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Article

Geospatial Analysis of COVID-19 Spread in Constantine, Algeria: Epidemiological Insights and Policy Recommendations.

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ABSTRACT

The COVID-19 epidemic has profoundly affected societies worldwide. In Algeria, the province of Constantine recorded 3,630 confirmed cases in 2020, ranking among the provinces with the highest infection rates in the country. This study aims to analyze the spatial distribution of COVID-19 cases across the municipalities of Constantine and to evaluate the effectiveness of public health interventions implemented during the pandemic. Using Geographic Information Systems (GIS), particularly ArcGIS 10.8, various thematic maps were produced to visualize infection hotspots and spatial transmission patterns. The results revealed that municipalities such as Constantine and El Khroub exhibited the highest infection densities, strongly associated with population concentration and proximity to major transport routes. Conversely, peripheral rural areas with lower population density recorded fewer cases. Government measures, notably lockdowns and curfews, contributed to a significant reduction in transmission intensity within several high-risk zones. This study highlights the crucial role of spatial analysis in understanding epidemic dynamics and supports the integration of GIS-based approaches into pandemic preparedness and public health decision-making.

KEYWORDS

COVID-19, Spatial distribution, Public health, Epidemiology, GIS.

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1. Introduction

The COVID-19 epidemic, which has become one of the most significant global health crises in modern history, is caused by the novel coronavirus (SARS-CoV-2). Since its first outbreak in December 2019, the virus has seriously affected millions of individuals and put tremendous strain on healthcare systems worldwide (Pollard et al., 2020). Understanding how the virus spreads and developing targeted public-health policies depend on tracking and evaluating the spatial distribution of COVID-19 cases (Li et al., 2020).

Geographic analysis provides crucial insights into the spatial dynamics of transmission by showing how factors such as population density, urbanization, and healthcare infrastructure contribute to disease dissemination (Kraemer et al., 2020). Municipal-level studies are particularly important, as they identify infection hotspots and assess local interventions (Xie et al., 2020). At the same time, effective containment strategies at the local level largely rely on detailed case-data analysis(Prem et al., 2020) (Rebouh et al., 2024).

In Algeria, and particularly in Constantine Province, high population density, rapid urbanization, and uneven access to healthcare create favorable conditions for the spread of infectious diseases (Ouamoucha & Bechta, 2021) (Algerian Ministry of Health, 2025). Despite this, few studies have investigated intra-provincial COVID-19 transmission patterns or applied GIS methods to analyze disease diffusion within Algeria. To address this gap, this study aims to answer three key research questions: (1) how population density correlates with COVID-19 infection rates across Constantine's municipalities, (2) which municipal characteristics, such as healthcare facilities and transport hubs, explain the observed spatial clustering of cases, and (3) how effective governmental interventions, including lockdowns and curfews, were in modifying the spatial distribution of COVID-19 cases. Accordingly, the study analyzes the spatial distribution of 3,630 confirmed COVID-19 cases in 2020 across Constantine's municipalities, identifies high-risk clusters, and evaluates how demographic and infrastructural factors influence the epidemic's local dynamics (Djebari & Bestandji, 2025) (Tout. F, 2023) .

2. Methods

This study focuses on the province of Constantine, located in northeastern Algeria, comprising 12 municipalities. Data on confirmed COVID-19 cases were obtained from the Provincial Directorate of Health (DSP Constantine) and covered the period from March to December 2020, corresponding to the first and most critical phases of the epidemic. The total number of recorded cases during this period was 3,630.

Complementary spatial and demographic data, including population density, healthcare facilities, road networks, and public transport stations, were collected from the National Statistics Office (ONS) and urban planning departments. All spatial datasets were georeferenced using ArcGIS 10.8 in the WGS 1984 coordinate system.

2.1. Data Preparation

COVID-19 case data were organized by municipality and standardized per 100,00 inhabitants to enable spatial comparison. Where incomplete records existed, missing values were handled using proportional estimation based on population size and neighboring data consistency. The datasets were converted into shapefiles and integrated through the ArcGIS Geodatabase structure to ensure consistency.

