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THE IMPACT OF PARKING LOTS ON SUSTAINABLE MOBILITY IN THE MZAB VALLEY (ALGERIAN SAHARA), PRELIMINARY RESULTS OF FIELD OBSERVATIONS

Abstract: Sustainable mobility reduces the consumption of space and resources, facilitates access, promotes economic dynamism, and creates a sustainable environment. This paper investigated the possibility of switching to a sustainable mobility system through parking management in the Mzab Valley and the city of Ghardaia, one of Algeria's classified heritage sites. Using the quantitative descriptive approach and the road network analysis method, the current situation of parking lots shows a high diversity and characterization of parking lots. The most important factors affecting parking lots were also identified, such as population density, vehicle ownership, and the road network. The study shows medium connectivity of the road network and traffic problems with a road saturation coefficient of almost 60%, where access to parking lots increases from 5 minutes to 10 minutes when driving to the city centre. The city centre has a high concentration of parking lots (81%). Furthermore, parking frequency is 5% higher in the morning compared to the evening, with an overall capacity of 12,495 parked cars and a deficit of 10,500 parking spaces. Linking the study to the social and policy aspects, the results indicate that trips for non-compulsory reasons dominate over mandatory trips for workers, where 50% of the population owns a private car and 10% use public transport. Based on the SWOT method, strengths, weaknesses, opportunities, and threats to be adjusted were identified. This research defines short- and medium-term solutions as a global vision for improving sustainable mobility in the Mazabite context or a similar region.

Key words: Mzab Valley, parking, network, management, sustainability

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Introduction

After the industrial revolution and the invention of the car, modern urbanism became centred around individual automobile usage (Caubel, 2007; Handy, 2002). Cities were redesigned and adapted to accommodate cars, leading to a significant increase in motorization rates (Di Méo et al., 1998; Dimitriou, 2011). This transformation has resulted in several negative consequences, including longer travel distances, higher costs, and increased distances between residential areas, workplaces, and essential services. Consequently, there has been a growing reliance on individual modes of transportation, accompanied by a rise in the number of daily journeys (Ibrahim, 2017).

These developments have given rise to the widespread problem of unsustainable urban mobility in many cities today. Recognising this issue, the United Nations Summit on Sustainable Development, held in New York in September 2015, emphasised the urgent need for a shift towards sustainable mobility policies. The World Business Council for Sustainable Development (WBCSD) defined sustainable mobility as the ability to fulfil society's requirements for unhindered movement, accessibility, communication, and trade. The WBCSD also emphasised the importance of fostering connections between businesses and citizens while preserving other crucial human and environmental values, both in the present and future. Additionally, the summit underscored the significance of integrating urban and transportation planning to effectively address the challenges associated with achieving the sustainable development goals by 2030.

Parking-related studies have explored various approaches to address parking problems and promote sustainable transportation. Some researchers suggest technological applications as a solution (Manjula et al., 2022; Siddiqui et al., 2022), while others emphasise the importance of reducing vehicle usage and promoting public and alternative transportation modes (Monteiro et al., 2023; Sharav et al., 2018). Urban planning is also considered crucial in developing sustainable mobility infrastructure that aligns with city functions (Merriman, 2016; Zheng et al., 2023). Parking management policies are recognised as effective tools for managing urban transport demand, as most car trips involve parking (Kirschner & Lanzendorf, 2020).

Vehicle ownership, usage, and parking availability are interconnected (Guo, 2013; McCahill et al., 2016). While reducing parking availability can have positive environmental outcomes, it may affect mobility and accessibility for individuals. Numerous studies have provided evidence demonstrating the positive impact of implementing parking pricing strategies (Simićević et al., 2012; Simićević et al., 2013). Road classifications play a significant role in evaluating the capacity, efficiency, and overall quality of a road network (Manual, 1994). Factors such as traffic volume, speed, manoeuvrability, and delay times are taken into account when assessing the performance and effectiveness of road infrastructure through levels of service analysis.

To ensure effective traffic control management, it is crucial to monitor traffic conditions accurately (Afrin & Yodo, 2020; Cárdenas-Benítez et al., 2016). Urban planners have implemented minimum parking requirements for different land uses as a means to address parking challenges (Shoup, 1999). European cities have recently adopted new parking management strategies to tackle mobility and congestion problems with a view to creating more attractive environments (Kodransky & Hermann, 2011).

The Algerian government has joined the ranks of those interested in this strategic sector by amending and enacting certain laws, including Law 17-88, aimed at liberalising the land transport sector. It has also planned a series of local development and investment projects with economic, social, and environmental dimensions. However, despite these interventions, a perennial problem persists. Like many cities around the world, most Algerian cities suffer from the issue of inadequate parking spaces. As a result, people spend a significant portion of their travel time searching for parking spots for their cars, which impedes the movement of other motor vehicles.

