Journal of Information Systems Engineering and Management
2025, 10(4)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

The Impact of Spatial Disparities on Access to Healthcare in the North-Central Region of Algeria, using Geographic Information System (GIS)

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ARTICLE INFO

Received: 20 July 2025

Revised: 02 Sept 2025

Accepted: 10 Sep 2025

ABSTRACT

The present work analyzes the spatial distribution of healthcare infrastructure and its correlation with the location and geographical characteristics in terms of access to healthcare in the north central region of Algeria. This region represents the most important spatial area in the country because it is the most favored region in terms of infrastructural attractiveness. However, significant inequalities in access to healthcare remain evident within the region, largely favoring Algiers and its metropolitan area. As the political and economic capital and the country's main hospital hub, Algiers benefits from extensive healthcare coverage, making it the primary concentration zone for health facilities nationwide. To analyze these differences in healthcare access, several methodological approaches were employed, including nearest neighbor analysis, together with the calculation of the centroids of healthcare facilities and standard distances to identify the ellipse of dispersion. Spatial analysis and geomatics methods such as buffer zones and location-allocation models were applied using (ArcGIS10.8). The results indicated a significant correlation between the quality of healthcare infrastructure distribution and geographical characteristics. Nevertheless, this relationship is not consistent across the different Wilayas. Despite similar geographical conditions, the eastern regions benefit from a higher level of service compared to the other regions. This situation requires serious state intervention to achieve social and spatial justice and the principles of sustainable development, particularly Sustainable Development Goal 3.

Keywords: Access disparities, Spatial distribution, geographical characteristics, North-Central Algeria, Inequalities, Health care infrastructure.

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Introduction

The Algerian Healthcare System

Algeria has a public healthcare system that is accessible and free for all Algerian citizens. Health planning, as part of the country's economic and social development strategy under the National Territorial Planning Scheme ensures the equitable, balanced, and rational distribution of human and material resources across the territory (Law No. 46)[1]. Law No. 10-02 [*SNAT 2025*], is based on four guiding principles: resource sustainability, the reduction of territorial disparities, territorial attractiveness and competitiveness, and social and spatial equity. The latter includes increasing healthcare provision in areas with high mortality rates and addressing inequalities in disadvantaged territories (Azzouzi and Acidi, 2017).

The Algerian government fully finances the public healthcare system, with total health expenditures rising from 3.49% to 6.6% of the Gross Domestic Product (GDP) between 2000 and 2013, while public health spending increased from 2.56% to 4.99% of GDP (Messaili and Kaïd, 2017). The government allocates approximately €340 per person each year for health expenditures, a value considered insufficient compared to France's €3430 per person (Fafa, 2007).

In 2021, Algeria dedicated 5.5% of its Gross Domestic Product (GDP) to healthcare financing. This percentage places the country slightly below average of the Eastern Mediterranean region (6.16%) and the European average (8.69%), although it remains close to the African regional average (5.76%) (Who, 2024). It is important to point out that the Finance Law of 2025 has significantly increased the budget of health sector by 19% (equivalent to 4 billion Algerian dinars) in comparison to the previous year. When compared to other countries in the region, Algeria has invested substantially in the health sector. (Akki-Alouani, A. (2015).

The Algerian healthcare system has undergone several phases, from post-independence to transitional stages, and up to the present day. It is structured around both public and private sectors. The Ministry of Health, Population and Hospital Reform (MSPRH) manages public hospitals and health services, as well as regulating the practice of the private sector.

The healthcare system is organized into four hierarchical levels. Level A comprises highly specialized care facilities and serves as the last resort for patients. Level B provides specialized services for medical conditions that do not necessarily require the involvement of level A hospitals. Level C encompasses general care services, while level D includes preventive measures and primary care (Youcef A. and Brahim B., 2018). This study specifically focuses on geographical accessibility, which is one of the most prominent and frequently employed indicators for assessing the spatial distribution of healthcare services. A detailed comprehension of spatial disparities in access to hospital care (Levels A, B, and C) is essential to ensure the efficiency of health policies and strategic planning. This research gives particular attention to Public Hospital Establishments (PHE), which represent the second tier in the healthcare delivery pyramid (secondary care). These institutions are responsible for addressing the healthcare needs of the population within a specific geographic zone, usually at the Daïra[2] (district) level. Their role is crucial, as they provide care in fundamental medical specialties such as pediatrics, obstetrics and gynecology, and general surgery. The Effective functioning of PHEs is essential in

[1]- Art. 7. — OFFICIAL JOURNAL OF THE ALGERIAN REPUBLIC No. 46 Law No. 18-11 of 18 Chaoual 1439 corresponding to July 2, 2018 relating to health.

[2]- daïra is an administrative subdivision of a wilaya (province) in Algeria. It encompasses several communes (municipalities) and is overseen by a daïra chief, who is responsible for coordinating and implementing administrative decisions at the local level.

Journal of Information Systems Engineering and Management
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alleviating the burden on University Hospital Centers (UHC)[3] and Specialized Hospital Establishments (SHE)[4], which are already under significant pressure (Ouali et al., 2025).

The Concept of Accessibility

Access and accessibility, although often confused, represent distinct concepts in the field of healthcare. Access is defined as the ability of populations to obtain healthcare services adapted to their needs, whereas accessibility refers to the characteristics of healthcare services, such as their location, organization, or cost, that influence the capacity of potential patients to seek and receive care (Haggerty et al., 2014). Access to healthcare is a multidimensional concept encompassing several factors that describe the relationship between the patient and the healthcare system, including service availability, accessibility, organization of care, financial feasibility, and acceptability of care according to patients' expectations and characteristics (Penchansky and Thomas,1981). Healthcare services are considered accessible when their characteristics correspond to patients' needs and expectations, that is, when they are perceived as appropriate (Guillaume and Chevillard, 2015). Accessibility is also influenced by the geographical context, whether it be urban, rural, or peri-urban (Steinhauser, 2014; Haggerty et al., 2014; Hunsaker and Kantayya, 2010; Russel et al., 2013). An expanded definition of access to healthcare services identifies four main dimensions: availability (the possibility of accessing quality services and providers), accessibility (the physical distance or travel time between the service location and the user), affordability (the relationship between service cost and users' financial capacity), and acceptability (the sensitivity of providers to patients' social and cultural expectations) (O'Donnell, 2007).

The Issue of Geographic Accessibility to Healthcare

The issue of geographic accessibility to healthcare services constitutes a major challenge in public health and the organization of healthcare systems. It refers to the difficulties faced by populations, especially those living in rural, peri-urban, or isolated areas, in physically accessing health infrastructures and healthcare professionals. This problem is influenced by various factors, including the distance to be traveled, the availability of transportation means, the uneven distribution of medical resources, and socio-economic disparities. These geographic barriers can lead to delays in receiving care, worsening of medical conditions, and inequality in access to healthcare, thereby compromising the equity and efficiency of healthcare systems.

