



Original Research Paper

Geographical Analysis and Spatial Justice Assessment of Educational Services in the Primary Stage Using GIS: A Case Study of the City of Bordj Bou Arreridj

Blida Kamilia¹, Assia Lifa²

¹Faculty of Earth Sciences, Geography, and Urban Planning, University of Constantine 1, Frères Mentouri, Algeria
Email: kamilia.blida@univ-bba.dz

²Faculty of Earth Sciences, Geography, and Urban Planning, University of Constantine 1, Frères Mentouri, Algeria
Email: assianahal@yahoo.fr

Abstract

Following the administrative restructuring of 1984, intermediate Algerian cities have experienced unprecedented urban expansion and profound demographic transformation. These accelerated spatial dynamics have generated severe planning challenges regarding the equitable allocation and physical accessibility of primary educational facilities. Traditional municipal planning approaches rely predominantly on aggregate population-to-facility ratios, systematically failing to account for spatial friction, catchment overlap, topographic barriers, and neighborhood-level accessibility deficits. This study establishes a comprehensive spatial evaluation of primary educational services in Bordj Bou Arreridj City—the administrative capital of Bordj Bou Arreridj Province, eastern Algeria—for the 2025/2026 academic year, deploying an integrated Geographic Information Systems (GIS) analytical framework. By combining Average Nearest Neighbor (ANN) spatial metrics, Standard Deviational Ellipse (SDE) analysis, Kernel Density Estimation (KDE), Network Service Area delineation, and Lorenz Curve equity modeling, this research systematically diagnoses spatial point patterns, directional tendencies, catchment boundaries, and spatial mismatches between educational supply and demographic demand. Empirical results reveal structural spatial disparities: central and historical census districts exhibit facility clustering and redundant service coverage, whereas rapidly growing peripheral urban expansion zones—particularly the northern and south-western residential corridors—suffer from acute coverage deficits and extended walking distances exceeding tolerable pedestrian thresholds. The calculated Nearest Neighbor Ratio ($R = 0.6115$, $Z = -5.842$, $p < 0.001$) confirms statistically significant clustering, while the Gini Coefficient ($G = 0.412$) quantifies moderate-to-severe spatial inequality in facility distribution relative to school-age population concentrations. To resolve these spatial inequities, a predictive GIS location-allocation optimization model is formulated to align future facility siting with urban growth vectors, demographic projections, and Sustainable Development Goal 4 (Quality Education) targets for 2030.

Keywords: Spatial Analysis; Primary Education; Geographic Information Systems (GIS); Spatial Equity; Nearest Neighbor Index; Service Catchment Area; Urban Planning; Location-Allocation Optimization.

*Corresponding Author:

Received: 15th June, 2026; Revised: 22th July 2026; Accepted: 21th August, 2026; Available Online: 26th September 2026

(DOI): 10.70102/AEJ.2026.18.7s.77

1. Introduction

The spatial organization of public services constitutes a foundational structural dimension of urban planning, directly conditioning quality of life, economic productivity, social mobility, and territorial cohesion (Harvey, 1973; Knox, 1982; Talen, 1998). Within the domain of social infrastructure, primary educational facilities occupy a position of particular strategic importance. As the initial institutional tier wherein cognitive development, foundational literacy, and social integration are systematically cultivated, primary schools must be distributed efficiently, equitably, and accessibly across the urban landscape (Tsou et al., 2005; UNESCO, 2022). Their spatial arrangement is not merely a technical planning parameter; it is a direct determinant of children's daily mobility patterns, parental labor market participation, and the reproduction of spatial inequalities across generations (Soja, 2010; Naylor et al., 2019).

In recent decades, cities across the Global South—particularly intermediate urban centers in North Africa—have undergone rapid demographic expansion and extensive physical sprawl driven by rural-to-urban migration, natural population growth, and administrative reclassification (Chibani, 2015; Bentrari & Sriti, 2019; UN-Habitat, 2022). In Algeria, the administrative reform enacted through Law No. 84-09 of February 4, 1984, which restructured the national territory into 48 *wilayas* (provinces) and formally elevated numerous towns to *chef-lieu de wilaya* status, triggered substantial demographic influx and accelerated urban expansion across medium-sized cities previously lacking adequate infrastructure endowment (Aissaoui, 2016; Chibani, 2015). This restructuring compressed into a few decades the urbanization trajectories that European cities had experienced over centuries, generating profound spatial planning challenges regarding the synchronization of infrastructure provision with demographic realities.

Bordj Bou Arreridj, designated capital of the *wilaya* bearing the same name, exemplifies these planning dilemmas acutely. Located in the High Plateaus (*Hauts Plateaux*) region of eastern Algeria at approximately 36°04'N, 4°46'E, at an elevation of approximately 900 meters above sea level, the city functions as a major administrative, industrial, and commercial center. According to the National Office of Statistics of Algeria (ONS), the *commune* of Bordj Bou Arreridj recorded a population of approximately 168,000 inhabitants in the 2008 General Population and Housing Census (RGPH 2008), growing to an estimated 175,000–195,000 residents by 2023–2025, based on inter-censal projection coefficients (ONS, 2023; DPAT Bordj Bou Arreridj, 2022). The city is particularly notable for its concentration of electronic

and mechanical manufacturing enterprises within its *zone industrielle*, attracting labor migration and generating sustained demographic pressure (DPAT Bordj Bou Arreridj, 2022).

Despite continuous public investments in educational infrastructure since the post-independence period and accelerated school construction programs following the 1984 administrative reform, spatial imbalances in primary school distribution persist across the urban fabric of Bordj Bou Arreridj. Older schools are concentrated within the consolidated urban core—particularly around the historic market district (*souk*), the administrative center, and the older collective housing estates (*cités HLM*)—while rapidly growing peripheral neighborhoods developed through the Programme National de Construction de 1000 Logements (AADL), the *Location-Vente* programs, and spontaneous individual housing construction lack adequate primary educational coverage (Aissaoui, 2016; Bouledroua, 2010).

Historically, urban public service planning in Algerian administrative contexts relied predominantly on descriptive statistical indicators and aggregate capacity metrics, specifically the normative ratio of one primary school per 1,200 to 1,500 inhabitants, as stipulated in Algerian urban planning norms (*normes d'équipement*) (MATE, 2003; Ministère de l'Éducation Nationale, 2020). However, these non-spatial methodologies suffer from the Modifiable Areal Unit Problem (MAUP) (Openshaw, 1984) and systematically fail to capture the spatial friction of physical distance, localized topographic barriers, pedestrian network impedances, and neighborhood-scale demographic variations (Apparicio et al., 2008; Luo & Wang, 2003). The result is a systematic planning blind spot: aggregate ratios may satisfy national normative thresholds while simultaneously masking severe localized coverage deficits and inter-neighborhood spatial injustices.

To address this empirical, methodological, and planning gap, this study operationalizes a multi-method GIS analytical framework to evaluate primary educational spatial equity in Bordj Bou Arreridj for the 2025/2026 academic year. The research addresses the following core questions:

1. What is the spatial point pattern and spatial arrangement of primary schools across the urban perimeter of Bordj Bou Arreridj for the 2025/2026 academic year?
2. What geographical, demographic, historical, and infrastructural factors structurally condition this spatial distribution?

3. To what extent does the spatial supply of educational services match the localized demographic demand of school-age populations (ages 6–11) across diverse neighborhoods and census districts?
4. How can GIS-based spatial analytics and network modeling be operationalized to detect service deficits, quantify spatial inequities, and formulate an optimized location-allocation model for future facility siting aligned with urban growth projections?