2.2. Geographical Examination

Geographic Information System (GIS) tools were used primarily for mapping and visualization purposes, allowing the integration of epidemiological data with demographic and infrastructural layers. COVID-19 case data were aggregated by municipality and displayed through thematic maps that illustrated differences in infection intensity across Constantine Province. Spatial layers including population density, healthcare facility distribution, and main transportation networks were overlaid to identify visually the municipalities most affected by the pandemic. This cartographic approach helped to highlight spatial disparities in infection rates and to support local decision-making, even though no advanced statistical spatial models (e.g., Moran's I or Kernel Density Estimation) were applied.

2.3. Ethical Issues

This study used only publicly available data, guaranteeing adherence to ethical research guidelines by not including direct patient information. Every data source was correctly referenced, and the study followed ethical guidelines for using publicly available information.

3. Results

Based on spatial analysis, this part offers a summary of the results showing important trends in the dissemination of COVID-19 among municipalities and the impact of topographical and infrastructure aspects.

3.1. Study Region Overview

Constantine is one of Algeria's principal urban and economic centers, featuring significant industrial, agricultural, and service sectors. Frequently regarded as a hub of knowledge and culture, it is renowned for its extensive university and research institutions. (Figure1)

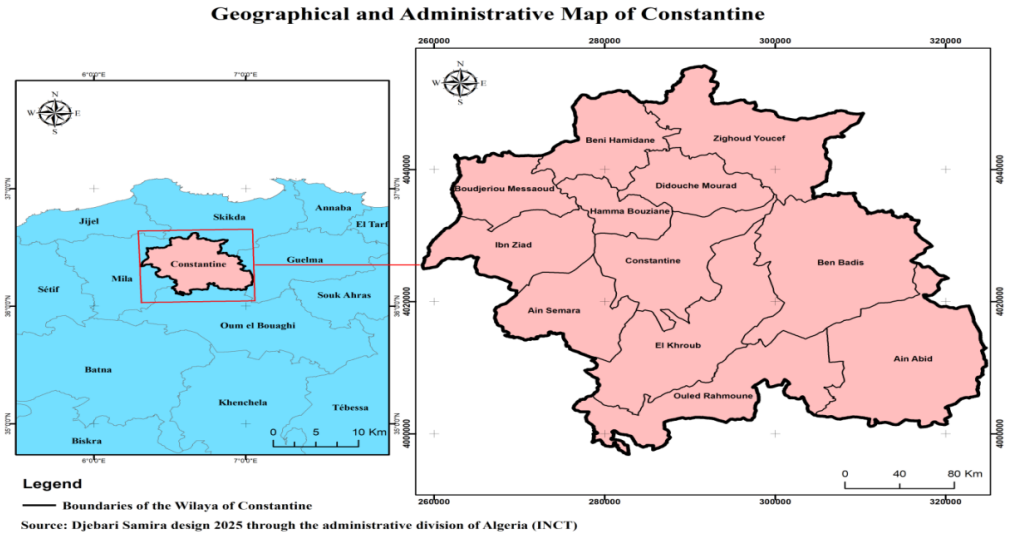

Fig 1.Geographical and Administrative Map of Constantine Source: design by Djebari Samira using ARCGIS10.8soft war. Data source: administrative division of algerie (INCT).

The Wilaya is nestled in northern Algeria. It borders Batna, Skikda, Guelma, Oum El Bouaghi, and Mila. It benefits from an excellent location between Algeria's eastern and central parts.

Among the province's main towns from 12 municipalities are Constantine, El Khroub, Ain Smara, Ibn Badis, Zighoud Youcef, Didouche Mourad, Ain Abid, and Ouled Rahmoun. Constantine city is the administrative capital of the province.

3.2. The COVID-19 pandemic's development in Algeria from its onset to the end of 2020

From the initial instance recorded to the waves of breakouts and the implementation of preventative actions, the COVID-19 epidemic in Algeria developed through several phases until the end of 2020.

