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Article

The Role of Spatial Analysis in Notifiable Disease Monitoring and Health Risk Management: A Case Study of Constantine

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ABSTRACT

The study aims to enhance understanding of the distribution of notifiable diseases using maps created with ArcGIS in Constantine. Over six years, it focused on the prevalence rates of waterborne diseases and zoonoses (e.g., tuberculosis, meningitis, and COVID-19). A database was created for each municipality using official data, which was processed using SPSS and Microsoft Excel and integrated into a geographic information system (GIS). The maps revealed a high prevalence of diseases in the state's centre, particularly in the municipalities of Constantine, El Khroub, Didouche, and Mourad. The analysis also highlighted a positive relationship between the increase in disease cases and population density, emphasising the critical role of urbanisation in disease spread. Furthermore, seasonal variations were observed in the distribution of certain diseases, indicating that environmental factors, such as temperature and rainfall, influence disease outbreaks. As a result of this study, the maps have demonstrated a fundamental role in monitoring diseases and their development, offering valuable insights for public health surveillance and policy formulation. By visualising trends and patterns, these maps can support decision-making processes to manage health risks better and allocate resources effectively in the region.

KEYWORDS

Disaster; health risk; spatial analysis; management; Covid-19; Constantine.

1. Introduction

Spatial analysis has evolved into a highly effective tool for risk control, particularly in healthcare. It provides insightful analysis of the geographical distribution and disease transmission patterns, enabling researchers and decision-makers to pinpoint high-risk locations and assess environmental, social, and ecological factors. Among the most well-known examples is John Snow's 1854 cholera mortality map of London's Soho. Using observational data, spatial epidemiology seeks to explain and characterise regional and temporal fluctuations in disease occurrence.

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Although John Snow's hand-drawn maps showed the connection between cholera cases and the Broad Street water pump, spatial epidemiologic studies and health data mapping did not become usual until the broad availability of Geographic Information Systems (GIS) in the 1990 (Pickle, 2009). These technical developments have significantly enhanced our ability to analyse illness trends and conduct public health campaigns based on statistical evidence.

This approach has proven particularly relevant in the context of emerging infectious diseases such as COVID-19, which has been described as a "creeping disaster" due to its prolonged and evolving nature (Jawahar, 2024).

GIS's benefits encompass performing repeated tasks, swiftly comparing spatial data, and handling large datasets. The amalgamation of GIS with spatial analytical techniques can produce a significant asset for investigating public health issues. (Rezaeian, 2007). The importance of geographic information science is increasingly recognised in spatial epidemiological research, as it provides the fundamental geographic context for exploring spatial patterns in data.

Recent studies have successfully applied GIS to assess the hazard risk of COVID-19 in different urban environments, emphasising its predictive value in disaster risk management. (Ulal, 2023).

The spatial dimension of health data is crucial for clarifying disparities in risk, as health status, environmental threats, population density, demographic and socioeconomic characteristics, and other relevant factors (e.g., vulnerability and exposure) vary across different geographical regions. In this context, geographic space exhibits notable changes across various locations and periods, resulting in unique habitats where people live and work. Geography defines the spatial context and attributes in which health issues arise. Movement across locations is significant; pollutants and other hazards that form concentrations can change as they move through the ecosystem, affecting different locations in varied ways. Furthermore, spatial risk patterns are confounded by differences in susceptibility and variances arising from the uniqueness of populations in particular regions. (Beale, 2008).

Among the most significant Algerian cities, Constantine's Wilaya has recently experienced repeated outbreaks of infectious diseases. Therefore, to understand the spatial dynamics of disease spread in this area, we have chosen to investigate this topic, including spatial analysis of health risk management. The first phase of the study involved interviewing the chiefs of preventive medicine, epidemiology, and prevention divisions at the Constantine Health Directorate to gather the required information. In the second phase, the data was processed and examined; thereafter, maps were created to help define patterns of disease distribution. This study employed geographical analytical methods to gain a thorough understanding of the epidemiological state over the past six years.

These findings aim to inform the development of targeted public health initiatives, enhance public health resilience in this area, and support preparedness for future outbreaks of infectious diseases.

2. Methods

2.1. Data collecting and study scope

This study examines environmentally related diseases in the Wilaya of Constantine over six years (2015–2020), in addition to the frequency of major waterborne and foodborne diseases (WBDs)—including typhoid fever, dysentery, viral hepatitis A, and collective foodborne infections—as listed in Table 1.

Three main variables guided data compiling:

- Kind of disease
- Year of occurrence
- Residential municipality

Official records from Constantine's Directorate of Epidemiology and Medical Prevention (DEPM) and the Directorate of Health and Population (DHP) guaranteed data accuracy and dependability.

2.2. Research Approach

The frequency and distribution of notifiable diseases were evaluated using a descriptive epidemiological method, thereby providing information on environmentally related health issues in Constantine. Including an analytical component emphasising particular case studies, one sought possible causal linkages between environmental risk factors and disease outbreaks.

2.3. Project Population and Area of Research

The research area includes all twelve municipalities of the Wilaya of Constantine: Constantine, El Khroub, Ouled Rahmoune, Ain Smara, Ain Abid, Ibn Badis, Hamma Bouziane, Didouche Mourad, Messaoud Boudjeriou, Ibn Ziad, Zighoud Youcef, and Beni Hamidene.

The target population includes all individuals affected by communicable diseases during the study period. By examining the spatial distribution of these diseases across municipalities, the study seeks to identify high-risk areas and support targeted public health interventions.

2.4. Geographic Mapping and Data Analysis

The instruments utilized for conducting comprehensive statistical and geographical analyses encompassed a selection of advanced software tools. Specifically, SPSS and Microsoft Excel 2010 were employed to perform various tasks, including descriptive statistics, trend analysis, and regression calculations. In addition, ArcGIS 10.8 was utilised for its robust capabilities in geographic mapping, allowing for effective cluster detection and the visualisation of disease distribution patterns, thereby enabling more profound insights into spatial data and trends.

2.5. Descriptive and Trend Analysis

The frequency, mean, and standard deviation of each disease were calculated using descriptive statistics over six years. Annual patterns were shown using time-series graphs.

- Analyzing linear regression

Simple linear regression models were employed to analyse temporal patterns and predict future disease occurrences. The regression model applied has a general form of $Y = a + bX$.

There:

YY = cases (dependent variable)

XX = year (variable independent);

aa = intercept

bb = slope—the rate of change—either increasing or decreasing

The prevalence of illness over time shows either an upward or a declining trend, as indicated by the regression coefficient βb. A positive bb number indicates a rising trend; a negative bb value suggests a declining trend.

- Equation Spread (Calculating Prevalence):

Prevalence rates were computed by the method to evaluate the spatial distribution of diseases:

Prevalence Rate=(Municipal Population Number of Reported Cases)×100,000

This allowed for consistent comparisons across towns with varying population counts.

2.6. Geospatial ArcGIS mapping

ArcGIS was used to create choropleth maps illustrating disease prevalence across municipalities. A gradient colour scheme—darker tones indicating more excellent rates and lighter tones indicating lower rates—was used to show prevalence rates.

ArcGIS involved steps like:

- Entering gathered statistics comprising local reported sickness rates and population numbers.
- Developing basic administrative maps to specify municipal limits.
- Group cities according to disease frequency with well-defined thresholds for every colour category.
- Visualizing geographical distribution using a colour gradient will help identify high-risk areas.
- Administrative boundary data, Georeferenced, were utilised to ensure alignment with demographic and epidemiological databases. Spatial transformations and modifications maintained consistency and improved the precision of the findings.

2.7. Research Limitations

This study has various limits despite providing insightful analysis that should be taken into account while reading the results:

Most of the data comes from official DHP and DEPM health records. Although usually trustworthy, these sources could be prone to underreporting or missing data from undiagnosed or unreported cases, thus underestimating the disease prevalence.

Though it does not prove causality, the descriptive epidemiological technique offers vital data on illness distribution. Cohort or case-control designs, as well as other more analytical approaches, are needed to verify causal links between environmental elements and disease outbreaks.

