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GIS analiza dostopnosti in opremljenosti prostora ob tramvajski progi v mestu Oran (Alžirija)

Spatial Accessibility and Service Coverage of the Oran Tramway (Algeria): A GIS-Based Analysis

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UDK: 711.4:004.65GIS:624.21.095.325(65)
Klasifikacija prispevka po COBISS.SI: 1.01
Prispelo: 18. 2. 2026
Sprejeto: 12. 6. 2026

DOI: 10.15292/geodetski-vestnik.2026.03.437-459
SCIENTIFIC ARTICLE
Received: 18. 2. 2026
Accepted: 12. 6. 2026

IZVLEČEK

Študija ocenjuje prostorsko učinkovitost tramvajske proge v mestu Oran z uporabo GIS pristopa, ki vključuje analizo storitvenih funkcij, vpetost v prometni sistem, gostoto prebivalcev in dostopnost javnih objektov. Za identifikacijo dobro in premalo oskrbovanih območij v 2 kilometra dolgem koridorju vzdolž tramvajske proge je bila uporabljena analiza prometnega omrežja, interpolacija z inverznim uteževanjem razdalj (IDW), ocena gostote jeder in Ripleyjeva K-funkcija. Rezultati kažejo, da je 57 % preučevanega območja na oddaljenosti 750 metrov od tramvajskih postajališč, medtem ko je 25 % območja več kot 1000 metrov oddaljeno od tramvajskih postajališč, ki so obenem nezadostno opremljena z javnimi in storitvenimi funkcijami. Najboljšo pokritost imajo osrednje gosto naseljene soseske, s povprečno gostoto 101,32 prebivalca na 100 m², v oddaljenosti do 300 metrov od postajališč, v katerih je tudi približno 28 % javnih objektov, zlasti športnih, izobraževalnih in kulturnih, medtem ko so zdravstvene in upravne storitve premalo zastopane. Zmerno koncentracijo javnih objektov okrog tramvajskih postajališč potrjuje tudi Ripleyjeva K-funkcija. Ugotovitve poudarjajo potrebo po bolj uravnoteženem multimodalnem načrtovanju, zlasti na nezadostno oskrbovanih obrobnih območjih, s čimer bi izboljšali učinkovitost prometnega sistema in zagotovili uravnotežen prostorski razvoj.

ABSTRACT

This study assesses the spatial efficiency of the Oran tramway using an integrated GIS-based approach combining service area analysis, network accessibility, population density, and public facility distribution. Network analysis, Inverse Distance Weighted (IDW) interpolation, Kernel Density Estimation, and Ripley's K-function were applied to identify well-served and underserved areas within a 2 km corridor along the tramway line. Results show that 57% of the study area lies within 750 m of tramway stops, while 25% is located beyond 1,000 m and is relatively underserved. Central and densely populated neighbourhoods have the best coverage, with an average population density of 101.32 inhabitants per 100 m² within 300 m of stops. About 28% of public facilities are located in areas with very high service coverage (<300 m), particularly sports, educational, and cultural facilities, whereas healthcare and administrative services are underrepresented. Ripley's K-function confirms significant clustering of public facilities around tramway stops. The findings highlight the need for more equitable multimodal planning, particularly in peripheral underserved areas, to improve spatial justice and system performance.

KLJUČNE BESEDE

dostopnost s tramvajem, mesto Oran, načrtovanje urbane mobilnosti, uravnotežen prostorski razvoj, opremljenost z javnimi funkcijami

KEY WORDS

Tramway accessibility, Oran city, Urban mobility planning, Spatial equity, Public facility coverage

1 Introduction

As urban populations continue to grow, public transportation systems have become a critical factor in promoting sustainable development, social equity, and economic efficiency (Collins et al., 2023); (Prus & Sikora, 2021); (Toledano et al., 2025). According to (Alamri et al., 2023), public transportation plays a significant role in cities by enabling the efficient and cost-effective movement of people. Urban transport systems are expected not only to meet mobility needs but also to enhance access to essential services, reduce dependence on private vehicles, and minimize environmental degradation (Hluško et al., 2024); (Li et al., 2024); (Yadav et al., 2024). In this context, tramway networks have emerged as increasingly popular solutions, offering a balance between capacity, environmental performance, and integration into urban landscapes (Méndez-Manjón & Plasencia-Lozano, 2025); (Moroń et al., 2024).

Recent studies reveal that resident's satisfaction with their living conditions is closely linked to the quality of transportation within their region (Połom & Wiśniewski, 2021). For this reason, among others, Algeria has launched ambitious transport infrastructure projects in recent years, with tramways forming a cornerstone of its urban mobility strategy. Among these projects, the Oran tramway network, serving Algeria's second-largest city, represents a major investment aimed at modernizing transportation, alleviating traffic congestion, and enhancing the urban experience for residents.

Operational since 2013, the Oran tramway was designed to connect peripheral neighborhoods with the city center and to facilitate access to major public institutions such as universities, hospitals, and administrative services (Boudjeriou & Kebiche, 2024). However, more than a decade after its inauguration, few in-depth studies (Rebouha, 2017) have evaluated whether the tramway system has effectively achieved these goals in both spatial and demographic terms.

Assessing tramway performance requires an analysis that goes beyond operational indicators such as ridership and service frequency. A key dimension of effectiveness lies in how well the network serves densely populated areas and whether it provides equitable access to public services and urban opportunities (Amorim et al., 2025)leading to different evaluation perspectives. Thus, our central objective in this work is to explore the scientific production around these two concepts through the lens of transportation, focusing on their connections and interpretations. A mixed-approach analysis (network analysis and semi-systematic review; (Din et al., 2022). In other words, spatial justice in public transportation must be considered alongside system efficiency. Accessibility, broadly defined as the ease with which individuals can reach desired destinations, is thus a central criterion for evaluating the social performance of urban transport systems (Abdelhalim, 2022); (Huguenin-Richard & Cloutier, 2021); (Jamei et al., 2022); (Levinson & Wu, 2020).