3.2.1. Initial Case Report and Virus Transmission (February–April 2020)

The first confirmed instance of COVID-19 in Algeria came from an Italian person who had visited Algeria on February 25, 2020. Days of reporting fresh cases among Algerians returning from France and Spain helped the virus spread steadily. The government closed mosques, colleges, and universities and limited travel and events by the middle of March.

3.2.2. Preventive actions and lockdown (April–June 2020)

The rapid increase in infections led authorities to impose partial lockdowns and night-time curfews in some provinces.

Non-essential economic activity was stopped, and all domestic and international flights were grounded.

Recording the first COVID-19-related deaths, the government decided to increase testing capacity and intensify preventive actions.

The government began reducing restrictions as the infection rate somewhat dropped, allowing the slow opening of mosques, schools, and some businesses from July through September 2020. Algeria saw an increase in cases in August and September following the loosening of restrictions, which raised concerns about a possible second wave.

3.2.3. The Second Wave (October–December 2020) Government Response

By October, cases began to climb dramatically; in Algeria, they peaked daily in November at more than 1,000 infections. As part of the government's additional tightening of rules, curfews were reinstated in several areas, and some commercial activity was closed. The countrywide immunization program is expected to start in early 2021; authorities agreed to buy vaccinations in December.

3.2.4. The epidemiological state by the end of 2020 will be

As of December 31, 2020, Algeria had recorded about 100,000 confirmed illnesses along with over 2,700 deaths. Two major waves of COVID-19 hit the country, leading to several government responses meant to stop the epidemic (WHO ,2025) (Johns Hopkins ,2025)..

3.3. Geographical Distribution of COVID-19 Cases

The map (Figure 2) shows COVID-19 incidences spread among Constantine's 2020 municipalities.

The map highlights the infection density in every municipality using a color-graded method, using hues ranging from yellow to red depending on the number of reported cases.

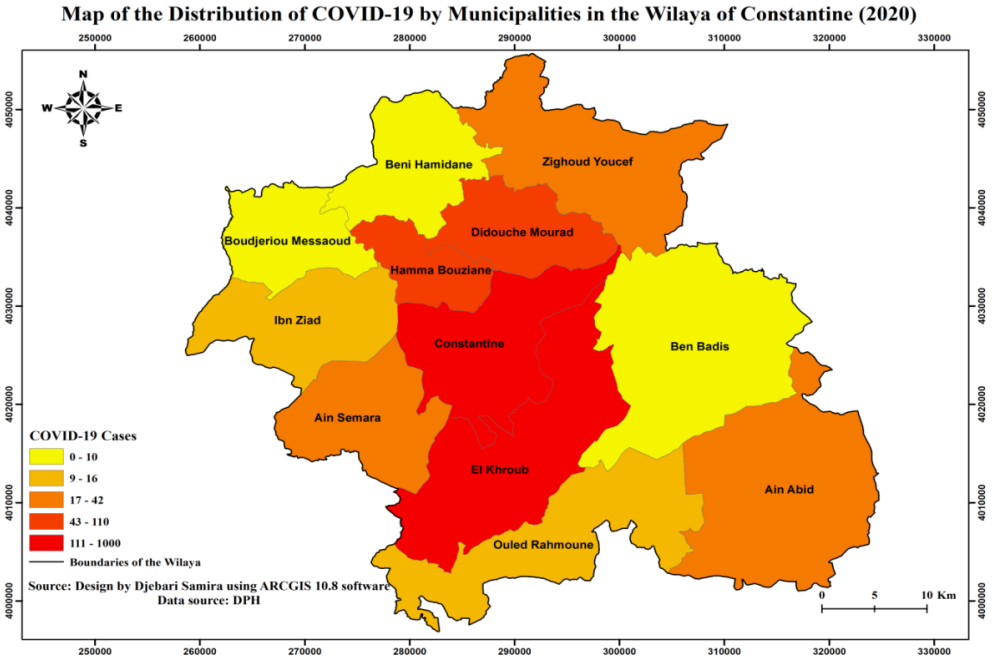

Fig 2. Map of the distribution of covid19 by municipalities in the wilaya of Constantine, 2020
Source: design by Djebari Samira using ARCGIS10.8software. Data source: DHP.

