfahan, and Bushehr and very cold spots were observed in three provinces of Kerman, Sistan and Baluchestan, and South Khorasan. In summer, Semnan and North Khorasan were hot and relatively hot spots, and Kermanshah and Ilam were cold and relatively cold spots. In autumn, in the western and northwestern half of the country, six provinces of West Azerbaijan, Kurdistan, Zanjan, Kermanshah, Lorestan, and Gilan were hot and relatively hot spots, and Kerman province was a relatively cold spot. In winter, Razavi Khorasan and South Khorasan were hot spots, and Lorestan and Ilam were cold and relatively cold spots, respectively.

The findings of the spatial autocorrelation analysis showed a clustering pattern of COVID-19 hospitalizations and deaths in the first month of the epidemic ($P < 0.001$). Furthermore, the results indicated a positive clustering pattern during the spring and autumn of 2021 for hospitalizations ($P = 0.005$ and $P = 0.033$, respectively) and in the spring of 2021 for deaths ($P = 0.009$). The spatial autocorrelation was random in other seasons.

Discussion

The study analyzed the spatial patterns of hospitalizations and deaths from COVID-19 in Iran from February 2020 to March 2022. The findings showed the presence of spatial clustering in hospitalizations and deaths during different stages of the epidemic as well as in subsequent seasons. Clusters initially appeared in northern and central provinces, gradually spreading to the west and east, while the south and southeast consistently had lower risks across multiple seasons.

During the four seasons of the first year (2020–2021), the pattern of hospitalization and deaths was not much different in the provinces, and there were fewer hot and cold spots. However, in the spring, there were several clusters of deaths and hospitalizations in hot and cold spots, mainly concentrated in the north, northwest, south, and southeast regions of the country. As the epidemic progressed, in the second year (2021–2022), there was an accumulation of hot or cold spots of hospitalizations and deaths in spring and autumn. In terms of hospitalizations, the western and southwestern provinces in the spring and the western provinces in the fall were identified as hotspots, and the cold spots were observed in two provinces in the southeast of the country in the spring. Concerning the clusters of mortality occurring during the spring and autumn seasons, they were predominantly observed within the central, western, and northern regions of the nation. During winter, however, these clusters changed to encompass two provinces located in the eastern and northeastern areas of the country. In addition, the results of the spatial autocorrelation analysis of hospitalization and death due to COVID-19 were consistent with the findings of the hotspot analysis, spanning a period of 2 years. In Iran, the largest epidemic waves were related to the spring to autumn of 2021. The dominant variants of COVID-19 in this period were the alpha and delta variants, which have the most destructive health effects and deaths.

Knowledge of the initial appearance and subsequent spread of clusters helps in early detection and response efforts while also enabling targeted resource allocation and intervention planning.[19,23,24] Findings of an import risk model of the spread of COVID-19 during the early phase of the pandemic represented that Iran was ranked in the top 10 Asian countries by level of risk among the most probable routes to spread from the international airport in Beijing. Based on this, being close to the capital city with transportation connections can be one of the causes of the start of a pandemic in the central and northern regions of the country.[25,26] The northern and central regions of Iran were the most affected and hotspots of hospitalization and deaths during the first month of the epidemic. In an initial study from February 19 to March 18, 2020, Tehran's neighborhoods were analyzed using global Moran's I and LISA. The study found that provinces with high urbanization, older populations, and higher temperatures were more prone to higher COVID-19 case numbers.[13]

Our findings over 9 months were consistent with prior research, showing the disease spread differently across Iran's 31 provinces. Initially, central, northern, and northwestern areas were most affected, with western and southwestern regions seeing a significant increase later. In addition, the eastern and southeastern regions had the lowest number of deaths. Although Moran's spatial correlation index was not significant in this study, in our study, this index was consistent with the seasonal pattern of hot and cold spots regarding cases of death and hospitalization.[27] Moreover, regions with consistently low risks suggest potential protective factors such as infrastructure, social behaviors, and medical interventions for further study. A spatiotemporal analysis from 2011 to 2016 identified western regions as influenza hotspots, recommending prioritized control and research programs in these areas.[28] Our investigation found that the western regions of Iran are also high-risk zones, similar to the spatial pattern observed for influenza. Therefore, it is imperative to closely monitor and prepare for potential outbreaks of respiratory illnesses in high-risk areas to reduce the burden and severity of the damage. In addition, it is important to pay more attention to movements in high-traffic cross-border areas, in addition to implementing general control measures.