2. Theoretical Framework and Literature Review

2.1 Urban Public Facility Location Theory

The theoretical grounding of this research synthesizes urban service location theory, spatial justice concepts, and geospatial accessibility modeling. Public facility location theory, originating in the seminal work of Teitz (1968) and elaborated by Morrill and Symons (1977) and Hodgart (1978), posits that the spatial distribution of public goods should simultaneously optimize two structurally competing objectives: spatial efficiency—minimizing aggregate travel distance or time costs for the total population—and spatial equity—minimizing spatial variance in accessibility across sub-regions, social groups, or administrative units. These dual objectives frequently enter into tension, as efficiency-maximizing solutions tend to concentrate facilities in high-density population cores, systematically disadvantaging low-density peripheral communities (Marsh & Schilling, 1994).

In educational geography specifically, primary schools are classified as neighborhood-level public goods with strict pedestrian access thresholds (Talen, 2001). Unlike secondary or tertiary educational facilities—wherein motorized commuting is socially expected and institutionally accommodated—primary school catchment planning is governed by child pedestrian safety imperatives, maximum tolerable walking distances calibrated to child physiological capacity, and environmental barrier mitigation (Shah et al., 2016; DeMers, 2008). International planning standards, including those from the World Health Organization (WHO, 2023), UNESCO (2022), and national Algerian normative frameworks (MATE, 2003), generally stipulate walking catchment radii of 400 to 1,000 meters as acceptable thresholds, corresponding to approximately 5 to 15 minutes of pedestrian travel for children aged 6 to 11 years.

2.2 Spatial Justice and Equity Dimensions

The concept of spatial justice, theorized comprehensively by Soja (2010) following foundational contributions from Harvey (1973) and Talen (1998), asserts that geographic space is not a

neutral container of social processes but an active producer and reproducer of social inequalities. Spatial injustice emerges when the location and accessibility of public goods systematically disadvantage particular communities based on their geographic situation rather than their needs or rights as citizens. In the context of primary education in rapidly urbanizing Global South cities, spatial injustice manifests as unequal walking distances to school, differential exposure to traffic hazards, and unequal access to school quality that overlaps with residential segregation patterns (Soja, 2010; Naylor et al., 2019).

Talen (1998; 2001) operationalized spatial equity measurement for public facilities through the application of Lorenz Curve analysis and Gini Coefficient computation—methods originating in income inequality economics (Lorenz, 1905)—adapted to measure the concentration of facility supply relative to population demand distributions across geographic units. This methodological transfer from economics to spatial planning has been validated and refined in subsequent studies across diverse urban contexts in Europe, North America, Asia, and North Africa (Tsou et al., 2005; Omer, 2006; Akakba & Lahmar, 2023).

2.3 GIS-Based Accessibility Modeling: Methods and Evolution

Geospatial technology provides powerful and progressively refined analytical capabilities for evaluating public service networks (Longley et al., 2015). The methodological evolution of GIS-based accessibility analysis has progressed through several generations: from simple Euclidean buffer zones through network-based service areas to the Two-Step Floating Catchment Area (2SFCA) method introduced by Luo and Wang (2003) and its Enhanced variant (E2SFCA) developed by Luo and Qi (2009), which incorporate capacity-to-demand ratios and distance-decay weighting functions.

For primary educational facility assessment in dense urban settings, network-based service area analysis retains strong methodological appropriateness because the primary access mode is pedestrian travel along actual street networks—rendering Euclidean buffers systematically inadequate in environments with irregular street grids, highway barriers, and topographic discontinuities (Apparicio et al., 2008; Lin et al., 2018). Algerian urban morphologies—characterized by combinations of colonial-era grid networks, organic medina-pattern streets, and post-independence housing estate access roads—amplify the gap between Euclidean and network-based accessibility measures (Chibani, 2015; Akakba & Lahmar, 2023).

Table 1. Conceptual Framework: Theoretical Foundations and GIS Operationalization

Conceptual Component	Theoretical Foundation	GIS Operational Indicator	Planning Objective
Spatial Pattern & Arrangement	Point Pattern Theory (Clark & Evans, 1954)	Average Nearest Neighbor Ratio (R)	Identify clustering, randomness, or dispersion of school locations
Directional Orientation & Centrality	Spatial Statistics (Fotheringham et al., 2000)	Standard Deviation Ellipse & Mean Center	Determine spatial orientation axis and center of gravity
Density & Concentration Surface	Continuous Surface Modeling (Silverman, 1986)	Kernel Density Estimation (KDE)	Map supply hotspots and coverage cold spots
Physical Walking Accessibility	Network Friction Theory (Guagliardo, 2004)	Network Service Area (500 m, 1,000 m)	Quantify pedestrian catchment zones and identify unserved areas
Spatial Equity & Distributional Balance	Economic Inequality Theory (Lorenz, 1905; Talen, 1998)	Lorenz Curve & Gini Coefficient (G)	Measure disparities between population distribution and facility

			allocation
Optimal Facility Siting	Location-Allocation Theory (Teitz, 1968)	Maximize Coverage / Minimize Impedance Models	Identify optimal sites for new school construction

3. Study Area Profile

3.1 Geographic and Administrative Context

Bordj Bou Arreridj City (*commune* and *chef-lieu de wilaya*) is situated in the High Plateaus (*Hauts Plateaux*) region of eastern Algeria, at geographic coordinates approximately 36°04'N, 4°46'E, at a mean elevation of 895–920 meters above sea level (Figure 1). The city is administratively located within the *wilaya* of Bordj Bou Arreridj (Wilaya 34), which borders the wilayas of Sétif to the east, Bêjaïa to the north, Bouira to the west, and M'Sila to the south. The city is traversed by National Road N5 (Algiers–Constantine axis), which historically structured the city's east-west development corridor, and intersects with National Road N76 and National Road N106 toward Bêjaïa (DPAT Bordj Bou Arreridj, 2022).

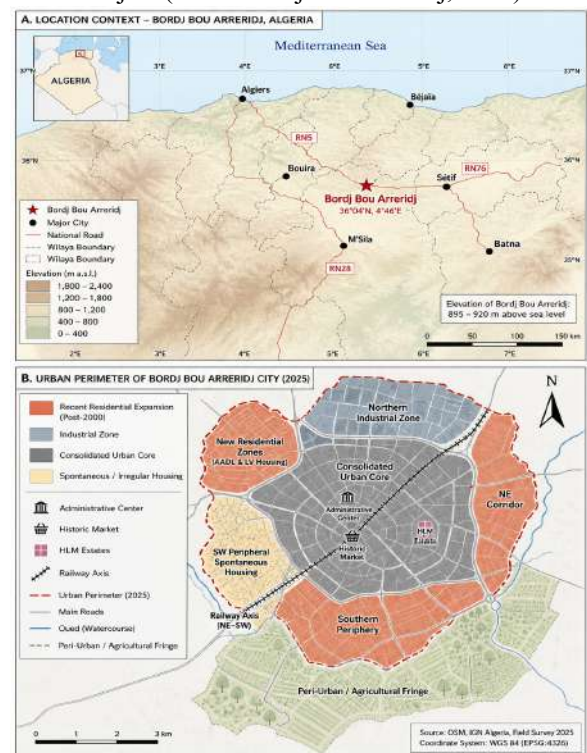


Figure 1. Geographic location of Bordj Bou Arreridj within northeastern Algeria and schematic urban structure (Authors' elaboration based on DPAT Bordj Bou Arreridj, 2022; ONS, 2023).

3.2 Demographic and Urban Growth Dynamics

Bordj Bou Arreridj's post-1984 demographic and urban trajectory has been characterized by sustained growth across successive inter-censal periods, as summarized in Table 2, based on ONS census records and provincial planning documents.

Table 2. Demographic Evolution of Bordj Bou Arreridj Commune (1977–2025 Projection)

Census Year / Period	Commune Population	Urban Population (City)	Annual Growth Rate (%)	Source
1977 (RGPH)	~42,000	~35,000	—	ONS (1977)
1987 (RGPH)	~85,000	~72,000	~7.4%	ONS (1987)
1998 (RGPH)	~129,000	~102,000	~2.8%	ONS (1998)
2008 (RGPH)	~168,000	~128,000	~2.2%	ONS (2008)
2023 (Projection)	~185,000	~168,000	~1.8%	ONS (2023); DPAT BBA (2022)
2025 (Projection)	~192,000	~175,000	~1.7%	Authors' projection

				ection
--	--	--	--	--------

Sources: ONS (1977; 1987; 1998; 2008; 2023); DPAT Bordj Bou Arreridj (2022).