While a substantial body of research has examined public transport systems using GIS-based approaches, most studies focus either on overall network performance or on a single dimension of analysis, such as accessibility (Buczek et al., 2018); (Domènech & Gutiérrez, 2017); (Droj et al., 2021); (Biswas et al., 2020); (Soldatke et al., 2024); (Talpur et al., 2024). However, fewer studies adopt an integrated spatial approach that simultaneously combines network-based accessibility, service coverage, population distribution, and the spatial distribution of urban facilities within a unified analytical framework. For instance, (Méndez-Manjón & Plasencia-Lozano, 2025) employed GIS to investigate the influence of tramway networks on urban development in four Spanish cities: Barcelona, Madrid, La Coruña, and Oviedo. Their findings indicate that tramway lines often stimulated significant urban growth, particularly within 250 meters of the lines, especially during the first five years following implementation. Similarly, (Yang et al., 2025) analyzed the impact of tram stop accessibility and proximity on housing prices in Chengdu, the capital of Sichuan Province, China. Their results show that property prices within 800 meters of tram stops are, on average, 1.4% higher than those located farther away. In another vein, (Tubis et al., 2023) examined whether tram stop accessibility standards meet the needs of individuals with disabilities, using Polish cities as a case study. Their research found that numerous barriers hinder implementation, and that people with disabilities continue to face significant challenges in using tramway services comfortably. This issue was also addressed in Melbourne by (Lope & Dolgun, 2020), who highlighted similar accessibility concerns.

The present study proposes an integrated GIS-based framework to evaluate the effectiveness of the Oran tramway in terms of accessibility of tramway stops and spatial coverage. Specifically, it aims to assess whether the tramway adequately serves densely populated areas and facilitates access to key public facilities such as schools, hospitals, and administrative centers. To this end, the research employs a combination of complementary spatial analysis techniques, including service area modeling, Urban Network Analysis (UNA), Kernel density estimation, and Ripley's K function within a unified analytical framework. This approach enables a detailed analysis of spatial mismatches between transportation infrastructure and urban needs and provides a transferable methodological framework that may be applied to other rapidly growing cities facing similar mobility and accessibility challenges.

2 Materials and methods

2.1 Description of the study area

Located in western Algeria, the city of Oran lies between longitudes -0.54° and -0.71° W and latitudes 35.34° and 35.76° N (Figure 1). The region has a generally gentle topography, with 77% of its area exhibiting a slope of less than 4%. Over the past decades, Oran has undergone rapid urban expansion and demographic growth. Its built-up area increased from 39.64 km^2 in 1984 to 110.57 km^2 in 2020, while the population grew from 344,172 inhabitants in 1966 to 1,370,259 in 2018. This expansion was accompanied by a substantial increase in housing units, rising from 42,564 in 1966 to 309,945 in 2008.

Initiated in 2008 and opened to the public in May 2013, the Oran tramway was introduced to address the growing mobility challenges in Algeria's second-largest city. Before its implementation, Oran's urban transport relied heavily on road-based modes, including private cars, taxis, and minibuses, which contributed to severe traffic congestion. The tramway, spanning 18.7 km with 32 stops along a single line from the Sidi Maârouf depot to the Es Sénia depot, was designed to connect peripheral neighborhoods with the city center and improve access to major public facilities such as universities, hospitals, and administrative services. It consists of 30 trains operating at 4 to 8-minute intervals during peak hours. According to (Khelf, 2023), it was designed to carry approximately 90,000 passengers per day, equivalent to nearly 88 million passengers annually. However, the actual average daily ridership is estimated at only 35,813 passengers (Boudjeriou & Kebiche, 2024); (Kaddouri et al., 2024).

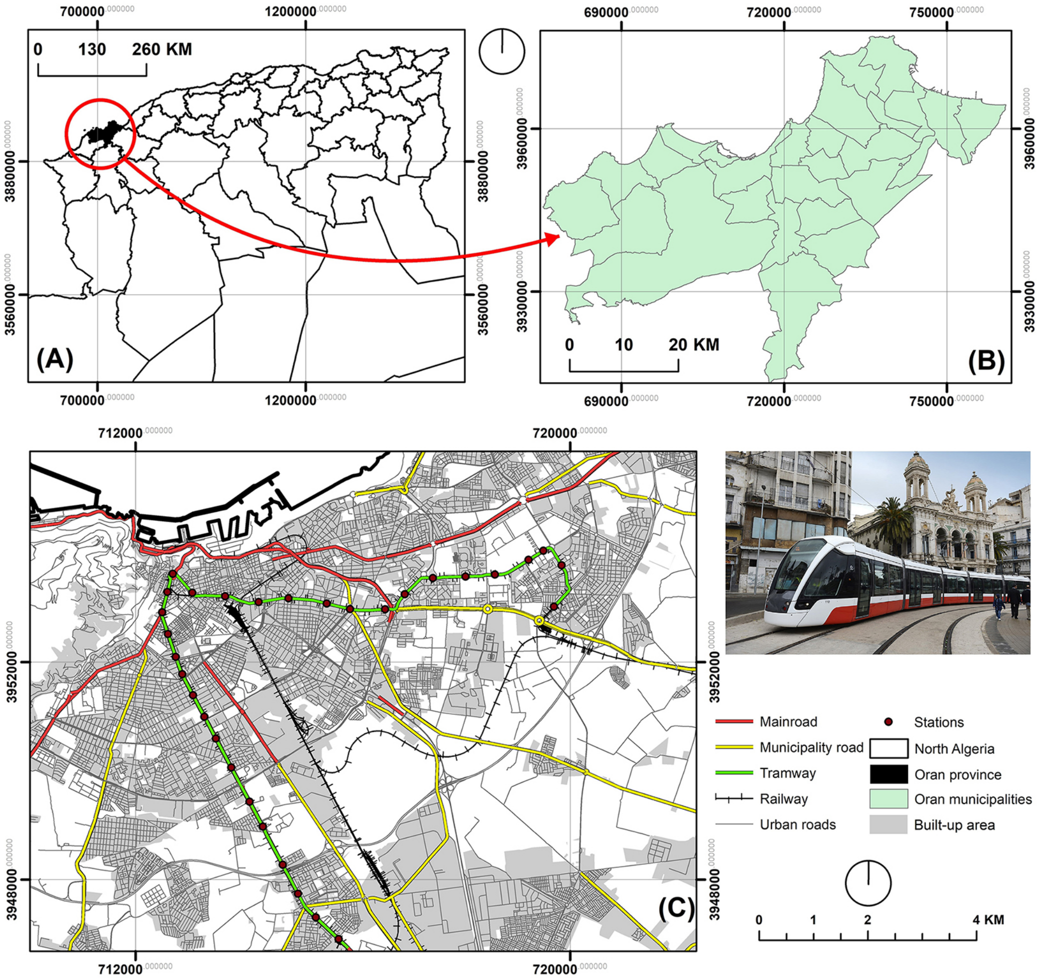

Figure 1: Study area (A) North Algeria, (B) Province of Oran, and (C) City of Oran

The Oran tramway demonstrates strong strategic integration with the existing public transport system. According to (Boudjeriou & Kebiche, 2024), a bus terminal located in Hai Essabah, about 500 meters from the tramway, serves 14 inter-provincial lines, 5 urban lines, and 5 suburban lines. A nearby railway station at Plateau, just 200 meters from the tramway, connects to 10 main lines, 52 regional lines, and 8 suburban lines. Additionally, two taxi hubs are located close to the tramway: Djamel Eddine (500 m), serving 8 inter-provincial lines, and USTO (200 m), serving 24 lines. Moreover, 18 tramway stops are located within 20 to 100 meters of nearby bus stops.

