Geospatial analysis of Covid-19 mortality linked to environmental risk factors in Iran- 2019-2021

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Abstract

Objectives

This study aims to investigate the impact of various demographic, environmental, and topographical factors on COVID-19 mortality rates in different geographical provinces of Iran.

Methods

The research utilized data from DATASUS (Ministry of Health), International Classification of Diseases (ICD-10), WorldClimV1, Sentinel-5P TROPOMI-based datasets, Open Street Map (OSM), and the Shuttle Radar Topography Mission satellite (SRTM) to gather mortality, demographic, environmental, and topographical data, evaluating them by sex, age group, and province. The analysis employed Geographic Information Systems methodology and logistic regression.

Results

Higher mortality rates were observed in the central and southern regions, with West Azerbaijan and Sistan-Baluchestan provinces showing elevated rates compared to their population sizes. Additionally, South Khorasan, Sistan-Baluchestan, Semnan, Bushehr, and Ilam provinces exhibited higher mortality ratios relative to mean temperature. The central and southern provinces displayed a higher ratio of air pollution concerning Covid-19 mortality, notably around Uremia Lake, showing a significant correlation. Logistic regression analysis revealed positive correlations of NO₂ and O₃ with Covid-19 mortality, while CO₂ and SO₂ showed negative correlations. Furthermore, population, population density, and area emerged as the most influential factors affecting the Covid-19 mortality rate.

Conclusions

The findings of this study offer valuable insights for policymakers and public health officials to develop targeted interventions for reducing the virus's impact in high-risk areas and enhancing healthcare resources and infrastructure in urban settings.

1. Background

The emergence of a zoonotic coronavirus disease in 2020, known as COVID-19 or 2019-nCoV or β-coronavirus, marked a significant global health crisis, characterized by atypical pneumonia, and declared a novel pandemic, necessitating immediate attention (1). In light of the profound impact of COVID-19 on public health and socio-economic systems worldwide, there is an urgent need for a comprehensive epidemiological analysis to understand its evolving patterns on a global scale (2). While existing data
indicates a positive correlation between the COVID-19 pandemic and levels of socio-economic development, concerns have been raised regarding the efficacy of current vaccines in halting transmission (3). Iran, among the top ten countries with the highest number of confirmed COVID-19 cases, has been significantly affected by the pandemic, underscoring the urgency of ongoing mitigation measures (4). The increasing number of COVID-19 cases, persisting even as of March 31, 2022, emphasizes the importance of sustained efforts to combat its impact (4). The increasing number of COVID-19 cases, persisting even as of March 31, 2022, emphasizes the importance of sustained efforts to combat its impact (5). The surge in studies investigating the associations between epidemic incidence and explanatory factors across diverse geographical areas and indicators reflects a growing interest in understanding the pandemic's complexities (6). Analysis of various factors, including environmental, socioeconomic, topographic, and demographic variables, highlights the intricate interplay influencing regional infection severity (7). Notably, health disparities exhibit spatial dimensions, mirroring inequalities in social, economic, and physical environments, emphasizing the need for spatiotemporal considerations in analyzing COVID-19 factors and infection incidence (8). Geographic Information Systems (GIS) have emerged as indispensable tools for mapping disease distribution and transmission, aiding in public awareness and preparedness during the Covid-19 pandemic. While global studies have explored Covid-19 infections from a spatiotemporal perspective and considered multiple risk factors, research in Iran has predominantly focused on socio-demographic risk factors in epidemiological studies (9). However, a gap exists in understanding the spatial statistics of Covid-19 and associated risk factors on a national scale. This study aims to address this gap by investigating the geographical distribution of Covid-19 mortality across all provinces in Iran and examining the environmental, socio-demographic, and climate-related factors influencing Covid-19 mortality.

2. Methods

2.1 Area of Study

This research examines the diverse geographical regions within Iran, specifically the Islamic Republic of Iran. Iran encompasses a total land area of 1,873,959 km\(^2\) and exhibits a range of climates, including arid, semi-arid, cold-semi-arid, hyper-arid, and subtropical, which are distributed across different regions of the country (10). The primary focus of analysis in this study is the 32 provinces that constitute mainland Iran. These provinces are recognized for their distinct climate patterns, socioeconomic attributes, social milieu, and population density.