The school-age population cohort (ages 6–11) in Bordj Bou Arreridj City is estimated at approximately **22,000–24,500 children** for the 2025/2026 academic year, representing approximately 13–14% of the total urban population, consistent with Algerian national demographic coefficients (ONS, 2023; Ministère de l'Éducation Nationale, 2023).

3.3 Educational Infrastructure Context

According to data from the *Direction de l'Éducation de la Wilaya de Bordj Bou Arreridj* (DEW-BBA, 2024) and the national school mapping system maintained by the *Ministère de l'Éducation Nationale* (MEN), the urban perimeter of Bordj Bou Arreridj hosts **28 operational primary schools** (*écoles primaires*) for the 2025/2026 academic year, providing approximately **530–560 classrooms** with a normative capacity of approximately **28,000–30,000 student-seats** (Table 3). However, this aggregate figure conceals profound spatial and qualitative disparities across the urban fabric.

Table 3. Primary Education Infrastructure Overview — Bordj Bou Arreridj City (2025/2026)

Indicator	Value	Source
Total operational primary schools	28	DEW-BBA (2024)
Total classrooms (estimated)	~545	DEW-BBA (2024); MEN (2023)
Total enrolled students (primary cycle)	~21,800	DEW-BBA (2024)
School-age population (6–11 years, urban)	~23,000	ONS (2023); Authors' projection
Aggregate school-age population/school ratio	~822 students/school	Authors' calculation

Algerian normative standard	1 school per 1,200–1,500 inhabitants	MA TE (2003); MEN (2020)
Mean distance between nearest school pairs (observed)	284.5 m	Aut hors' GIS analysis

4. Materials and Methods

4.1 Data Acquisition and Geodatabase Construction

A spatial geodatabase was compiled integrating high-resolution spatial data and municipal administrative records for the 2025/2026 academic year. The geodatabase was structured within the WGS 84 / UTM Zone 31N coordinate reference system (EPSG: 32631), appropriate for this geographic region of Algeria. Primary data inputs included:

Point Feature Class: Precise spatial coordinates (X, Y) of all 28 operational primary schools within the urban perimeter of Bordj Bou Arreridj, georeferenced through a combination of GPS field surveys, cross-referenced against the *Ministère de l'Éducation Nationale* school registry (MEN, 2024), satellite imagery interpretation from Google Earth Pro (imagery dates 2022–2024), and municipal cadastral records obtained from the *Direction de l'Urbanisme, de la Construction et de l'Habitat* (DUCH) of the Wilaya of Bordj Bou Arreridj.

Polygonal Feature Class: Administrative census district boundaries (*îlots de recensement*) and neighborhood administrative units (*cités, quartiers*), joined spatially with demographic attribute tables derived from the 2008 RGPH (ONS, 2008) and updated through projection using provincial intercensal coefficients (ONS, 2023; DPAT BBA, 2022). Attribute fields include total resident population, estimated school-age population (ages 6–11), housing density, and urban typology classification.

Linear Feature Class: A topologically clean street network dataset for Bordj Bou Arreridj's urban perimeter, constructed through digitization of OpenStreetMap (OSM) data (downloaded November 2024), validated against Google Earth Pro imagery and field surveys. Network attribute fields include segment length (meters), street hierarchy classification (primary arterial, secondary collector, local residential, pedestrian pathway), mean pedestrian walking speed assignment (1.2 m/s for adults; 0.9 m/s for children aged 6–11, following established pediatric pedestrian speed standards), and walkability impedance flags (highway crossings,

railway barriers, dead-end segments, steep gradient segments exceeding 8%).

Supplementary Layers: Urban master plan (*Plan Directeur d'Aménagement et d'Urbanisme*, PDAU) vector boundaries delineating existing urbanized zones, future residential expansion zones approved under the current PDAU revision cycle, and topographic contour data derived from SRTM 30-meter resolution digital elevation models.

4.2 Spatial Analytics Protocol and Mathematical Formulations

4.2.1 Average Nearest Neighbor (ANN) Spatial Pattern Analysis

The spatial point pattern of primary schools was evaluated using the Average Nearest Neighbor (ANN) index R , which compares the observed mean distance between each school and its nearest neighboring school against the expected mean distance under a hypothetical spatially random (complete spatial randomness, CSR) distribution (Clark & Evans, 1954). The index R is formulated as:

$$R = \frac{\bar{D}_O}{\bar{D}_E}$$

Where $\bar{D}_O$ represents the observed mean nearest-neighbor distance:

$$\bar{D}_O = \frac{\sum_{i=1}^n d_i}{n}$$

And $\bar{D}_E$ represents the expected mean distance given a random distribution over study area A containing n point features:

$$\bar{D}_E = \frac{0.5}{\sqrt{n/A}}$$

The statistical significance of the deviation from CSR is assessed via the standardized Z-score:

$$Z_{score} = \frac{\bar{D}_O - \bar{D}_E}{SE}$$

Where the standard error is:

$$SE = \frac{0.26136}{\sqrt{n^2/A}}$$

Interpretation: $R = 1$ indicates complete spatial randomness; $R < 1$ signifies spatial clustering; $R > 1$ denotes spatial dispersion or regularity. Statistical significance is assessed at $\alpha = 0.01$.

4.2.2 Standard Deviational Ellipse (SDE) and Mean Center

To identify the spatial centrality and directional orientation of the primary school network, the Mean Center ($\bar{X}, \bar{Y}$) and Standard Deviational Ellipse were computed (Fotheringham et al., 2000). The Mean Center coordinates:

$$\bar{X} = \frac{\sum_{i=1}^n x_i}{n}, \bar{Y} = \frac{\sum_{i=1}^n y_i}{n}$$

The rotation angle θ of the ellipse major axis, determining the primary orientation of facility spatial distribution:

tan □

$$= \frac{(\sum_{i=1}^n \tilde{x}_i^2 - \sum_{i=1}^n \tilde{y}_i^2) + \sqrt{(\sum_{i=1}^n \tilde{x}_i^2 - \sum_{i=1}^n \tilde{y}_i^2)^2 + 4(\sum_{i=1}^n \tilde{x}_i \tilde{y}_i)}}{2 \sum_{i=1}^n \tilde{x}_i \tilde{y}_i}$$

Where $\tilde{x}_i = x_i - \bar{X}$ and $\tilde{y}_i = y_i - \bar{Y}$ are deviation vectors from the mean center.

Standard deviations along the major and minor axes (σ_x , σ_y) define the spatial spread of the distribution.

4.2.3 Kernel Density Estimation (KDE)

Continuous spatial density surfaces of primary school supply concentration were generated using the quadratic Kernel Density function following Silverman (1986). The estimated density at point (x, y) :

$$f(x, y) = \frac{1}{nh^2} \sum_{i=1}^n K\left(\frac{d_i}{h}\right)$$

Where:

- h = bandwidth (search radius), set at **800 meters** based on Silverman's rule-of-thumb applied to the point distribution characteristics
- n = total number of primary schools (28)
- d_i = Euclidean distance from location (x, y) to school point i
- $K(\cdot)$ = quadratic kernel weighting function

Output cell size was set at 20 meters to capture intra-neighborhood density gradients effectively.

