

Functional hierarchy using GIS: Diagnosis and traffic regulation solutions in Batna City (Northeastern Algeria)

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Abstract:

Introduction/purpose: The city of Batna in northeastern Algeria has experienced rapid population expansion. This growth has intensified mobility needs and placed significant pressure on a limited and aging road network. Congestion now affects the main urban corridors and central districts. The study aims to diagnose these dysfunctions and propose a strategic framework for improving traffic circulation. It also evaluates the effectiveness of GIS-based spatial analysis for urban mobility planning.

Methods: The research uses Geographic Information Systems and satellite imagery to analyze Batna's transportation system. The study area covers

primary and secondary road axes within the urban core. Data include topographic maps, demographic layers, land use, and field observations. ArcGIS tools were applied to identify congestion hotspots, measure network accessibility, evaluate hierarchy consistency, and model current and future mobility scenarios.

Results: The results reveal recurrent congestion along Avenue de l'Indépendance, Route de Biskra, and the northern ring road. Several intersections show saturation levels exceeding functional thresholds. The analysis highlights structural discontinuities, insufficient road widths, and poorly connected radial axes. Spatial correlations indicate that high-density zones and commercial clusters strongly influence traffic bottlenecks. The maps produced reveal gaps in east-west connectivity and limited alternatives for bypassing the city center.

Conclusion: The findings support a set of targeted interventions, including new link roads, optimized junctions, and redistribution of traffic flows. The results confirm that GIS enhances diagnostic accuracy and supports evidence-based planning. The proposed framework offers a scalable method for improving mobility in rapidly urbanizing cities. The study demonstrates that integrating spatial modeling with strategic planning leads to more resilient and adaptive transportation systems aligned with sustainable development goals.

Key words: urban road network, functional hierarchy, traffic regulation, GIS analysis, Batna, Algeria.

Introduction

The socio-economic dynamics of Batna, Algeria, have spurred rapid urban expansion driven by population growth, intensified economic activities, and the city's strategic geographical position (Tout, 2024). This expansion presents two contrasting trends. On one hand, Batna has retained its historic core and central urban fabric, underscoring its cultural and administrative significance. On the other hand, the emergence of new mobility patterns, most notably the increasing dependence on private vehicles, has profoundly reshaped travel behavior and intensified pressure on existing transport infrastructure.

Despite these transformations, the city's road network has not developed in parallel. As one approaches the city center, urban infrastructure becomes progressively insufficient to accommodate the growing volume of motorised traffic. The concentration of commercial, administrative, and service activities within the core area generates heavy traffic flows, leading to recurrent congestion and inefficiencies, especially during peak hours. These conditions strain mobility, reduce accessibility, and diminish residents' quality of life (Faheem, 2024).

This disparity between evolving mobility demands and the limited capacity of the road network underscores the urgent need for data-informed planning and intervention. Conventional traffic management strategies have proven inadequate to address these complex challenges effectively. Consequently, this study explores the use of geomatics tools, particularly Geographic Information Systems (GIS) and remote sensing, to develop an integrated and evidence-based framework for analysis. By leveraging these tools, the research aims to classify, assess, and optimise Batna's road network to mitigate congestion and promote sustainable urban mobility.

The primary objective is to apply ArcGIS-based analysis to establish a functional classification of the city's road network. This classification will not only differentiate roads according to their capacity and function but also pinpoint critical areas requiring intervention. The resulting framework will support the efficient management of traffic flows and guide the strategic planning of future infrastructure development (Metz, 2024).

Geomatics and remote sensing technologies offer distinctive advantages in addressing these urban challenges. They facilitate the integration of heterogeneous datasets such as population density, traffic intensity, and land use into a unified analytical environment (Khiredine & Aichour, 2022). This integration enables evidence-based decision-making, allowing planners to design targeted, equitable, and environmentally sustainable mobility solutions. Furthermore, GIS methods provide powerful visual and analytical representations of traffic dynamics, congestion hotspots, and the hierarchical structure of road systems, enhancing both diagnosis and planning capabilities.

The analysis of Batna's road network thus serves as a case study illustrating the potential of GIS-driven methodologies for addressing urban mobility issues. By focusing on the specific context of Batna, this research contributes to a broader understanding of how integrated spatial analyses can foster resilient, efficient, and sustainable transportation systems in rapidly expanding urban environments.

Materials and methods

Overview of the study area

The city of Batna, acknowledged as both the capital of the Aurès region and the administrative center of the Wilaya of Batna, occupies a pivotal position within eastern Algeria. Situated approximately 435 kilometers southeast of Algiers and 113 kilometers southwest of Constantine, the city extends over a total area of 11.641 hectares. Its

geographical configuration places it at the heart of the northeastern part of the wilaya, where it stands at the junction of major regional and national transportation corridors linking Constantine, Biskra, and Khenchela. This advantageous location has historically fostered Batna's emergence as a strategic urban center and a hub of socio-economic interaction in the Aurès.