2.2 Data Sources

The primary objective of this study is to assess the efficiency of the Oran tramway, both in terms of its spatial coverage and its integration within the urban fabric, as well as its accessibility to the populations it serves. To this end, a rigorous methodological approach was adopted, relying on the collection, processing, and analysis of various geospatial and demographic data sources.

Before presenting the detailed data sources, it is important to clarify the spatial extent of the analysis. This study does not cover the entire city of Oran. The analysis focuses on a 1-kilometer buffer zone on each side of the tramway line, resulting in a total corridor width of 2 kilometers. This perimeter corresponds approximately to a 10-minute walking distance and is based on previous studies that consider such a distance representative of the direct urban influence of a major public transport corridor (L'Hostis, 2016); (Stambouli, 2005). However, as noted by (Pan et al., 2011), there is no universally accepted distance threshold to define the service radius of a transit line, as this varies depending on urban density, land use mix, and spatial configuration (Chorus & Bertolini, 2016).

Initially, data related to the road network, the tramway route, stops locations, and public facilities (e.g., schools, hospitals, administrative buildings) were collected, corrected, and integrated into a Geographic Information System (GIS). This enabled the development of a suite of spatial, geostatistical, and network analyses. These analyses were designed to improve the understanding of the spatial distribution of transit services, user accessibility, and the interactions between the tramway network and other urban infrastructure systems. For demographic data, we employed the Google Earth Engine platform to access population density information from the WorldPop Global Project Population Data. These raster datasets, available at a spatial resolution of 92.77 meters, offer a refined and up-to-date estimation of population distribution. In the absence of official data from the most recent national census (2022), these raster data serve as a credible alternative. According to several studies, population density is a critical factor in transport planning and user interaction (Aljoufie, 2021); (Aljoufie et al., 2013); (Zhang & Guindon, 2006).

Regarding the urban road network and public facilities, data were obtained freely in Shapefile format from the official OpenStreetMap website (https://www.openstreetmap.org), under the Open Database License (ODbL). These open-source datasets provide a sufficiently detailed representation of the urban road network to support service area delineation, accessibility modelling, and spatial analysis of public facilities at the city scale. However, despite its overall reliability, the data are not entirely error-free. Nevertheless, studies indicate that both absolute and relative error rates have been decreasing over time (SinghSehra et al., 2013); (Wang et al., 2013); (Borkowska & Pokonieczny, 2022). As for the Oran Tramway route and its 32 stops, we performed a precise digitalization based on data from the official operating company (SETRAM Oran). This allowed for an accurate reconstruction of the actual tramway alignment, which is essential for service area, accessibility, and connectivity analyses.

To ensure the integrity and consistency of all integrated datasets, a thorough verification process was undertaken. All spatial data were georeferenced using the UTM WGS84 Zone 30N, thereby ensuring spatial compatibility. In addition, a typological control was conducted to identify and eliminate redundancies, standardize entity types, and correct any geometric or semantic inconsistencies. A detailed summary of all datasets used, including their sources, formats, and technical characteristics, is presented in Table 1.

Table 1: Data used in the study

Input Data	Type of Data	Time of Generation	Source of Data	Analysis Type	Output Resolution (m)
Urban network (roads)	Vector	2024	OpenStreetMap	Network analyst service area, UNA Closeness	30
Public facilities	Vector	2024	OpenStreetMap	Spatial analysis Kernel Density	30
Tramway stops	Vector	2025	SETRAM Oran	Inverse Distance Weighted (IDW), Network analyst service area	30
Population density	Raster	2022	WorldPop Global Project Population Data	/	92
Tramway line	Vector	2025	SETRAM Oran	/	/

2.3 Data Processing

Figure 2 illustrates the methodology adopted to assess the performance of the Oran tramway system. This approach is structured into three main stages.

2.3.1 Service area analysis

The first stage involved the creation of a Network Dataset from the urban road network using ArcGIS Network Analyst. Once generated, this network dataset enabled the calculation of service areas around each tramway stop. These service areas represent the actual walking catchment zones accessible to pedestrians and constitute a fundamental step in evaluating which parts of the city are effectively served by the tramway. Based on the study conducted by (Rosset, 2013), the following impedance thresholds were adopted: less than 300 meters, 500 meters, 750 meters, 1,000 meters, and greater than 1,000 meters. These distances correspond approximately to 4, 7, 10, and 14 minutes of walking time, respectively.

2.3.2 Network accessibility analysis

The integration of accessibility measures into transport planning has become a key priority (Negm et al., 2025). In this context, the second stage focuses on evaluating the accessibility of tramway stops for residents, defined as the ease with which different locations in the city can reach the nearest tramway stop through the urban street network. This analysis was conducted using the Urban Network Analysis (UNA) tool, specifically the Closeness centrality metric. In this study, tramway stops were considered as destination nodes, while the surrounding urban space was represented through the street network. The Closeness metric measures accessibility by calculating the inverse of the total shortest-path distances between each location in the network and all tramway stops. Higher closeness values indicate areas where residents can reach multiple stops through shorter and more direct paths, reflecting better accessibility of tramway stops. Conversely, lower values correspond to areas where access to tramway stops requires longer or less efficient routes within the network. According to (Sevtsuk et al., 2013), the Closeness metric is defined by Equation 1:

$$C[i]=\frac{1}{\sum_{j\in V(G)-\{i\},d[i,j]\leq r}(d[i,j].W[J]} \tag{1}$$

$C[i]$ denotes the closeness centrality, $d[i,j]$ represents the shortest path between nodes i and j, $W[J]$ is the weight associated with each destination j.