The Mzab Valley, the research area of this paper, is located in southern Algeria in the state of Ghardaia (Figure 1). The link between the north and south is via National Road No. 1, which is considered a crossroads of cultural and trade routes (Adams, 2016). The Mzab Valley comprises five traditional palaces with a unique architectural character that have attracted renowned contemporary architects and urban planners, such as Le Corbusier, Bouillon, and Raveiro (Adams, 2016). The town was built in the 11th century, and UNESCO declared it a World Heritage Site in 1982. It is situated on rocks between 450 and 550 meters high. The depth of the valley varies between 100 and 150 meters (Meziani, 2014), posing a challenge for the planning of the road network and local development. In light of these circumstances, the research aims to explore the feasibility of transitioning towards a sustainable mobility system by implementing parking management strategies in the study area.
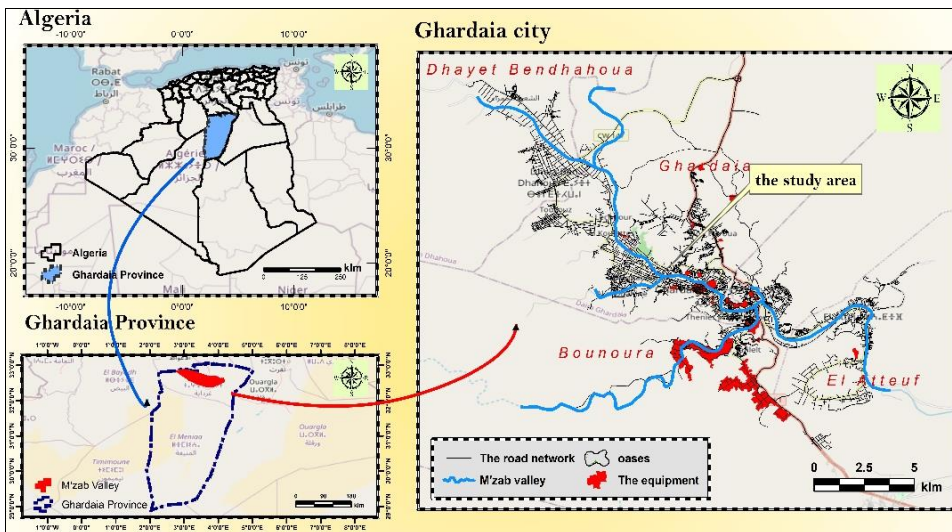

Fig. 1. Location of the study area

The research paper is organized as follows, in the first section, there is an explanation of how to select the literature relating to the subject, objectives, and methodology of the research. The second section comprises a description and analysis of the factors affecting car parks, followed by an assessment of the current situation of car parks in the Mzab Valley. It also includes the identification of strengths and opportunities for improvement, as well as weaknesses and challenges that threaten the proper management of car parks in the city. This analysis is conducted using the SWOT method.

This study aims to address two questions:

- What are the causes of parking problems in the valley?
- Is it possible to move towards a sustainable transport system by managing car parks and reducing private car use?

Methodology and context

Methodology

In alignment with the objectives of the sustainable development document and considering the parking phenomenon in the Mzab Valley, this study presents a coherent approach and new tools to examine potential transformations that can contribute to the primary goal of reducing private car usage through parking management.

The study is divided into two parts: the first part focuses on gathering scientific material, which is primarily presented in the introduction. The second part delves into the stages of the research work. It begins by defining the field of study, introducing it, and providing a diagnosis of its general characteristics at the urban, social, and economic levels.

The subsequent step involves analysing the data on factors influencing the phenomenon under study in the city of Mzab Valley within the context of sustainable development challenges. Descriptive and quantitative methods are employed to gain a comprehensive understanding of the field of study. Factors considered include population growth, car ownership rates, land uses, and the road network.

Following this, the study proceeds with a quantitative approach and spatial analysis method to examine and analyse the current state of car parks in the Mzab Valley. The approach developed (Diallo et al., 2015) incorporates two additional indicators: car park accessibility and the feasibility of access from facilities to car parks.

In the final step, after conducting the aforementioned analyses, the study utilises the SWOT (Strengths, Weaknesses, Opportunities, and Threats) (Uhunamure & Shale, 2021) approach as a tool to evaluate the current status of car parks and urban management policies in the Mzab Valley. This approach assists in decision-making for stakeholders by identifying strengths and weaknesses, enhancing the success prospects of the parking project, mitigating the threats posed by increased demand for parking spaces, and presenting priorities and recommendations in the form of a vision to achieve a sustainable city within the temporal and spatial context of the Mzab Valley.

Location and characteristics of the study area

The Mzab Valley holds significant importance as the primary urban centre for the province of Ghardaia. It is situated in the northern part of the state of Ghardaia, which, in turn, is located in the middle of the Algerian desert. The valley is located 600 km north of Algiers and serves as a crucial connection point through the National Road N 1, also known as the African Union Road, leading to Tamanrasset. Geographically, the Mzab Valley extends from north to south for 450 km and from east to west for 200 km, covering a total area of 306.47 km².