4.2.4 Network Service Area Analysis

Pedestrian accessibility catchment zones were delineated along the actual street network topology using **ArcGIS Pro 3.2 Network Analyst** extension. Service area polygons were generated for two standard thresholds calibrated to international and Algerian planning standards:

- **500-meter catchment (Buffer 1):** Equivalent to 9–10 minutes of child pedestrian travel at 0.9 m/s — representing the optimal accessibility threshold recommended for primary-school-age children
- **1,000-meter catchment (Buffer 2):** Equivalent to 18–20 minutes of child pedestrian travel — representing the maximum acceptable walking limit as defined by Algerian normative planning standards (MATE, 2003) and WHO (2023) guidelines

Network impedance was computed as cumulative pedestrian path length (meters), with penalty multipliers applied to segments involving arterial road crossings ($\times 1.5$), railway crossing points ($\times 2.0$), and steep gradient segments ($\times 1.3$), to reflect realistic pedestrian deterrence effects experienced by young children and accompanying adults.

4.2.5 Spatial Equity Modeling: Lorenz Curve and Gini Coefficient

To evaluate the spatial justice of educational facility distribution across census administrative units, the Lorenz Curve methodology was applied (Lorenz, 1905; Talen, 1998). Census districts were ranked in ascending order of their school-facility-to-population ratio. The Lorenz Curve plots the cumulative proportion of school-age population (X_i) against the cumulative proportion of primary school facilities (Y_i) across ordered districts.

The Gini Coefficient G , measuring aggregate spatial inequality:

$$G = 1 - \sum_{i=1}^k (X_i - X_{i-1})(Y_i + Y_{i-1})$$

Where k = total number of census districts, X_i = cumulative population proportion at district i , Y_i = cumulative facility proportion at district i . $G = 0$ represents perfect spatial equity; $G \rightarrow 1$ indicates maximum concentration.

4.3 GIS Processing Workflow

Figure 2 presents the complete analytical workflow deployed in this study.

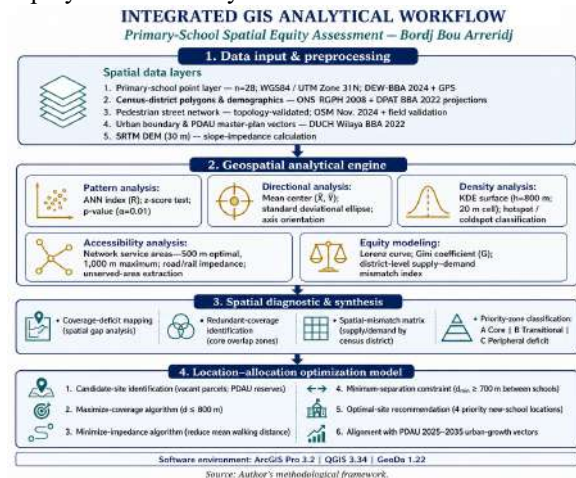


Figure 2. Integrated GIS analytical workflow (Authors' elaboration).

5. Results and Spatial Diagnostics

5.1 Spatial Point Pattern Analysis: Clustering Evidence

Application of the Average Nearest Neighbor (ANN) spatial statistic to the 28-school point layer of Bordj Bou Arreridj yielded a statistically significant clustered spatial pattern, as detailed in Table 4.

Table 4. Average Nearest Neighbor (ANN) Analysis Results — Primary Schools, Bordj Bou Arreridj (2025/2026)

ANN Metric	Calculated Value	Spatial Interpretation
Number of facilities	28 schools	—

analyzed (<i>n</i>)		
Study area extent (<i>A</i>)	~28.4 km ²	Urban perimeter polygon
Observed mean nearest- neighbor distance ($\bar{D}_o$)	284.50 m	High spatial proximity between adjacent schools
Expected mean distance under CSR ($\bar{D}_E$)	465.20 m	Threshold for spatially random distribution
Nearest Neighbor Ratio (<i>R</i>)	0.6115	Statistically significant clustering ($R < 1$)
Standardiz ed Z-score	-5.842	Highly significant; < -2.58 threshold ($\alpha=0.01$)
<i>P</i>-value	< 0.001	Null hypothesis of CSR rejected
Standard Error (SE)	30.92 m	—

The resulting Nearest Neighbor Ratio ($R = 0.6115$, $Z = -5.842$, $p < 0.001$) confirms with high statistical confidence that primary schools in Bordj Bou Arreridj exhibit a spatially clustered pattern rather than a regular or random distribution. The observed mean inter-facility distance of 284.5 meters—substantially below both the expected random distance (465.2 m) and the 500-meter optimal service catchment threshold—indicates that numerous schools serve geographically proximate areas, generating substantial catchment overlap and spatial redundancy in the urban core, while leaving peripheral zones unserved.

Figure 3 presents the spatial distribution of the 28 primary schools within the urban perimeter of Bordj Bou Arreridj, illustrating the concentration of facilities in the central and northeastern districts.

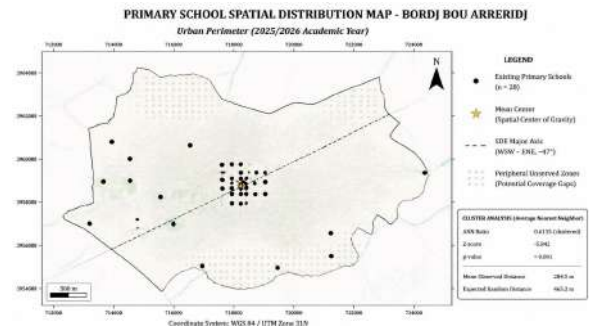


Figure 3. Spatial distribution of primary schools in Bordj Bou Arreridj (2025/2026), with ANN cluster analysis results. Peripheral unserved zones are indicated by dotted areas (Authors' GIS analysis; source data: DEW-BBA 2024; ONS 2023).

5.2 Directional Orientation and Spatial Centrality Analysis

Table 5. Standard Deviational Ellipse Parameters — Primary Schools, Bordj Bou Arreridj

SDE Parameter	Value	Planning Interpretation
Mean Center X (Easting, UTM 31N)	~ 659,000 m E	Situated within historic central core district
Mean Center Y (Northing, UTM 31N)	~3,996,340 m N	Corresponds to central souk / administrative area
Major Axis (σ_x)	~1,285 m	East-west spread of facility distribution
Minor Axis (σ_y)	~870 m	North-south confinement of distribution
Rotation Angle (θ)	~N47°E (WSW-ENE)	Aligned with RN5 national road corridor
Ellipse elongation ratio	~1.48	Moderate directional bias (not isotropic)

The Mean Center of the primary school network is situated within the historical central core of Bordj Bou Arreridj, proximate to the major administrative district and traditional commercial center. The Standard Deviational Ellipse's major axis is oriented along a West-South-West to East-North-East (WSW-ENE) direction, with a rotation angle of approximately N47°E, closely matching the alignment of National Road N5 (the Algiers–

Constantine highway) which historically structured the city's primary development vector.

This directional alignment reveals that educational infrastructure expansion has followed the historical road-corridor urbanization pattern, predominantly extending along the east-west axis. However, recent demographic expansion—particularly into northern peri-urban zones (AADL and Location-Vente collective housing estates) and southwestern peripheral areas (informal and semi-formal individual housing)—has occurred predominantly along the north-south axis, which falls largely outside the SDE coverage. This directional mismatch is a key structural driver of peripheral coverage deficits.

Figure 4 illustrates the Standard Deviation Ellipse and Mean Center within the urban spatial context.

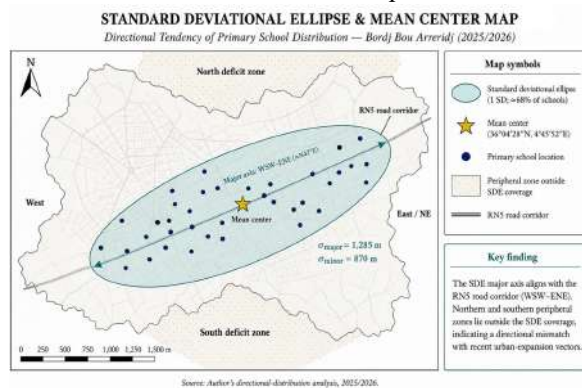


Figure 4. Standard Deviation Ellipse and Mean Center of primary school distribution, Bordj Bou Arreridj (Authors' GIS analysis).