However, to achieve a more continuous and meaningful interpretation of the results across the study area, it was necessary to convert the accessibility values into a raster surface. For this purpose, an interpolation was performed using the geostatistical method known as Inverse Distance Weighting (IDW), which enables the generation of a smoothed surface reflecting the spatial distribution of accessibility. The most commonly used interpolation techniques include Inverse Distance Weighting (IDW), Gaussian kriging, spherical kriging, and cokriging (ESRI, 2026). However, several studies have shown that no single interpolation method demonstrates universal superiority over others (Gong et al., 2014), as the optimal approach depends on the specific characteristics of the phenomenon being analyzed. In this study, IDW interpolation was selected to generate a continuous accessibility surface from UNA closeness values. The method assumes that nearby observations exert a greater influence on predicted values than distant observations, which is appropriate for urban accessibility patterns where spatial influence decreases with distance.

According to (Benmoshe, 2025) the IDW interpolation is defined by Equation 2:

$$V(x)=\frac{\sum_{j=1}^{N}w_{j,idw}(x)\,v_j}{\sum_{j=1}^{N}w_{j,idw}(x)} \tag{2}$$

Where $V(x)$ is the interpolated value at point x, and v_j is the value of measurement j. The weight (w) that is given to each point can be calculated as follows:

$$w_{j,idw}(x)=\frac{1}{d(x,x_j)^p} \tag{3}$$

Where d is the distance between the interpolated point and the measurement point, and p is the power variable that affects the weight of nearby measurements.

2.3.3 Public facilities distribution and spatial clustering

The third stage aimed to assess the performance of the tramway in relation to the spatial distribution of public facilities. A Kernel density analysis was first conducted to map the concentration of public facilities across the study area. The resulting density surface was then overlaid with the tramway service area maps produced in the first stage. This combined approach allowed us to evaluate not only the spatial distribution of facilities, but also their level of accessibility relative to the tramway network. In this context, the service areas represent the actual pedestrian catchment zones around tramway stops, defined by the selected walking distance thresholds (300 m, 500 m, 750 m, and 1,000 m).

Upon completing this step, it becomes essential to analyze the spatial distribution of public facilities (whether dispersed or clustered) along the tramway route. For this purpose, Multi-Distance Spatial Cluster Analysis (Ripley's K Function) was employed. According to (Abdelhalim, 2022), Ripley's K function enables the extraction of additional insights for exploring the spatial structure of data across a range of distances. The Multi-Distance Spatial Cluster Analysis tool relies on a commonly used transformation of the K function, in which the observed results are compared to a random distribution of points over the specified distances. The K function is defined as follows:

$$L(d)=\sqrt{\frac{A\sum_{j=1}^{n}\sum_{j=1,\,j\neq i}^{n}k(i,j)}{\pi n(n-1)}} \tag{4}$$

where A is the area size, n is the number of points, d is the distance threshold and $k(i, j)$ is the weight, which is 1 when the distance between i and j is less than or equal to d and 0 when the distance between i and j is greater than d.

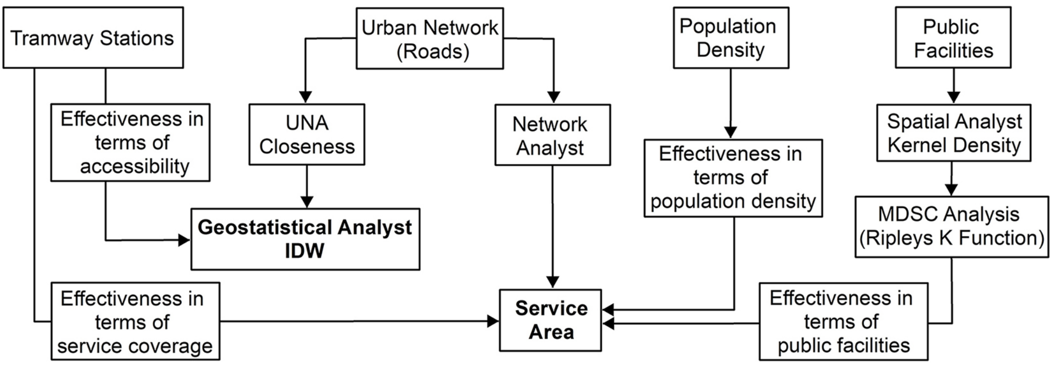

Figure 2: Flowchart of the methodology adopted

In this study, the selection of methods was guided by the need to capture multiple dimensions of spatial accessibility. Service area analysis was used to evaluate pedestrian-based coverage around tramway stops, providing an intuitive interpretation of distance thresholds. Urban Network Analysis (UNA) closeness centrality was selected to assess network-based accessibility, as it accounts for the configuration of the street network and shortest path distances. Kernel density estimation was employed to identify spatial concentrations of public facilities, while IDW interpolation allowed for the transformation of discrete accessibility values into a continuous surface for better spatial interpretation. Finally, Ripley's K-function was applied to detect spatial clustering patterns at multiple scales. The combination of these methods provides a complementary and comprehensive framework, although each method relies on specific assumptions that must be considered when interpreting the results.

3 Results

Based on a methodology grounded in Geographic Information Systems (GIS), this study maps and quantifies the effectiveness of the Oran tramway according to four key dimensions: service coverage area, accessibility of tramway stops, population density served, and the number of public facilities covered.

3.1 Effectiveness of the Tramway in Terms of Service Area

Using a network analysis with impedance thresholds of 300, 500, 750, and 1,000 meters, the results reveal a heterogeneous distribution of tramway accessibility across the study area (Figure 3). Overall, the spatial pattern highlights a clear contrast between well-served central areas and less accessible peripheral zones.

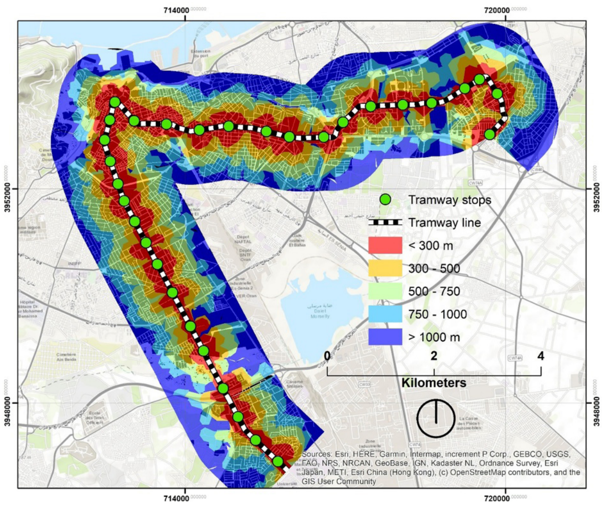

Figure 3: Effectiveness of the Tramway in Terms of Service Area

Table 2 indicates that areas with high to very high accessibility (within 500 meters of tramway stops) account for approximately 38% of the study area. These zones, located in immediate proximity to tramway stops, benefit from optimal walking access. Moderate accessibility zones cover about 19% of the area and correspond to transitional zones where access remains acceptable but starts to decline. In contrast, low to very low accessibility zones (beyond 750 meters) account for the remaining 43% of the study area. These more distant locations, particularly in peripheral neighborhoods, are associated with less convenient access that may discourage regular use of the tramway and highlight significant coverage gaps.