The map (Figure 2) shows the spatial distribution of confirmed COVID-19 cases across the municipalities of Constantine Province in 2020.

The geographic representation illustrates the accumulation of cases using a color gradient ranging from bright orange to deep red, with darker shades indicating higher prevalence.

The municipalities most affected by the COVID-19 pandemic are as follows:

- *Constantine Municipality*, shown in dark red, was particularly impacted, with a total number of cases ranging from 801 to 1,000. This situation may be attributed to the high population density, significant human mobility, and the presence of advanced healthcare facilities that attract patients from across the region. These factors likely contributed to the rapid spread of the virus.
- *El Khroub* and *Hamma Bouziane* municipalities also reported a considerable number of cases

(Between 501 and 800). The spread of the virus in these urban areas was facilitated by their proximity to Constantine's city center.

- Some municipalities, such as Didouche Mourad, Zighoud Youcef, and Ouled Rahmoun, show moderate incidence levels, with the number of cases ranging between 101 and 500. The spread of the epidemic may have been limited by their relatively low population density.

In summary, the rural municipalities of BéniHamidane, Ben Badis, Aïn Abid, and Aïn Smara reported fewer than 100 confirmed cases. The diffusion of the virus appears to have been slowed by low population density, mobility restrictions, and relative isolation.

3.4. Influence of Factors such as Population Density, Urbanization, and Healthcare Infrastructure.

3.4.1. Corrélation du COVID-19 avec la densité de population

The map (Figure 3) shows the distribution of COVID-19 cases per the different municipalities of Constantine, and their correlation with population density in 2020.

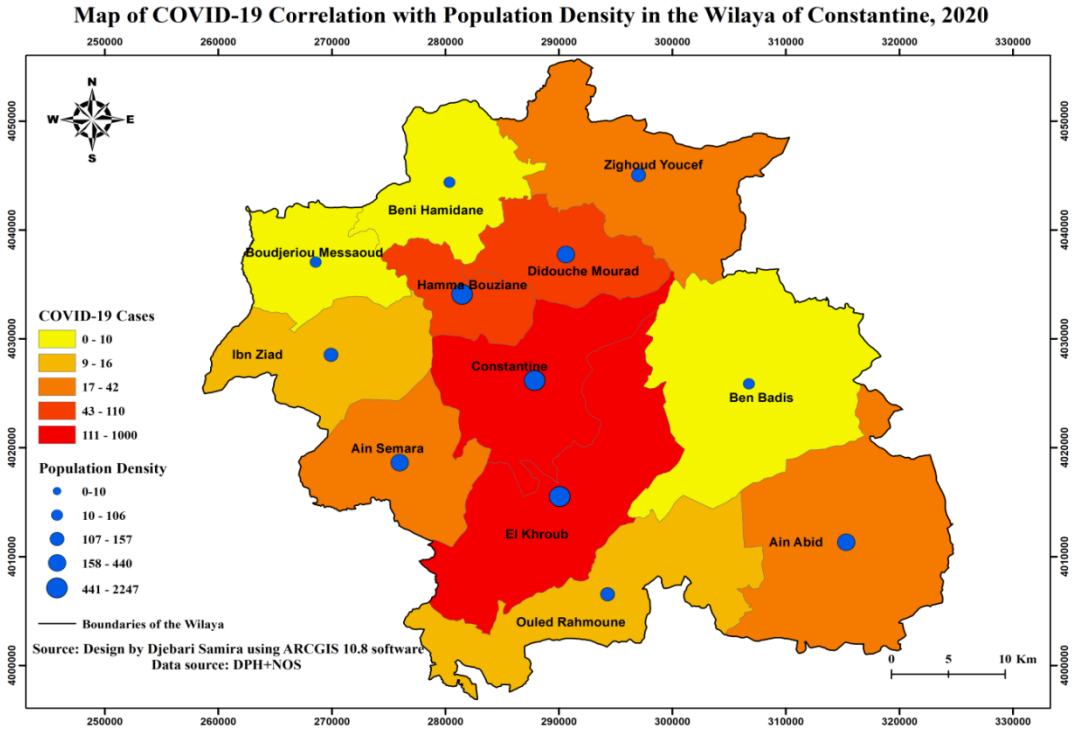

Fig 3.Map of Covid19 correlation with Density in the Wilaya of Constantine 2020.
Source: design by Djebari Samira using ARCGIS10.8software
Data source:DHP + NOS.