In Algeria, as in many other developing countries, there are significant inequalities in the distribution of both general and specialized hospitals within the north-central region. A study conducted in the Wilaya of Bejaia in 2020 highlighted that the distance to the nearest hospital accounted for half of the reasons for renouncing specialized care (CHeurfat and Kaid, 2020). Similar studies have reached the same conclusions in Tanzania (Hanson, 2015), Mali (Sidiki T. UMI, 2024), and even in developed countries such as France, where geographic remoteness from a doctor makes rapid access to consultations very difficult. Thus, multiple components affect healthcare accessibility. The spatial distribution of healthcare supply influences both availability and proximity to services, and constitutes one of the main factors of inequality. Access to healthcare varies according to geographic areas because the distribution of healthcare services and population is not uniform, which results in inevitable inequalities of access (Tanser et al., 2009; Medjadj and Baudelle, 2022). Furthermore, distance also

3- University Hospital Centers (CHU): Provide integrated activities in education, patient care, and research.
4- Specialized Hospital Institutions (EHS): Deliver education, patient care, and research activities, typically focused on a single specialty or occasionally dual specialties (e.g., urology-nephrology, cardiovascular, psychiatry, mother-child care, etc.).

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depends on the type of care, being more discriminatory for access to general practitioners than for hospital care (Comber et al., 2011). The distance separating populations from healthcare supply can indeed have deterrent effects on their health status, access to healthcare, and more generally on their care pathways.

Indicators Used in Socio-Health Typologies or to Describe Healthcare Supply

To describe the state of healthcare supply, many indicators such as density, workforce evolution, or distance to healthcare professionals are frequently used (Amat-Roze, 2011; Bessières et al., 2005; Coldefy and Lucas, 2012; Fnors, 2006, 2010; Vigneron, 2012), in addition to other indicators like practitioner activity or age (Bessières et al., 2005). The potential localized accessibility to healthcare professionals is a multidimensional indicator that takes into account the level of supply, local and surrounding demand (Barlet et al., 2012). Service use also correlates positively with educational level, in that the higher the level of education, the more frequently individuals engage with the various services analyzed (Wiśniewski, 2025). All these factors can be summarized in this diagram.

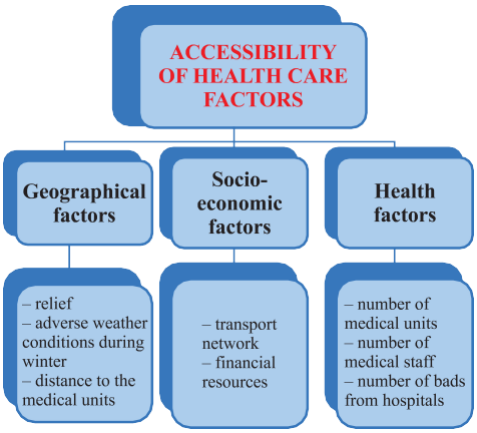

Fig.1.The factors influencing the accessibility of healthcare services (Ursulică, T. E. 2016).

Data Presentation

All datasets used in this study are georeferenced. They include data on healthcare infrastructure—namely, highly specialized care facilities, specialized care facilities, and general healthcare services. Health-related data were obtained from the Ministry of Health and Hospital Reform (MSPRH)[5]. Population data were provided by the National Office of Statistics (NOS)[6].

Due to the unavailability of the final results from the most recent population census (2022), population estimates were derived based on the 2008 census using the following exponential growth formula:

$P(t) = P_0 * (1 + r)^{}$ where:

- P(t) is the estimated population at time t,
- P_0 is the initial population,

5- The Ministry of Health, Population and Hospital Reform (MSPRH) is the health ministry of Republic of Algeria. The Ministry is responsible for public health facilities and population monitoring.
6- The National Office of Statistics (NOS) is the Algerian ministry charged with the collection and publication of statistics related to the economy, population, and society of Algeria at national and local levels. Algiers

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e-ISSN: 2468-4376
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- r is the annual growth rate (expressed as a decimal),
- t is the number of years since the initial population count.

Analytical Procedures

Spatial Analysis of Public Hospital Establishments (PHE)

The spatial distribution of PHE infrastructure was analyzed through the following steps:

1. Nearest Neighbor Index: This method was used to assess the degree of spatial clustering or dispersion of PHE facilities.
2. Buffer Analysis: Buffers were applied around healthcare facilities to evaluate coverage areas and service accessibility.
3. Allocation Method**:** This technique helped to identify optimal healthcare facility placements in relation to population distribution and accessibility demands.

Materials And Methods

Study Area Presentation

The North-Central region of Algeria covers an area of approximately 33,470.5 km², which represents 1.49% of the total surface area of the country. Despite its relatively small size, it is considered as the mosturbanized and densely populated region, accounting for nearly one-third of Algeria's total population**.** The population increased from 7.7 million inhabitants in 1987 to over 10 million by 2008(Hraoubia, 2016), with projections estimating a population of 13,280,454 by the year 2025(NOS)**.** The region is composed of ten wilayas located in the central Tell zone, which includes 441 of thecountry's 1541 municipalities. These wilayas are organized into two concentric zones first ring**:** Algiers, Blida, Boumerdès, and Tipaza and Second ring**:** Béjaïa, TiziOuzou, Bouira, Médéa, Aïn Defla, and Chlef.(Bouder, 2007; Ait-Taleb, 2019). This region has historically and naturally become the most intensely utilized area for human activities, particularly due to its strategic geographical location and socioeconomic significance. The capital city, Algiers, plays a central role in this dynamic.

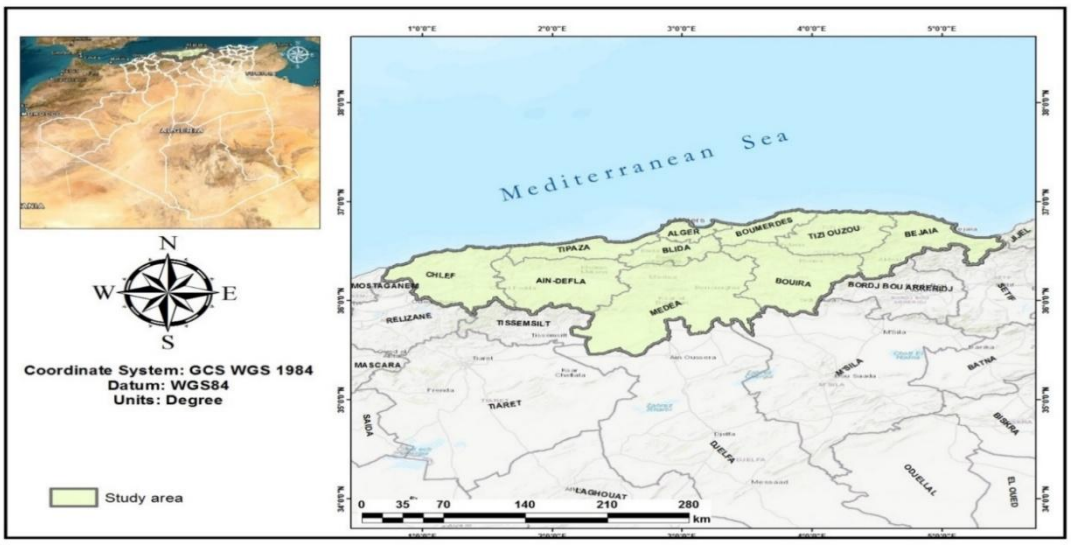

Fig. 2. Location map of the study area north-central region.