The study spans the period from 2015 to 2020; trends or changes occurring outside this period were not included.

3. Results

3.1. Epidemiological surveillance using spatial analysis

Surveillance is one of the essential functions of public health; according to (Thacker, 1996), environmental health surveillance is defined as the “continuous and systematic collection, analysis and interpretation of data essential for the planning, implementation and evaluation of health practices, closely associated with the timely dissemination of these data to those who need them. The final step in the surveillance cycle is the application of these data to the control and prevention of diseases and accidents”. This implies the continuous or repeated collection of data on health and its determinants at the population level, allowing for the geographical and temporal evolution of health problems and their risk factors and enabling the identification of health signals when a trend changes. Surveillance, therefore, requires the realisation of different joint activities: data collection, analysis and interpretation. If the objective of surveillance can be summarised as “describe, alert and evaluate” (Astagneau, 2011), its goal is to guide action by promptly producing and disseminating relevant information.

This information enables us to positively influence the population and inform decision-makers responsible for the programs and services offered, thereby supporting the planning and adaptation of these to meet the population’s needs (Kirby, 2017).

Over the past twenty years, the development of computer tools—especially geographic information systems—has dramatically simplified the handling of spatial data (collecting, storage, analysis, visualisation, etc.), enabling the consideration of the spatial dimension in the study and monitoring of infectious or parasitic diseases.

Another recent development—that of Earth observation satellites—now gives access to a significant volume of environmental data (land usage, climate data, etc.). In epidemiology, these facts help to incorporate the ecological dimension and consider the interactions among the several living entities in the epidemiological system and their surroundings.

Illness mapping is a fundamental approach in spatial epidemiology whereby illness incidence or prevalence is visually shown over several geographical areas. Health officials can find locations with high disease rates using GIS techniques, enabling focused treatments. For example, disease mapping has greatly aided in tracking the spread of infectious diseases such as malaria and dengue fever.

3.1.1. Utilization of GIS and Spatial Statistics in Disease Surveillance

Geographic Information Systems and spatial analytic methodologies have been extensively employed in surveillance systems for various infectious and non-communicable diseases. Key applications encompass:

- Outbreak Detection and Monitoring: Spatial clustering techniques, including Kriging interpolation and spatial autocorrelation, facilitate the identification of nascent epidemics by examining temporal patterns of disease incidence (Kulldorff, 1997). Spatial scan statistics were employed to identify clusters of COVID-19 infections during the pandemic, informing quarantine protocols and other public health measures. (Desjardins, 2020).

- Vector-Borne Disease Surveillance: Environmental conditions, including temperature, humidity, and vegetation, significantly impact the transmission of malaria, dengue, and Lyme disease. Remote sensing data integrated with GIS helps forecast vector distribution and pinpoint high-risk areas (Beck, 2000).

- Environmental Health Risks: Spatial epidemiology plays a crucial role in assessing the impact of air pollution, water contamination, and industrial waste on public health. Research indicates significant relationships between geographical changes in air pollution and respiratory disorders, including asthma (Jerrett, 2005).

3.2. Study Region Overview

The total area of the Wilaya of Constantine (Algeria) is 2,187 square kilometres, making it a medium-sized region within Algeria.

The wilaya enjoys a strategic location, as Skikda borders it to the north, Oum El Bouaghi to the south, Mila to the west, and the wilaya of Guelma to the east ,It is divided into 12 municipalities and six districts. Figure 1 shows the distribution of Wilaya's municipalities.

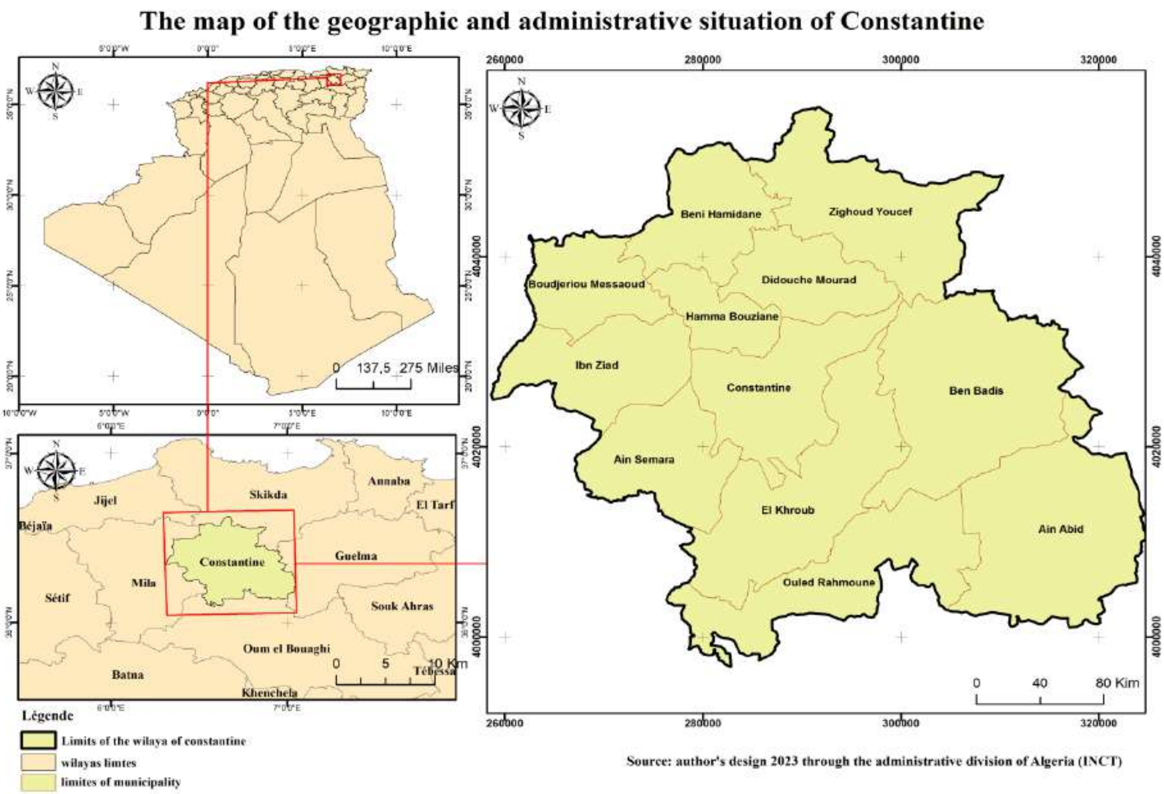

Figure1. Geographical and administrative location map of the Wilaya of Constantine.

Source: Author's design based on the administrative division of Algeria (INCT) 2023.

3.2.1. Type of Climate

Constantine province has a continental climate affected by its topography and geographical location. The following are the primary traits of this climate:

Generally speaking, winters are cold, with temperatures in mountainous regions often dropping below 0°C.

Particularly in plains and metropolitan regions, summers are marked by extreme heat—temps above 30°C.

- precipitation:

The yearly rainfall accumulation is somewhat low, particularly to the averages of the past thirty years—about 348.8 mm.

Although it is mainly concentrated in autumn and winter, rainfall is insufficient to meet water needs, occasionally resulting in drought.

- Temperances:

Though it shows a slight rise from past averages, the yearly temperature is about 15.9°C. In summer, the maximum temperature can be somewhat high, and in winter, the minimum temperature might drop significantly.

- Wind:

Although they can be more vigorous in spring and autumn, maximum wind speeds are constant and near seasonal averages.

3.2.2. The population density

The National Bureau of Statistics (ONS, 2020) estimated the state's population to be approximately 1.3 million in 2020, spread across 12 municipalities. Population density, expressed as the number of people per square kilometre, varies significantly among municipalities, highlighting the differences in urbanisation and settlement patterns (Figure 2).