According to the statistics provided by the Directorate of Programming and Budget Monitoring (DPSB, 2018, 2020), the population of the Mzab Valley is estimated to be 403,734 inhabitants. The population density is calculated at approximately 130.83 individuals per square kilometre, and the region has experienced a growth rate of 2.58.

The study area encompasses three districts and four municipalities: Dhaya, Bounoura, El Atteuf, and Ghardaia (the capital of the state). These districts and municipalities were established as part of the national regional organisation in 1984. The municipalities, particularly Ghardaia, are distinguished by the presence of numerous administrative institutions and services.

From an urban perspective, the Mzab Valley region exhibits two distinct types of urban fabric. The primary urban fabric comprises the five palaces, which form the original core of the Mozabite urban structure dating back to the 16th century. This historic urban core possesses a unique character and was recognised as a UNESCO World Heritage Site. On the other hand, the secondary urban fabric represents a more modern development that, despite being an extension of the first core, lacks homogeneity. This secondary fabric emerged during the colonial era in 1830 and does not conform to the traditions of the conservative Mozabite society, nor does it take into account the region's climatic or geological conditions.

Result and discussion

Factors Affecting Car Parking

Population density

Population is considered the most dynamic and influential factor across various sectors of the city (Adams, 2016; Toralles, 2023), making it the primary focus of the initial diagnosis stage. The size of the population, particularly the working population, along with the rate of demographic change, population density, distribution of the working population, and car ownership rate, are fundamental data and indicators for the car park study.

In terms of demographics, the Mzab Valley is home to 21,108 inhabitants, accounting for 53% of the total population of the state, estimated at 471,656 inhabitants. Among these, 62.89% reside in the capital city of Ghardaia, which occupies an estimated surface area of 4,037.34 km², representing 12.21% of the total land area of the Ghardaia state. Notably, the capital city has the smallest surface area among the municipalities in the valley, encompassing only 7.59% (Table 1).

Population density serves as a crucial indicator in geographical studies, providing insight into the relationship between an area and its residents (Grove, 2016). Its purpose is to identify the most attractive municipalities for residents and assess the degree of variation among them.

An analysis of population densities across the municipalities of the Mzab Valley reveals an uneven distribution of the population. Ghardaia municipality has experienced significant densification, recording the highest density rate at 433.19 inhabitants/km². It is followed by Bounoura municipality with a rate of 56.15 inhabitants/km², and Atteuf municipality with 27.22 inhabitants/km², occupying the top three positions in terms of population density at the state level. This variation can be

attributed to the concentration of facilities and services in these attractive centres (Table 1) (DPBM, 2018).

Tab. 1. Representation of the area, population and density of the municipalities in the Mzab valley

Municipality	Ghardaia	Al-Daya	El- Atteuf	Bounoura	Total
Area (km²)	306.47	2,234.94	717.01	778.92	4,037.37
Population(n)	132,761	15,069	19,518	43,740	211,088
Density (H/km²)	433.19	6.74	27.22	56.15	-

Source: Director of Programming and Budget Monitoring (DPBM), 2018

Labour distribution according to the National Employment Directorate in 2018

The spatial distribution of activities within the study area enables the identification of sectors characterized by a high concentration of jobs. In relation to the category of workers, it is noteworthy that 47% of all state workers are employed in the Mzab Valley, with 73.5% of them working in the state capital. The administrative sector employs the majority of workers in the Mzab Valley, accounting for 62% of the workforce, with 70% of them located in the state capital. This data reaffirms the functional significance of the municipality of Ghardaia (Table 2).

Tab. 2. Distribution of labour in the Mzab Valley municipalities

Municipality	Administration	Public works	Industry	Other sectors
Ghardaia	36,459	8,745	2,008	14,848
Al-Daya	4,737	805	37	903
El-Atteuf	3,503	404	34	590
Bounoura	7,728	1,203	206	2,234
El Oued	52,427	11,157	2,285	18,575

Source: State Employment Directorate, 2018

Vehicle ownership rate

The proportion of private cars in the Mzab Valley accounts for 46.2% of the total number of vehicles in the state of Ghardaia. This figure represents nearly half of all vehicles in the region. In terms of car ownership rate, the valley has an average of 0.11 cars per individual, which is equivalent to 3 cars for every ten families. Put differently, approximately 30% of families in the valley own a car. While this ownership rate is deemed acceptable when compared to the national car ownership rate in Algeria (37.7%, according to the Ecotechnical Engineering Office, July 2003), it still poses challenges in the Mozabite context. The ancient urban structure of the valley, established over ten centuries ago, was not designed with cars in mind. The narrow streets, numerous curves, and historical focus on tracks for horse carriages limit viable solutions for vehicular mobility (Table 3).

Tab. 3. Distribution of labour in the Mzab Valley municipalities.

Number of private cars	Total vehicle park
22,664	44,728

Source: ONS, 2018 (ONS is the National Statistics Office is a public administrative body responsible for collecting, processing and disseminating socio-economic statistical information)

The car ownership density coefficient is calculated by dividing the number of people by the number of cars. The numerical substitution gives: 211088/22664 = 9.31.