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Results and Discussion

Healthcare facilities: Between the challenge of distribution and accessibility to care

Health of the population is one of the main criteria for the sustainable development of regions. (Svetlana et al., 2015). This is what we will diagnose in the following paragraphs. In the wilayas of the North-Central region, healthcare infrastructure is particularly concentrated. A census carried out in 2013 by the Ministry of Health, Population, and Hospital Reform (MSPRH) on healthcare infrastructure revealed that, among a total of 7,841 healthcare establishments in Algeria (including University Hospital Centers (HUC), Specialized Hospital Establishments (HSE), Public Hospital Establishments (PHE), polyclinics, and health posts), approximately **(**26.2%) were located in the North-Central region**.**

By 2025, the North-Central region has known a significant increase in national healthcare infrastructure. It now accounts for 28.31% of Public Hospital Establishments (PHE), 60% of University Hospital Centers (HUC), and 27.47% of Specialized Hospital Establishments (HSE) throughout the country. Table 1 provides a more detailed illustration of this phenomenon.

Table1. The distribution of healthcare establishments in the north-central region.

Wilaya	PHE	SHE	UHC	Numbers of beds PHE	number of beds UHC+SHE	number of beds UHC+SHE +PHE	population estimate 2005	Numbers of doctors/1 000 inhabitant s
Algiers	6	15	5	1250	9760	11010	3679729	2.99
Béjaïa	7	2	1	944	581	1525	1067601	1.42
Tizi-Ouzou	10	4	1	1415	1235	2650	1276563	2.07
Médéa	6	0	0	1392	0	1392	951837	1.46
Ain Defla	3	0	0	990	0	990	986454	1.00
Boumerdés	4	0	0	874	0	874	1061668	0.82
Bouira	8	0	0	1231	0	1231	853288	1.44
Blida	4	2	2	696	2492	3188	1352366	2.35
Chlef	8	1	0	1273	120	1393	1293490	1.07
Tipaza	5	1	0	1195	159	1354	746531	1.81
Total	61	25	9	11260	14347	25607	13280454	1.92

Source: MSPRH, NOS and authors' calculations.

Table1 summarizes the distribution of public hospitals, specialized hospitals, and university hospitals within the North-Central region, noting that polyclinics and health centers were not included in the analysis. The examination of Table1clearly highlights the position of the Wilaya of Algiers as a regional and national healthcare hub, as it accounts for 43% of the total hospital beds in the region, with 88.64% of these beds are dedicated to specialized care. Moreover, it concentrates 60% of the specialized (SH E) hospitals and 55.55% of the university hospitals (UHC) at the regional level, reflecting the central role of the capital city. Indeed, the provision of specialized care requires high-quality material and human resources, which are only available in large urban agglomerations. It is important to note that over 65% of the hospital beds in the region belong to specialized establishments, thereby enhancing the healthcare

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attractiveness of the region. Consequently, this study focuses on general hospitals (PHE), which are subject to the principle of proximity in their distribution. The examination of the table also reveals evident imbalances and disparities in the geographic distribution of healthcare structures, which affect the quality of medical supervision as indicated by the doctors per 1000 inhabitants ratio. The gaps are significant and alarming, with a difference of approximately 3.64 times between the maximum and minimum values. The density of hospital beds remains generally problematic in the wilayas of Chlef, Boumerdès. and Ain Defla.

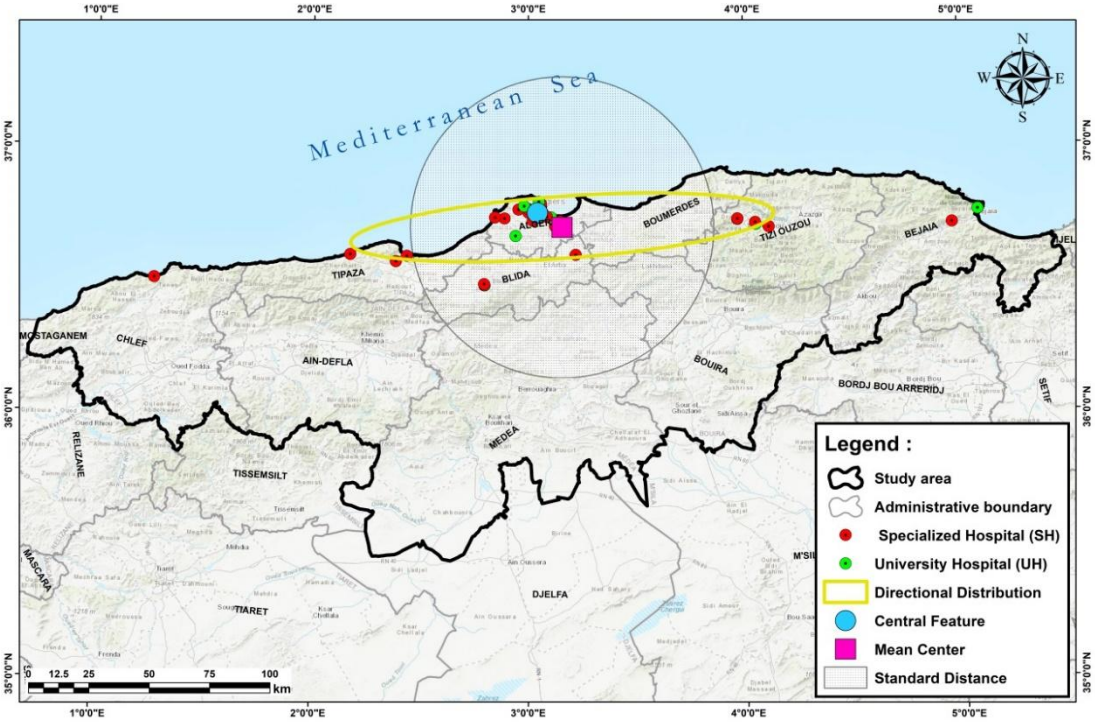

Fig. 3. Distribution of University and Specialized Hospitals (HUC and HSE) in north-central region.