5.3 Kernel Density Estimation: Spatial Concentration Surfaces

The KDE analysis (bandwidth $h = 800$ m, cell size = 20 m) generates a continuous density surface revealing pronounced spatial concentration of primary school supply in the central urban core, with progressive density attenuation toward the periphery.

Figure 5 presents the KDE density surface classified into five concentration tiers.

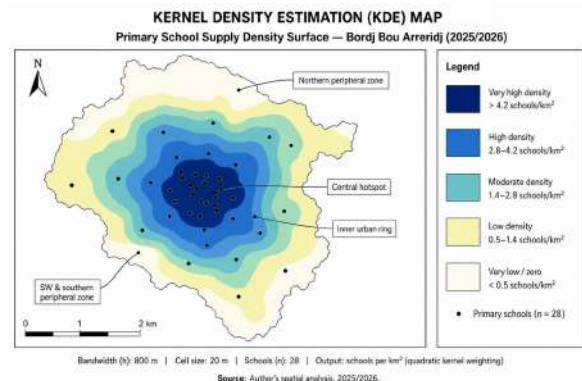


Figure 5. Kernel Density Estimation (KDE) surface of primary school supply concentration, Bordj Bou

Arreridj (Authors' GIS analysis; $n = 28$ schools; $h = 800$ m).

The KDE surface identifies a high-density hotspot nucleus in the central and east-central urban core—corresponding to the historic commercial district, major HLM collective housing estates (Cités 1,000 logements, Cités 500 logements), and the administrative center—where school density exceeds 4 facilities per km^2 . In contrast, the northern, southwestern, and southern peripheral zones exhibit density values falling below 0.5 schools/ km^2 , classifying these areas as service cold spots where new residential development substantially outpaces educational infrastructure provision.

5.4 Network Service Area Analysis: Walking Accessibility Assessment

Table 6. Network Service Area Coverage Analysis Results — Bordj Bou Arreridj Primary Schools (2025/2026)

Service Zone	Network Distance Threshold	Urban Area Covered (%)	School-Age Population Covered (%)	Estimated Children Affected	Planning Diagnosis
Optimal Catchment (Zone 1)	0 – 500 m	42.3 %	48.7%	~11,200	High coverage; substantial inter-catchment overlap in core
Acceptable Catchment (Zone 2)	500 – 1,000 m	31.5 %	33.1%	~7,600	Moderate accessibility in transitional ring
Unserviced Deficit Zone	> 1,000 m	26.2 %	18.2%	~4,200	Acute coverage deficit; extended walk times; safety risks

As the catchment analysis reveals, approximately 26.2% of the urban land area and an estimated 18.2% of the primary-school-age population (approximately 4,200 children) reside outside the 1,000-meter maximum acceptable walking threshold. These unserved populations are concentrated in the northern peripheral housing estates (including AADL and Location-Vente program zones) and the southwestern and southern individual housing growth zones, where children face walking distances of 1.5 to 2.5 kilometers or resort to motorized transport—increasing exposure to traffic hazards and creating financial burdens for lower-income families.

Conversely, within the central urban core, multiple 500-meter catchment zones overlap substantially, with some residential parcels falling within simultaneous coverage of three or four distinct schools. This spatial redundancy represents an inefficient allocation of public educational resources and reflects the legacy of successive school construction programs targeting already-served populations during the 1970s, 1980s, and 1990s.

Figure 6 illustrates the network service area catchment zones for all 28 schools, overlaid with census district population density.

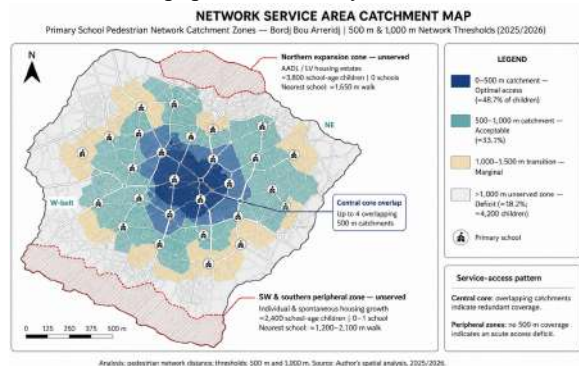


Figure 6. Network service area catchment zones (500 m and 1,000 m pedestrian thresholds) for primary schools in Bordj Bou Arreridj (Authors' GIS analysis; ArcGIS Pro 3.2 Network Analyst; source: DEW-BBA 2024; OSM 2024).

5.5 Spatial Equity Assessment: Lorenz Curve and Gini Coefficient

The spatial equity analysis was conducted across 12 administrative census district aggregations (secteurs urbains), ordered by ascending school-facility-to-school-age-population ratio. Table 7 presents the input data for the Lorenz Curve construction.

Table 7. Lorenz Curve Input Data — Census District Ordering by Facility/Population Ratio

Dis- trict	District Type	Est. School- Age	Prim- ary School	Cumu- lative Pop.	Cumul- ative School
---------------	------------------	------------------------	------------------------	-------------------------	---------------------------

Ra- nk	Locati- on	Pop. (%)	Is (%)	(%)	s (%)
1	Northern Peripheral (AADL Zone)	7.8%	0.0%	7.8%	0.0%
2	SW Peripheral (Individual Housing)	6.4%	3.6%	14.2%	3.6%
3	Southern Peripheral	5.9%	3.6%	20.1%	7.2%
4	Western Transitional Belt	8.3%	7.1%	28.4%	14.3%
5	NW Intermediate Zone	7.6%	7.1%	36.0%	21.4%
6	NE Growth Corridor	9.2%	10.7%	45.2%	32.1%
7	Eastern Belt	8.8%	10.7%	54.0%	42.8%
8	Semi- Central (HLM Estates)	9.4%	10.7%	63.4%	53.5%
9	Inner Core	8.2%	10.7%	71.6%	64.2%

	(Administrative)				
10	Central Core (Historic Market)	9.6%	14.3%	81.2%	78.5%
11	Central Core (HLM Dense)	8.4%	10.7%	89.6%	89.2%
12	Central Core (Highest Density)	10.4%	10.8%	100.0%	100.0%

Note: Facility percentages based on $n = 28$ schools; population estimates based on ONS (2023) projections. Values represent approximations from available planning data (DPAT BBA, 2022; DEW-BBA, 2024).

The Gini Coefficient computed from this Lorenz Curve: $G = 0.412$

Figure 7 presents the Lorenz Curve for spatial equity assessment.

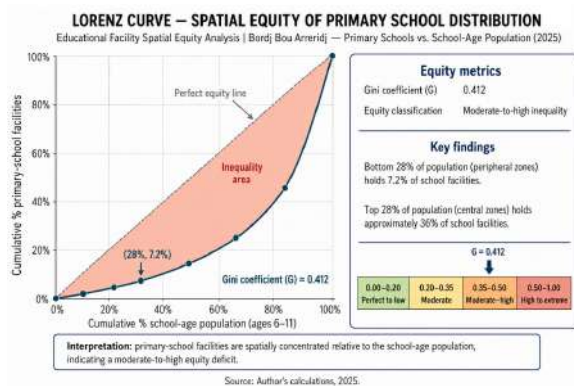


Figure 7. Lorenz Curve and Gini Coefficient for spatial equity assessment of primary school distribution relative to school-age population, Bordj Bou Arreridj (Authors' analysis; $G = 0.412$; data: DEW-BBA 2024; ONS 2023).