Geographically, Batna's coordinates range from $6^{\circ}7'59''$ to $6^{\circ}13'31''$ East Longitude and $35^{\circ}31'26''$ to $35^{\circ}34'23''$ North Latitude, with an average altitude of 1.040 meters above sea level. Its elevated topography, combined with its centrality in the regional landscape, enhances its climatic distinctiveness and strengthens its function as a key crossroads within Algeria's transportation network. The city's strategic importance is further emphasized by its integration into two major infrastructural axes that structure the national transport framework:

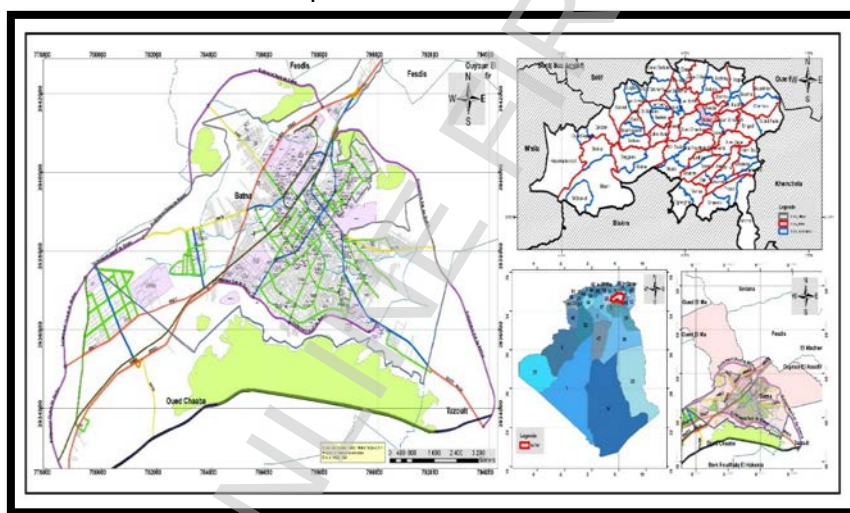


Figure 1 - Map 1, overview of the study area

The North–South corridor, which consolidates connectivity between Algeria's northern coastal regions and the southern arid zones; and the East–West axis, which traverses the high plateaus, ensuring continuity and accessibility between the eastern and western territories of the country.

Through this dual orientation, Batna plays a crucial role in regional and national mobility, serving as both a gateway for economic exchange and a vector of territorial cohesion. Its positioning within this multidirectional transport system makes it a focal point for infrastructure planning, urban development, and traffic management policies.

Population

The demographic expansion of the city of Batna mirrors a broader trend affecting numerous Algerian urban centers, reflecting the combined effects of natural growth, rural–urban migration, and inter-wilaya mobility. Together, these forces have profoundly reconfigured the city's population dynamics and urban morphology over recent decades.

A primary driver of this expansion is the natural increase in population, resulting from a persistently high birth rate and notable improvements in public health services, which have contributed to a marked decline in mortality rates. This demographic context has sustained continuous population growth, fostering both spatial and social transformations within the urban fabric.

In addition, Batna experienced a significant influx of rural migrants during the period of rural exodus, particularly throughout Algeria's "black decade" of the 1990s. In this era of sociopolitical turmoil and rural insecurity, many individuals and families sought refuge in relatively stable urban centers such as Batna. The city's perceived safety, coupled with better access to essential services, employment, and educational infrastructure, reinforced its attractiveness as a destination for internal migration (Aicha, 2022).

A further dimension of Batna's demographic evolution is inter-wilaya migration, driven by the pursuit of enhanced economic opportunities, academic institutions, and living conditions. Batna's strategic geographic position at the intersection of major economic and administrative axes has consolidated its status as a regional magnet for population movements, intensifying its urban growth (Pisarevskaya & Scholten, 2022).

Collectively, these interacting demographic forces have produced a complex pattern of urban expansion, leading to accelerated urbanization and mounting pressure on infrastructure systems, particularly the road and transport networks. A comprehensive understanding of these dynamics is therefore essential for urban planners and policymakers, as it underpins the formulation of sustainable development strategies, infrastructure enhancement programs, and effective mobility and traffic management frameworks.

Population density

Population density constitutes a fundamental indicator of urban balance and service efficiency, particularly in relation to traffic management and mobility planning. Variations in density—whether excessive, uneven or insufficient—have a direct impact on traffic

circulation, infrastructure demand, and the overall performance of urban systems. In the case of Batna, the close interdependence between population concentration and mobility patterns reveals the complexity of the city's traffic and transport challenges.

High-density areas tend to generate significant mobility needs, as they usually coincide with the concentration of residential, economic, administrative, and social functions. These overlapping activities intensify congestion during peak hours, placing considerable pressure on the existing road infrastructure and public transport systems. In contrast, low-density zones often suffer from limited accessibility and the underutilization of transport facilities, which undermines the efficiency and integration of the overall urban network.

In Batna, the population is distributed across ten distinct urban sectors, each characterized by specific density profiles and spatial arrangements. These range from highly compact central districts—such as Bouakal and the city's traditional core—to more dispersed peripheral sectors like Bouzourane and the Tazoult Road area. For instance, Bouakal, with an estimated density of around 310 inhabitants per hectare, exemplifies zones with intense mobility demand and high pressure on public services. Conversely, ZHUN II, where the density reaches only 47 inhabitants per hectare, reflects a fragmented settlement pattern marked by issues of connectivity, accessibility, and service provision.

The table below presents the detailed distribution of population density across Batna's ten sectors, providing a clear overview of the spatial disparities that shape mobility dynamics and guide infrastructure planning within the city.

The variation in population density across Batna's urban sectors underscores the complexity of traffic management and road network planning within the city. In high-density areas, targeted interventions such as increasing road capacity, establishing dedicated public transport lanes and implementing advanced traffic flow optimization systems are essential to mitigate congestion and enhance overall mobility performance. Conversely, low-density sectors call for improved connectivity through the development of secondary and feeder roads, ensuring equitable access to essential services and economic opportunities.

Addressing these disparities necessitates a comprehensive and sector-specific planning approach that integrates population density analysis with the functional classification of the road network (Kalla, 2015). Such an integrated framework enables the urban mobility system to respond effectively to the distinct needs of each sector, thereby enhancing



traffic efficiency, accessibility, and the long-term resilience of Batna's urban structure (Ben Yahia, 2023).