The maps presented in (Fig. 3) illustrate a heterogeneous distribution of healthcare services throughout the territory of the North-Central region, particularly for highly specialized facilities, which exhibit a highly centralized pattern. The density of these establishments decreases progressively as one distance from the capital and major cities such as Blida, Béjaïa, and TiziOuzou. In terms of general care facilities, there appears to be a certain balance at the macro-regional scale, but internal disparities exist between the northeastern wilayas and the remaining wilayas (Fig. 4). To better elucidate this phenomenon, a density map was created using the kernel density estimation method. However, the accuracy of this representation remains limited due to the large extent of the study area and the relatively limited number of hospitals. The density map is provided in the appendix. In the light of these preliminary findings and to achieve a more comprehensive and precise understanding of healthcare disparities, a spatial analysis of Public Hospital Establishments (PHE) was conducted.

Spatial Analysis of Public Hospital Establishments (PHE)

This phase analyzes the spatial distribution of (PHE) through spatial statistical methods, including the mean center, standard distance, and standard deviation ellipse. These tools allow for

a better comprehension of the geographical distribution, concentration, and associated territorial dynamics of healthcare facilities. The data derive from a geocoded census of (PHE) in a projected coordinate system. The analysis is based on three main spatial statistics tools:

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- Mean Center: Calculated from the x and y coordinates of each (PHE), the mean center represents the geographic centroid or center of gravity of the spatial data set. It is a central tendency measure used in geography and spatial analysis to identify the point that minimizes the sum of distances to all other points (Guagliardo, 2004).
- Standard Distance: Measures the spatial dispersion or spread of points around the mean center.
- Standard Deviation Ellipse: Visualizes the directional trend and intensity of spatial dispersion.

The formulas used are as follows:

1. Calculation of the centroid (mean center):
2. $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad ; \quad \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$

2. Calculation of the standard distance:

$$SD = \sqrt{\frac{\sum_{i=1}^{n} ((x_i - \bar{x})^2 + (y_i - \bar{y})^2)}{n}}$$

Table 2. calculation results

Field	Value	Interpretation
Center X	524 496,1614	The centroid of public health facilities PHE is located at 52.4 km (east-west position).
Center Y	4 038 141,996	The centroid of PHE is located at 403.8 km (north-south position).
Xstd Dist	34 161,75338	EPH facilities are dispersed at an average distance of 34.1 km from the center along the east-west axis.
Ystd Dist	144 038,8144	EPH facilities are dispersed at an average distance of 144 km from the center along the north-south axis.
Rotation	82,726011°	The orientation angle of the dispersion ellipse, measured in degrees from the X-axis (eastward).
Std Dist	104,676.1803	The standard distance (approx. 104 km) indicates high spatial dispersion. Such a distribution may suggest a well-balanced service coverage across the study region.
Intersection with EPH	33	More than half (51.56%) of PHE facilities intersect with the mean center, indicating clustering near the central distribution point.

Source Arc (GIS), version 10.8.and authors' calculations.

Spatial Distribution Analysis of PHE Healthcare Facilities

The results indicate that PHE healthcare facilities are more widely dispersed along the north-south axis (144 km) than along the east-west axis (34 km). The primary orientation of the standard deviational ellipse, at approximately 82.7°, suggests a spatial alignment almost parallel to the east-west axis, reflecting an elongation in this direction. The standard distance of approximately 104 km indicates a moderate to high degree of spatial dispersion, with 51.56% of (PHE) facilities located within the one standard deviation ellipse. This suggests a concentration around the mean center, while also highlighting extensive spatial coverage. The fact that more than half of (PHE) facilities are situated near the mean center suggests a certain degree of balance in their distribution. However, the pronounced vertical dispersion points to potential inequalities in accessibility across different Wilayas. The east-

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west orientation may reflect underlying geographical or socio-economic constraints. Further analysis at the Wilaya level would help to a more precise identification of areas with insufficient hospital coverage.

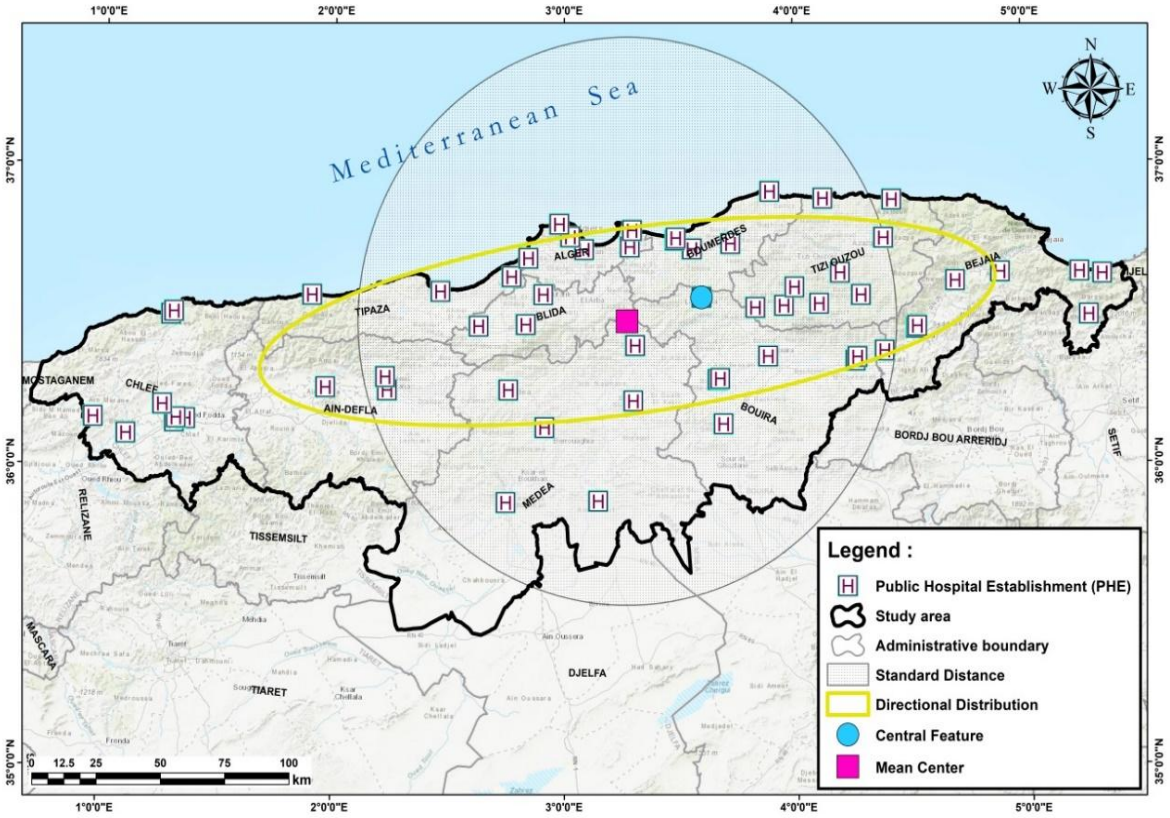

Fig. 4. Distribution of **Public Hospital Establishments (EPH)** in **north-central region.**

Analysis of the Distribution of EPH Healthcare Infrastructure

The Nearest Neighbor Index (NNI) is a statistical measure used to evaluate the spatial distribution of points within a given region (Mathian H et al., 2014). In health geography, this index is used to examine the distribution of healthcare infrastructure (hospitals, clinics) in order to identify spatial clustering or underserved areas.