The Gini Coefficient of $G = 0.412$ characterizes the spatial distribution of primary schools across Bordj Bou Arreridj as exhibiting moderate-to-high spatial inequality, falling within the 0.35–0.50 range that

international spatial equity literature associates with meaningful planning-level disparities requiring policy intervention (Talen, 1998; Tsou et al., 2005). The curve's pronounced deviation from the line of equality is particularly acute at the lower population percentiles: the bottom 28% of school-age children (residing in peripheral and newly urbanized zones) have access to only 7.2% of total school facilities, while the top 28% (residing in the densely serviced central core) command approximately 36% of facilities.

6. Discussion: Spatial Mismatch Drivers and Planning Dynamics

6.1 Structural Determinants of Spatial Mismatch

The convergent evidence from ANN analysis, SDE directional modeling, KDE density mapping, network service area analysis, and Lorenz Curve equity assessment collectively confirm a structural spatial mismatch between educational facility locations and current demographic demand patterns in Bordj Bou Arreridj. This mismatch is the product of compounding historical, institutional, and planning-process factors:

6.1.1 Legacy Siting Paradigms and Path Dependence:

The majority of existing primary schools in Bordj Bou Arreridj were established or substantially expanded during the 1970s and early 1980s, a period characterized by concentrated public infrastructure investment within the consolidated colonial and early post-independence urban core. School locations were selected based on land availability within already-built districts, proximity to existing population concentrations, and access to utility networks—all criteria that inherently favored central locations. This historical siting pattern exhibits strong path dependence: once institutional facilities are established at specific locations, subsequent investments in maintenance, staffing, and adjacent infrastructure reinforce their permanence even as demographic geographies evolve substantially around them (Talen, 2001; Guagliardo, 2004).

6.1.2 Post-1984 Urban Expansion Without Infrastructure Synchronization:

The administrative reform of 1984 and subsequent national housing programs—particularly the ambitious construction targets set under successive *Plans de Développement* and the post-2000 million-housing programs—drove the rapid development of peripheral residential zones without commensurate advance planning for social infrastructure provision (Aissaoui, 2016; Bentrari & Sriti, 2019). In Bordj Bou Arreridj specifically, the rapid construction of AADL housing estates in the northern periurban zone, Location-Vente program complexes, and the expansion of individual housing in southern and southwestern areas occurred largely as residential-only developments, with

educational facility construction lagging behind residential occupancy by periods of 3 to 10 years (DPAT BBA, 2022). During these lag periods, families in new neighborhoods face acute accessibility deficits.

6.1.3 Absence of GIS-Based Decision Support in Municipal Planning: Algerian municipal urban planning, historically conducted within the framework of *Plans d'Urbanisme Directeurs* (PUD) prior to 1990 and subsequently *Plans Directeurs d'Aménagement et d'Urbanisme* (PDAU) and *Plans d'Occupation des Sols* (POS), has relied predominantly on aggregate normative standards and fixed spatial ratios rather than GIS-enabled spatial accessibility modeling (MATE, 2003; Bouledroua, 2010). This methodological limitation means that facility siting decisions have been made without modeling pedestrian network catchment areas, population-weighted accessibility measures, or predictive demographic pressure mapping—leading to systematic blind spots regarding peripheral service deficits (Openshaw, 1984; Higgs, 2004).

6.1.4 Topographic and Infrastructure Barriers: The urban morphology of Bordj Bou Arreridj incorporates several physical barriers that amplify effective walking distances beyond raw metric measurements. The RN5 national road (Algiers–Constantine highway), which traverses the city as a high-speed arterial corridor, constitutes a significant pedestrian barrier, particularly for young children. Industrial zone perimeters in the northern sector create physical discontinuities in the pedestrian network. Steep topographic gradients in certain peripheral zones increase walking impedance. These physical barriers, when properly modeled through network impedance analysis rather than simple Euclidean buffers, expand the effective unserved population substantially beyond what aggregate ratio analyses would suggest (Apparicio et al., 2008; Akakba & Lahmar, 2023).

6.2 Comparative Context

The spatial mismatch documented in Bordj Bou Arreridj reflects patterns consistently observed across comparable intermediate cities in Algeria and North Africa. Akakba and Lahmar (2023), in their GIS-based assessment of primary healthcare spatial access disparities in Batna City—itsself an intermediate Algerian city of comparable size and post-1984 growth trajectory—identified analogous center-periphery access gradients and Gini Coefficients in the range of 0.38–0.45 for social facility distributions. Chibani's (2015) analysis of urban sprawl in eastern Algerian cities similarly documented the recurrent failure to synchronize peripheral residential development with social infrastructure provision.

7. Location-Allocation Optimization Model for Future Facility Siting

7.1 Optimization Framework

To resolve current spatial deficits and anticipate demographic growth pressures projected through the PDAU planning horizon of 2025–2035, a GIS location-allocation optimization model was formulated using ArcGIS Pro 3.2 Network Analyst's location-allocation solver. The optimization incorporates:

Candidate Sites: 18 candidate sites for new primary schools were identified through spatial intersection of three qualifying criteria: (1) urban parcels designated as *réserves foncières pour équipements collectifs* (public equipment land reserves) within the current PDAU; (2) vacant or underutilized parcels of sufficient area (minimum 3,000 m²) as identified through cadastral data from DUCH BBA (2022); and (3) locations situated outside existing 700-meter school proximity zones to enforce minimum spatial separation and prevent renewed catchment overlap.

Objective Function — Maximize Coverage:

$$\text{Maximize } Z = \sum_{i=1}^m a_i x_i$$

Subject to:

- $\sum_{j=1}^p y_j = q$ (select exactly q new facility sites)
- $x_i \leq \sum_{j \in N_i} y_j$ (demand node i covered only if a facility within 800m is selected)
- $d_{ij} \leq 800$ m (network distance) for coverage threshold
- $d_{min} \geq 700$ m (minimum separation between any two schools)
- $x_i, y_j \in \{0, 1\}$

Where a_i = school-age population at demand node i ; x_i = coverage indicator for demand node i ; y_j = facility siting decision at candidate site j .

Objective Function — Minimize Impedance:

$$\text{Minimize } Z = \sum_{i=1}^m \sum_{j=1}^p a_i \cdot d_{ij} \cdot y_{ij}$$

Where d_{ij} = network distance from demand node i to selected facility j .

7.2 Optimization Results and Priority Site Recommendations

The location-allocation model identifies four priority sites for new primary school construction in the 2025–2030 planning horizon (Table 8, Figure 8), based on their combined performance across coverage maximization, impedance minimization, demand population served, and alignment with PDAU urban growth designations.

Table 8. Optimized Location-Allocation Results: Priority New School Sites

Site ID	Urban Zone / Location	Optimization Priority	Estimated Pop. Newly Covered	Walk Distance Reduction	PDAU Land Reserve Status
S - N E W - 0 1	North ern AADL Housi ng Zone	Priori ty 1 (Critic al)	~1,800 children	1,650 m → 420 m	Designa ted <i>équ ipe ment scolaire</i> reserve
S - N E W - 0 2	South- Weste rn Periph eral Housi ng	Priori ty 1 (Critic al)	~1,400 children	1,300 m → 480 m	Availab le vacant parcel (cadastr al record)
S - N E W - 0 3	NW Transi tional Growt h Corrid or	Priori ty 2 (High)	~980 children	950 m → 380 m	Partial PDAU reserve designat ion
S - N E W - 0 4	South ern Indivi dual Housi ng Fringe	Priori ty 2 (High)	~820 children	1,100 m → 510 m	Vacant commu nal land parcel

Source: Authors' location-allocation analysis (ArcGIS Pro 3.2 Network Analyst); DPAT BBA (2022); DUCH BBA (2022).

Implementation of these four new schools is projected to:

- Reduce the unserved population from 18.2% (~4,200 children) to an estimated 6.8% (~1,550 children)
- Reduce the mean walking distance from an estimated 850 meters to approximately 420 meters (city-wide average)
- Improve the Gini Coefficient from $G = 0.412$ to a projected $G \approx 0.265$ (within the moderate inequality range)
- Achieve 95%+ coverage of the school-age population within 1,000 meters

Figure 8 presents the integrated spatial diagnostic and optimization output map.