Theanalysisofthemap(Figure3)showsacorrelationbetweenpopulationdensityandCOVID-19cases: The large blue circles indicate areas of high population density, which correspond to the red zones of high COVID-19 incidence.

In contrast, the small circles (low population density) are associated with less-affected areas, which can be explained by lower human density and limited social interactions.

- The municipalities of Constantine and El Khroub are the most affected due to their high population density and intense social interactions.
- Zighoud Youcef, Ain Abid, and Didouche Mourad show intermediate levels.
- Ben Badis, Béni Hamidane, and Boudjeriou Messaoud present few cases, linked to lower population density and reduced social interactions.

We conclude from this analysis that population density is a determining factor in the spread of the virus, and that densely populated urban areas present a higher risk, while rural regions remain less exposed. The COVID-19 pandemic is therefore an eminently urban phenomenon.

3.4.2. Covid-19 Case Distribution and Bus Station Locations in Constantine Wilaya

(Figure 4) shows the locations of Covid-19 bus stations and stops within Constantine 2020's Wilaya.

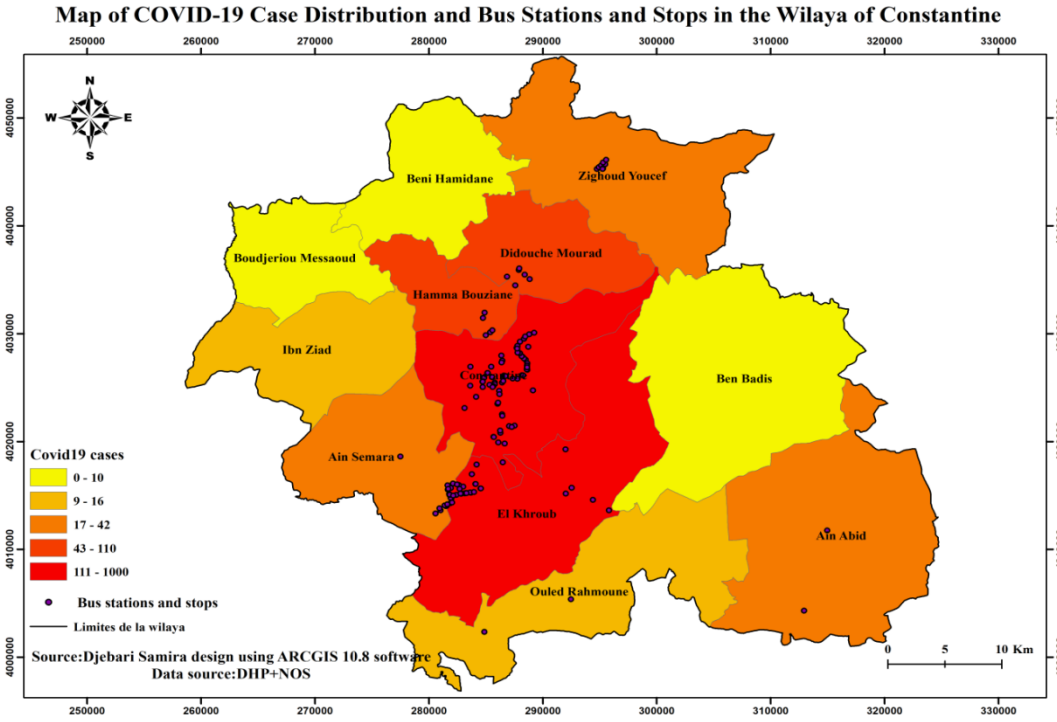

Fig 4. Map of covid19 Case Distribution and Bus Stations and Stops in the Wilaya of Constantine 2020.
Source: design by Djebari Samira using ARCGIS10.8software
Data source: DHP + NOS.