The Nearest Neighbor Index (NNI) is calculated by comparing the observed average distance between each healthcare facility (EPH) and its closest neighboring facility with the expected average distance that would occur under a random spatial distribution of the same number of points within the study area. Formally, the index is defined as follows:

$$NNI = \frac{D_{\text{obs}}}{D_{\text{exp}}} = \frac{\sum_{i=1}^{n} d_i/n}{0.5/\sqrt{n/A}}$$

where d_i is the distance between a point and its nearest neighbor, n is the number of points, and A is the area under study.

The geostatistical analyses, particularly the Nearest Neighbor Index (NNI) applied at the scale of the wilayas, revealed significant disparities in the spatial distribution patterns ofhospitals. These results highlight inconsistencies in the territorial allocation of healthcare infrastructure, especially in terms of the distances between facilities and their distribution density. Such findings underscore unequal spatial planning and raise critical questions about the efficiency and equity of healthcare service accessibility within the studied region.

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The spatial distribution of university and specialized hospitals (HUC and HSE) within the North-Central region reveals a significant concentration in the capital and certain coastal wilayas. The average inter-hospital distance was estimated at 15.2 km (Fig. 5), reflecting a strong spatial clustering (NNratio = 0.37, *p-value* ≈ 0), which confirms statistically significant aggregation patterns. This pronouced centralization around principal urban centers raises concerns about the existence of medical deserts in peripheral and rural areas, where access to specialized health services may be significantly limited.

In contrast the (PHE) exhibit a more dispersed spatial pattern, with an average inter-facility distance of 11.5 km (Fig. 6). This finding is consistent with their intended role as local health service providers, ensuring territorial continuity of care**.**

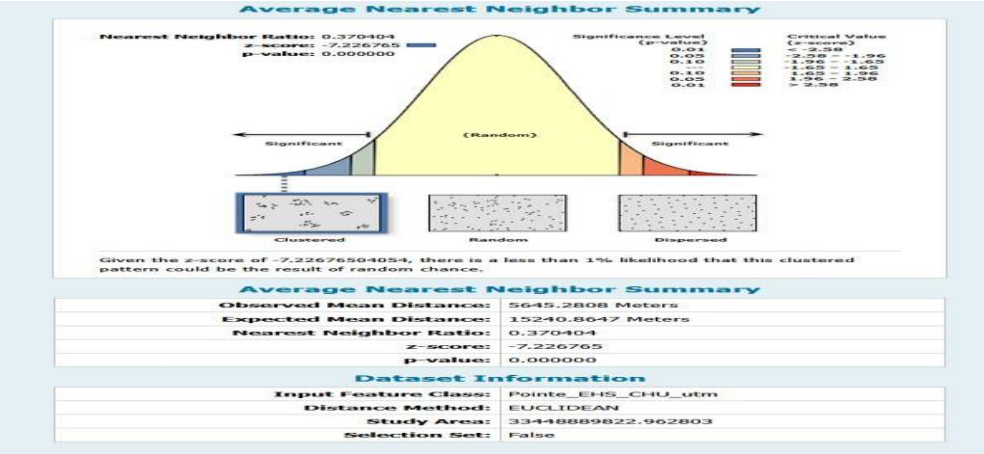

Fig 5: Nearest Neighbor Index – Distribution of University and Specialized Hospitals (HUC and HSE) in the North-Central Region

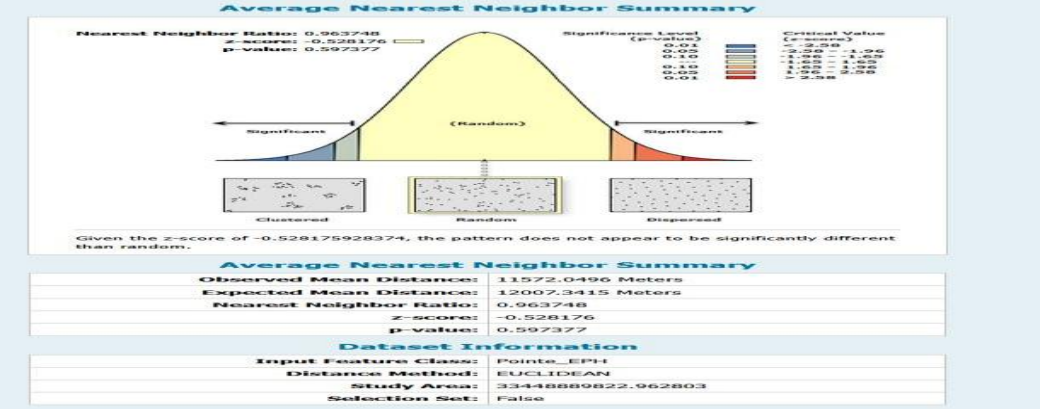

Figure 6: Nearest Neighbor Index – Distribution of Public Hospital Establishments (EPH)**in** north-central region.

The results reveal a significant imbalance in the spatial distribution of hospital infrastructure, characterized by a high concentration of facilities in urban centers and a marked dispersion in certain rural areas. To better identify and illustrate these spatial disparities, two complementary analytical methods were employed: the Buffer method and the Allocation method**.**

The Buffer method is widely used in regional and spatial health planning as it enables the creation of zones of spatial influence around healthcare facilities, thereby facilitating the assessment of geographic

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accessibility (Guagliardo, 2004; Kang and Cho, 2012; Tanser et al., 2006; Shi and Wang, 2017). By delineating service catchment areas around hospitals, this approach allows for the identification of well-served zones and areas with insufficient hospital coverage. Thus, it serves as a critical tool in evaluating territorial health inequalities and in informing public policy strategies aimed at improving the spatial equity and efficiency of hospital service provision.

In this study, a buffer radius of 11.5 km was defined, based on the results of the Nearest Neighbor Index (NNI), to represent an average threshold of spatial accessibility to hospital care within the study region (Fig. 06).

Despite the lack of universally established standards regarding the optimal distance between patients and the nearest hospital, studies suggested a range of 25–35 km as a critical threshold (Jordan et al., 2004, cited by Teodora E. U., 2016). In the context of the absence of international norms, we employed the Buffer method, setting a radius of 11.5 km around each hospital based on Nearest Neighbor Analysis results.