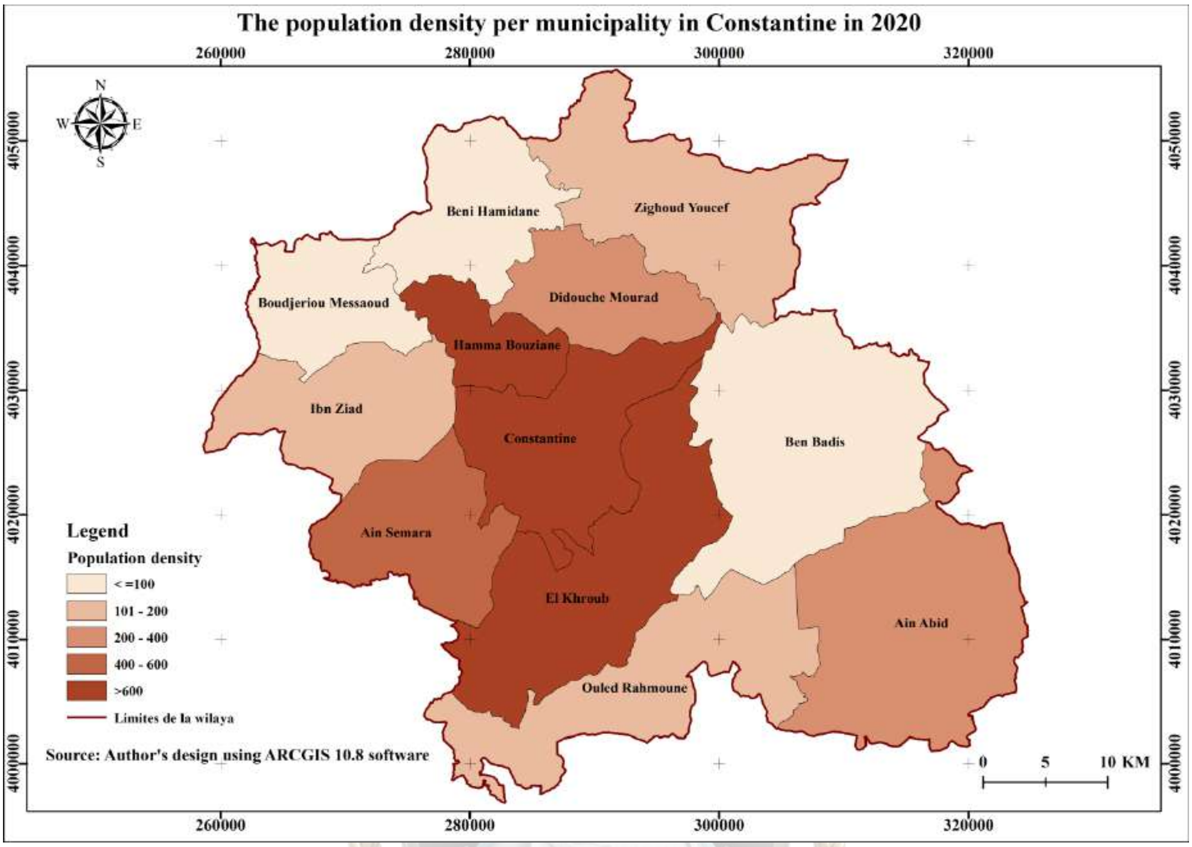

Figure 2. Population density map of the Wilaya of Constantine 2020.

Source: Author's design with ArcGIS 10.8 software.

Analysis of (Figure 2) indicates that the majority of the population within the state is concentrated in two central municipalities: the municipality of Constantine, with 40% of the population, followed closely by El-Khroub, with 30%. This is due to their economic, administrative and social importance. This reflects the highest population density in the centre of the wilaya. Additionally, the municipalities of Ain Smara and Didouche Mourad occupy second place in terms of population density, which contributes significantly to the regional demographic distribution. This settlement and population density pattern is consistent with the Constantine urban triangle development framework, which emphasises the spatial compatibility between urban growth and population distribution.

- ***DEPM of the Wilaya of Constantine***

The Epidemiology and Preventive Medicine Services (DEPM) are responsible for disease surveillance at the local level. Their primary mission is to prevent the transmission of infectious diseases while maintaining a strong and effective epidemiological surveillance system. In addition to these responsibilities, the DEPM plays a pivotal role in verifying accurate health information and transmitting it to the higher public health authorities, the Directorate of Health, for decision-making and policy development. In the wilaya of Constantine, six DEPM units are currently operating. These units are strategically located to maximise their coverage and effectiveness, distributed across five municipalities, as detailed in (Table 1). This positioning allows for monitoring and response in the event of a health disaster throughout the region.

Table 1. The Epidemiology and Preventive Medicine Services of Constantine

Municipalities	DEPM
Constantine	2
El Khroub	1

Hamma Bouziane	1
Ain Abid	1
Zighoud Youcef	1

[1] Source: Own author's draft based on data from the epidemiology department

- Directorate of Health and Population

The Directorate of Health and Population of the State of Constantine is the primary administrative body responsible for overseeing public health and addressing health issues affecting the population within the region. The headquarters of the Directorate is located in the state's centre, in the municipality of Constantine, which enables the Directorate to coordinate health services efficiently, implement public health programs, and meet the needs of the local population. The Directorate ensures the establishment of a body specialised in collecting, analysing, and reporting health, epidemiological, and demographic information. It also prepares emergency plans in consultation with the relevant authorities and participates in organising and coordinating first aid in the event of disasters of any nature.

3.2.3. Population Density and Health Infrastructure Distribution

Figure 3 illustrates that the spatial distribution of health facilities within the wilaya is unequal compared to the population density data. Areas with high population density, particularly in the central and northern metropolitan regions, exhibit constrained access to healthcare services, underscoring the potential danger of swift disease propagation in the absence of adequate medical assistance. The spatial disparity between population demand and healthcare supply poses a significant problem for disaster risk management and epidemic preparedness.

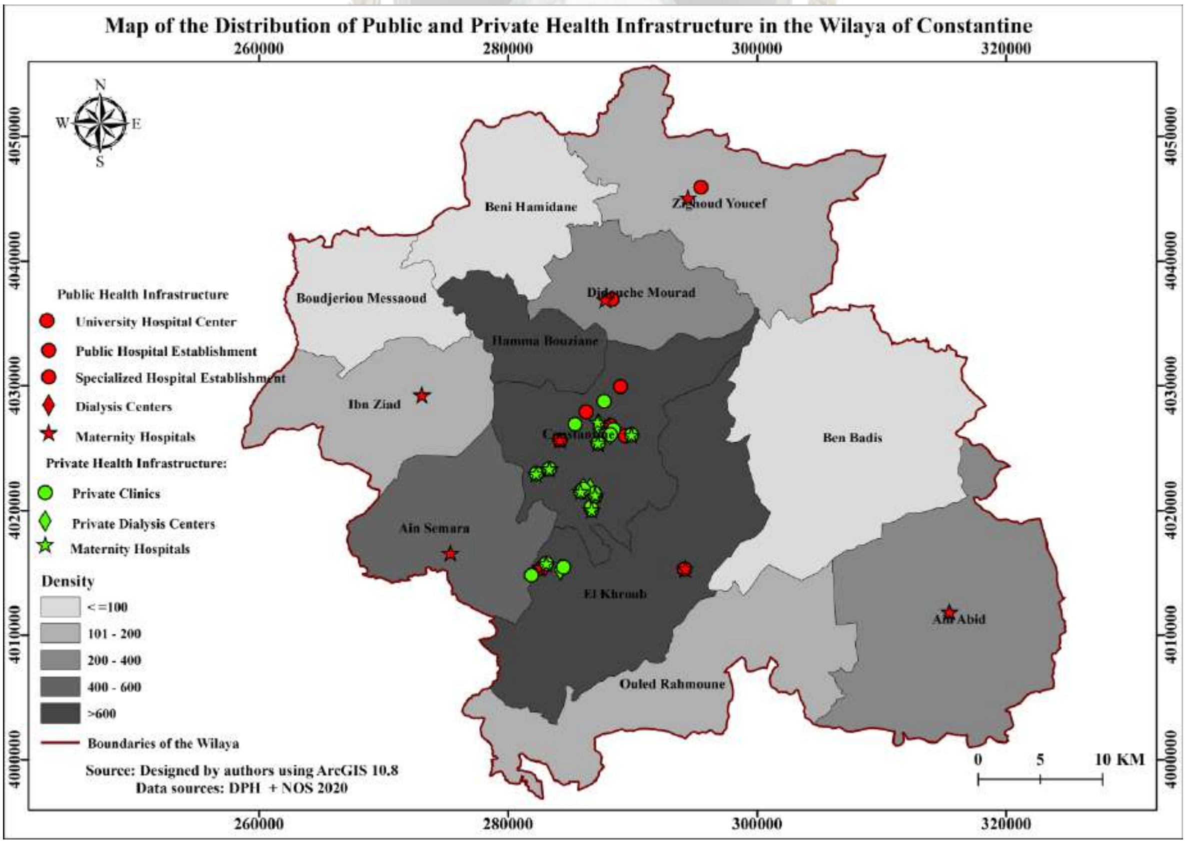

Figure 3. Population Density and Health Infrastructure Distribution in Constantine