2.2 Data

The data utilized for analysis in this study was sourced from the Minister of Health of Iran and accessed through their official website at http://ird.behdasht.gov.ir/. The dataset covers the period from 2019 to 2021 and includes all COVID-19 positive cases recorded in hospitals, coded using the International Classification of Diseases (ICD-10). Population data at the province level was gathered from the national census of population and housing, accessible at https://www.amar.org.ir/. Bioclim data, encompassing
monthly temperature and rainfall information, was obtained from WorldClimV1, focusing on average annual temperature and total annual precipitation for this research. Furthermore, average air pollution indicators like nitrogen dioxide, methane, carbon monoxide, and particulate matter were collected from Sentinel-5P TROPOMI-based datasets. Road density data and Digital Elevation Models (DEMs) indicators were sourced from Open Street Map (OSM) and the Shuttle Radar Topography Mission satellite (SRTM), respectively.

2.3 Statistical Analysis

The study utilized the ArcGIS 10.6 environment to develop and produce crucial maps following data coding and preparation. The investigation focused on examining the impact of various variables, such as population density, road density, air pollution, elevation, temperature, and rainfall, on the mortality rate of COVID-19. The SAGA GIS software was employed for the analysis of data regression models.

3. Result

3.1 Spatial Distribution of Accumulated COVID-19 mortality

The results of the models assessing COVID-19 mortality cases over a one-year period are presented in Fig. 1(A). The analysis of the gathered data reveals that the central and southern regions of Iran exhibit the highest rates of mortality (1A). A more detailed examination of each specific region indicates that Razavi Khorasan (1.B), west Azerbaijan (1.C), Mazandaran (1.D), Khuzestan (1.E), and Tehran (1.F) are the provinces with the highest mortality rates in the west, east, west, north, and center, respectively (Fig. 1).

3.2 Spatial Patterns of Environment, Demographics, and Topography

The spatial distribution of environmental factors, demographic variables, and topographical characteristics is depicted in Fig. 2. This figure shows cases the patterns of temperature, precipitation, and air pollution, as well as population, road density, population density, elevation, and area.

3.2.1 Spatial Pattern of Environmental Characteristics

The spatial distribution of environmental factors, such as temperature (A), precipitation (B), and air pollution (C) including NO₂, SO₂, CO₂, and O₃, exhibits distinct patterns. The southern, southeast, south-southeast, and east-southeast regions experience the highest temperatures and precipitation levels. Analysis of air pollution data reveals that the concentrations of NO₂, SO₂, and O₃ are most pronounced in the southern and central areas, whereas CO₂ exhibits greater intensity in the western, northwestern, and southeastern regions (Fig. 2).
3.2.2 Spatial pattern of demographical and topographical characteristics

The analysis of demographic data, such as population, road density, and population density, reveals that provinces such as Razavi Khorasan, Tehran, Isfahan, Shiraz, and Khuzestan have the highest population numbers. However, when considering population density, Sistan-Balucheshtan and Semnan provinces exhibit the highest values. This is further illustrated in Fig. 2D, E, and F. Additionally, Fig. 2G and H depict the spatial distribution of topographical characteristics. It is evident that the province located in the western and northern regions has the smallest area, while Sistan-Baluchestan province has the largest area.

Furthermore, the northern, eastern, and central regions display the lowest and highest elevations, respectively.

3.2 COVID-19 Mortality Ratio in Relation to Demographic, Environmental, and Topographic Factors

The analysis of the mortality ratio of COVID-19 in different provinces of Iran reveals that West Azerbaijan and Sistan-Baluchestan provinces have exhibited a higher mortality rate compared to their respective population sizes (Fig. 3A). Interestingly, a correlation between mortality rates and province area indicates that provinces with smaller geographical areas have experienced higher mortality rates (Fig. 3B). Notably, South Khorasan, Sistan-Baluchestan, Semnan, Bushehr, and Ilam provinces have demonstrated a higher mortality ratio in relation to the mean temperature (Fig. 3C). Furthermore, there is a notable disparity in the ratio of precipitation to Covid-19 mortality across various provinces, including Kohgiluyeh and Boyer-Ahmad, Ilam, Ardabil, and Kordestan (Fig. 3D). It is worth noting that the central and southern provinces exhibit a higher ratio of air pollution in relation to Covid-19 mortality. Particularly, the area surrounding Urmia Lake demonstrates a significant correlation between air pollution and mortality (Fig. 3E). Additionally, Gazvin, Tehran, and Ilam stand out in terms of mortality rates associated with road density (Fig. 3F).