Note: the vehicle ownership rate is different from the vehicle density factor. Regarding the socio-economic data analysis for the state of Ghardaia, it indicates a significant spatial variation. The municipality of Ghardaia stands out as the primary centre of attraction, with 62.89% of the total population in the Mzab Valley, 73.49% of jobs, and 45.17% of students located there. This municipality plays a crucial role in terms of population concentration, employment opportunities, and educational institutions. On the other hand, the municipality of Bounoura serves as a secondary centre for transportation exchanges, contributing to the overall dynamics of the region.

Land use (functional diversity of the study area and functional specialisation for each municipality in the study area)

According to Michael and Barkin from the University of Pennsylvania, urban traffic and land use are interdependent factors, directly influencing each other and resulting in various forms of traffic (Mitchell & Rapkin, 1954). Building upon this perspective, functional specialisation is determined for each of the four municipalities within the Mzab Valley to assess the impact of land use on daily travel (Figure 2).

The total surface area of the Mzab Valley is 403,737 hectares. This area is divided into two main categories:

- Agricultural zones: These zones cover 179,475 hectares, but only 3% of the agricultural land is actively farmed. The climatic conditions of the region, characterised by sparse and irregular rainfall, high evaporation rates, and the absence of groundwater, limit agricultural activities.

- Land designated for infrastructure, housing, business parks, industrial zones, squares, and roads: This category encompasses 224,259 hectares, which accounts for 77% of the total surface area. These areas are primarily situated along roads and paths, accommodating various forms of infrastructure and development.

This division of land use highlights the significant portion dedicated to non-agricultural activities and infrastructure within the Mzab Valley.
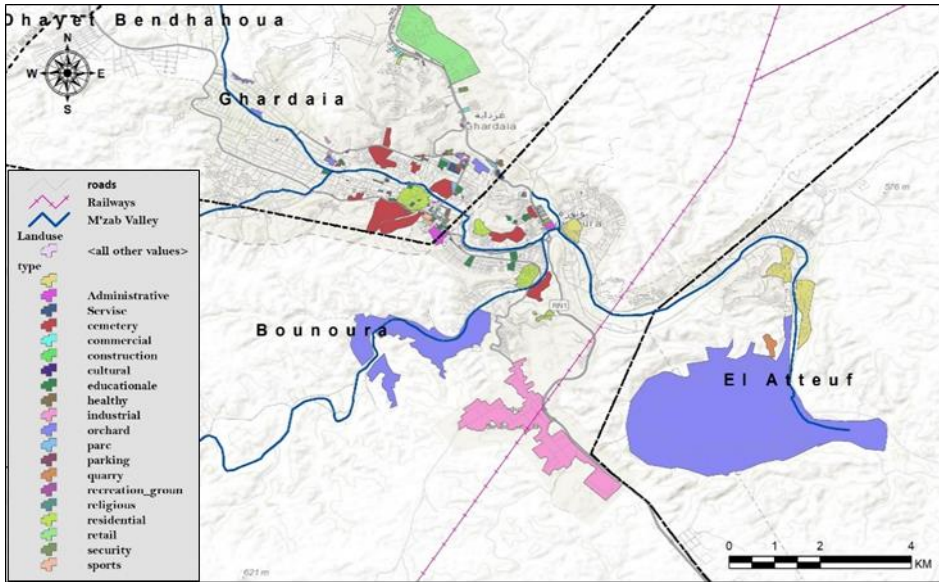
Fig. 2 Land use plan for the city of Ghardaia

Based on available statistics and field observations, the functional diversity and specialisation of each municipality within the Mzab Valley are as follows:

- Municipality of Ghardaia: This municipality serves as a hub for commercial services. Approximately half of the administrative offices and businesses are concentrated in the capital city of Ghardaia, indicating its significance as a centre for commercial activities.
- Municipality of Al-Daya: Al-Daya is primarily dedicated to agricultural activities, accounting for 33.3% of the total land used for agriculture in the region. This municipality benefits from the presence of 20 wells with a combined flow rate of 727 litres per second, along with a substantial water reserve covering an area of 800,000 square metres in the Grand Erg Al Sharqiah. The surface layer of the land in this area consists of siliceous clay soil, which facilitates water retention.
- Municipality of El-Atteuf: El-Atteuf is characterised as a tourist and agricultural town. It serves as the first core of the Mzab Valley, established in the year 102. The town boasts numerous historical monuments, including the Ammi Ibrahim mosque and the Okhira chapel. Additionally, it is home to three libraries that serve as museums and preserve Ibadhi manuscripts: the library of the Ami Salem mosque (Dar Arwan), the Bakri library, and the Nahda library.
- Municipality of Bounoura: Bounoura is predominantly an industrial area, housing the oldest and largest industrial zone in the state. The industrial zone covers an extensive area of 234.5 hectares, highlighting its significance in terms of industrial activities within the region.

These functional specialisations across the four municipalities demonstrate the diverse economic and cultural characteristics of the Mzab Valley.