Source: Author's design with ArcGIS 10.8 software

3.3. Environment-Related Infectious Diseases in the Wilaya of Constantine:

The study encompasses approximately 8,179 cases of environmentally related infectious diseases reported in the province of Constantine by the DEPM over six years, from 2015 to 2020. It focuses primarily on two main categories of diseases: (waterborne Diseases and Zoonosis), infectious diseases transmitted from animals to humans. Among the zoonoses identified and analysed in this context are tuberculosis, rabies, brucellosis and the COVID-19 pandemic with global impact, as shown in (Table 2).

Table 2. Infectious diseases linked to the environment in the wilaya of Constantine

Type de risque		Diseases
Health risks related to water	Waterborne Diseases (WBDs)	Typhoid Fever Viral Hepatitis A Dysentery Malaria Collective foodborne illness (CFI)
Environmental health risks	Zoonoses	Tuberculosis Rage Leishmaniasis Brucellosis Covid19

[2]Source: Author's draft based on data from the epidemiology department.

According to Article 3 of Decree No. 179 of November 17, 1990, all diseases listed in Table 02 are nationally monitored notifiable (NDs), except for COVID-19. Severe acute respiratory syndrome (SARS-CoV-2, COVID-19) is listed among the 14 notifiable diseases under international surveillance, as per Executive Decree No. 22-250 of June 30, 2022, which establishes the list of communicable diseases subject to mandatory reporting under international surveillance (Ministry of Health, 2022).

3.4. Mapping of Waterborne Diseases (WBD)

This study provides an overview of the epidemiological situation concerning waterborne diseases (WBDs) in the Wilaya of Constantine from 2015 to 2020. It constitutes a descriptive analysis based on cases reported to the DHP in Constantine, categorised by disease type, municipality, and year. Our study recorded about 2040 cases of waterborne diseases. This map (Figure 4) provides a visual representation of the prevalence of waterborne diseases across the municipalities of Constantine over a six-year period from 2015 to 2020, highlighting areas with the highest case numbers and identifying areas with significant outbreaks.

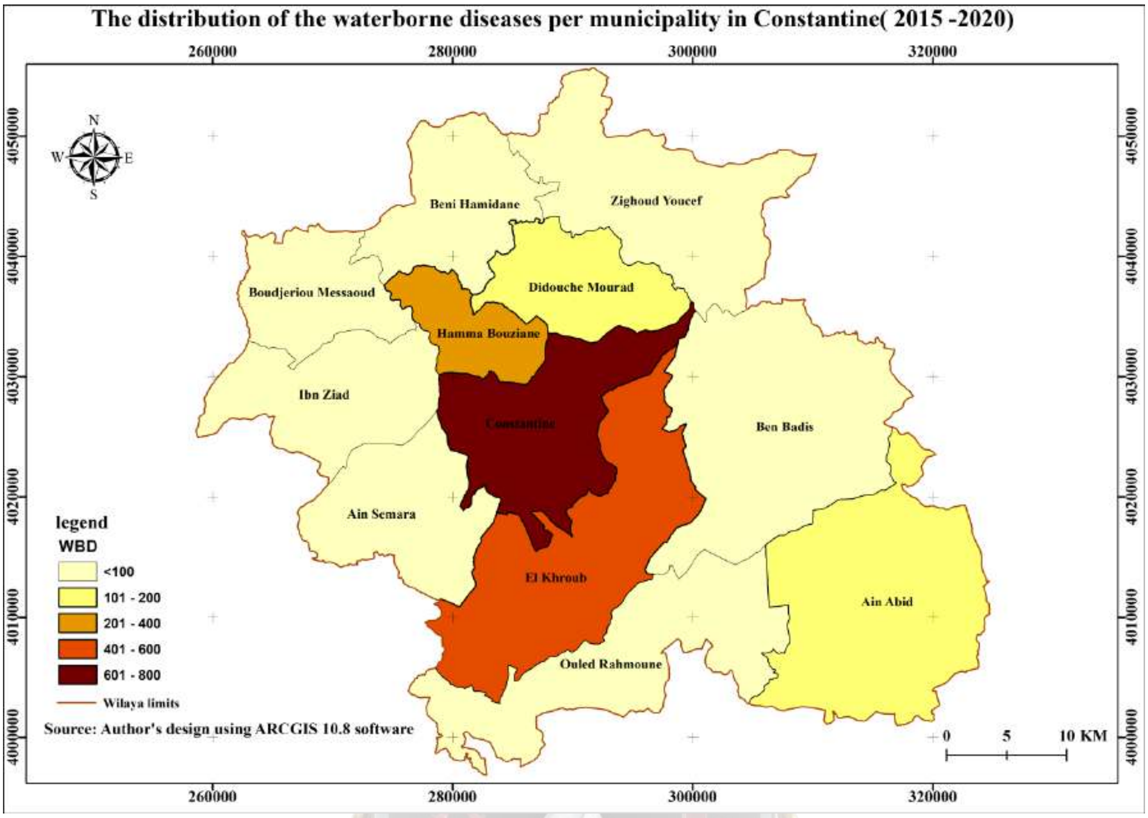

Figure 4. Distribution map of WBD by municipalities within the Wilaya of Constantine (2015-2020).

Source: Author's design from DHP data with ArcGIS 10.8

An analysis of the distribution of waterborne infections in the Wilaya of Constantine reveals that central municipalities—particularly Constantine, El Khroub, and Hamma Bouziane—are the most affected, in contrast to outlying or rural municipalities across the province

Certain towns have certain similar traits that help to explain the higher concentration of waterborne infections in certain places:

3.4.1. High urban population density:

In particular, Constantine, the capital of Wilaya, welcomes many people and immigrants and has a high population density. This strains the sewage system and fuels great demand for drinking water. Although they are urban areas, these municipalities occasionally suffer from shortcomings in wastewater management and water supply networks, particularly during heavy rainfall or extreme heat, which results in the contamination of drinking water sources and raises the risk of disease outbreaks.

3.4.2. Seasonal and climatic variables:

Intense rainfall and flooding: Rainy seasons significantly contribute to the prevalence of waterborne infections in these towns, particularly when the state experiences significant rainfall that can lead to flooding and pipeline damage.

Climate change exacerbates these conditions by increasing the frequency and severity of rainfall and flooding, affecting the availability of drinking water and, consequently, the risk of waterborne illness epidemics.

3.4.3. The correlation between population density and waterborne diseases among localities

The results of a linear regression computed between population density and the number of waterborne illness (WMD) cases (Figure) were as follows:

- Slope = roughly 0.28: This indicates that an estimated increase of roughly 0.28 WMD cases results from every unit increase in population density (persons/km²).
- Intercept = 3.04: Under zero density, the expected count of cases
- R2R2: 0.87; the coefficient of determination indicates the strength of the association between the two variables since the model explains almost 87% of the variance in the number of occurrences.