However, travel time for the same distance varies significantly due to disparities in transport accessibility, which is primarily influenced by effective travel speed itself dependent on road conditions, service levels, and infrastructural characteristics (Appert and Chapelon, 2003; Chapelon, 2006; Hilal, 2004, cited by Bakor et al., 2018). To ensure methodological rigor, we applied theoretical speed limits, also known as free-flow speeds, based on Algerian road regulations. These standards specify a speed limit of 80 km/h for national roads and 60 km/h for regional (wilaya) roads. Field observations were undertaken to enhance the accuracy of initial estimates, highlighting notable spatial disparities in average travel speeds across various territorial settings. In the mountainous regions of the northern wilayas, difficult topography combined with infrastructural constraints limits average speeds to between 20 and 30 km/h, resulting in travel times of approximately 23 to 34.5 minutes for a distance of 11.5 km. Conversely, rural areas in the southern wilayas are characterized by relatively flat terrain, which facilitates higher average speeds ranging from 30 to 40 km/h. As a result, the same distance can be traversed in roughly 17.25 to 23 minutes. These results emphasize the substantial impact of physical and infrastructural factors on mobility and accessibility core elements in regional planning and the equitable distribution of public services.(Fig. 8**)** reveals that 59 communes fall outside the defined healthcare coverage area (11.5 km buffer), representing 13.37% of the total number of municipalities in the region and 27.72% of the region's total surface area. The population without hospital coverage in these communes is estimated at 1272670 inhabitants**,** accounting for 9.58 % of the total population of this region. While these results suggest an overall satisfactory level of coverage, a disaggregated analysis at the wilaya level uncovers marked and evident spatial disparities**:**

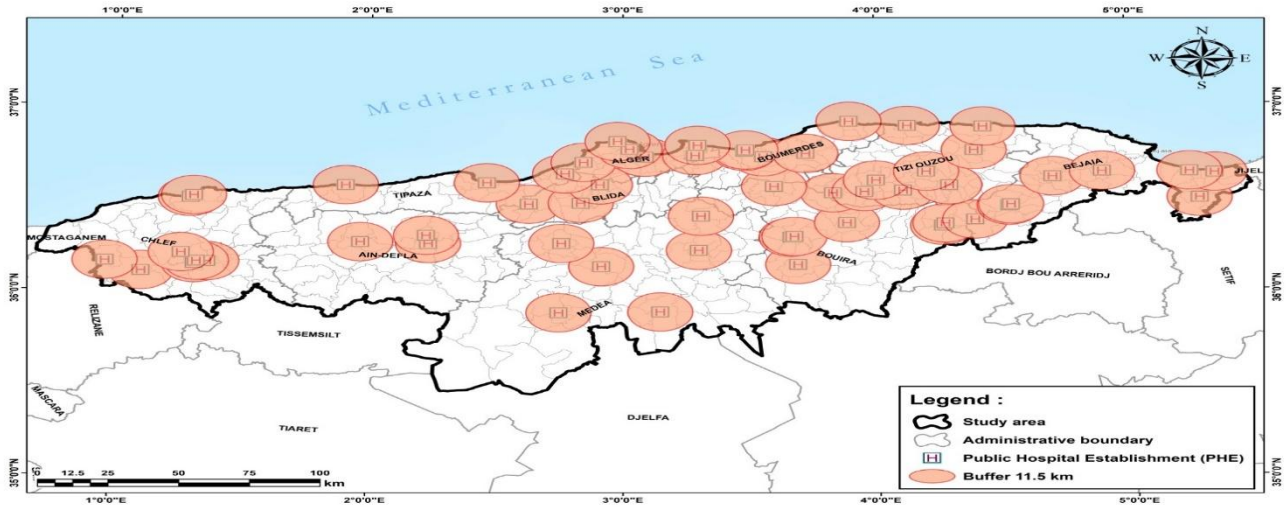

Fig. 7. Attractive areas of **Public Hospital Establishments (EPH)**in the **area north-central region.**

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Indeed, the wilaya of Ain Defla records the highest proportion of its population traveling more than 11.5 km (23 to 34.5 minutes) to reach the nearest hospital, with 361,219 inhabitants, representing 36.61% of the wilaya's total population and 28,38 % of the population without healthcare coverage in the region, spread across 17 municipalities. It should be noted that all these municipalities are rural, located in mountainous and rugged areas, with many rural roads that are not paved and become impassable in winter, which further increases the difficulty for the population to access healthcare services.

In second place is the Wilaya of Médéa, with a total population of 151,995 citizens, representing 15,96 % of the wilaya's population and 11.94% of the region's population without healthcare coverage, spread across 12 municipalities. The northern municipalities are characterized by difficult terrain and severe climate, which extends the travel time to more than 34.5 minutes, especially in winter, thus worsening the difficulties faced by the population in reaching hospitals for medical care. In contrast, the southern municipalities are situated in the steppe zones, characterized by low development levels and large territorial areas, which increases the travel time to more than 23 minutes. Additionally, the low population density further complicates the efforts of local authorities to provide adequate healthcare coverage.

In third place, the wilaya of Chlef has a population of 247,616 inhabitants who are not covered, representing 19.14% of the wilaya's population and 19,45 % of the inhabitants of the territory not covered by EPH health services. These people are distribuated across 11 municipalities, which are mostly semi-urban with an agricultural focus. These municipalities aredeficient in essential urban infrastructure, forcing a large part of the population to travel more than 11.5 km to reach the nearest hospital, often under difficult conditions due to the lack of public transportation, the poor road network, and specific characteristics related to the agricultural nature of the region. As a result, the travel time to access healthcare exceeds 23 minutes.

In fourth place, the wilaya of Bouira records 75,661 inhabitants without adequate healthcare coverage, which accounts for 8.86% of the total population of the wilaya and 5, 94 % of the total underserved population in the region. These residents are distributed across eight municipalities, primarily located in the southern part of the wilaya, characterized by steppe landscapes. These municipalities classified as rural or semi-urban and are deficient in essential urban infrastructure, which significantly restrict access to healthcare services. Consequently, the affected populations are compelled to travel distances exceeding 11.5 km, with average travel times ranging from 17.25 to 23 minutes to reach the nearest hospital. This challenge is exacerbated by the insufficient availability of public transportation and the deteriorated state of road infrastructure.

In the northern part of the wilaya, the affected municipalities are situated in mountainous and forested zones, marked by steep gradients that present serious geographical barriers, especially during winter when heavy snowfall occurs. These environmental constraints, combined with the poor condition of road networks and a lack of collective transport services, severely hinder patient access to hospital care.

The wilaya of Tipaza, which is ranked fifth, has a total population of 99,545. Among these, 13.33% live in areas not covered by public health services (EPH), representing 7.82% of the total population that is not served by these infrastructures within the region. This population is spread over five communes, mostly semi-urban and agricultural, which suffer from a lack of basic urban infrastructure. As a result, a significant proportion of the population has to travel more than 11.5 km to reach the nearest hospital. This journey is all the more penalizing because of the difficulties of public transport, the inadequate road network and the specific characteristics linked to the predominant agricultural activity in the region. This lack of accessibility considerably lengthens journey times, with an average access time of over 23 minutes.