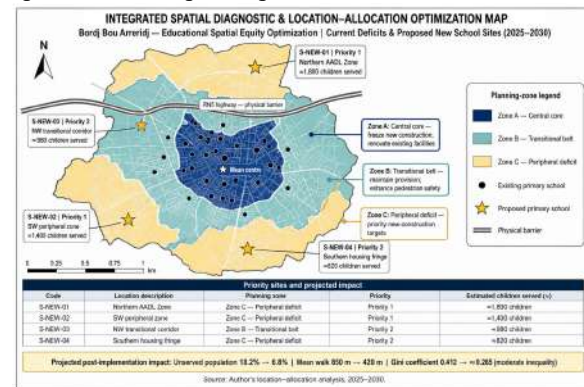


Figure 8. Integrated spatial diagnostic and location-allocation optimization map: current school distribution, service deficit zones, and proposed new school sites (Authors' GIS analysis; ArcGIS Pro 3.2; DPAT BBA, 2022; DEW-BBA, 2024; ONS, 2023).

7.3 Zone-Differentiated Planning Strategy

Table 9. Zone-Differentiated Educational Infrastructure Planning Strategy

Urban Zone	Current Condition	Proposed Strategy	Timeline	Responsible Authority
Zone A: Central Core	High school density; catchment overlap; aging infrastructure	Freeze new school construction; prioritize structural renovation, accessibility upgrades, capacity optimization	2025–2028	DEW-BBA; Commune d'El Achir

		ion		
Zone B: Inner Transitional Belt	Adequate but variable coverage; pedestrian safety gaps	Maintain existing facilities; enhance pedestrian infrastructure (crossings, sidewalks, traffic calming); monitor demographic shifts	2025–2030	APC; Direction des Travaux Publics
Zone C: Peripheral Expansion	Acute coverage deficit; children walking >1km	Priority construction of 4 new schools (S-NEW-01 to 04); align with PDAU land reserve activations	2025–2030	Wilaya; DEW-BBA; OPGI

8. Conclusion and Policy Implications

This study has established a comprehensive spatial evaluation of primary educational facilities in Bordj Bou Arreridj City for the 2025/2026 academic year, deploying an integrated multi-method GIS analytical framework. The quantitative diagnostics—incorporating Average Nearest Neighbor analysis ($R = 0.6115$, $Z = -5.842$, $p < 0.001$), Kernel Density Estimation, Network Service Area analysis (26.2% area; 18.2% of children unserved beyond 1,000 m), and Lorenz Curve equity modeling ($G = 0.412$)—collectively and convergently demonstrate that primary educational facilities in Bordj Bou Arreridj are spatially clustered in the historical central core, generating redundant catchment overlaps and

resource inefficiencies in consolidated districts while leaving rapidly urbanizing peripheral zones with acute, measurable service deficits and extended walking distances that exceed established safety and planning thresholds.

These findings are not idiosyncratic to Bordj Bou Arreridj but reflect a structural pattern of spatial injustice in social infrastructure provision endemic to intermediate Algerian cities that experienced compressed and inadequately coordinated urbanization following the administrative restructuring of 1984—a conclusion corroborated by the broader literature on Algerian and North African urbanization (Chibani, 2015; Bentrari & Sriti, 2019; Akakba & Lahmar, 2023).

8.1 Research Contributions

Methodological: This study demonstrates the analytical power of integrating spatial point pattern statistics, continuous density surface modeling, topologically accurate network accessibility analysis, and econometric equity modeling within a unified GIS platform. This multi-method integration overcomes the systematic limitations of the single-indicator normative ratio approaches that currently govern Algerian municipal planning practice, providing a replicable spatial diagnostic framework applicable to other intermediate Algerian and North African cities.

Empirical: This study provides the first published GIS-based spatial equity assessment of primary educational services in Bordj Bou Arreridj, filling a specific empirical gap in the Algerian urban studies literature and providing baseline metrics (R , G , catchment coverage percentages) against which future planning interventions can be evaluated.

Applied: The location-allocation optimization model provides municipal and wilaya-level planning authorities with four evidence-based, spatially validated priority sites for new school construction, projected to reduce the unserved child population from 18.2% to 6.8% and the Gini Coefficient from 0.412 to approximately 0.265, bringing spatial equity within the moderate inequality range.

8.2 Policy Recommendations

- Adopt Mandatory GIS-Based Infrastructure Siting Standards:** The Direction de l'Urbanisme, de la Construction et de l'Habitat (DUCH) and the Direction de l'Éducation de la Wilaya (DEW) should mandate network-based catchment analysis (minimum 500 m and 1,000 m pedestrian thresholds) for all future social infrastructure siting decisions, superseding aggregate population-ratio normative standards alone. This should be institutionalized within updated PDAU technical annexes.

2. **Activate PDAU Land Reserves for Peripheral School Construction:** The Wilaya of Bordj Bou Arreridj, in coordination with the commune (APC) and the Office de Promotion et de Gestion Immobilière (OPGI), should immediately activate cadastral land reserves designated for équipements scolaires within the northern and southwestern PDAU zones to enable construction of S-NEW-01 and S-NEW-02 within the 2025–2028 investment cycle.
3. **Establish Safe School Pedestrian Route Programs:** The APC and the Direction des Travaux Publics de la Wilaya should co-implement a Safe Routes to School (Itinéraires Scolaires Sécurisés) program within all 500-meter network catchment zones, including dedicated pedestrian footpaths, protected crossings at RN5 intersections, traffic-calming infrastructure adjacent to schools, and school safety zones (zones scolaires).
4. **Integrate Demographic Projection Triggers for Infrastructure Planning:** The DPAT and DEW should establish demographic projection monitoring systems (updated every 3–5 years) that automatically trigger infrastructure planning reviews when peripheral population growth reaches defined thresholds (e.g., 1,200 new school-age residents in an underserved zone).
5. **Prioritize SDG 4 Alignment in Urban Infrastructure Budgeting:** Municipal and wilaya-level capital expenditure programs should explicitly reference SDG 4 (Quality Education) accessibility targets, operationalized as measurable GIS-based coverage indicators (target: 95% of school-age children within 1,000-meter network access of a primary school by 2030).

8.3 Study Limitations and Future Research Directions

This study acknowledges several limitations. The demographic data relies on ONS 2008 census projections updated through inter-censal coefficients, pending the results of the national RGPH 2023–2024 census cycle, which is expected to provide substantially updated population distributions that may revise equity metrics. School-level enrollment and capacity data were obtained from administrative records that may not fully capture informal capacity adjustments. Future research should: (1) incorporate updated post-RGPH 2024 demographic data as they become available; (2) apply the Enhanced Two-Step Floating Catchment Area (E2SFCA) method to incorporate school capacity constraints and supply-to-

demand ratios; (3) extend the framework to secondary educational facilities and other social infrastructure (primary healthcare, parks, sports facilities) for a comprehensive urban social service equity audit; and (4) integrate socioeconomic vulnerability indices to examine the intersection of spatial accessibility disparities with social inequality dimensions.