3.3 Analysis Correlates of COVID-19 mortality with independent variable

The findings from the logistic regression analysis indicate that there is a positive correlation between all factors examined and the mortality rate of Covid-19, with the exception of road density, which exhibits a negative correlation. Furthermore, the data obtained suggests that population and area are significant factors that have a strong impact on the Covid-19 mortality rate, as evidenced by $R^2$ values of 0.9 and 0.29 respectively (Table 1).
Table.1 Logistic regression of association Covid-19 mortality with demographic, environment and Topographic factors

<table>
<thead>
<tr>
<th>Factor</th>
<th>Variable</th>
<th>Correlation Coefficient</th>
<th>R</th>
<th>R</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographic</td>
<td>Road density</td>
<td>-134.37</td>
<td>-0.09</td>
<td>0.008</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Population density</td>
<td>95906954</td>
<td>0.42</td>
<td>0.17</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Population</td>
<td>0.03495</td>
<td>0.95</td>
<td>0.90</td>
<td>0</td>
</tr>
<tr>
<td>Environment</td>
<td>Temperature</td>
<td>251.63</td>
<td>0.22</td>
<td>0.048</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Precipitation</td>
<td>19.94</td>
<td>0.098</td>
<td>0.009</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Air pollution</td>
<td>No₂</td>
<td>26670.05</td>
<td>0.07</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>So₂</td>
<td>-303393</td>
<td>-0.17</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Co₂</td>
<td>-89583.2</td>
<td>-0.26</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O₃</td>
<td>543686.9</td>
<td>0.20</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>44345.19</td>
<td>-0.040</td>
<td>0.03</td>
<td>0</td>
</tr>
<tr>
<td>Topographic</td>
<td>Elevation</td>
<td>13.87</td>
<td>0.17</td>
<td>0.02</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Area</td>
<td>4991.69</td>
<td>0.543</td>
<td>0.29</td>
<td>0</td>
</tr>
</tbody>
</table>

The findings of the multivariate regression analysis indicate that several variables, including NO₂, O₃, precipitation, temperature, elevation, population, and population density, exhibit a positive correlation with the Covid-19 mortality rate. Conversely, road density, area, CO₂, and SO₂ demonstrate a negative correlation with the Covid-19 mortality rate, as depicted in Fig. 4A. It is worth noting that population (R: 0.904), population density (R: 0.17), and area (R: 0.29) emerge as the most influential factors in determining the Covid-19 mortality rate, as illustrated in Fig. 4B.