Table 1- Distribution of population density across Batna's urban sectors

Sector	Population (2010)	Density (Hab/ha)	Area (ha)	Classification by sector
Downtown	22.057	98	225.52	05
Traditional neighborhoods	32.914	293	112.26	02
Bouakal	66.180	310	223.33	01
Kechida	42.647	122	349.19	04
Feeding area	46.377	106	437.40	07
Bouzourane	12.015	50	239.83	09
Shouhada	25.800	181	142.88	03
Route of Tazoult	36.560	157	282.85	10
ZHUN I	31.589	96	330.77	06
ZHUN II	20.800	47	403.79	08

Population evolution and forecasts

The city of Batna, like many other major Algerian urban centers, has undergone remarkable population growth over recent decades. This rapid demographic expansion has profoundly influenced the city's spatial equilibrium and the quality of urban services, particularly those related to mobility and traffic management. The increasing population has exerted growing pressure on Batna's road infrastructure, often surpassing its design capacity and generating considerable challenges in meeting escalating transport demands.

An examination of population density patterns, as illustrated in the map below, reveals a pronounced spatial imbalance among the city's sectors. While certain districts such as Bouakal and other historic neighborhoods record densities exceeding 70.000 inhabitants, others, including Bouzourane and the industrial zone, remain sparsely populated.

This uneven distribution presents a dual challenge for urban planners: high-density areas experience recurrent congestion and infrastructure strain, whereas low-density sectors suffer from weak connectivity and underutilized resources.

Population trends and forecast data underscore these spatial disparities and their implications for urban mobility. As Batna's population grows, such imbalances are expected to intensify, heightening the need for targeted interventions that ensure equitable access to transportation and urban services. The spatial analysis highlights the necessity of sector-

specific strategies where densely populated zones require expanded infrastructure and enhanced public transport, while peripheral areas demand improved connectivity through feeder and collector roads.

To effectively manage these challenges, a data-driven and forward-looking approach to urban and mobility planning is essential. Incorporating demographic projections into road network classification and management enables planners to design a transport system capable of balancing mobility needs across the city. In this context, high-density sectors should prioritize the development of mass transit systems, congestion mitigation measures, and pedestrian-friendly zones, whereas low-density sectors should focus on improving accessibility via secondary and connecting roads.

By addressing these disparities through integrated planning, the city of Batna can foster a resilient, efficient, and equitable urban mobility system that supports sustainable growth and enhances the overall quality of life for its residents. Moreover, by integrating demographic trends into the planning of future road networks, this approach provides a solid basis for developing a city that is not only well connected but also capable of adapting to the evolving challenges of urban growth and transformation.

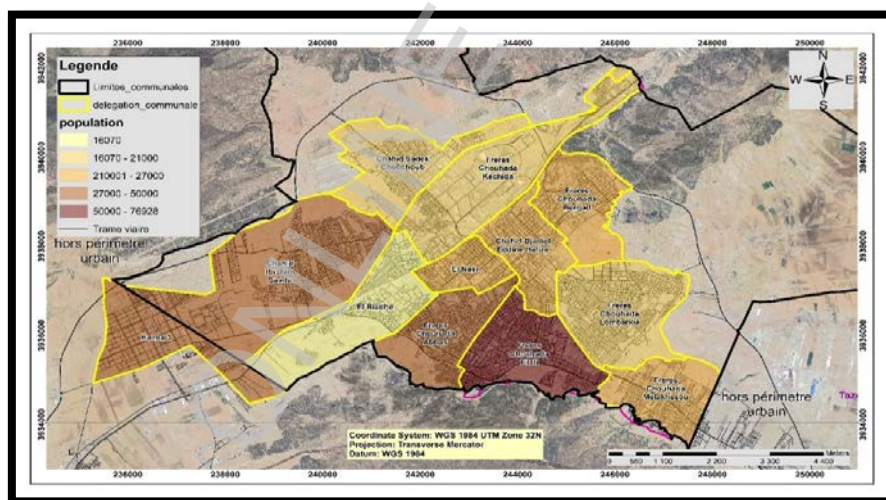


Figure 2 - Map 2, distribution of the population by sector

Urban roads

The road infrastructure of the city of Batna has been developed to accommodate a broad spectrum of traffic demands, addressing both local mobility requirements and regional transportation flows. This dual

functionality stems from Batna's strategic geographical position at the intersection of two major national transportation corridors: RN3, a key north–south axis, and RN31, which ensures east–west connectivity across the highlands. Together, these routes establish Batna as a vital hub for economic exchange, trade, and goods and people throughout Algeria.

City bypasses

Bypasses are designed to divert regional and long-distance traffic away from the congested urban core. They facilitate smoother transit around the city, thereby reducing inner-city congestion and preventing heavy freight vehicles and through-traffic from disrupting local mobility. However, their effectiveness is often constrained by factors such as limited access points, inadequate maintenance, and insufficient integration with the inner urban road network. Enhancing these aspects is crucial to ensure that bypasses fully achieve their decongestion and connectivity objectives.

Urban routes (local road network)

This component of Batna's infrastructure supports intra-urban mobility, linking residential neighborhoods with commercial, industrial, and administrative areas, thus forming the backbone of daily urban activity. These routes must balance multiple demands, including pedestrian circulation, public transport operations, and private vehicle use. Such complexity frequently results in congestion, particularly in high-density zones and during peak travel periods. The efficiency of these routes is further strained by the city's rapid demographic and spatial expansion, which continually amplifies mobility demand.

Challenges and planning perspectives

Despite its strategic layout, Batna's road network faces several structural and operational challenges that undermine its overall performance. Rising traffic volumes, insufficient coordination between bypasses and urban routes, and the absence of intelligent traffic management systems have led to recurrent bottlenecks and travel delays (Efrat, 2024). Additionally, ongoing urban sprawl has intensified pressure on existing infrastructure, underscoring the urgent need for targeted upgrades and adaptive planning.