Table 2: Spatial distribution of the service area by surface area

Service Area Classes (m)	Description	Area (ha)	Area (%)
< 300m	Very high Service Area	731.01	21.57
300 - 500	High Service Area	555.52	16.39
500 - 750	Moderate Service Area	638.32	18.84
750 – 1,000	Low Service Area	598.55	17.66
>1,000m	Very low Service Area	864.64	25.52

3.2 Tramway Efficiency in Terms of accessibility of tramway stops

The comparison between the accessibility of tramway stops and the tramway alignment (Figure 4) reveals that 7 tramway stops in the city center benefit from high accessibility, due to the dense street network characterizing this area. An additional 8 tramway stops, situated in the immediate vicinity of the city center, also exhibit high accessibility. In contrast, only 3 tramway stops are associated with moderate accessibility, indicating a spatial imbalance. Low and very low accessibility levels are observed for 13 tramway stops, accounting for approximately 42% of the entire tramway route. This pronounced disparity can be attributed to the contrasting urban fabric: the dense and structured street layout inherited from the French colonial period (before 1962), versus the more sprawling and less integrated development patterns characteristic of post-independence urbanization.

Table 3 summarizes the spatial distribution of tramway accessibility derived from the UNA closeness centrality. The five accessibility classes were automatically generated by the UNA tool. These values represent the relative efficiency of the street network in connecting tramway stops to surrounding urban areas. Higher values indicate locations where shorter paths to multiple destinations are available, reflecting better network integration and easier movement within the city. Conversely, lower values correspond to areas that are more spatially isolated, with longer travel paths and reduced connectivity. Overall, accessibility exhibits a clear spatial gradient, with lower levels concentrated in the eastern and southern peripheral sectors of the city and higher levels observed in the central urban core and its immediate surroundings. Areas characterized by low to very low accessibility are generally associated with less dense street networks and weaker connectivity to tramway stops. These zones are mainly located in the eastern neighborhoods of Hai El Yasmine and Hai Ennour, as well as in the southern sector, particularly Es Senia. In contrast, moderate accessibility is observed in transitional urban areas such as USTO, El Morched, and Hai Es Salem, reflecting a more balanced level of network connectivity.

High and very high accessibility are predominantly concentrated in the central districts, including Cité Djamel Eddine, Les Castors, and Hai El Makkri. These sectors benefit from a dense and well-structured urban network that facilitates efficient pedestrian access to tramway stops. The concentration of very high accessibility areas, which account for nearly 23% of the study area, highlights the strong spatial integration of the tramway system within the urban core.

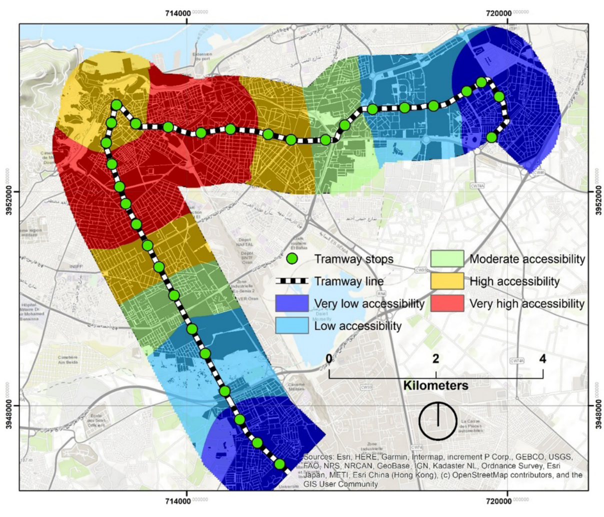

Figure 4: Effectiveness of the Tramway in Terms of accessibility of tramway stops

Table 3: Spatial distribution of accessibility of tramway stops by surface area

Accessibility Classes (m^{-1})	Description	Area (ha)	Area (%)
4.36e-006 - 5.34e-006	Very low accessibility	689.90	20.97
5.34e-006 - 6.67e-006	Low accessibility	732.30	22.26
6.67e-006 - 7.65e-006	Moderate accessibility	449.21	13.65
7.65e-006 - 8.36e-006	High accessibility	673.76	20.48
8.36e-006 - 8.88e-006	Very high accessibility	744.74	22.64

3.3 Tramway Efficiency in Terms of Population Density

Table 4 presents the spatial distribution of population density across the study area. Overall, population density follows a clear spatial pattern, with lower densities concentrated in the southern parts of the city, particularly in the commune of Es Senia, and progressively increasing toward central and eastern areas.

Very low and low-density zones are mainly located in peripheral areas, especially in the southern sector and along the northern fringes of the city center, reflecting more dispersed urban development. Moderate density areas are distributed across transitional zones, including Es Senia, the eastern sector (USTO), and neighborhoods such as El Morched and Cité Djamel Eddine, indicating a more balanced urban structure. High-density areas are the most extensive, accounting for approximately 35% of the study area, and are concentrated in central districts such as USTO, Les Castors, and Hai El Mokrani. Finally, very high-density zones are primarily located in the city center and eastern neighborhoods such as Hai Essabah and Hai Ennour, reflecting the strong concentration of population in these highly urbanized areas.

The comparison between spatial population density and the Oran tramway network (Figure 5) demonstrates a clear intent by urban planners to serve a significant portion of the population, with a particular focus on the most densely populated areas. Statistically, 20 tramway stops (64%) are located in zones with high to very high population density (>93.74 inhabitants per 100 m^2), while 8 tramway stops are situated in areas of moderate population density (68.68–93.73 inhabitants per 100 m^2). In contrast, only 3 tramway stops are located in zones with low to very low population density (<68.67 inhabitants per 100 m^2).