In the current study, during the 2-year pandemic, Gilan, Sistan and Baluchestan, and Kerman provinces were categorized as relatively hot, cold, and cold spots of mortality risk, respectively. According to estimates of the population ratio over 65 years old in the year 2021, Gilan had the highest rate of elderly population at 13.2%, while Sistan and Kerman had the lowest rates at 3.2% and 5%, respectively.[29] Based on this, the risk can be influenced by features such as the age structure of the population in the provinces.

The current study found a positive and significant correlation between the risk of COVID-19 hospitalization and hospital rates. However, this correlation was not observed with death rates. Interestingly, a positive correlation was detected between death cold spots and hospital rates. This suggests that the existence of health services and infrastructure may serve as a protective factor against COVID-19 deaths. In a study conducted in 2024 to cluster and rank 31 provinces according to 11 health indicators—such as the number of health workers, medical facilities, and available hospital beds—the results highlighted that the provinces of Ilam, Yazd, Semnan, South Khorasan, Zanjan, Ardabil, Fars, Kohgiluyeh and Boyer-Ahmad, and Chaharmahal and Bakhtiari achieved the highest health index scores.[30] Our findings also showed that Ilam, South Khorasan, and Kohgiluyeh and Boyer-Ahmad experienced a lower mortality rate among hospitalized patients, which may correlate with their better health indicator performance.

In a study on health system equity in Iran (2020), macro-level data revealed a relatively fair distribution of hospital beds across provinces. Although generally at the provincial level, hospital beds were more concentrated in the capital cities of each province and relatively unevenly distributed. Fair distribution of hospital beds has created equal geographical access to the community and is a prerequisite for health for everyone, but not enough. Hospitals' efficiency; fair use of hospital services; social, cultural, and economic factors; the type and severity of the disease; and insurance affect the use of people's use of hospital services.[31]

One of the key advantages of our study was to identify the spatial and seasonal trends of COVID-19 hospitalizations and deaths during the initial 2 years of the pandemic when the nation experienced its most devastating impact. These findings provide evidence-based images of the epidemic's behaviors over time, particularly during critical epidemic waves. The study also suggests the development of seasonal planning strategies such as enhancing surveillance systems to track and monitor variants in high-risk regions during specific seasons. Implementing preventative measures such as conducting widespread vaccination drives with a special emphasis on the elderly and other susceptible populations, particularly in areas with high infection rates, is recommended. Furthermore, the research offers significant knowledge of the geographical trends of COVID-19 hospitalization and fatalities, which can guide future initiatives for pandemic readiness and response.

Limitations

The study acknowledges several limitations that warrant consideration in the interpretation of findings. Primarily, the analysis was constrained to provincial-level data, precluding a more detailed examination at the hospital level within each province. Confounding factors, such as population characteristics, social distancing measures, vaccination rates, healthcare capacity, and socioeconomic factors, were not explicitly accounted for. The study's focus on population sizes and spatial proximity oversimplified potential influences on COVID-19 patterns. Despite the assumption of uniform national-level interventions, variations at the provincial level may exist. The reliance on seasonal data analysis, while providing a broader planning perspective, may have limitations compared to short-term analysis in terms of prompt response. The study exclusively examined hospitalization and deaths, acknowledging a lower bias compared to population-level data. Notably, during the initial phases of the pandemic in Iran, PCR testing was primarily conducted on hospitalized cases under follow-up, ensuring more reliable disease rates in this population subset. Finally, although Global Moran's analysis was employed for spatial autocorrelation, the study recognizes the potential enhancement of efficiency through the incorporation of modified Moran's indices and other autocorrelation techniques, particularly in large, heterogeneous regions.