Addressing these challenges requires a comprehensive and integrated planning approach that harmonizes the functions of bypasses and urban routes within a unified mobility framework. Investments in Intelligent Transport Systems (ITS), systematic road maintenance, and the strategic extension of bypass infrastructure could substantially enhance

the network's capacity to accommodate both local and regional traffic flows. Moreover, implementing a hierarchical road classification system would help prioritize interventions, ensuring that each road category effectively fulfills its designated role. By reinforcing the synergy between bypasses and urban routes, Batna can develop a resilient, efficient, and adaptive road network—one capable of responding to present mobility demands while anticipating future urban growth.

Classification of urban roads

a. Administrative classification of urban roads

The classification of urban roads constitutes a fundamental component of urban mobility planning, offering a structured framework for the organization and management of road networks. In the case of Batna, urban roads are classified according to two main criteria, ensuring a clear understanding of their design, function, and administrative jurisdiction.

1. Technical criterion

Motorways: High-capacity roads designed for long-distance travel, featuring controlled access points and minimal intersections. They facilitate the rapid and uninterrupted movement of heavy traffic between major cities and regions.

Expressways: Similar in function to motorways but primarily serving urban and peri-urban areas. They accommodate substantial traffic volumes over shorter distances, ensuring efficient connectivity between key urban zones.

2. Administrative and legal criterion

This classification is based on the governance structure and legal jurisdiction under which roads operate, clarifying responsibilities for their management and maintenance. Roads are thus classified into:

Highways: Managed at the national level, connecting major cities and forming the backbone of inter-regional transport.

Urban Highways: Designed for high-speed traffic within city limits, providing seamless links between the urban core and peripheral areas.

National Roads (NR): Connecting Batna to neighboring wilayas, these roads serve both regional and urban transport functions.

Wilaya Roads (WR): Secondary routes linking smaller towns and rural areas to Batna, playing a crucial role in regional accessibility.



Municipal Roads (MR): Local roads serving neighborhoods and districts, facilitating everyday mobility and access to essential services within the city.

The spatial distribution and hierarchy of these road types are illustrated in Map N°3, which depicts how each category integrates into Batna's overall transport network, emphasizing the interaction between technical functionality and administrative jurisdiction.

3. Significance and implications

This dual classification system is vital for effective traffic management and strategic urban planning. Motorways and expressways are prioritized for intercity and high-speed mobility, thereby reducing congestion and enhancing regional connectivity (Wang, 2024). Conversely, Wilaya and municipal roads meet local mobility needs, ensuring equitable access to services and improving residents' quality of life. The integration of Geographic Information Systems (GIS) into this framework enables planners to identify congestion points, optimize traffic circulation, and prioritize road maintenance activities. Through these tools, Batna can develop a resilient, adaptive transport system capable of meeting current demands while accommodating future urban growth. This classification not only establishes an organizational structure for the city's roads but also serves as a strategic basis for implementing targeted interventions aligned with Batna's socio-economic and mobility objectives.

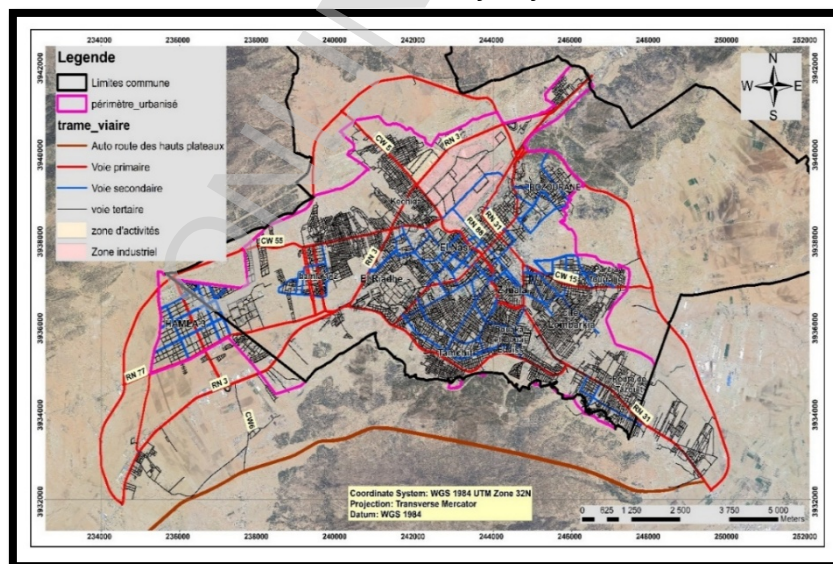


Figure 3 – Map 3, urban roads classification 1



b. Functional classification of urban roads

The functional classification of road networks is a critical planning tool that categorizes streets based on their purpose, traffic volume, and connectivity within the urban structure. In Batna, the network can be broadly divided into three categories: local (deserted) streets, arterial roads, and rapid urban roads.

This approach provides insight into the operational dynamics of the city's transport grid and serves as a foundation for optimizing traffic efficiency and prioritizing infrastructure investment.

1. Local (deserted) streets

These streets represent the most localized level of the urban network, serving low-density residential areas with minimal traffic demand. They generally have low vehicular volumes and limited connectivity to larger roads. While primarily intended to ensure local access, they play an important role in maintaining accessibility in the city's peripheral and less densely populated zones.

2. Arterial roads

Arterial roads form the backbone of Batna's transport system, facilitating the movement of medium to high traffic volumes between residential, commercial, and industrial areas. They balance accessibility with mobility.

In Batna, they link the city center to surrounding neighborhoods, distributing traffic efficiently and mitigating congestion. Proper planning and maintenance of these roads are crucial for supporting socio-economic activities.

3. Rapid urban roads

Designed as expressways or high-capacity corridors, these roads prioritize high-speed travel across and beyond the city. Characterized by minimal intersections and uninterrupted flow, they connect major urban zones with external regions.