The black dots represent bus stations and stops, illustrating their spatial distribution. In particular, in the center of Constantine (Figure 4), areas with high infection rates show a noticeable density of bus stops, suggesting a possible relationship between public transportation and the spread of COVID-19.

Urban centers, unlike rural areas, sometimes display a higher number of COVID-19 cases, possibly due to greater human mobility and social connections.

- *Public transport and viral transmission:* the clustering of cases near transport hubs suggests that, during the epidemic, bus stations may have contributed to the spread of the virus.
- *Peripheral areas***:** rural and remote zones, characterized by inadequate transport infrastructure, generally show fewer occurrences.

3.4.3. Distribution of Covid-19 Cases with density and Healthcare Infrastructure in the Wilaya of Constantine

This map (Figure 5) depicts the spread of the epidemic in the Wilaya of Constantine Province in 2020, along with the relationship between population density and healthcare facilities and cases. The map shows the spatial interaction between the number of reported cases and the concentration of public and private healthcare institutions, including hospitals, maternity clinics, dialysis centers, and specialized health centers.

The final map was generated by overlaying several thematic layers, including COVID-19 cases, population density, and healthcare facilities, to obtain an integrated spatial.

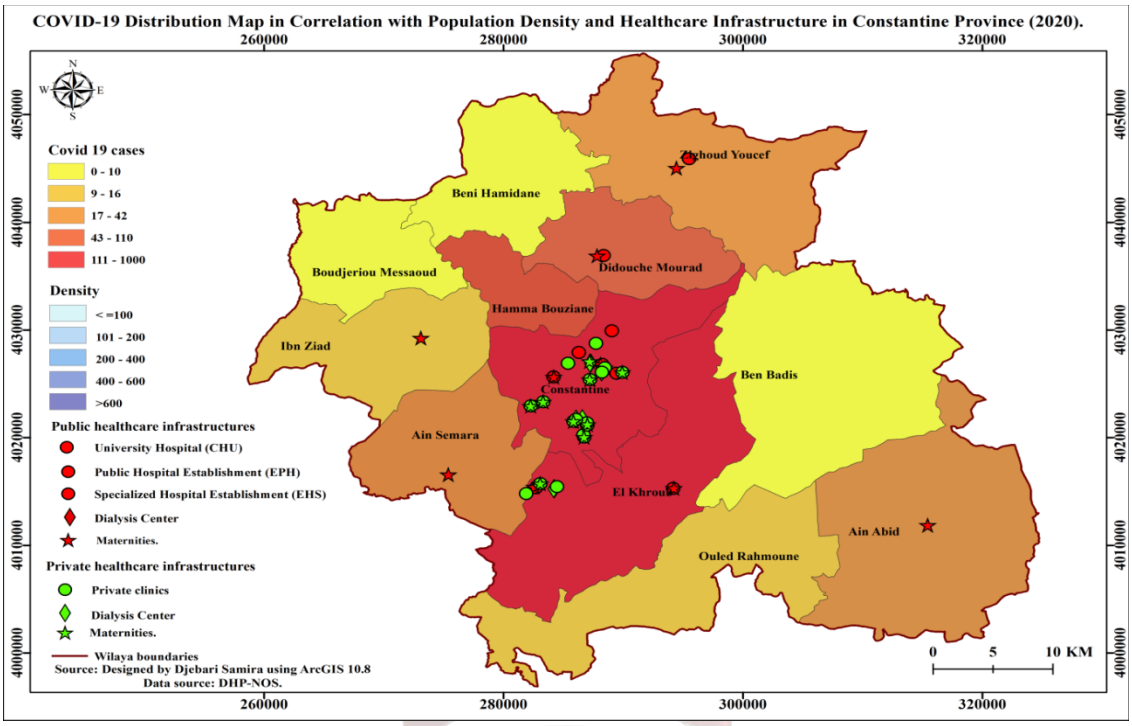

Fig 5. Map of the distribution of covid19 in correlation with density and health care infrastructure by municipalities in Constantine province2020
Source: design by Djebari Samira using ARCGIS10.8software
Data source: DHP +NOS.