Conclusions

This study identified seasonal clusters of COVID-19 hospital admissions and deaths across different geographical areas in Iran. High-risk areas initially appeared in the northern and central provinces, spreading to the western and eastern regions. South and southeastern regions consistently had lower risks. Understanding the initial appearance and subsequent spread of clusters aids in early detection and response efforts, allowing for effective control measures. In addition, the identification of high-risk and low-risk areas enables targeted resource allocation and intervention planning, optimizing healthcare resources and strategies. Further research should focus on investigating the potential protective factors or successful interventions in regions with consistently low risks, which ultimately can inform the development of targeted interventions and strategies. In addition, exploring the impact of infrastructure, interventions, social behaviors, and medical follow-up in shaping the spatial dynamics of COVID-19 can provide valuable insights for future public health policies and interventions.

Ethical issues

The study was reviewed and approved by the Research Ethics Committee at the Pasteur Institute of Iran (Ethics approval code: IR.PII.REC.1399.081).

Acknowledgments

This paper is a part of PhD thesis in the Pasteur Institute of Iran where funded this study. We acknowledge the contributions of the Pasteur Institute of Iran, and the Ministry of Health and Medical Education for conducting the research and data collection.

Authors' contributions

EM was the project manager and coordinated the study and data acquisition. EM, MMG and LM contributed to the conceptualization, methodology and design of the study. LM and FE contributed to data cleaning. LM conducted the statistical analyses. LM, EM, MA, SE, SGH wrote the first draft of the manuscript. LM, EM, FE, AH, MP, SGH, SE, FB and MMG contributed to the analysis and interpretation of the findings. All authors critically appraised the manuscript and approved the final version. All authors had access to all data in the studies.

Ethics approval code

IR.PII.REC.1399.081.

Financial support and sponsorship

This work was supported by the Pasteur Institute of Iran.

Conflicts of interest

Dr. MMG had been the former director of the Iranian Center for Communicable Diseases at the Ministry of Health during the time of the study. All other authors declare that they have no competing interests.