In Batna, rapid urban roads facilitate intercity mobility, reduce travel times, and divert transit traffic away from congested centers, thus contributing to economic productivity and regional integration.

Map N°4 illustrates the evolution of Batna's functional road hierarchy, revealing a clear shift toward expanding arterial and rapid urban roads to accommodate growing traffic demands. This evolution underscores the city's adaptation to urban growth and changing mobility needs.



By leveraging this classification, planners can identify priority investment areas, optimize traffic distribution, and promote sustainable long-term development.

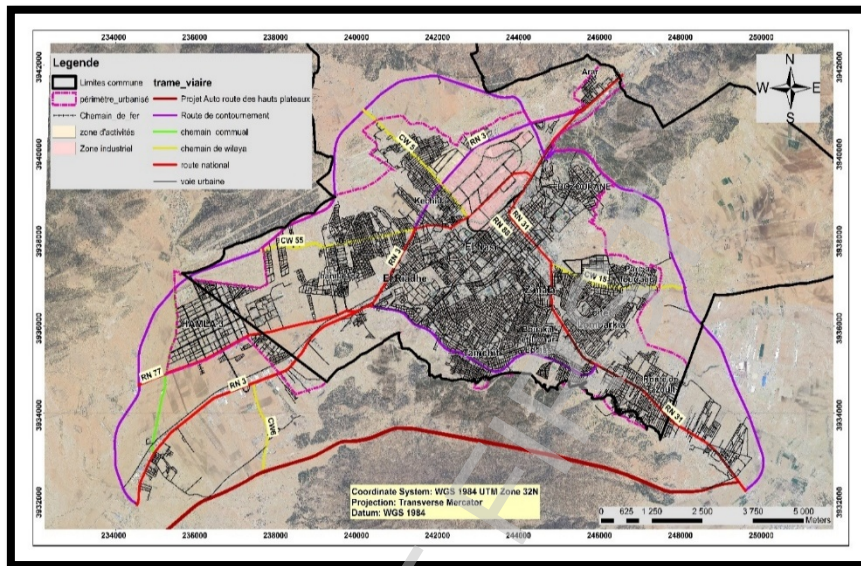


Figure 4 - Map 4, urban road classification 2

c. Diachronic classification of urban roads

Over the past two decades, Batna's road network has undergone major transformation driven by rapid urbanization, demographic growth, and rising mobility demands (Khiredine & Aichour, 2022). This diachronic analysis traces the network's evolution between 2000 and 2018, highlighting key spatial and functional developments.

In 2000, the road network was strongly centralized, with the city center functioning as the primary traffic hub. The absence of bypasses and peripheral connections led to frequent congestion and restricted access to suburban areas (Khiredine & Aichour, 2022).

By 2018, the construction of new arterials, bypasses, and secondary routes had decentralized traffic, improved accessibility, and strengthened connections between the urban core and peripheral areas. Maps reveal both quantitative growth in road length and qualitative improvement in network hierarchy.

Despite these advances, challenges remain: peripheral districts are still under-connected, and the absence of adaptive traffic management

limits the system's responsiveness (Louati & Rafik, 2024). Some expansions also lack integration within the broader mobility framework.

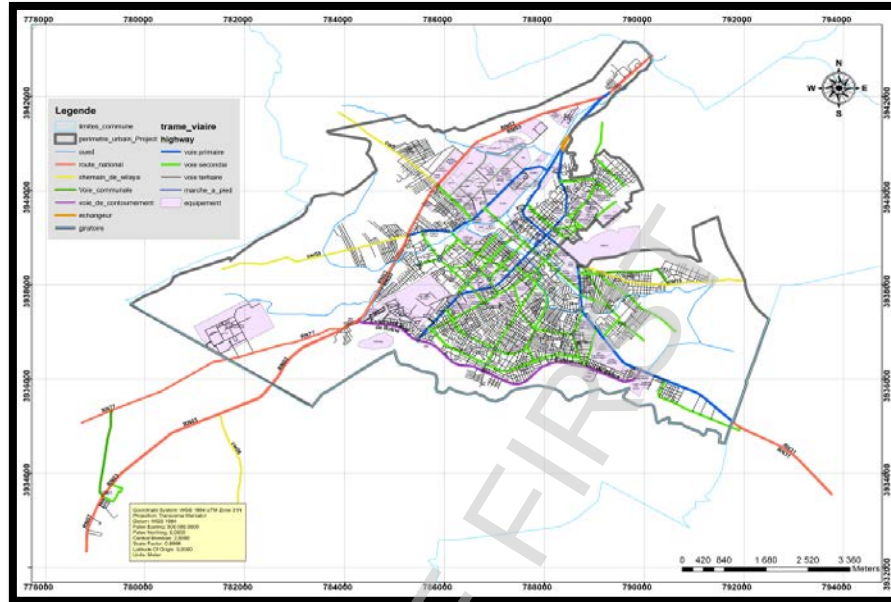


Figure 5 – Map 5, evolution of the city of Batna (2000)