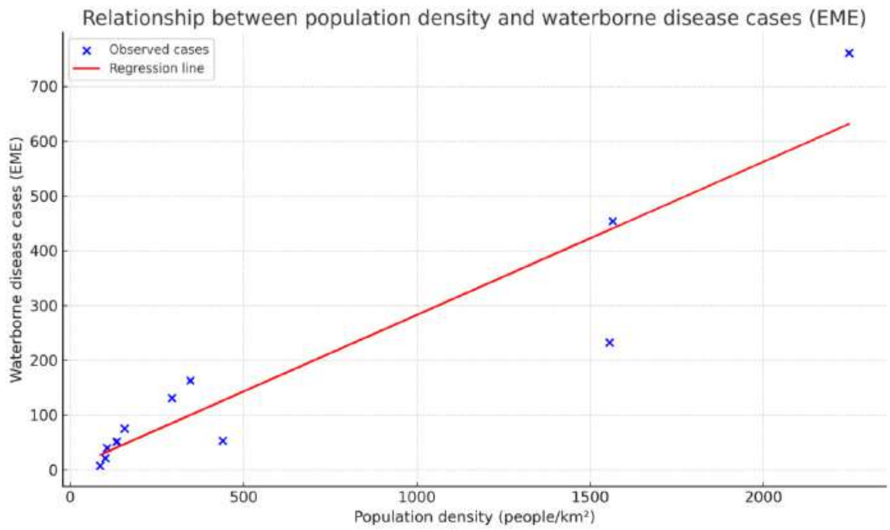

Figure 5. Linear regression analysis reveals the relationship between population density and waterborne disease cases across several municipalities in Constantine Province. Software Used**:** Python (Matplotlib & Seaborn libraries) for data analysis and visualisation based on municipal health and demographic data.

3.5. Mapping of Zoonoses

Figure 6 illustrates the geographical distribution of zoonotic diseases by municipality in the Wilaya of Constantine over a six-year period (2015–2020).

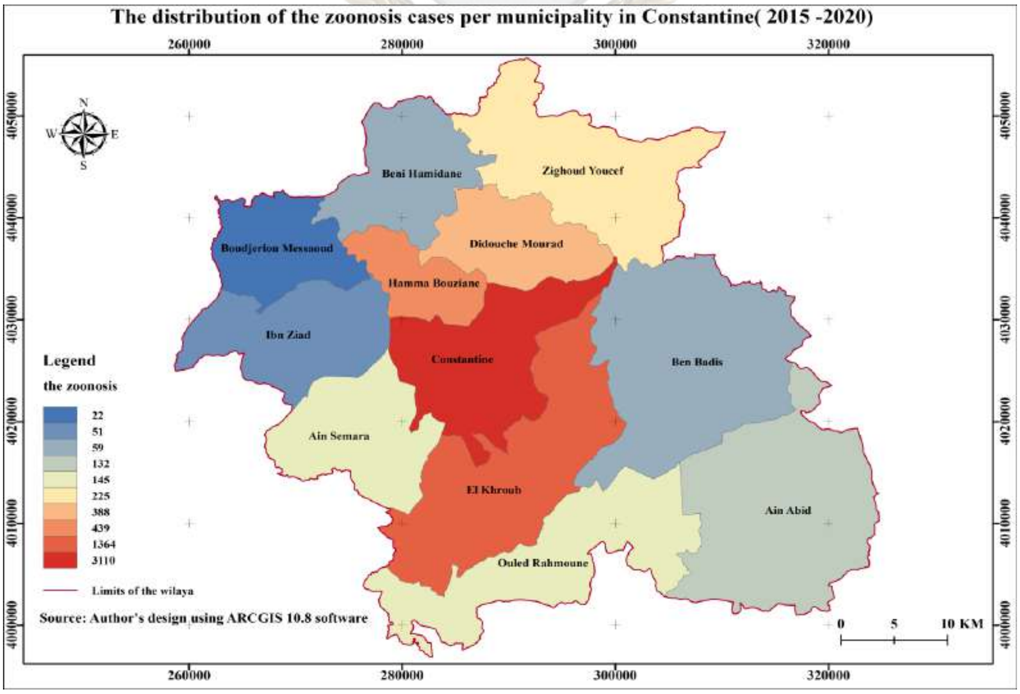

Figure 6. Zoonosis distribution map according to the municipalities of the wilaya of Constantine (2015-2020)

Source: Author's design from DHP data with ArcGIS 10.8

With a total of 3,110 cases, accounting for over 50% of all cases recorded in the wilaya, the distribution of zoonosis cases over six years reveals a high concentration in three central municipalities, with Constantine being the most affected. Following it with 22% of all zoonosis cases is the municipality of El Khroub. With 439 cases, Hamma Bouziane was also severely impacted.

These three towns together account for around 80% of the total zoonosis cases in the Wilaya, which emphasises their high concentration in these areas.

3.5.1. Elements causing the great case concentration:

Several elements can help to explain the concentration of zoonotic disease cases in the central municipalities of Wilaya, particularly Constantine, El Khroub, and Hamma Bouziane. Among them is the incredible population density in certain towns. El Khroub and Hamma Bouziane are situated close to rural areas and cattle farms, where regular human-animal interaction is evident. Better healthcare infrastructure and diagnostic facilities also benefit these towns, which could help detect zoonotic infections early on and improve their management compared to rural areas.

Though the remaining municipalities are less affected, the distribution of cases in other municipalities still accounts for 20% of the overall zoonotic cases. Among these cases' various municipalities are Ain Smara, Ouled Rahmoun, Didouche Mourad, Ouled Abid, Ben Badis, Beni Hamidane, Ibn Ziad, and Messaoud Boudjerou.

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3.5.2. The correlation between population density and zoonotic diseases among localities

Calculating a linear regression between population density and zoonotic disease case (Figure 7) count, the following was obtained:

- Slope: around 1.05 → This implies that roughly 1.05 disease cases should rise for every one person/km² increase in population density.
- Intercept: instead -115.21 → When population density is zero—which is unreal but theoretically required—this is the expected value.
- R^2, or efficiency of determination: about 0.76 → Population density can thus help to explain about 76% of the variance in the number of instances.

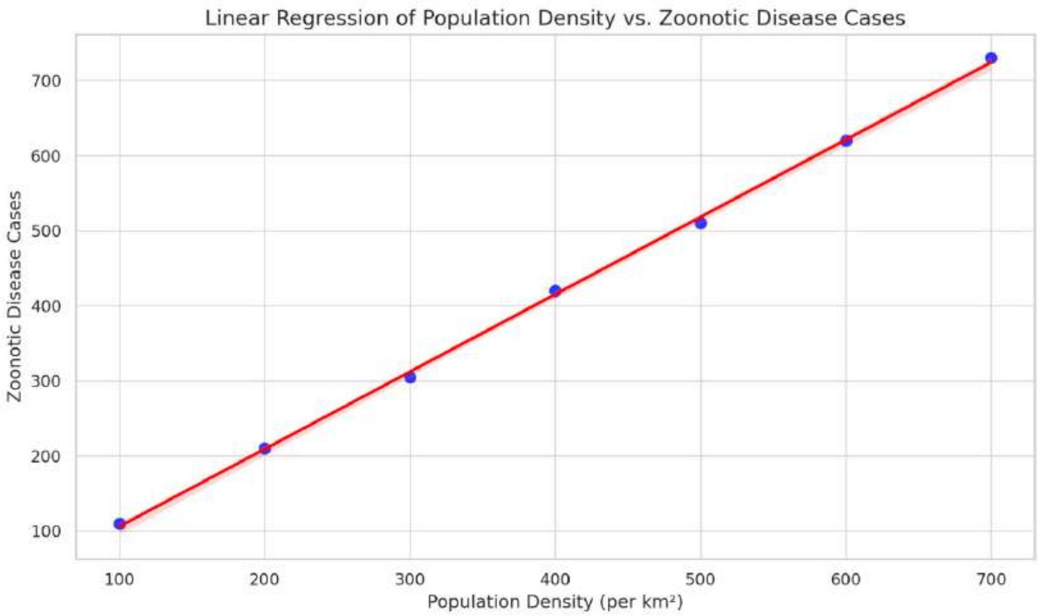

Figure 7. Linear regression curve illustrating the relationship between population density (per square kilometre) and zoonotic disease cases. Software Used**:** Python (Matplotlib & Seaborn libraries) for data analysis and visualisation based on municipal health and demographic data.