Received: 13 May 24 **Accepted:** 11 Sep 24
Published: 24 Apr 25

References

1. Mahase E. China coronavirus: WHO declares international emergency as death toll exceeds 200. BMJ 2020;368:m408. doi: 10.1136/bmj.m408.
2. Wise J. Covid-19: WHO declares end of global health emergency. BMJ 2023;381:1041.
3. Kolahchi Z, De Domenico M, Uddin LQ, Cauda V, Grossmann I, Lacasa L, *et al*. COVID-19 and its global economic impact. In: Coronavirus Disease-COVID-19. Springer; 2021. p. 825-37.
4. Lison A, Banholzer N, Sharma M, Mindermann S, Unwin HJT, Mishra S, *et al*. Effectiveness assessment of non-pharmaceutical interventions: Lessons learned from the COVID-19 pandemic. Lancet Public Health 2023;8:e311-7. doi: 10.1016/S2468-2667 (23) 00046-4.
5. Bollyky TJ, Castro E, Aravkin AY, Bhangdia K, Dalos J, Hulland EN, *et al*. Assessing COVID-19 pandemic policies and behaviours and their economic and educational trade-offs across US states from Jan 1, 2020, to July 31, 2022: An observational analysis. Lancet 2023;401:1341-60.
6. Mounesan L, Eybpoosh S, Haghdoost A, Moradi G, Mostafavi E. Is reporting many cases of COVID-19 in Iran due to strength or weakness of Iran's health system? Iran J Microbiol 2020;12:73-6.
7. Ahmadi A, Fadaei Y, Shirani M, Rahmani F. Modeling and forecasting trend of COVID-19 epidemic in Iran until May 13, 2020. Med J Islam Repub Iran 2020;34:27.
8. Doosti-Irani A, Haji-Maghsoudi S, Haghdoost A, Eybpoosh S, Mostafavi E, Karami M, *et al*. The dynamic effective reproductive number of COVID-19 during the epidemic in Iran. Iran J Public Health 2022;51:886-94.
9. Ebrahimoghli R, Abbasi-Ghahramanloo A, Moradi-Asl E, Adham D. The COVID-19 pandemic's true death toll in Iran after two years: An interrupted time series analysis of weekly all-cause mortality data. BMC Public Health 2023;23:1-9.
10. Sadeghi K, Zadheidar S, Zebardast A, Nejati A, Faraji M, Ghavami N, *et al*. Genomic surveillance of SARS-CoV-2 strains circulating in Iran during six waves of the pandemic. Influenza Other Respir Viruses 2023;17:e13135. doi: 10.1111/irv. 13135.
11. Mostafavi E, Eybpoosh S, Karamouzian M, Khalili M, Haji-Maghsoudi S, Salehi-Vaziri M, *et al*. Efficacy and safety of a protein-based SARS-CoV-2 vaccine: A randomized clinical trial. JAMA Netw Open 2023;6:e2310302. doi: 10.1111/irv. 13135.
12. Hay SI, Battle KE, Pigott DM, Smith DL, Moyes CL, Bhatt S, *et al*. Global mapping of infectious disease. Philos Trans R Soc Lond B Biol Sci 2013;368:20120250.
13. Ramírez-Aldana R, Gomez-Verjan JC, Bello-Chavolla OY. Spatial analysis of COVID-19 spread in Iran: Insights into geographical and structural transmission determinants at a province level. PLoS Negl Trop Dis 2020;14:e0008875. doi: 10.1371/journal.pntd. 0008875.
14. Samany NN, Toomanian A, Maher A, Hanani K, Zali AR. The most places at risk surrounding the COVID-19 treatment hospitals in an urban environment-case study: Tehran city. Land Use Policy 2021;109:105725.
15. Franch-Pardo I, Napoletano BM, Rosete-Verges F, Billa L. Spatial analysis and GIS in the study of COVID-19. A review. Sci Total Environ 2020;739:140033.
16. Getis A. A history of the concept of spatial autocorrelation: A geographer's perspective. Geogr Anal 2008;40:297-309.
17. Cliff AD, Ord K. Spatial autocorrelation: A review of existing and new measures with applications. Econ Geogr 1970;46(suppl 1):269-92.
18. Lak A, Maher A, Zali A, Badr S, Mostafavi E, Baradaran HR, *et al*. 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;35:128.
19. Rahnama MR, Bazargan M. Analysis of spatio-temporal patterns of Covid-19 virus pandemic and its hazards in Iran. Environ Manage Hazards 2020;7:113-27.
20. Jesri N, Saghafipour A, Koohpaei A, Farzinnia B, Jooshin MK, Abolkheirian S, *et al*. Mapping and spatial pattern analysis of COVID-19 in central Iran using the Local Indicators of Spatial Association (LISA). BMC Public Health 2021;21:1-10.
21. Shariati M, Jahangiri-rad M, Mahmud Muhammad F, Shariati J. Spatial analysis of COVID-19 and exploration of its environmental and socio-demographic risk factors using spatial statistical methods: A case study of Iran. Health Emerg Disasters Q 2020;5:145-54.
22. Manepalli U, Bham GH, Kandada S. Evaluation of hotspots identification using kernel density estimation (K) and Getis-Ord (Gi*) on I-630. In: 3rd International Conference on Road Safety and Simulation. United States: National Academy of Sciences Indianapolis Indiana; 2011.
23. Calderón Peralvo F, Cazorla Vanegas P, Avila-Ordóñez E. A systematic review of COVID-19 transport policies and mitigation strategies around the globe. Transp Res Interdiscip Perspect 2022;15:100653.
24. Pourghasemi HR, Pouyan S, Heidari B, Farajzadeh Z, Shamsi SRF, Babaei S, *et al*. Spatial modeling, risk mapping, change detection, and outbreak trend analysis of coronavirus (COVID-19) in Iran (days between February 19 and June 14, 2020). Int J Infect Dis 2020;98:90-108.
25. Zhang L, Yang H, Wang K, Zhan Y, Bian L. Measuring imported case risk of COVID-19 from inbound international flights - A case study on China. Journal of Air Transport Management 2020;89:101918.
26. Brockmann D, Helbing D. The hidden geometry of complex, network-driven contagion phenomena. Science 2013;342:1337-42.
27. Hazbavi Z, Mostfazadeh R, Alaei N, Azizi E. Spatial and temporal analysis of the COVID-19 incidence pattern in Iran. Environ Sci Pollut Res Int 2021;28:13605-15.
28. Panahi MH, Parsaeian M, Mansournia MA, Khoshabi M, Gouya MM, Hemati P, *et al*. A spatio-temporal analysis of influenza-like illness in Iran from 2011 to 2016. Med J Islam Repub Iran 2020;34:65.
29. Iran statistics centre, population statistics. Available from: https://www.amar.org.ir/. [Last accessed on 2024 Oct 16].
30. Ashtarinezhad E, Ahmadi K, Mojiri A. Clustering and ranking Iranian provinces based on some health indicators. Payesh (Health Monitor) 2024;23:7-17.
31. Janbabaei G, Kalantari B, Darrudi A, Dehnavi H. Equity in distribution of hospital beds in Iran. Sci J Kurdistan Univ Med Sci 2020;24:12-36.