Road Network

The road network in the Mzab Valley is primarily focused on the main axis, which is National Road No. 1, running along the valley. However, connections between the traditional palaces (manor houses) and the newer districts are limited and often poorly developed. As a result, most inter-district roads either pass through the town centre or take longer routes outside the urban area (Figure 3).

The road transport network in the Mzab Valley is dense and varied due to the linear geographical direction of the valley and its urban formation. The main roads run east-west, starting from El Atteuf and passing through Bounoura, Beni Isguen, Malika, Ghardaia, and further to Dhaya Ben Dahwa. These main roads resemble the branches of a tree, with tracks serving the neighbourhoods on both sides of the axis. The town's traffic hubs are formed by seven road intersections, including two in the Bounoura commune (Sidi Abaz crossroads and Beni Isguen crossroads) and five in the Ghardaia commune (5 Juillet crossroads, Marrakech crossroads, Talbi Ahmed crossroads, Place de l'Indépendance crossroads, and Colonel Lotfi crossroads).

The road network in the Mzab Valley consists of two main components: The main network and the secondary network.

The main network of road infrastructure in the Mzab Valley includes side lanes, interchanges, and service routes. The side lanes have generally acceptable technical characteristics, with a width of around 10 metres. However, in areas where heavy vehicles are present, they may pose potential problems. The northern bypass plays a significant role in handling transit traffic, accounting for 35% of such traffic. It primarily serves the western states of Al-Bayd, Saeeda, and Naama. Additionally, it provides a connection between the towns of Ghardaia, offering improved transportation options. In terms of interchanges and feeder roads, the city of Ghardaia has a well-defined classification of roads based on their functions. The main network in Ghardaia runs from east to west and consists of national roads (N 1) and state roads (N 105 and 147). This main network covers approximately 30% of the road network in the Mzab Valley. It serves as a crucial link between Ghardaia and neighbouring municipalities, facilitates communication between the city centre and peripheral districts, and connects various districts within the city. Key intersections along this network include the 5th July Road, the 1st May Road, the Prince Abdel Qader Road, and the Ahmed Boushaba Road. During peak times, this network experiences high traffic volume due to the concentration of public administrations in the city centre. It is also the primary arrival point for urban public transport lines, except for the Ghardaia-El Dhaya line. The Prince Abdul Qadir Road plays a significant role in handling traffic as it serves as a convergence point for all traffic on these roads. However, it should be noted that these roads also intersect with areas of commercial activity, causing them to serve various functions beyond traffic management. This situation leads to underutilization of the road network's full potential and contributes to congestion issues. Challenges such as pedestrians walking on the road due to narrow or poorly maintained sidewalks, mobile stalls or street vendors occupying the road, chaotic parking by motorists, and inconsiderate stops by taxis and buses further compound the congestion and hinder efficient traffic flow.

The secondary network in the Mzab Valley consists of municipal roads and lanes that connect different districts and palaces. This network constitutes approximately 70% of the

total road network in the valley and has a combined length of 102.1 kilometres. These roads and lanes serve as important connections within the valley, facilitating local transportation and providing access to various residential areas, landmarks, and historical sites. They play a crucial role in enabling intra-valley mobility and supporting day-to-day activities for residents and visitors.
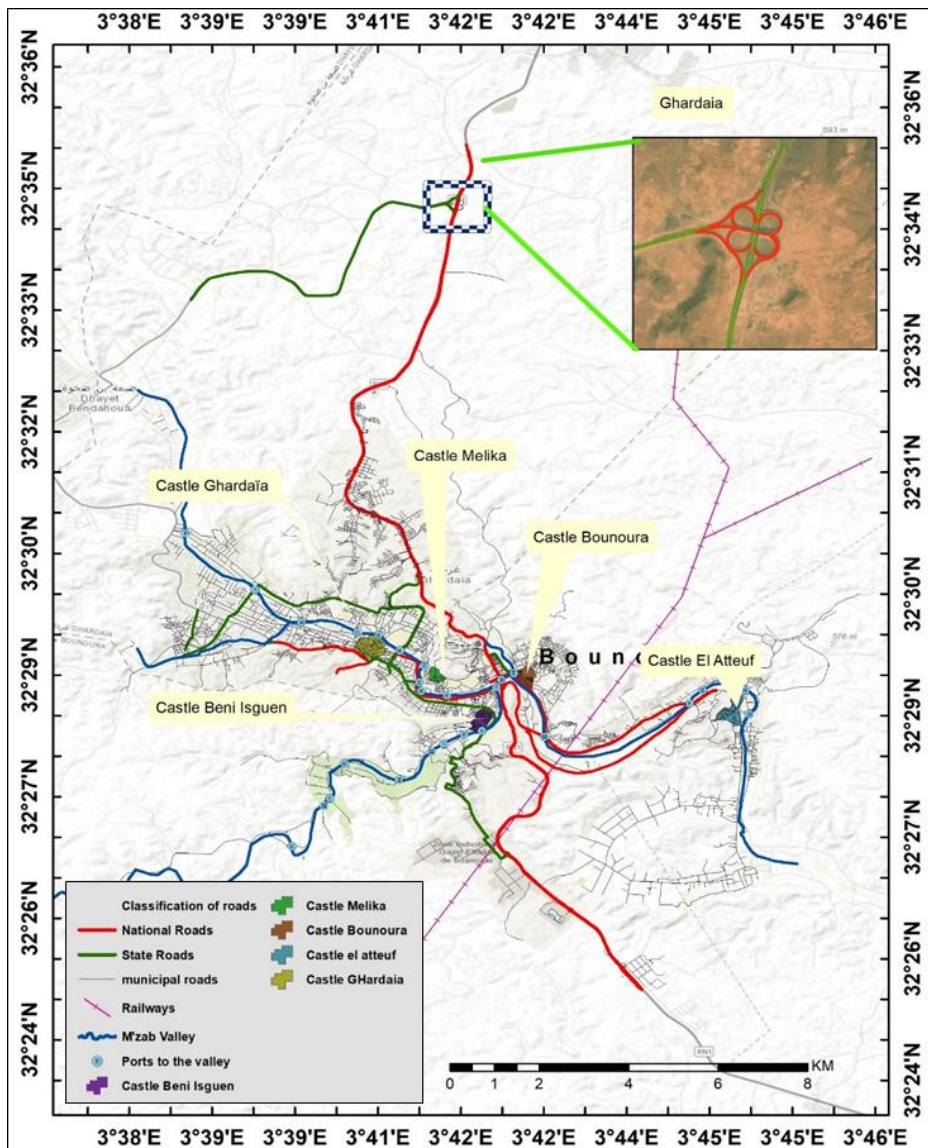