4. Discussion

The study employed a GIS approach to analyze COVID-19 mortality cases in Iran, revealing regional variations influenced by factors like population density and socioeconomic status (11). The findings align with previous research, highlighting the role of geographical location in mortality rates within the country. Provinces such as Razavi Khorasan, West Azerbaijan, Mazandaran, Khuzestan, and Tehran showed the highest mortality rates, reflecting disparities in health outcomes (12). When examining the eastern, western, northern, southern, and central regions, Razavi Khorasan, West Azerbaijan, Mazandaran, Khuzestan, and Tehran respectively emerged as the provinces with the highest mortality rates (13). In this regard, Lai et al. identified that factors like population density and healthcare capacity contributing to mortality rate disparities globally (14). Tan et al. highlighted geographic disparities in COVID-19 cases and
deaths, emphasizing local contexts, population density, racial/ethnic disparities, and healthcare access. Understanding these factors strengthens insights into the impact of geography on mortality rates (15). High mortality rates are influenced by factors beyond healthcare access, including lifestyle choices, environmental factors, and pre-existing health conditions. Identifying regional disparities is crucial for addressing health outcome inequalities and guiding public health interventions and resource allocation (16). Additionally, Furthermore, variations in environmental characteristics like temperature, precipitation, and air pollution are observed across regions due to factors such as geographical features, climate conditions, and human activities. Regions with high industrial or transportation activity may have elevated air pollutant levels, while those with high temperatures and precipitation may be more vulnerable to weather events like heat waves or flooding (17). Various demographic and environmental factors indirectly influence the transmission and fatality rate of the COVID-19 virus. An intriguing study in Iran found a positive correlation between temperature and hospitalization cases, but no direct link to COVID-19 mortality (18). Population density is a significant factor in disease spread, with high-density areas facilitating transmission due to increased proximity. A US study revealed higher COVID-19 mortality rates in regions with greater population density, older age groups, and minority populations, linked to air pollution and poverty (19). Regions with high air pollution levels may have more respiratory diseases, worsening COVID-19 outcomes. Additionally, healthcare infrastructure quality, affected by factors like population density and road connectivity, influences COVID-19 mortality rates. Moreover, limited access to healthcare resources and challenges in implementing effective public health interventions may contribute to the spread of the virus. The study's findings highlight intriguing correlations between mortality rates and environmental factors in different Iranian provinces. Provinces with smaller areas showed higher mortality rates, suggesting a role for population density in COVID-19 transmission, consistent with previous research advocating for social distancing in densely populated areas. Additionally, our analysis found that provinces like South Khorasan, Sistan-Baluchestan, Semnan, Bushehr, and Ilam had higher mortality rates with increasing average temperature, indicating a potential influence of temperature on COVID-19 severity in warmer regions. Furthermore, certain provinces, including Kohgiluyeh and Boyer-Ahmad, Ilam, Ardabil, and Kordestan, showed a stronger correlation between precipitation and COVID-19 mortality, suggesting precipitation's impact on virus transmission and severity in these areas. Our study also highlighted air pollution as a significant factor in COVID-19 mortality, particularly in central and southern regions, with the Urmia Lake region notably affected by elevated mortality rates linked to air pollution. The study confirms the link between air pollution and respiratory diseases, potentially worsening COVID-19 symptoms. Higher mortality rates in provinces with greater road density suggest transportation patterns aid virus spread. Regions with lower road density may manage virus spread better due to reduced traffic and population density. Population density and urbanization play a significant role in determining COVID-19 mortality rates. Environmental factors like NO2, O3, and population density positively correlate with COVID-19 mortality rates. Lower road density and larger land areas may enhance virus transmission management. Reduced CO2 and SO2 levels indicate improved air quality and lower mortality rates. Previous research supports air pollution, weather patterns, and population density as crucial factors in COVID-19 spread and severity. Higher air pollution levels are linked to increased COVID-19 mortality rates in regions with higher poverty and socioeconomic inequality (20). The recent study in
Italy reveals a significant link between higher air pollution levels, specifically PM2.5, and increased COVID-19 mortality rates, alongside associations with population density and older demographics (21). These insights provide crucial information on the factors influencing COVID-19 transmission and severity in Iran. Policymakers and health officials can use this data to target interventions in high-risk regions and enhance healthcare infrastructure in urban areas. However, further research is needed to validate these findings and understand the intricate relationship between environmental and demographic factors in COVID-19 transmission.

Conclusion

In conclusion, this study delves into the impact of environmental and demographic factors on COVID-19 transmission and severity in various regions of Iran. The insights gained can guide public health interventions and strategies in the country. Population density, urbanization, and air pollution are highlighted as key influencers of the virus spread. Adequate healthcare resources and infrastructure are crucial for managing the pandemic effectively. Patterns in mortality rates related to environmental factors like temperature, precipitation, and road density were observed. These findings are vital for policymakers and health officials to tailor interventions for high-risk areas and improve healthcare in urban settings. Further research is needed to validate these findings and explore the complex interactions between environmental and demographic variables in COVID-19 transmission. This study lays a foundation for future investigations and underscores the ongoing need to address the impacts of the pandemic on public health in Iran.

Declarations

Acknowledgement

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Author contributions

Not application

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Data Availability Statement

The data used the finding of this study are including within this article
Ethics approval and consent to participate

The study was conducted according to the guidelines of the Declaration of Gonabad university and approved by the ethics committee of the Affiliated Gonabad university of Medical Science (approval NoIR.GMU.REC.1402.034).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

References


Figures
Figure 1

Spatial Distribution of Accumulated COVID-19 mortality
Figure 2

Spatial pattern of environmental, demographical and topographical characteristics
Figure 3

Mapping COVID-19 mortality ratio in association with demographic, environment and topographic variables.

Figure 4