3.6. Mapping of COVID-19 Distribution

Figure 8 illustrates the geographic distribution of COVID-19 cases across the municipalities of Constantine in 2020, highlighting regions with elevated case counts.

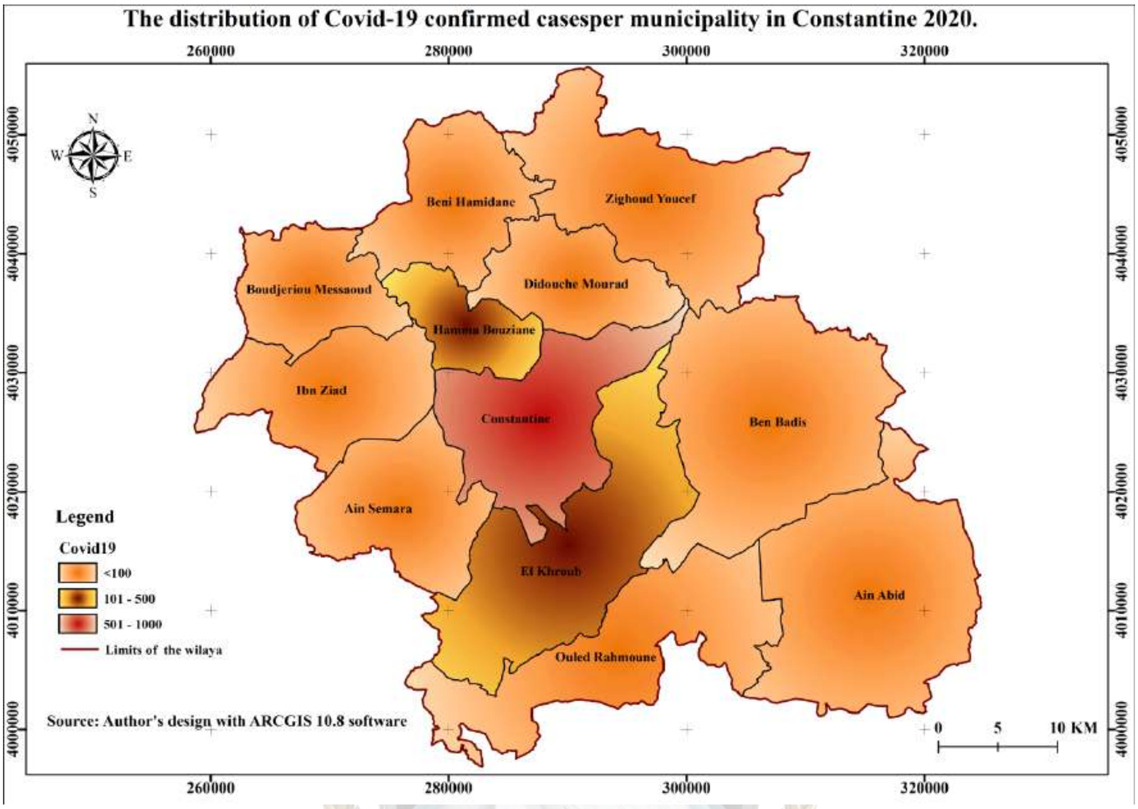

Figure 8. Distribution map of COVID-19 cases according to the municipalities of the Wilaya of Constantine (2020). *Source: Author's design from DHP data with ArcGIS 10.8.*

The regional distribution of confirmed COVID-19 cases among Constantine's 2020 municipalities is shown on the map (Figure 8). With darker tones signifying greater case concentrations, the *colour* gradient—which spans bright orange to dark red—represents the total verified cases.

3.6.1.COVID-19's most impacted municipalities:

Constantine: With a dark red colour, suggesting a high number of cases (between 801 and 1,000 instances), Constantine is the most severely impacted municipality. This is a result of its high population density and excellent human mobility, in addition to the fact that health facilities draw many disease cases, which are likely elements responsible for the rapid spread of the virus.

El Khroub and Hamma Bouziane have also shown large case counts (501–800). Their metropolitan character and proximity to Constantine facilitated the spread of the infection.

The moderately affected municipalities of Douche Mourad, Zighoud Youcef, and Ouled Rahmoun have a COVID-19 case prevalence ranging from 1 to 5%. Their relatively low population density and weaker human connections could have helped prevent the disease from spreading.

Represented by lower scores, Beni Hamidane, Ben Badis, Ain Abid, and Ain Smara have reported less than 100 confirmed cases. Their rural character, low population density, and low mobility could influence the limited virus propagation. Potential contributing elements influencing case distribution include:

- Urban density: The virus has been shown to spread rapidly in densely populated areas.
- Movement and economic activity: The highest *number of cases have come from major administrative and economic hubs, underscoring the role of human movement* in the virus's dissemination.

- Access to healthcare and testing capacity: Higher testing capacity in municipalities with superior healthcare infrastructure—such as Constantine—may have led to more cases being recorded. On the other hand, rural communities lacking more healthcare facilities could have understated cases.
- Preventive measures and public awareness: Variations in *the application of public health policies, including mask mandates, social distancing, and lockdown compliance, may* have impacted the spatial distribution of COVID-19 cases.

Linear regression analysis highlights a strong linear relationship between population density and COVID-19 cases. The two variables are positively correlated, with the number of cases increasing as population density increases.

3.7. Prevalence of Waterborne Diseases (WBDs) by Municipality

Figure 9. Represents the Prevalence of Waterborne Diseases in the municipality of Constantine.

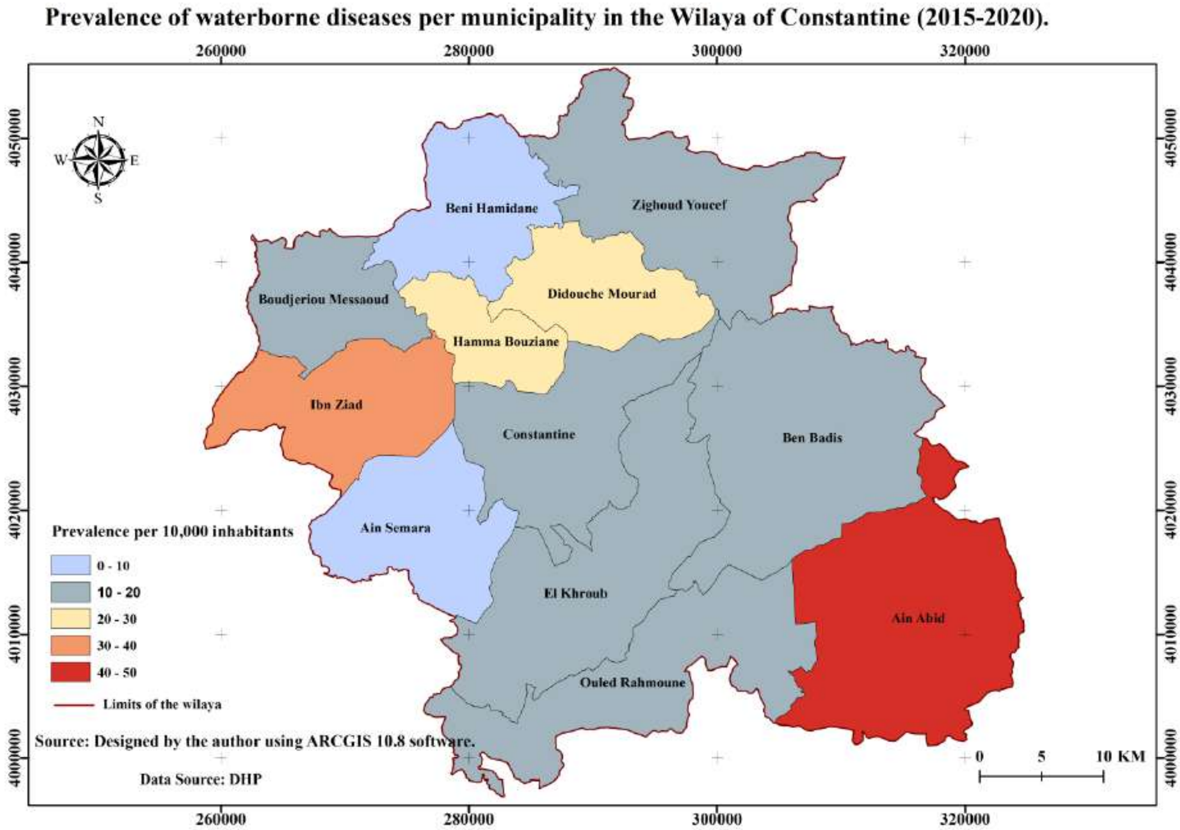

Figure 9. Map of the prevalence of MTH by municipalities of the wilaya of Constantine (2015-2016).
Source: Author's design from DHP data with ArcGIS 10.8