The spatial analysis also reveals that the area located within 300 meters of tramway stops exhibits an average density of 101.32 inhabitants per 100 m^2, indicating a high concentration of residential settlement in immediate proximity to the infrastructure. The intermediate zone, situated between 300 and 500 meters from the tramway line, remains densely populated with an average of 97.43 inhabitants per 100 m^2, suggesting that this portion of the territory also benefits from satisfactory pedestrian accessibility. However, beyond 500 meters, a gradual decline in population density is observed: 95.02 inhabitants per 100 m^2 within the 500–750 m range, decreasing to 87.97 inhabitants per 100 m^2 between 750 and 1,000 m, and falling to 70.61 inhabitants per 100 m^2 beyond 1,000 meters. This progressive decline in residential density with increasing distance from the tram network reflects a relative decrease in direct accessibility to the tramway.

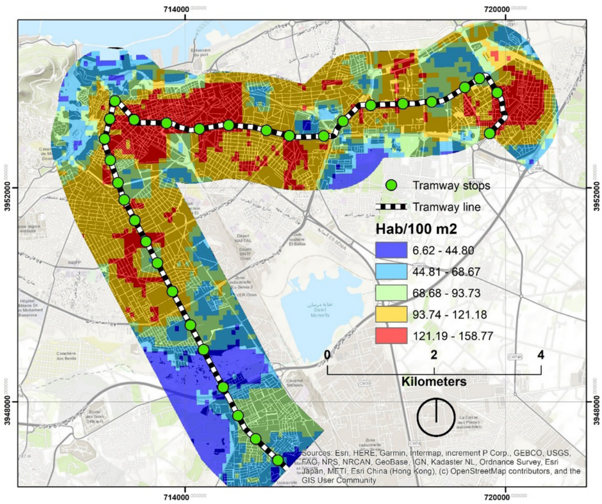

Figure 5: Tramway Efficiency in Terms of Population Density

Table 4: Spatial distribution of the population density by surface area

Population Density Classes (inhabitants per 100 m²)	Description	Area (ha)	Area (%)
6.62 - 44.80	Very low density	311.63	9.50
44.81 - 68.67	Low density	618.35	18.86
68.68 - 93.73	Moderate density	714.29	21.78
93.74 - 121.18	High density	1,132.77	34.55
121.19 - 158.77	Very high density	501.88	15.31

3.4 Efficiency of the Tramway in Terms of Public Facility Distribution

Figure 6 and Table 5 present the spatial distribution of public facility density across the study area. Overall, the pattern reveals a clear concentration of facilities in central urban areas, with decreasing densities toward the periphery. Areas characterized by very low and low facility density are widely distributed across the eastern and southern parts of the city, including zones such as USTO, Les Castors, Cité Djamel Eddine, Hai Medina Jedida, and Es Senia. These areas reflect a relatively limited presence of public services and facilities. Moderate density zones are more centrally located and extend across transitional areas, including USTO, El Morched, Les Castors, and parts of the city center, indicating a more balanced distribution of facilities. In contrast, high-density areas are more spatially concentrated, primarily in USTO and the downtown area, where urban functions and services are more intensively developed. Finally, very high facility density is exclusively observed in the city center and represents a relatively small portion of the study area (approximately 5%), highlighting the strong spatial concentration of services within the urban core.

The spatial distribution of public facilities offers particularly valuable insights into the spatial efficiency of the tramway system. As shown in Table 6, the analysis highlights a clear relationship between the spatial distribution of public facilities and their level of accessibility of tramway stops.

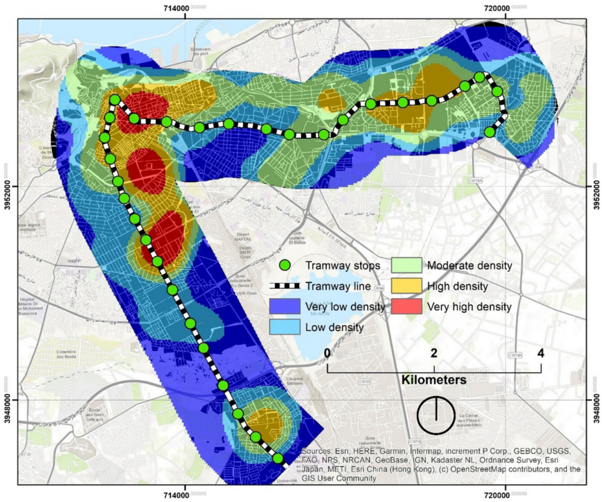

Figure 6: Efficiency of the Tramway in Terms of Public Facility Distribution

Table 5: Spatial distribution of the public facility by surface area

Public Facility Density Classes	Description	Area (ha)	Area (%)
0 - 9.0e-6	Very low density	921.75	28.28
9.0e-6 – 1.80e-5	Low density	909.14	27.89
1.80e-5 – 3.0e-5	Moderate density	833.91	25.59
3.0e-5 – 4.62e-5	High density	430.43	13.21
4.62e-5 – 7.41e-5	Very high density	164.04	5.03

A substantial proportion of facilities (28.24%) is located within the highest accessibility zone, indicating strong proximity to the tramway network. This concentration suggests that the tramway alignment partly reflects a strategic positioning aimed at facilitating access to essential services, particularly for daily users such as employees. Facilities located within intermediate accessibility zones remain reasonably well connected, with approximately 17% to 23% of facilities falling within walking distances generally considered acceptable in urban contexts. In contrast, accessibility declines in more distant areas, where about 16% of facilities are located in low-accessibility zones, and nearly 15% lie beyond the effective service range of the tramway network. These areas may experience reduced connectivity, potentially leading to greater reliance on alternative transport modes and highlighting spatial disparities in service provision.

In addition, comparing the distribution of public facilities with population density further reinforces these findings. Approximately 420 facilities (64%) are located in highly populated areas (greater than 93 inhabitants per 100 m²), while 178 facilities (26%) are situated in zones of moderate population density (68.68–93.73 inhabitants per 100 m²). In contrast, only 58 facilities are found in low-density areas (less than 68.68 inhabitants per 100 m²).