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e-ISSN: 2468-4376
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Despite the wilaya's geographical proximity to the capital, where health services are generally more developed, the level of health infrastructure in the region remains inadequate. This situation raises the question of the wilaya's strategic role in the process of decongesting the capital, particularly through the development of healthcare facilities tailored to local needs. The establishment of such facilities could not only improve the wilaya's health attractiveness, but also help to reduce the influx of patients to the capital for medical treatment. This phenomenon highlights the need for a regional planning policy designed to rebalance healthcare provision throughout the region, while taking into account the specific socio-economic and geographical features of the wilaya. It is important to note that these wilayas benefit from a good level of health coverage, despite geographical conditions similar to those of the previously mentioned wilayas. This situation raises the question of territorial equity and the fair distribution of resources and development tools among all populations. This is a major challenge for the State in the concrete implementation of the principle of social justice on a territorial scale.

In contrast, the wilayas of Algiers (the capital) provides full health coverage for its entire population, with all residents travelling less than 11.5 km to reach the nearest hospital. This reflects a good level of health provision in the capital region and its surrounding area. In urbanized areas such as the capital and its periphery, extended travel times are mainly attributed to traffic congestion. Unlike remote territories where access is hindered by topographical constraints or infrastructural deficiencies, in these highly urbanized settings, it is the saturation of the road network that limits accessibility more than natural conditions or the availability of transportation.

This analysis underscores the need for an integrated territorial planning approach that takes into account topographic, demographic, and socio-economic specificities to optimize the spatial distribution of healthcare infrastructure. Improving road networks, expanding urban infrastructure in rural and semi-urban zones, and accounting for climatic and geographic constraints are key strategies for reducing inequalities in healthcare access and ensuring equitable service coverage across the region.

The present study reveals significant regional disparities in healthcare coverage among the studied wilayas. Geographic factors such as rugged terrain and harsh climates, along with demographic characteristics like low population density and rurality, shape disparities in healthcare access. Urban-oriented wilayas like Algiers, Blida and Boumerdès demonstrated near-complete coverage, whereas rural and mountainous wilayas such as Chlef, Bouira, and AïnDefla showed marked deficits due to inadequate infrastructure and transport. It should also be noted that, despite the difficult geographical conditions of the Tizi Ouzou and Béjaïa wilayas, the quality of healthcare there remains satisfactory. This reflects the considerable efforts that have been made in these areas, illustrating a proactive public policy of planning and reducing regional disparities. Addressing these disparities requires the implementation of integrated territorial planning policies focused on the development of road and public transport networks and the equitable distribution of healthcare infrastructure, all while considering the region's climatic and geographical challenges. To further identify well-served and underserved areas in terms of hospital infrastructure, we apply the allocation method (Fig. 8), which plays a crucial role in optimizing the assignment of populations to healthcare facilities based on both geographic proximity and available capacity. This spatial modeling approach facilitates the identification of both adequately equipped territories and those suffering from service deficits, thereby contributing to fair and effective access to care for the entire population.

Table 3. Allocation and Service Coverage of Public Hospital Establishments (PHE) in the Wilaya of Médéa

PHE	Allocated Area (km²)	Population Served	Number of Beds	Beds per 1,000 Inhabitants
Médéa	851.31	92,930	580	6.24

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e-ISSN: 2468-4376
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Tablat	959.50	104,778	101	0.96
Béni Slimane	1,025.93	112,032	192	1.71
Aïn Boussif	1,573.68	171,846	121	0.70
Ksar El Boukhari	3,411.51	372,528	204	0.54
Berrouaguia	894.89	97,723	194	1.98
Total	8,716	951,837	1,392	1.46

Source**:** MSPRH, ONS, and authors' calculations.

To assess the current situation in the study area, we employed Geographic Information Systems Arc (GIS) to analyze the spatial influence zones of each hospital. (Map. 5) reveals pronounced disparities between wilayas, particularly in terms of the number of hospitals per administrative unit and the territorial extent of each wilaya. The Wilaya of Médéa was selected as a case study to illustrate these spatial imbalances in a concrete and localized manner.

Médéa, the largest wilaya within the study area, covers an area of approximately 8716 km**²** and accomodates951,837 inhabitants, yielding an average population density of 109.2 inhabitants per square kilometer. The wilaya is served by six hospitals with a combined capacity of 1,392 beds**,** which corresponds to an overall hospital bed ratio of 1.46 beds per 1,000 inhabitants**.** However, a detailed spatial and demographic analysis reveals substantial inequalities in the level of healthcare coverage provided by each facility.