3.7.1. Spatial analysis of prevalence rates

• Municipalities with high prevalence (40-50 cases per 10,000 inhabitants):

- Ain Abid: Located in the southeastern part of the state, Ain Abid shows the highest prevalence of waterborne diseases.

• Municipalities with medium prevalence (30-40 cases per 10,000 inhabitants):

- Ibn Ziad: This municipality is located in the western part of the state and has a relatively high prevalence rate.

- Possible factors include limited access to safe drinking water and sanitation.

-Also, reliance on contaminated surface or groundwater sources and the lack of inadequacy of sanitation infrastructure.

• Municipalities with low prevalence (10-30 cases per 10,000 inhabitants):

Boudjeriou Messaoud, Didouche Mourad, and Hamma Bouziane have medium prevalence rates. Constantine, El Khroub, Ouled Rahmoun, Zighoud Youcef, Beni Hamidane, and Ben Badis have the lowest prevalence rates.

3.8. Prevalence of Zoonotic Diseases (Zoonoses) by Municipality:

Figure 10 illustrates the prevalence of zoonotic diseases across municipalities in the Wilaya of Constantine over six years from 2015 to 2020. The map highlights the distribution of zoonotic disease cases, emphasising areas with higher disease rates and those that have experienced notable outbreaks.

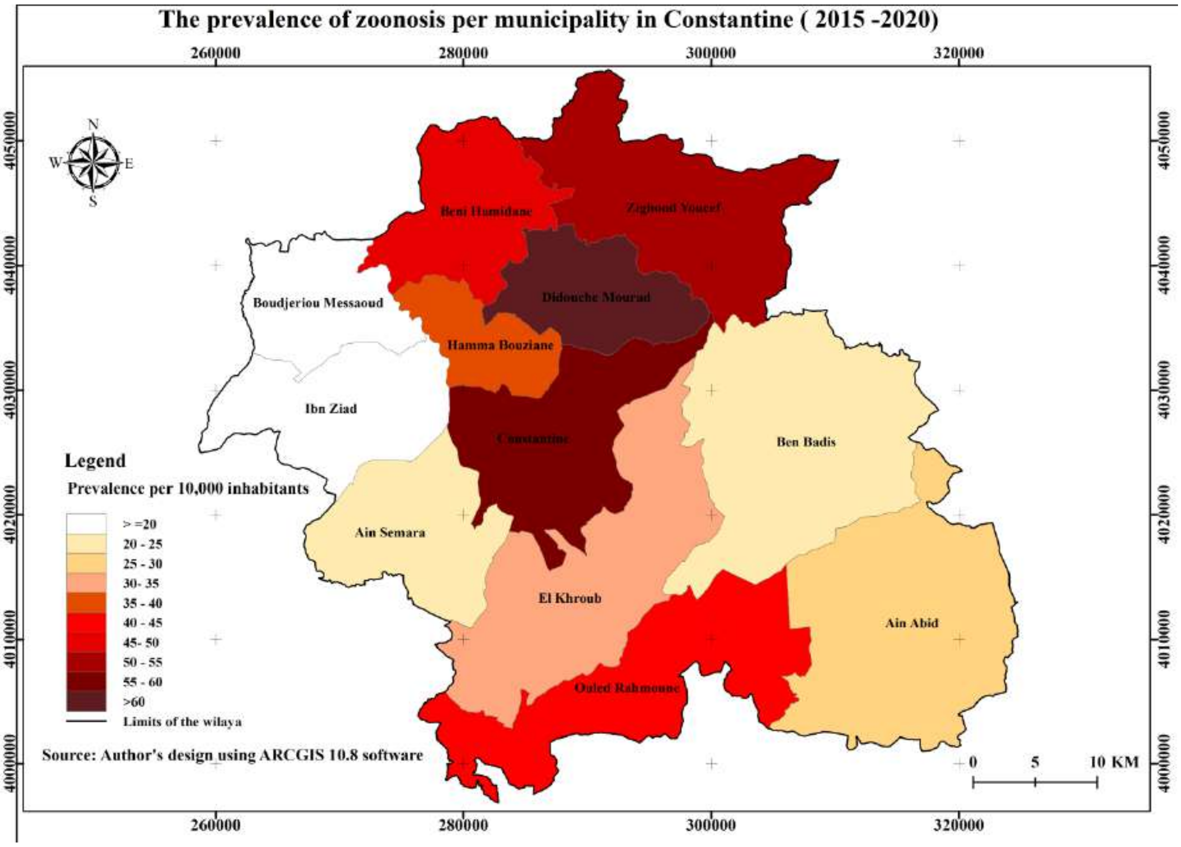

Figure 10. Map of the prevalence of zoonosis per municipalities of the wilaya of Constantine (2015-2016)

Source: Author's design from DHP data with ArcGIS 10.8

The frequency of zoonoses in Constantine's Wilaya reveals a varied spatial distribution across several areas. The towns of Constantine, Hamma Bouziane, Didouche Mourad, Zighoud Youcef, and Beni Hamidane note the most excellent prevalence rates—between 50 and >66 cases per 10,000 residents. These dark red highlighted spots indicate an intense concentration of zoonoses.

The localities of El Khroub and Oued Rahmoun indicate medium prevalence rates (between 30 and 50 cases per 10,000 residents), indicating a modest but concerning level.

The localities of Ain Smara, Ben Badis, and Ain Abid have the lowest prevalence rates (<30 cases per 10,000 people), indicating reduced exposure to zoonoses.

This visual study provides important new insights into the geographical distribution of zoonotic illnesses, identifying areas that require targeted health interventions and preventive actions to prevent disease transmission from animals to humans.

3.9. Prevalence of COVID-19 by Municipality

This map (Figure 11) provides a thorough depiction of the COVID-19 epidemic's spread among several Constantine municipalities during 2020, highlighting the areas most impacted by the epidemic during this period and those with the highest case counts.

This geographical study is crucial for understanding how the disease spreads among multiple towns and informing targeted public health campaigns.