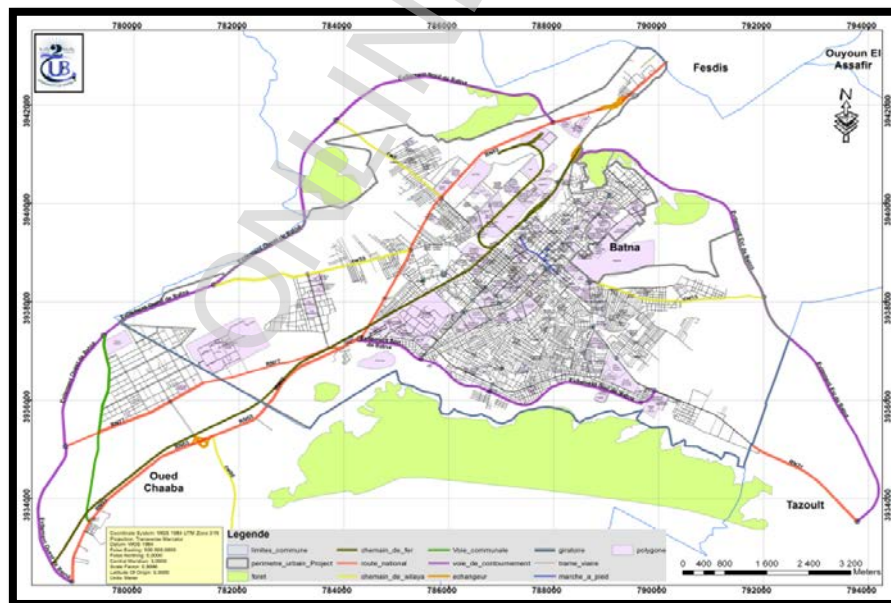


Figure 6 - Map 6, evolution of the city of Batna (2018)

A forward-looking strategy should therefore focus on strengthening peripheral connectivity, adopting intelligent traffic management, and promoting sustainable, balanced urban growth.

Overall, Batna's road network evolution between 2000 and 2018 demonstrates clear progress toward a more efficient and resilient urban transport system.

d. Town and country planning and the role of GIS

Town and country planning, as a multidisciplinary domain, plays a crucial role in structuring the spatial organization of human activities. It entails the systematic consideration of spatial relations, land-use dynamics, accessibility, and socio-economic interdependencies to promote efficient resource allocation and sustainable development. The objective is to design spatial frameworks that balance urban, suburban, and rural functions, fostering inclusive, resilient, and environmentally responsible territories (Metz, 2024).

Over the past few decades, the emergence of Geographic Information Systems (GIS) has profoundly transformed spatial planning and development practices (Reddy, 2021). These sophisticated computer-based systems surpass traditional cartographic methods by allowing planners to visualize, analyze, and interpret complex spatial datasets with exceptional accuracy. GIS facilitates the integration of heterogeneous information — including demographic profiles, transportation networks, environmental conditions, and land-use patterns into coherent analytical models that support evidence-based decision-making.

Unlike static mapping techniques, GIS enables dynamic, multi-layered representations of spatial phenomena, empowering planners to simulate scenarios and forecast potential outcomes. For example, GIS can assess the impact of new infrastructure on traffic distribution, identify zones at risk of flooding or pollution, and evaluate the implications of zoning modifications. Such capabilities enhance the strategic dimension of planning by ensuring that proposed interventions are both feasible and aligned with long-term sustainability objectives.

Furthermore, GIS has become an essential instrument for addressing complex challenges in spatial management and governance. By providing analytical precision and transparency, it supports the identification of urban sprawl patterns, transportation bottlenecks, and land-use conflicts. Through this, planners and policymakers can design targeted, equitable, and efficient solutions to optimize the use of space and resources.

In conclusion, the integration of Geographic Information Systems (GIS) into town and country planning represents a significant paradigm

shift in contemporary spatial management. By bridging the gap between theoretical frameworks and practical implementation, GIS enhances the analytical and decision-making capacities of planners, enabling them to address complex, multidimensional challenges more effectively. This integration fosters the formulation of intelligent, adaptive, and sustainable spatial development strategies that support long-term territorial resilience and balanced growth.

In contemporary planning practice, GIS extends beyond visualization to encompass predictive modeling, real-time monitoring, and participatory planning. These functions enable adaptive management of territories in response to rapid urbanization, environmental degradation, and climate change (Reddy, 2021). As such, GIS not only strengthens spatial analysis but also facilitates collaborative decision-making among planners, institutions, and communities.

Results and discussion

Diachronic monitoring of Batna's urban evolution (2000 and 2018)

The diachronic analysis of Batna's urban evolution between 2000 and 2018 provides insights into the structural transformation of both the city's urban fabric and its road network. Over this period, rapid urbanization and uncoordinated spatial expansion have contributed to the fragmentation of the urban fabric, resulting in multiple functional inconsistencies.

These include the emergence of disconnected neighborhoods, unequal accessibility, and a growing disparity between central and peripheral zones. Such fragmentation illustrates the challenges associated with unmanaged urban growth and the absence of integrated spatial planning strategies.

Concurrently, Batna's road network underwent significant spatial and functional restructuring during this 18-year period. As illustrated in the accompanying maps, this evolution is marked by an expansion in total road length and the reorganization of the network's hierarchical structure. The development of arterial corridors, bypasses, and secondary roads reflects efforts to accommodate rising mobility demands and support the city's expanding urban footprint.

The 2000 map depicts a highly centralized network, concentrated around the urban core, which served as the main hub for both local and regional traffic. This configuration led to severe congestion, particularly during peak hours, as peripheral districts remained insufficiently connected to the main transportation system. The absence of bypass

routes exacerbated these bottlenecks by channeling intercity traffic through the already congested downtown area.

By contrast, the 2018 map reveals a more decentralized network structure, characterized by the emergence of peripheral roads and bypasses designed to redistribute traffic flows. This evolution demonstrates a deliberate planning effort to reduce dependence on central arteries, improve access to suburban areas, and facilitate urban expansion into newly developed zones. Quantitative analysis further indicates a notable increase in road network density, reflecting the city's response to rising population pressures and economic growth.

Despite these advances, several challenges persist. The expansion of the road network has not entirely mitigated the fragmentation of the urban fabric, as some recently urbanized areas remain poorly integrated into the overall transport system. Moreover, functional disparities continue to affect network performance due to the lack of adaptive traffic management systems and uneven infrastructure quality across districts.