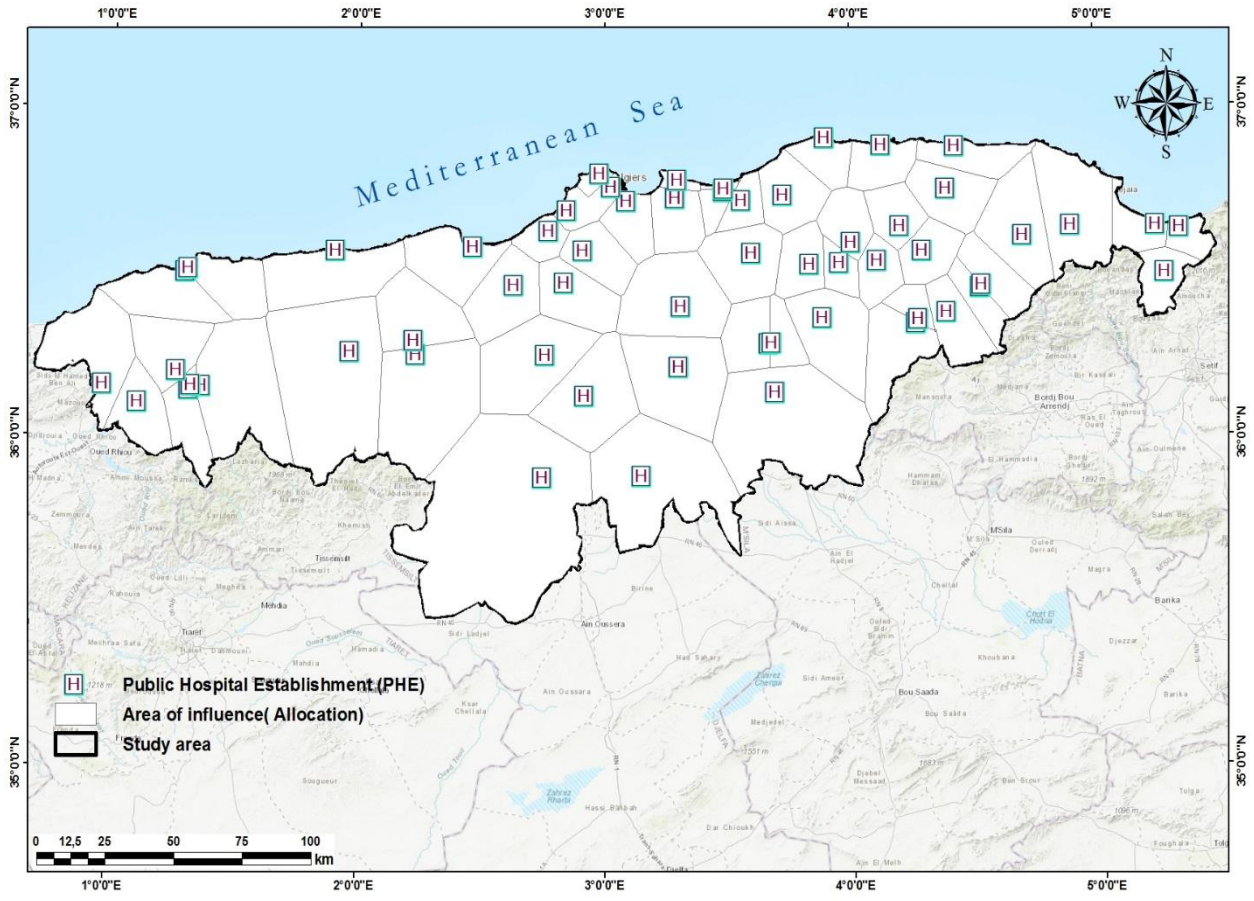

Fig 8. Allocation areas of Public Hospital Establishments (EPH)in th**e** area north-central region.

Journal of Information Systems Engineering and Management
2025, 10(4)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

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Conclusion

This study revealed persistent and significant territorial disparities in the distribution of public hospital infrastructure within the North-Central region of Algeria, despite ongoing efforts by the national government to enhance healthcare provision and promote spatial equity in service delivery. As one of the country's most economically dynamic regions largely due to the presence of the political and economic capital it benefits from a relatively high level of development and considerable natural and economic potential. However, this has not translated into equitable access to healthcare services across all territories within the region.

Using spatial analysis methods such as 11.5 km buffer zones, kernel density estimation, hospital service allocation, and doctors/1000 inhabitants, this study highlights significant discrepancies in both geographic and demographic coverage. More than 800,000 individuals reside beyond the 11.5 km threshold from the nearest hospital, often in areas with challenging geographic and infrastructural conditions. Some hospitals are required to serve territories exceeding 3,400 km² and populations of more than 370,000 inhabitants, with as few as 0.54 doctors/1000 inhabitants. These statistics underscore the systemic weaknesses in healthcare accessibility and reveal the spatial inefficiencies in current infrastructure planning.

The variation in healthcare service quality and accessibility across the study area is influenced by a combination of administrative centrality, population density, topography, and settlement patterns. A clear east-to-west gradient emerges, wherein the number of hospitals decreases progressively, leading to broader hospital service zones, increased travel distances, and higher population loads per facility. These conditions have resulted in overburdened public hospitals, longer wait times, and reduced quality of care, especially in rural, mountainous, and steppe-oriented regions located in the northwest and south-central zones of the region. Conversely, wilaya capital sand urban centers benefit from their administrative status, which facilitates better access to healthcare services due to higher infrastructure investment and service concentration. These core areas benefit from enhanced spatial and functional coverage, in contrast to the marginalization of peripheral territories.

In conclusion, the study calls for a recalibration of healthcare infrastructure planning and investment, grounded in principles of territorial equity, population needs, and geographic justice. The integration of spatial analytics into the formulation of national health policy can help mitigate regional disparities, improve accessibility for underserved populations, and support more balanced regional development to ensure healthy lives and promote well-being for all.

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Annexes

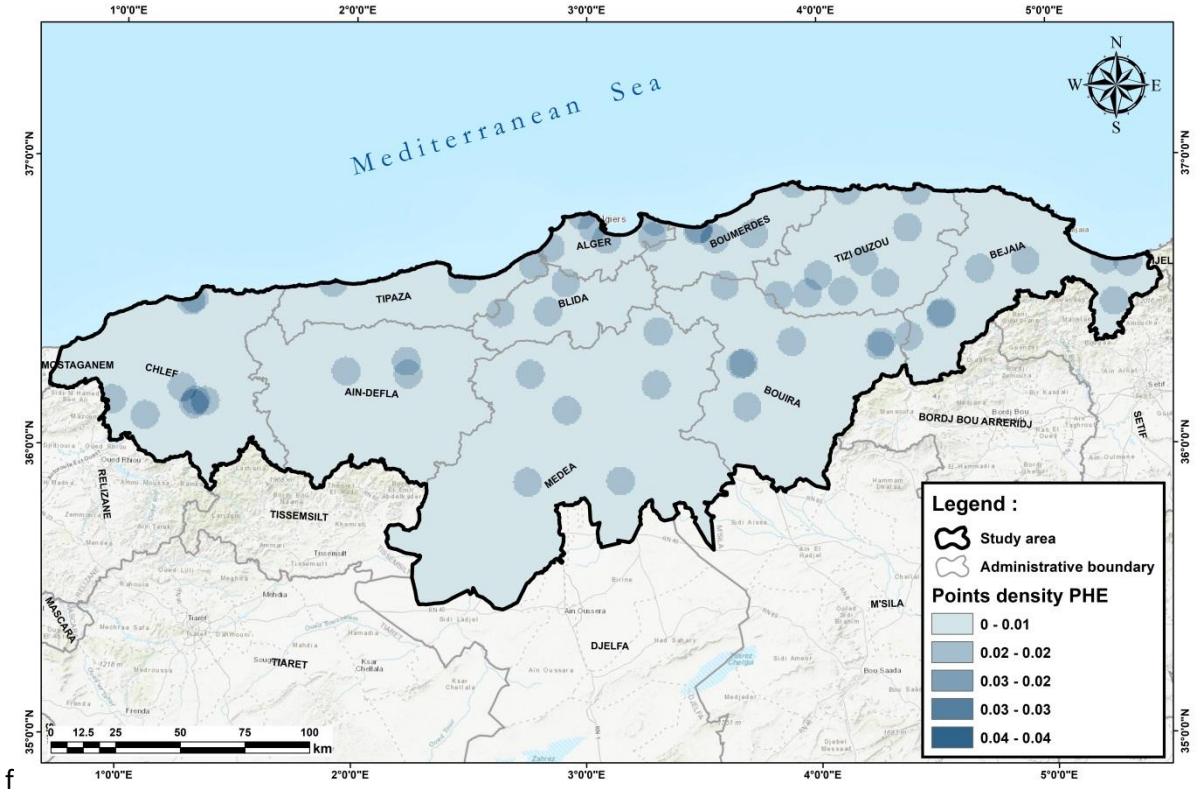

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Fig. 1. Density of public health facilities (PHE) in the north-central region.