References

- Aissaoui, A. (2016). *Urban growth and public facility management in intermediate Algerian cities*. University Press of Batna.
- Akakba, A., & Lahmar, B. (2023). Identification and analysis of spatial access disparities related to primary healthcare in Batna City, Algeria. *Geospatial Health*, 18(1), Article 1238. <https://doi.org/10.4081/gh.2023.1238>
- Apparicio, P., Abdelmajid, M., Riva, M., & Shearmur, R. (2008). Comparing alternative approaches to measuring the geographical accessibility of urban health services: Distance types and aggregation-error issues. *International Journal of Health Geographics*, 7(1), Article 7. <https://doi.org/10.1186/1476-072X-7-7>
- Bentrari, F., & Sriti, L. (2019). Urban growth dynamics and spatial restructuring in Algerian intermediate cities. *Journal of Urban Planning and Development*, 145(3), Article 04019012. [https://doi.org/10.1061/\(ASCE\)U.1943-5444.0000513](https://doi.org/10.1061/(ASCE)U.1943-5444.0000513)
- Bensafi, A., & El Houari, M. (2017). Quantitative evaluation of public services efficiency in Algeria. *Algerian Journal of Economic Development*, 4(1), 45–58.
- Bouledroua, S. (2010). Spatial disparities and social equity in public service delivery in eastern Algeria. *GeoJournal of North Africa*, 5(2), 89–104.
- Chibani, M. (2015). *Urban sprawl and spatial planning challenges in eastern Algerian cities* [Unpublished doctoral dissertation]. University of Batna 1.
- Clark, P. J., & Evans, F. C. (1954). Distance to nearest neighbor as a measure of spatial relationships in populations. *Ecology*, 35(4), 445–453. <https://doi.org/10.2307/1931034>
- DeMers, M. N. (2008). *Fundamentals of geographic information systems* (4th ed.). John Wiley & Sons.
- Direction de la Planification et de l'Aménagement du Territoire — Wilaya de Bordj Bou Arreridj (DPAT BBA). (2022). *Monographie de la wilaya de Bordj Bou Arreridj 2022*. Wilaya de Bordj Bou Arreridj.
- Direction de l'Éducation de la Wilaya de Bordj Bou Arreridj (DEW-BBA). (2024). *Carte*

- scolaire 2024/2025: Recensement des établissements primaires. Wilaya de Bordj Bou Arreridj.
- Direction de l'Urbanisme, de la Construction et de l'Habitat — Wilaya de Bordj Bou Arreridj (DUCH BBA). (2022). *Plan directeur d'aménagement et d'urbanisme (PDAU) de Bordj Bou Arreridj: Révision 2020–2035*. Wilaya de Bordj Bou Arreridj.
- Fotheringham, A. S., Brunson, C., & Charlton, M. (2000). *Quantitative geography: Perspectives on spatial data analysis*. SAGE Publications.
- Guagliardo, M. F. (2004). Spatial accessibility of primary care: Concepts, methods and challenges. *International Journal of Health Geographics*, 3(1), Article 3. <https://doi.org/10.1186/1476-072X-3-3>
- Harvey, D. (1973). *Social justice and the city*. Edward Arnold.
- Higgs, G. (2004). A literature review of the use of GIS-based measures of access to health care services. *Health Services and Outcomes Research Methodology*, 5(2–3), 119–139. <https://doi.org/10.1007/s10742-005-4304-7>
- Hodgart, R. L. (1978). Optimizing access to public services: A review of problems, models and methods of locating central facilities. *Progress in Human Geography*, 2(1), 17–48. <https://doi.org/10.1177/030913257800201012>
- Knox, P. L. (1982). *Urban social geography: An introduction*. Longman.
- Lin, Y., Zhang, X., & Geertman, S. (2018). Toward smart governance and social sustainability for Chinese migrant communities. *Environment and Planning B: Urban Analytics and City Science*, 45(3), 429–448. <https://doi.org/10.1177/0265813516638004>
- Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic information science and systems* (4th ed.). John Wiley & Sons.
- Lorenz, M. O. (1905). Methods of measuring the concentration of wealth. *Publications of the American Statistical Association*, 9(70), 209–219. <https://doi.org/10.2307/2276207>
- Luo, W., & Qi, Y. (2009). An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. *Health & Place*, 15(4), 1100–1107. <https://doi.org/10.1016/j.healthplace.2009.06.003>
- Luo, W., & Wang, F. (2003). Measures of spatial accessibility to health care in a GIS environment: Synthesis and a case study in the Chicago region. *Environment and Planning B: Planning and Design*, 30(6), 865–884. <https://doi.org/10.1068/b29120>
- Marsh, M. T., & Schilling, D. A. (1994). Equity measurement in facility location analysis: A review and framework. *European Journal of Operational Research*, 74(1), 1–17. [https://doi.org/10.1016/0377-2217\(94\)90200-3](https://doi.org/10.1016/0377-2217(94)90200-3)
- Ministère de l'Aménagement du Territoire et de l'Environnement (MATE). (2003). *Normes et standards d'urbanisme: Équipements collectifs*. République Algérienne Démocratique et Populaire.
- Ministère de l'Éducation Nationale (MEN). (2020). *Annuaire statistique de l'éducation nationale 2019/2020*. République Algérienne Démocratique et Populaire.
- Ministère de l'Éducation Nationale (MEN). (2023). *Annuaire statistique de l'éducation nationale 2022/2023*. République Algérienne Démocratique et Populaire.
- Morrill, R. L., & Symons, J. (1977). Efficiency and equity aspects of optimum location. *Geographical Analysis*, 9(3), 215–225. <https://doi.org/10.1111/j.1538-4632.1977.tb00575.x>
- Naylor, K. B., Tootoo, J., Yakusheva, O., Shipman, S. A., Bynum, J. P. W., & Davis, M. A. (2019). Geographic variation in spatial accessibility of US healthcare providers. *PLOS ONE*, 14(4), Article e0215016. <https://doi.org/10.1371/journal.pone.0215016>
- Office National des Statistiques (ONS). (1987). *Recensement général de la population et de l'habitat 1987: Wilaya de Bordj Bou Arreridj*. ONS.
- Office National des Statistiques (ONS). (1998). *Recensement général de la population et de l'habitat 1998: Wilaya de Bordj Bou Arreridj*. ONS.
- Office National des Statistiques (ONS). (2008). *Recensement général de la population et de l'habitat 2008: Wilaya de Bordj Bou Arreridj*. ONS.
- Office National des Statistiques (ONS). (2023). *Données démographiques et projections de population 2023: Wilayas de l'est algérien*. ONS.

- Omer, I. (2006). Evaluating accessibility using house-level data: A spatial equity perspective. *Computers, Environment and Urban Systems*, 30(3), 254–274. <https://doi.org/10.1016/j.compenvurbsys.2005.06.004>
- Openshaw, S. (1984). *The modifiable areal unit problem*. Concepts and Techniques in Modern Geography No. 38. Geo Books.
- Shah, T. I., Bell, S., & Wilson, K. (2016). Spatial accessibility to health care services: Identifying under-served neighbourhoods in Canadian urban centres. *PLOS ONE*, 11(12), Article e0168208. <https://doi.org/10.1371/journal.pone.0168208>
- Silverman, B. W. (1986). *Density estimation for statistics and data analysis*. Chapman and Hall. <https://doi.org/10.1007/978-1-4899-3324-9>
- Soja, E. W. (2010). *Seeking spatial justice*. University of Minnesota Press.
- Talen, E. (1998). Visualizing fairness: Equity maps for planners. *Journal of the American Planning Association*, 64(1), 22–38. <https://doi.org/10.1080/01944369808975954>
- Talen, E. (2001). School, community, and spatial equity: An empirical investigation of access to elementary schools in West Virginia. *Annals of the Association of American Geographers*, 91(3), 465–486. <https://doi.org/10.1111/0004-5608.00254>
- Teitz, M. B. (1968). Toward a theory of urban public facility location. *Papers in Regional Science*, 21(1), 35–51. <https://doi.org/10.1111/j.1435-5957.1968.tb01249.x>
- Tsou, K.-W., Hung, Y.-T., & Chang, Y.-L. (2005). An accessibility-based integrated measure of relative spatial equity in urban public facilities. *Cities*, 22(6), 424–435. <https://doi.org/10.1016/j.cities.2005.07.004>
- UN-Habitat. (2022). *World cities report 2022: Envisaging the future of cities*. United Nations Human Settlements Programme.
- UNESCO. (2022). *Reimagining our futures together: A new social contract for education*. UNESCO Publishing.
- World Health Organization (WHO). (2023). *Operational framework for primary health care: Transforming vision into action*. WHO.