Fig. 3. Plan roads for the city of Ghardaia

Table 4 indicates that in the Mzab Valley, municipal roads make up the majority of the road network, covering 56% of the total. National roads constitute the second largest category, accounting for 30% of the road network, followed by state roads with a share of 14%. The remaining portion consists of unpaved paths.

In the specific case of Ghardaia, the municipal road network alone covers almost half (49%) of the total road network in the city. Among the roads in Ghardaia, 59% are national roads, 38% are state roads, and 45% are municipal roads. The remainder of the road network in Ghardaia comprises unpaved roads.

These figures highlight the significant role of municipal roads in providing local connectivity within the Mzab Valley, particularly in Ghardaia. National and state roads also play a crucial role in connecting the valley to the wider transportation network. The presence of unpaved roads suggests that there may be areas in need of further development and improvement in terms of road infrastructure.

Tab. 4. Classification of the road network by municipality, type and length in the Mzab Valley (length in km)

Municipality	National Roads	State roads	Municipal roads	Total
Ghardaia	26	8	36.3	70.3
Al-Daya	-	1.5	17.6	19.1
El-Atteuf	10	6	13.7	29.7
Bounoura	8	5	13.5	26.5
Total	44	21	81.1	145.2

Source: Ghardaia State Transportation Plan, 2021

Assessment of the road network

The assessment of the road network efficiency in the Mzab Valley includes the calculation of two parameters: the connectivity coefficient (Taran et al., 2016) and the road saturation coefficient.

Connectivity Coefficient: The gamma coefficient (y) is calculated based on the number of lines (e) and intersections (v) in the road network. For the Mzab Valley, the calculation is as follows: $y=e/3(v-2)$ -› $y=76/3(51-2)$ -› $y = 0.52$.

For the municipal roads of Ghardaia, the gamma coefficient is 0.41, with e = 38 and v = 29. These gamma coefficients indicate an average level of connectivity for both the roads in the Mzab Valley and the municipal roads of Ghardaia. The sudden change in the urban fabric to a modern urban model has affected the functional hierarchy that previously distinguished the roads and paths in the Mzab Valley and Ghardaia.

Road Saturation Coefficient: The road saturation coefficient was calculated for the most important roads in the Mzab Valley, specifically in the municipality of Ghardaia (the state capital). The saturation coefficient for these roads ranges between 47% and 119%, with an average saturation coefficient of 57.92%. This indicates that the main roads in the valley experience traffic problems that require prompt intervention.

These coefficients provide insights into the connectivity and congestion levels of the road network in the Mzab Valley, highlighting the need for improvements to address traffic issues and enhance efficiency.

Tab. 5. The saturation coefficient of the main roads in the Mzab Valley

	Streaming (UVP)	Registered Capacitance per road	Saturation Coefficient (%)
Didouche Mourad Road	4,331	2,500	96
5th July Road	4,205	4,500	93
Istiklal Road	4,217	5,400	78
Alamir Abd Al Qadir Road	3,149	4,500	70
1st November Road	1,041	2,100	50

Source: Transport plan + field investigation, 2021

Based on Table 5 and road planning standards, as well as the Levels of Service for Road Transportation (Manual, 1994), the roads in the study area can be categorised into different levels based on their characteristics and traffic conditions. Three roads, namely Al-Istiklal Road, Prince Abdul-Qader Road, and 1st November Road, fall under level C classification. These roads are associated with challenging driving conditions and low speeds, making manoeuvring difficult for drivers. On the other hand, Didouche Mourad Road and 5th July Road belong to level E, which is characterised as "creeping traffic chaos". These roads experience congested traffic, resulting in reduced speeds and significantly increased delay times for commuters. These classifications provide valuable insights into the road conditions and traffic congestion levels on specific roads in the study area, allowing for a better understanding of the challenges faced by drivers.