Table 6: Distribution of public facilities by accessibility of tramway stops level

Accessibility classes	Service Area (m)	Percentage of public facilities
Very low accessibility	> 1,000 m	15.26
Low accessibility	750 – 1,000	16.16
Moderate accessibility	500 – 750	23.26
High accessibility	300 – 500	17.07
Very high accessibility	< 300	28.24

Furthermore, the analysis of the spatial distribution of public facilities using Multi-Distance Spatial Cluster Analysis (Ripley's K Function) reveals a statistically significant spatial clustering across all examined distances (Figure 7). According to (Bendib, 2022), when the observed K value exceeds the expected K value, this indicates a tendency toward spatial clustering, whereas values lower than the expected K suggest a more dispersed pattern. In addition, when the observed K curve lies above the upper confidence envelope (HiConfEnv), the clustering can be considered statistically significant. In this study, the observed K values consistently exceed both the expected values and the upper confidence envelope, confirming the presence of strong and statistically significant clustering of public facilities within the study area. This result suggests that the tramway route and the placement of its stops were strategically designed, taking into account the locations of key public facilities. Consequently, the tramway appears to be deliberately positioned near major service hubs to maximize accessibility for users and enhance the overall efficiency of the public transportation network.

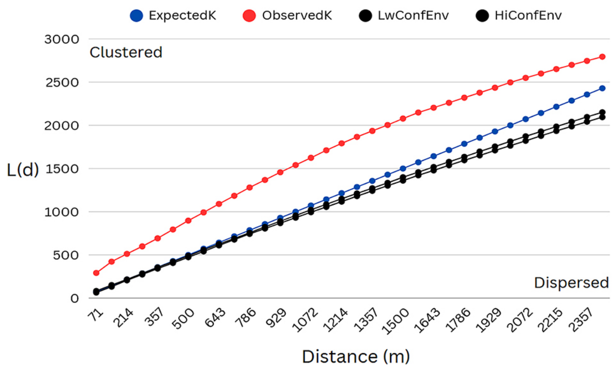

Figure 7: Multi-Distance Spatial Cluster Analysis (Ripley's K Function)

The typology of the facilities served further supports this analysis. As shown in Figure 8, the facilities most connected to the tramway network predominantly fall within the sports and leisure sector, accounting for a total of 217 installations. This predominance can be interpreted as the outcome of an urban planning strategy aimed at enhancing the attractiveness and accessibility of urban recreational spaces. The education sector follows, with 127 facilities located close to tramway stops. This finding is particularly significant, as access to schools and universities represents a critical lever for promoting sustainable mobility and territorial equity. The cultural sector, with 62 facilities served, also enjoys notable representation in well-connected areas. The security sector (e.g., police stations, fire stations) includes 33 facilities situated near the tramway. Lastly, although strategically important, the health and administrative sectors each account for a relatively low total of only 13 serviced facilities. This underrepresentation may warrant closer attention from policymakers, as access to healthcare and administrative services is a central issue of spatial justice.

To better assess the significance of these figures, the distribution of facilities served by the tramway was compared with the total number of public facilities in the city of Oran. This comparison confirms that the tramway alignment was strategically designed. Indeed, 31% of all sports and leisure facilities in the city (217 out of a total of 699) are located within 1,000 meters of a tramway stops. Similarly, approximately 30% of educational facilities fall within this buffer zone. For cultural, health, and administrative facilities, the share drops to 28% each. In contrast, only 20% of security facilities are effectively served by the tramway.

In summary, the spatial distribution of public facilities based on their proximity to the tramway network highlights a certain degree of functional selectivity. While service coverage for sports, education, and cultural infrastructure is generally adequate, that of health and administrative services appears more limited.

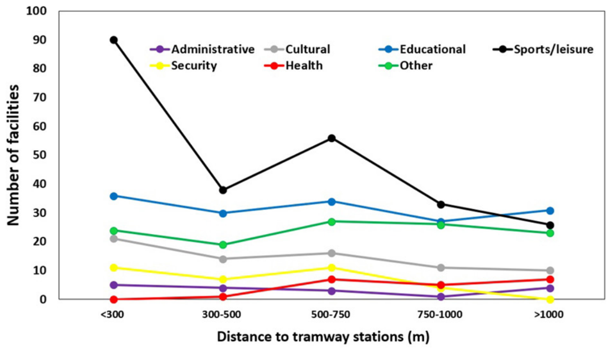

Figure 8: Number of public facilities by service area classes

4 Discussion

This study provides insight into the spatial efficiency of the Oran tramway, focusing on tramway stop accessibility, population coverage, and proximity to public services. The results highlight both the strengths of the network and several structural limitations that should be considered in future urban and transport planning strategies. Mapping of service areas reveals that nearly 57% of the study zone lies within 750 meters of a tramway stops, indicating a relatively good level of spatial coverage according to commonly used urban mobility standards. These coverage figures are the combined outcome of both the spacing between tramway stops and the density and connectivity of the walking path in different parts of the study area. The analysis therefore, suggests that the tramway is relatively well integrated within several central sectors of the urban fabric. However, approximately 25% of the study area remains beyond the 1,000-meter threshold, revealing important spatial disparities in accessibility. These peripheral areas may experience comparatively lower levels of access to public transport services, particularly for residents who depend heavily on collective mobility options (Kamruzzaman et al., 2016); (Pot et al., 2025).

Field surveys conducted by (Boudjeriou & Kebiche, 2024) support these findings. In their comparative study of tramway impacts in Oran and Constantine, more than 1,000 tram users were surveyed. For Oran, 66.3% of respondents evaluated accessibility positively, while 28.7% considered it moderate and

5% perceived it as poor. These perceptions suggest that although the tramway performs satisfactorily in central sectors, accessibility conditions remain uneven across different parts of the city.

The relationship observed between tramway accessibility and population density indicates that the network primarily serves densely populated urban sectors. Areas located within 500 meters of tramway stops generally correspond to zones of higher population density and better accessibility conditions, which is consistent with findings reported in previous studies on public transport accessibility and urban form (Champagne & Negron-Poblete, 2012); (Tammaru et al., 2023). This observation also aligns with planning recommendations proposed by the (Société de transport de Montréal, 2007), which suggest an optimal spacing of approximately 600 meters between major public transport corridors. According to (Bachri & Triki, 2022), the Oran tramway also benefits from several operational advantages, including extended operating hours and regular service frequency, factors that may contribute to its continued use by residents.

Beyond simple distance-based interpretation, the results also provide several indicators of spatial equity. The comparison between tramway accessibility and population density reveals that the network disproportionately benefits central and densely populated districts, where accessibility values and service coverage are highest. Approximately 64% of tramway stops are located within high- to very high-density areas, indicating that the tramway alignment generally prioritizes sectors characterized by stronger demographic concentration. Similarly, the average population density within 300 meters of tramway stops reaches 101.32 inhabitants per 100 m², compared with only 70.61 inhabitants per 100 m² beyond 1,000 meters. From a Spatial efficiency perspective, these findings suggest a relatively close correspondence between tramway infrastructure and population distribution, although accessibility benefits remain unevenly distributed across the metropolitan territory.