From a planning perspective, the diachronic monitoring of Batna underscores the need for a comprehensive and integrated urban development strategy. To address the persistent issues of fragmentation and inefficiency, future interventions should prioritize:

Enhanced Strategic Connectivity: Strengthening linkages between central and peripheral areas through well-coordinated arterial and secondary road systems.

Adaptive Traffic Management: Implementing intelligent transportation technologies to regulate congestion and optimize traffic flows in real time.

Sustainable Urban Growth: Aligning transport infrastructure development with broader spatial planning objectives to promote balanced, inclusive, and environmentally responsible growth.

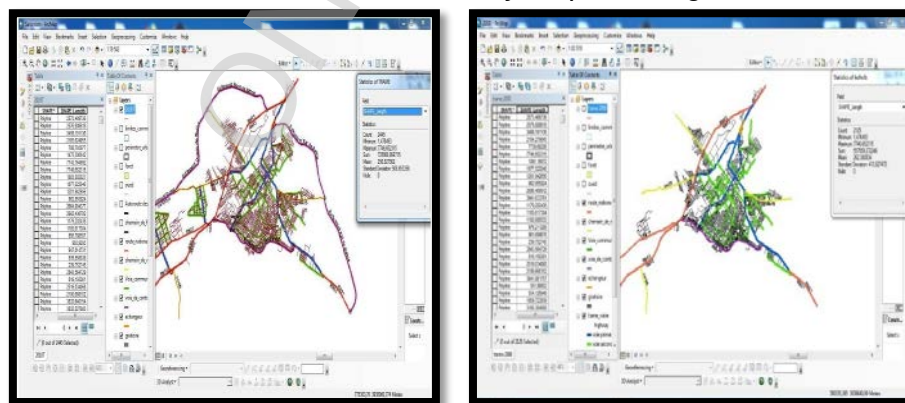


Figure 7 - Diachronic monitoring of the city of Batna (2000-2018)

Results of the urban road classification in Batna

The analysis of the urban road classification in Batna reveals a series of structural dynamics and functional challenges directly influencing traffic regulation and mobility efficiency. The existing road network, composed of bypass routes, exchange roads, and arterial roads, provides a foundational framework for urban mobility. However, it remains insufficient to accommodate the city's rapidly evolving transportation demands (Metz, 2024).

1. Connectivity disparities

Recently urbanized peripheral areas exhibit limited connectivity with the city center and other strategic zones. This deficiency stems from the fragmentation of the road network, which hinders the functional integration of different urban sectors and restricts mobility flows.

2. Central area congestion:

Persistent traffic congestion in the city center, particularly during peak hours, continues to generate major bottlenecks. The saturation of principal roads is exacerbated by the absence of adaptive traffic management systems capable of dynamically redistributing flows across the network.

3. Underutilization of bypass routes:

Although the northern and southern bypasses were designed to divert transit traffic from the central core, their actual use remains limited. This underutilization is largely attributed to insufficiently developed access points, inadequate directional signage, and a lack of integration with primary road arteries.

4. Network-wide congestion propagation:

Localized congestion frequently produces a chain reaction across the urban network. Traffic delays originating at specific intersections propagate upstream, affecting adjacent routes and amplifying network-wide inefficiencies.





Figure 8 - Map 7, hierarchy of urban roads

Functional classification in planning

Effective planning of Batna's overall road network requires a functional classification of its roads. This classification prioritizes routes based on demographic and socio-economic criteria, as well as their functionality within the city's broader urban transport system. Roads are categorized primarily by their role in facilitating connectivity, with motorways being the exception, where design parameters serve as the primary determinant. Additional factors, such as traffic volume and road quality, are used as secondary criteria to characterize and prioritize main roads.

By employing this approach, Batna's road network is designed to optimize traffic flow and address congestion issues strategically. Roads serving higher traffic densities and critical urban zones are prioritized for upgrades, ensuring that key transportation corridors remain efficient and effective.

Implementation of "taps" access control

To further enhance traffic management, Batna has implemented a regulatory strategy utilizing an access control system known as "taps."

These "taps" consist of strategically located traffic lights placed along penetration axes (exchange lanes) at intersections with the internal ring

road and at entry points to the city center. Their primary function is to manage the flow of vehicles into the city center during periods of high congestion (Gwalani, 2024).

By temporarily holding back vehicles attempting to enter the city, these access control measures help maintain traffic fluidity within the hyper-center. Vehicles are delayed upstream but eventually navigate through the improved flow conditions within the central network.

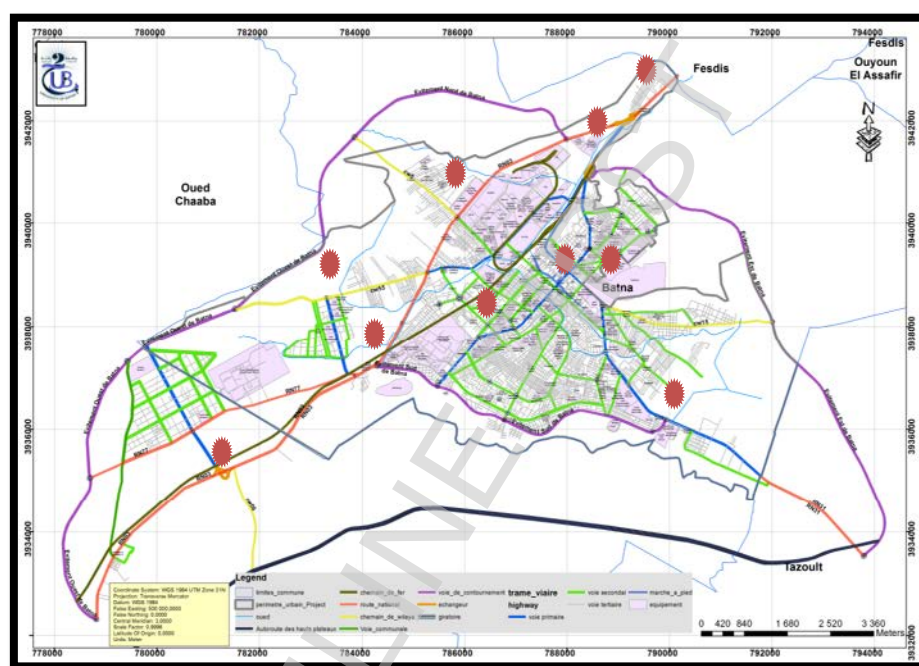


Figure 9 - Map 8, taps control

Structure and congestion in Batna's road network

Batna's road network exhibits a dense and highly interconnected structure, composed of several key components:

Bypasses (northern and southern), designed to divert transit and heavy vehicles away from the urban core;

Exchange roads, which penetrate the city and connect peripheral districts to central areas;

Arterial and distribution roads, ensuring internal accessibility and linking major functional zones within the city.

Together, these elements form a relatively extensive and integrated transportation framework that supports mobility across Batna's urban fabric.

However, despite this structural connectivity, the network frequently experiences reduced operational efficiency due to recurrent congestion.

Traffic saturation often generates chain reactions, where queues originating at one intersection propagate upstream to neighboring junctions, resulting in interdependent and widespread delays throughout the network.

These cascading effects considerably undermine the overall performance and reliability of Batna's road system.

Conclusion

The functional classification of Batna's urban road network provides a coherent framework for analyzing traffic dynamics and improving mobility efficiency. By distinguishing between bypass, exchange, arterial, and local roads, it clarifies network hierarchies and supports targeted planning interventions.

Findings reveal that while the network is well connected, persistent issues such as the underuse of bypasses, congestion in central arteries, and insufficient local infrastructure continue to limit efficiency. Addressing these requires coordinated interventions that strengthen primary routes, modernize secondary roads, and integrate multimodal options such as public transport, cycling, and walking.

Regular updates to road classifications and their integration into zoning and urban planning policies are essential to ensure responsiveness to demographic and spatial change. GIS technologies further enhance this process by identifying congestion hotspots, modeling future scenarios, and linking mobility data with socio-economic and geographic factors.

Despite these advances, network fragmentation and localized congestion remain significant challenges. An adaptive, data-driven approach to planning and regulation is therefore crucial. Overall, the combination of functional classification and GIS offers a replicable model for developing efficient, resilient, and sustainable urban transport systems—both in Batna and comparable urban contexts.

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Funkcionalna hijerarhija primenom GIS-a: dijagnostika i rešenja za regulaciju saobraćaja u gradu Batna (severoistočni Alžir)

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OBLAST: geonauke

KATEGORIJA (TIP) ČLANKA: originalni naučni rad

Sažetak:

Uvod/cilj: Grad Batna u severoistočnom Alžiru beleži ubrzan rast broja stanovnika, što je povećalo potrebe za mobilnošću i doveo do značajanog pritiska na ograničenu i dotrajalu putnu mrežu. Zagušenja utiču na glavne gradske saobraćajne koridore i centralne gradske zone. Cilj ovog istraživanja je da dijagnostikuje ove disfunkcionalnosti i predloži strateški okvir za unapređenje odvijanja saobraćaja. U radu se takođe procenjuje efikasnost prostorne analize zasnovane na GIS-u za potrebe planiranja urbane mobilnosti.

Metode: U istraživanju se koriste geografski informacioni sistemi (GIS) i satelitski snimci za analizu saobraćajnog sistema Batne. Područje istraživanja obuhvata primarne i sekundarne saobraćajne pravce unutar urbanog jezgra. Podaci obuhvataju topografske karte, demografske slojeve, namenu zemljišta i terenska opažanja. Alati ArcGIS koriste se za prepoznavanje kritičnih tačaka saobraćajnih zagušenja, merenje

Adjroud, S. et al, Functional hierarchy using GIS: Diagnosis and traffic regulation solutions in Batna City (Northeastern Algeria), pp.

pristupačnosti mreže, procenu usklađenosti hijerarhije puteva i modelovanje sadašnjih i budućih scenarija mobilnosti.

Rezultati: Rezultati ukazuju na ponavljajuća saobraćajna zagušenja duž puta Avenue de l'Indépendance, puta za Biskru i severne obilaznice. Na nekoliko raskrsnica utvrđeni su nivoi zasićenja koji prelaze funkcionalne pragove. Analiza ukazuje na strukturne diskontinuitete, nedovoljnu širinu kolovoza i slabo povezane radijalne pravce. Prostorne korelacije ukazuju na snažan uticaj zona velike gustine naseljenosti i komercijalne koncentracije na pojavu saobraćajnih uskih grla. Izrađene karte otkrivaju nedostatke u povezivanju u pravcu istok–zapad i ograničene mogućnosti za zaobilazanje gradskog centra.

Zaključak: Rezultati podržavaju niz ciljanih intervencija, uključujući izgradnju novih poveznih saobraćajnica, optimizaciju raskrsnica i preraspodelu saobraćajnih tokova. Rezultati potvrđuju da GIS unapređuje preciznost dijagnostike i podržava planiranje zasnovano na dokazima. Predloženi okvir predstavlja skalabilan metod za unapređenje mobilnosti u gradovima koji se ubrzano urbanizuju. Istraživanje pokazuje da integracija prostornog modelovanja sa strateškim planiranjem vodi ka otpornijim i adaptivnijim saobraćajnim sistemima koji su usklađeni sa ciljevima održivog razvoja.

Ključne reči: urbana putna mreža, funkcionalna hijerarhija, regulacija saobraćaja, GIS analiza, Batna, Alžir.

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