Parking study

The current situation of car parks in the Mzab Valley is examined in this section, employing the methodology developed in the study conducted by (Diallo et al., 2015). In addition to the established methodology, two additional indicators are incorporated: accessibility to car parks and accessibility of facilities to car parks. The study focuses on determining the location of car parks, their usage and users, and examining how they are managed and administered. Various methods are employed to measure specific indicators that are relevant to the field of car parks in the area. By examining these indicators, researchers aim to gain insights into the characteristics and functioning of car parks in the Mzab Valley, which can help in assessing their effectiveness and identifying any areas that require improvement (Figure 4).
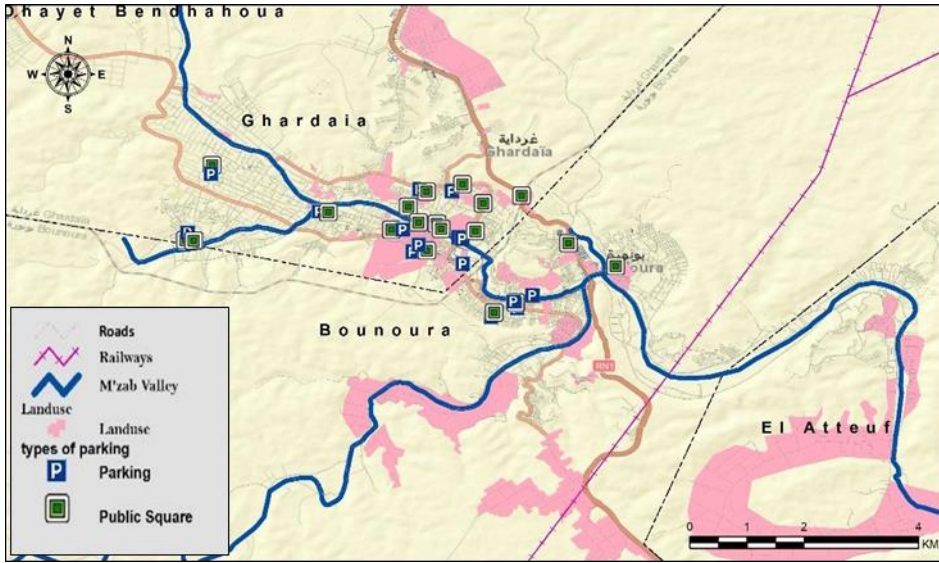
Fig. 4. Planned of parking spaces and public squares

Table 6 presents a comprehensive overview of the parking spaces available in the Mzab Valley, showcasing a total of 1,998 spaces. This information is crucial to understanding the current parking infrastructure and its capacity within the valley. The table likely includes data such as the location of the parking spaces, the type of parking, and the capacity of each parking facility.

Tab. 6. Type, number, and location of car parkings in the Mzab Valley

Type	Number	Site
On the side of the road	288	1st November Road
	262	Al-arbi Ben Mhidi Road
	117	5th July Road
	481	Bab Alhada Square, Albaraka Square, Chikh Mohamed Road, Silla Road, Alamir Abd Alkader Road, and Talbi Mohamed Road
Out of the road	510	Bakadish Road
	340	Talbi Mohamed Road

Source: Ghardaia transport plan +Field investigation, 2021

Figure 4 and table 6 provide data regarding the distribution of car parks in the Mzab Valley, highlighting that a significant majority, approximately 81%, of the available car parks are concentrated in the city centre of Ghardaia. This concentration indicates the high demand for parking facilities in this bustling area.

Further analysis reveals that within the Ghardaia city centre, approximately 58% of the car parks serve a dual purpose as multi-purpose courtyard. These courtyards are utilised as car parks during working hours to accommodate the parking needs of busi-

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nesses and offices in the area. However, outside of working hours, they transform into spaces for gatherings and entertainment, serving as versatile communal areas for various social activities.

The remaining 42% of the car parks in Ghardaia city centre are specifically designed and constructed to meet technical standards for accommodating vehicles. These car parks are intended solely for parking purposes and adhere to established guidelines to ensure the safe and efficient utilisation of the available space.

Access to car parks

One notable observation is that the two main roads, namely Al-Arabi Ben Mhidi Road and 1st November Road, collectively occupy almost half of the total width on both sides of the road, accounting for 47.92% of the road space. These roads are situated in the central area of the municipality of Ghardaia and suffer from severe congestion issues. This congestion is primarily attributed to their location in the city centre, where traffic volume is high and various activities take place.