The results also reveal notable disparities in the spatial distribution of public facilities. Sports, educational, and cultural facilities generally appear well represented within tramway service areas, whereas healthcare and administrative services remain comparatively less accessible. Only 13 out of 47 health facilities are located within 1,000 meters of a tramway stops, suggesting an uneven spatial relationship between essential services and the transport network. These findings underline the importance of stronger coordination between land-use planning and transport planning in future urban development strategies.

Recent urban and demographic transformations in Oran further emphasize these challenges. According to (Benyamina, 2025), the relocation of the Es Sénia university campus toward Belgaïd in eastern Oran has shifted major mobility flows toward areas that currently remain insufficiently connected to the tramway system. Similarly, large-scale housing relocation programs have progressively transferred thousands of households from central districts toward peripheral zones in eastern Oran. While these operations have improved housing conditions for many residents, they have also contributed to increasing travel distances and additional pressure on existing transport infrastructure. At the same time, some public facilities and transport nodes appear to have developed in closer proximity to the tramway corridor, particularly around USTO, Hai Essabah, and parts of the city center, indicating partial spatial integration between transport infrastructure and urban services. However, this integration remains spatially uneven and limited in several expanding peripheral sectors.

Compared to similar tramway and light rail systems internationally, The Oran tramway presents patterns that are broadly consistent with observations reported in other urban contexts, where central and densely populated areas benefit from higher accessibility and better service coverage, while peripheral zones remain less served. This trend has been widely observed in both European and Asian cities, highlighting the common challenge of balancing operational efficiency and spatial equity in public transport planning (Méndez-Manjón & Plasencia-Lozano, 2025); (Yang et al., 2025); (Chen et al., 2022); (Negm et al., 2025).

The organization of urban mobility in Oran also remains influenced by fragmentation between public and private transport operators. (Kaddouri et al., 2024) emphasize that private operators tend to concentrate their services in densely populated and economically profitable corridors, whereas less profitable peripheral areas rely more heavily on public transport services. Such dynamics may contribute to reinforcing existing spatial inequalities in accessibility and complicate the implementation of integrated mobility policies.

In summary, the analysis indicates that the Oran tramway plays an important role in structuring accessibility and mobility within central urban areas characterized by high population density and concentration of services. However, the results also reveal important spatial inequalities affecting peripheral sectors and certain categories of public facilities. These findings underline the importance of adopting more integrated approaches that combine transport planning, land-use management, and urban development policies to improve territorial accessibility and support more balanced urban growth.

5 Methodological Limitations

Several limitations should nevertheless be acknowledged. First, the study primarily focuses on spatial accessibility and does not incorporate socio-economic variables, travel behavior, ticket affordability, or passenger flow data, all of which may influence tramway use and mobility patterns.

Second, the analysis is restricted to a 1-kilometer buffer zone on each side of the tramway line (a 2 km corridor in total). While this focus is justified by the direct influence area of the tramway and common practice in transit corridor studies, it excludes a large part of the city. A more comprehensive accessibility analysis covering the entire city of Oran and integrating other public transport modes (buses, taxis, and rail) would provide a broader understanding of the overall urban mobility system and the tramway's role within it.

Furthermore, the analysis is limited to the current tramway configuration and does not simulate future network extensions, demographic growth scenarios, or evolving urban mobility dynamics.

Moreover, accessibility was evaluated mainly through walking distance thresholds and network-based spatial indicators without fully accounting for travel time variability, service frequency fluctuations, or multimodal integration. In addition, the selected distance thresholds (300 m, 500 m, 750 m, and 1,000 m), while based on commonly accepted planning standards, remain partly arbitrary.

Additionally, while this study focuses on spatial proximity and network-based accessibility, accessibility is inherently multi-dimensional, encompassing cost, service frequency, comfort, safety, and perceived accessibility. These aspects were not included due to data constraints and therefore represent important directions for future research.

Sixth, the analysis relies partly on open-source datasets, particularly OpenStreetMap data, which may contain certain inaccuracies or incompleteness in the representation of the road network and public facilities. Although efforts were made to validate and clean these datasets, some inconsistencies may still remain.

Finally, the population data derived from the WorldPop project represent modeled estimates rather than exact census counts and may therefore not fully capture local demographic variations, especially in rapidly changing urban areas.

6 Conclusion

This study provides a spatially integrated GIS-based assessment of the Oran tramway's performance by combining service area analysis, network-based accessibility (Urban Network Analysis), population density mapping, kernel density estimation of public facilities, IDW interpolation, and Ripley's K-function. The methodological contribution of this study lies in integrating multiple spatial approaches to evaluate tramway accessibility, service coverage, population distribution, and public facility concentration simultaneously, rather than examining each component separately. This unified framework offers a more comprehensive understanding of the relationships between transport infrastructure, urban population dynamics, and the spatial organization of public services. The results indicate that the Oran tramway is more strongly connected to the city's densely populated central districts, with nearly 57% of the study area located within a 750-meter walking distance of tramway stops. The analysis also shows relatively high levels of accessibility to sports, educational, and cultural facilities. However, significant spatial disparities remain. Healthcare and administrative services are comparatively less accessible, while approximately 25% of the study area — particularly peripheral sectors and rapidly expanding eastern districts — remains located beyond 1,000 meters from tramway stops. Recent urban relocation policies and demographic redistribution processes may have contributed to reinforcing some of these accessibility imbalances.

Overall, the findings indicate that although the Oran tramway contributes positively to urban mobility and accessibility within central areas, its spatial coverage remains uneven across the metropolitan territory. These results highlight the importance of integrating transport planning, population dynamics, and public facility distribution into future tramway expansion strategies. Improved multimodal integration and greater attention to underserved peripheral sectors could contribute to reducing spatial disparities in accessibility.

Future research could therefore extend this framework by integrating travel-time measures, behavioral and socio-economic data, multimodal transport interactions, equity indicators, and sensitivity analyses of accessibility thresholds. Simulation of future tramway extensions and demographic growth scenarios would also provide valuable insights into the long-term sustainability and inclusiveness of urban transport planning. Beyond the Oran case study, the proposed methodological framework may also apply to other rapidly growing cities facing similar challenges related to urban expansion and unequal access to transport infrastructure.

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