The map (Figure 5) shows the spatial interaction between the number of reported cases and the concentration of public and private healthcare facilities, including clinics, dialysis centers, specialized health establishments (EHS), university hospitals (CHU), and public hospitals (EPH). It also highlights differences in access to healthcare between municipalities.

Densely populated urban areas have higher infection rates, while rural areas with fewer medical facilities have fewer cases. This analysis illustrates the impact of healthcare infrastructure and population density on the regional distribution of COVID-19.

- Healthcare infrastructure and its contribution to the spread:

Urban areas, which are better equipped with healthcare facilities, show the highest infection rates, particularly in Constantine and El Khroub.

The presence of the University Hospital Center (CHU) of Constantine makes these localities major healthcare hubs. This concentration places considerable pressure on the local health system and contributes to more extensive case detection and reporting, which may artificially increase the apparent potential for transmission.

The lower number of reported infections in less populated areas can be explained by the lack of adequate healthcare facilities. Moreover, the reduced number of reported cases in Beni Hamidane, Ain Abid, and Zighoud Youcef may result from limited testing and diagnostic options.

We conclude that there is a direct relationship between population density, high COVID-19 case rates, and the presence of healthcare infrastructure, demonstrating how large gatherings and healthcare concentration can influence virus transmission.

4. Discussion

The study's results indicate a strong spatial correlation between population density and the spread of COVID-19 in Constantine Province during 2020. The municipalities of Constantine and El Khroub recorded the highest infection rates, which can be attributed not only to their high population density but also to intense mobility and frequent social interactions.

The presence of major healthcare facilities, including the university hospital, likely increased case detection due to improved access to testing and diagnosis. This phenomenon, however, may have created a reporting bias where areas with better health infrastructure recorded more confirmed cases, while rural zones with limited testing capacity—such as Béni Hamidane and Ben Badis—reported fewer cases.

These findings align with GIS-based spatial analyses conducted in other North African contexts. For example, similar patterns were observed in Cairo (Abdallah et al., 2021) and Tunis (Ben Ahmed et al., 2022), where high urban density and public transport networks were strongly associated with increased infection rates. Studies in Morocco (El Amrani et al., 2021) also confirmed that population mobility and healthcare accessibility are critical drivers of spatial disparities in COVID-19 transmission. Compared with these cases, Constantine's situation reflects an intersection between urban expansion, uneven health infrastructure, and socio-spatial inequality in disease exposure.

Nevertheless, this study faces some limitations. First, the spatial analysis relied on officially reported cases, which may not capture asymptomatic or untested infections, especially in rural areas. Second, the temporal evolution of the epidemic could not be analyzed due to the lack of continuous time-series data. Finally, factors such as population behavior, compliance with preventive measures, and socioeconomic conditions were not quantitatively integrated, though they likely influenced the observed patterns.

Future research should consider dynamic spatio-temporal analyses and incorporate socioeconomic and behavioral variables to better understand the multi-dimensional drivers of epidemic spread at the local scale.

5. Conclusions

This study demonstrates that the transmission dynamics of COVID-19 in the province of Constantine are primarily shaped by structural and geographical factors. The analysis identified population density, transportation networks, and healthcare infrastructure as the main determinants influencing the spatial distribution of cases.

1. *High-density urban areas*, particularly Constantine and El Khroub, experienced the highest infection rates due to intense human mobility and concentration.
2. *Public transport hubs* emerged as potential facilitators of viral spread, highlighting the role of mobility patterns in transmission.
3. *Unequal distribution of healthcare services* contributed to spatial disparities in case detection and management, particularly disadvantaging rural municipalities.
4. *Integrating GIS-based spatial analysis into public health policy* can enhance epidemic preparedness and support equitable allocation of healthcare resources.

Strengthening healthcare infrastructure in densely populated and underserved areas, combined with geographically informed surveillance, will be essential for mitigating the effects of future epidemics in Constantine and similar regions.

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Conflicts of Interest: "The authors declare no conflict of interest."

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