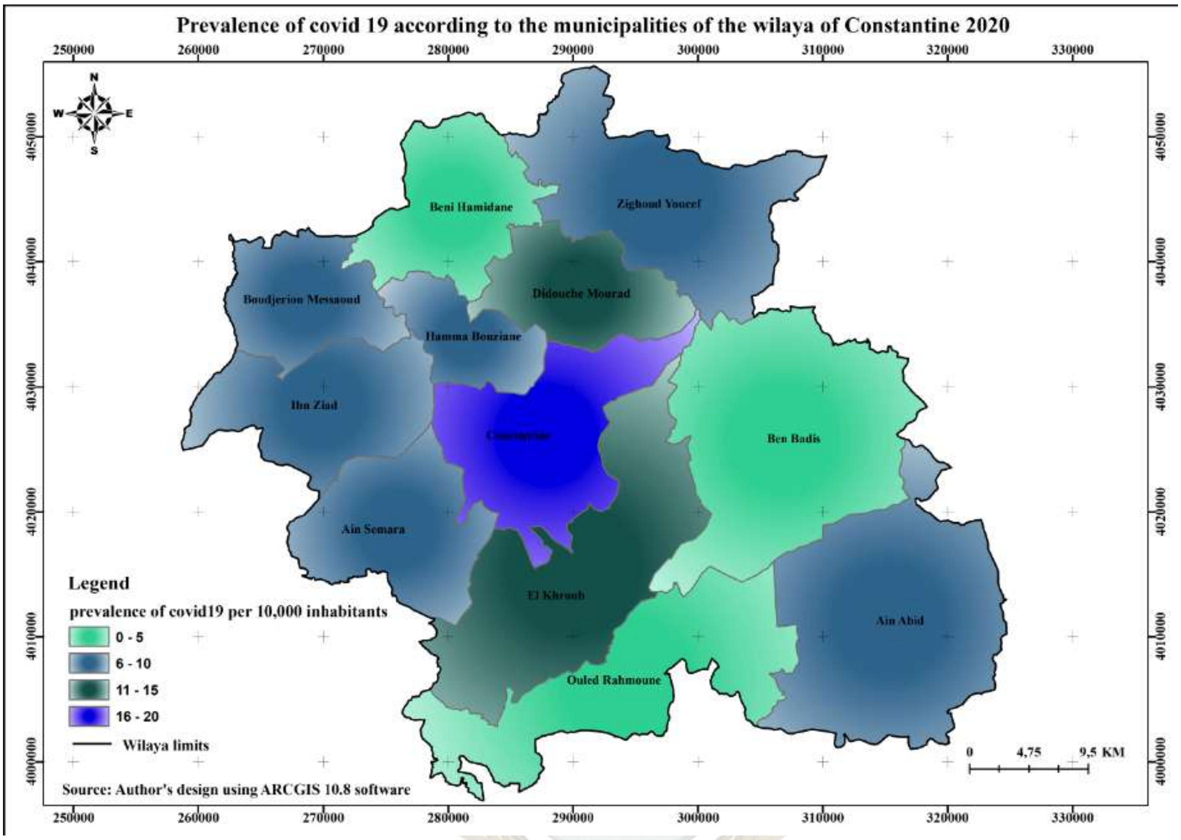

Figure11. Map of the prevalence of Covid 19 by municipalities of Constantine Wilaya (2020)

Source: Author's draft from DHP data with ArcGIS 10.8.

The map (*Figure 11) displays the COVID-19 incidence for every 10,000 people* living in several municipalities within Constantine's Wilaya. Made using ArcGIS 10.8 based on gathered data, COVID-19's spatial frequency distribution is Represented in dark blue; the municipality of Constantine is the *epicentre* of the epidemic and most impacted (≥ 16 cases / 10,000 people). El Khroub comes next in relatively high frequency.

3.9.1. Moderately impacted domains:

The virus has a modest frequency (6–15 infections per 10,000 residents), as evidenced by the communities of Hamma Bouziane, Didouche Mourad, and Zighoud Youcef. Ben Badis, Ain Abid, Ain Smara, Ibn Ziad, and Beni Hamidane exhibit the lowest infection rates, likely due to low population density and minimal social interaction, making them the least impacted places (≤ 5 cases/10,000 inhabitants).

As the most *urbanised* and densely populated cities, Constantine and El Khroub demonstrate higher infection rates due to their high human concentration and frequent social connections.

Movement within urban municipalities may have facilitated the rapid spread of the pathogen. Enhanced access to medical facilities in urban areas may *increase* testing rates, thus boosting the reported instances. Low population density and reduced mobility in towns such as Ain Abid or Ben Badis could account for the low recorded cases.

4. Discussion

The statistical analysis results indicate a strong direct association between population density and the recorded incidence of waterborne illness cases in Constantine's provincial municipalities. According to a linear regression model, density clearly explained 87 % of the variance in the number of recorded events. The results of our investigation align with earlier studies that emphasise the role of population density in facilitating the spread of the virus and increasing the risk of exposure to contaminated water supplies (Port & Jawahar, 2024; Beale et al., 2008).

This phenomenon is typically attributed to the high population density, which places a significant load on urban infrastructure, particularly water supply and sewage systems, leading to leaks and contamination. Municipalities such as Constantine and Hamma Bouziane, which have recorded the highest number of cases, further support this statistical link.

In addition to waterborne diseases, zoonotic diseases—also influenced by population density—demonstrated a similar statistically significant correlation. Our regression analysis revealed that, with a coefficient of 1.05, every additional person per square kilometre correlates with approximately one additional zoonotic disease case. The regression model (P-value = 0.0002; R^2 = 0.763) provided substantial support for this outcome, thereby emphasising the stability of the link.

Such results mirror past studies on zoonotic and pandemic disease patterns in densely crowded environments (Ulal & Karmakar, 2023; Cvetković et al., 2020; 2022; Janković et al., 2020). Beyond statistics, the spatial analysis of disease distribution, including COVID-19, zoonotic, and waterborne illnesses, revealed significant geographic disparities across the municipalities of Constantine. Municipalities for every disease include Constantine, El Khroub, and Hamma Bouziane, which are repeatedly ranked as high-risk areas.

Combining population density, urbanisation, and infrastructure shortcomings related to sanitation and water drives this spatial concentration. Comparable spatial clustering tendencies have been observed in many worldwide studies using GIS-based health risk assessments (Ocal et al., 2020; Rezaeian, 2007). This regional perspective is crucial in managing health risks by guiding geographically informed resource allocation, supporting targeted public health policies, and improving epidemic surveillance over time. Incorporating spatial analysis into public health planning enables the more accurate detection of high-risk areas and facilitates the development of tailored interventions. In line with current global findings, our work emphasises the importance of integrated spatial-statistical techniques in addressing environmental health hazards in various local settings effectively (Beale et al., 2008; Rezaeian, 2007). These insights reinforce the significance of adopting localised, data-driven approaches in managing public health threats in rapidly urbanising.

5. Conclusions

Especially in the wilaya of Constantine, this study emphasises the importance of spatial analysis as a valuable tool for monitoring infectious diseases in Algeria. By comparing our results with those of previous international studies, it appears that population density plays a significant role in the spread of diseases, as areas with high population density increase health risks related to waterborne and zoonotic diseases. The study also highlights the role of spatial analysis using geographic information systems (GIS) in identifying high-risk areas, which helps improve the allocation of health resources more effectively and efficiently.

Our results demonstrate that spatial analysis is a crucial tool for tracking disease frequency, facilitating the development of health strategies tailored to the social and environmental characteristics of each region. This study also highlights the need to improve sanitation and water infrastructure, aligning with previous studies that have called for enhanced environmental monitoring and improved public sanitation facilities in areas with weak infrastructure.

The analytical maps created in this study greatly facilitated the identification of high-risk areas and the most vulnerable population categories, thereby enhancing our ability to track infectious disease trends. These results underscore the importance of early preventive surveillance and rapid response to epidemics, which necessitates the development of a comprehensive health risk management strategy that considers the spatial dimension of these risks. Moreover, strengthening the resilience of the healthcare system in the Wilaya of Constantine requires expanding healthcare infrastructures, improving resource management, and enhancing cooperation among various stakeholders, thereby contributing to increasing the region's capacity to manage health risks. Thanks to the results of this study, it can be affirmed that integrating spatial analysis into the region's public health policies will play a significant role in the early forecasting and prevention of future epidemics, thereby improving the well-being of the population and the quality of life in the wilaya of Constantine.

Author Contributions:

Project conceptualisation, data collection, statistical analysis, and mapping: D.S.; data validation, study supervision, and result interpretation: B.S.; writing – original draft preparation: D.S.; writing – review and editing: D.S. and B.S.; B.S. provided guidance throughout the research process and contributed to revisions to ensure scholarly accuracy. All authors have read and agreed to the published version of the manuscript. The authors collaborated throughout the research process, from data collection to final revisions, each offering their specialised expertise to distinct elements of the study.

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