Appendix 1: Demographic and geospatial data at the provincial level, including population, area, number of hospital-reported data in this study, and the number of hotspots and cold spots

Provinces	Population estimation (in 2020)	Area (km^2)	Hospitals (*n*)	Hospitals (per 100,0000 pop)	Death rate	Mortality*
Alborz	2,922,400	5121.69	22	0.75	2.18	17.62
Ardabil	1,295,200	17,799.99	16	1.24	2.00	12.86
Bushehr	1,240,500	22,742.74	20	1.61	1.58	12.15
Chaharmahal and Bakhtiari	983,600	16,328.35	11	1.12	1.77	11.15
East Azerbaijan	4,040,400	37,411.39	52	1.29	1.94	15.48
Fars	5,054,700	122,607.94	89	1.76	1.50	19.42
Gilan	2,563,000	14,041.89	36	1.40	1.77	15.34
Golestan	1,972,700	20,367.13	28	1.42	1.55	13.14
Hamadan	1,766,500	19,367.90	25	1.42	1.73	9.91
Hormozgan	1,933,800	70,697.28	28	1.45	1.25	12.59
Ilam	594,200	20,132.84	11	1.85	1.93	6.66
Isfahan	5,343,800	107,017.65	72	1.35	1.56	15.72
Kerman	3,330,800	180,725.57	38	1.14	1.47	10.18
Kermanshah	1,992,300	25,009.27	29	1.46	1.44	9.95
Khuzestan	4,994,000	64,055.00	59	1.18	2.05	15.13
Kohgiluyeh and Boyer-Ahmad	745,300	15,504.07	13	1.74	1.33	8.26
Kurdistan	1,665,900	29,136.55	22	1.32	1.31	9.83
Lorestan	1,791,200	28,293.99	24	1.34	1.47	8.42
Markazi	1,462,800	29,124.16	20	1.37	2.04	14.97
Mazandaran	3,375,900	23,841.64	50	1.48	1.75	9.6
North Khorasan	877,200	28,434.31	11	1.25	2.36	12.5
Qazvin	1,326,400	15,567.30	16	1.21	2.03	16.67
Qom	1,399,400	11,526.26	11	0.79	2.30	15.22
Razavi Khorasan	6,889,200	118,851.44	73	1.06	1.87	19.29
Semnan	757,200	97,490.81	13	1.72	2.03	10.79
Sistan and Baluchestan	3,085,200	181,785.28	22	0.71	0.85	22.62
South Khorasan	818,300	95,384.97	16	1.96	1.62	8.2
Tehran	14,033,400	13,692.41	173	1.23	1.44	11.28
West Azerbaijan	3,445,500	45,650.47	32	0.93	2.04	14.28
Yazd	1,252,500	129,284.86	20	1.60	2.01	12.57
Zanjan	1,101,700	21,773.29	14	1.27	1.63	13.41

*Percentage of deaths associated with hospitalizations