In terms of car park area, the total occupied space amounts to 47,952 square metres. By conducting a network analysis using a map (Figure 5), it is evident that the proximity to the city centre of Ghardaia significantly increases the likelihood of accessing car parks within a 5-minute timeframe. This is due to the fact that the most important roads, such as National Road 1, National Road 147, and National Road 105, pass through the city centre, facilitating easier access to car parks in this area.

However, as one moves further away from the city centre, the accessibility to car parks within a 5-minute timeframe diminishes. Instead, accessibility within a 10-minute timeframe becomes more prevalent. This change in accessibility is influenced by the presence of palm oases that are more prominent in the surrounding areas, resulting in a slightly longer travel time to reach car parks.
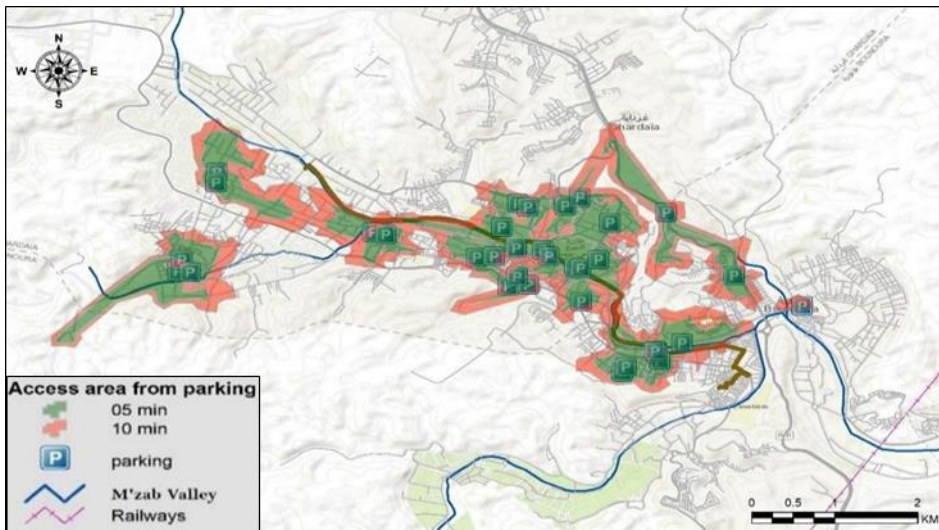

Fig. 5. Spatial analysis scheme for parking and public squares

Access from the facilities to the car parking

The network analysis conducted to assess the accessibility from facilities to car parks within a 5 minute and 10-minute timeframe, as depicted in figure 6, indicates that the accessibility from facilities to car parks in less than 5 minutes is considered acceptable. This can be attributed to the concentration of car parks in the area where various administration and service facilities are located. Furthermore, the presence of key roads in this region, such as National Road 1, National Road 147, and National Road 105, contributes to improved accessibility.

The close proximity of car parks to the administrative and service facilities ensures convenient access for individuals visiting these establishments. It reduces the travel time required to reach the car parks, enabling efficient and hassle-free parking for users. The strategic placement of car parks near important roads facilitates quick and easy access, enhancing the overall accessibility from facilities to car parks within a 5-minute timeframe.
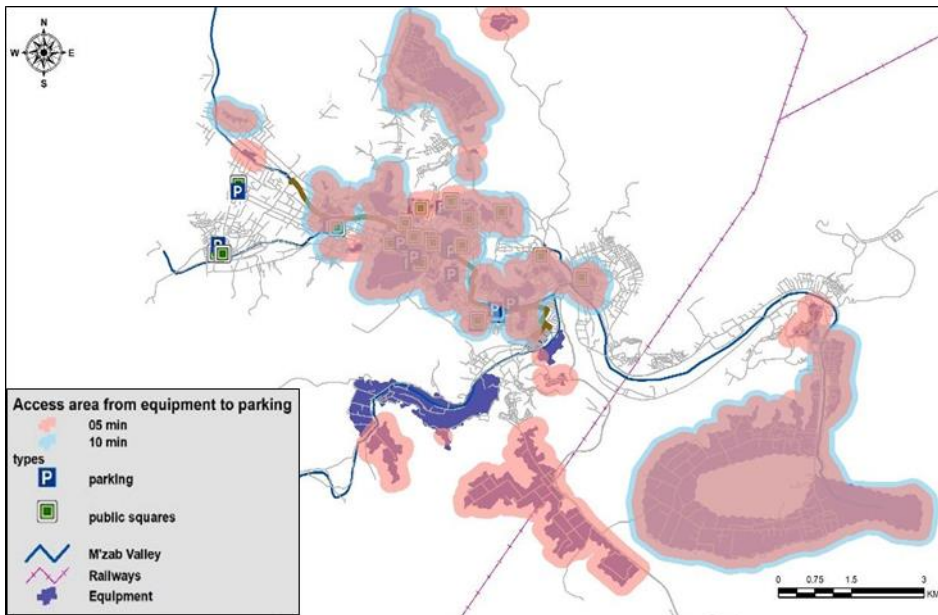

Fig. 6. Spatial analysis scheme for equipment to parking and public squares

Usages

The demand for parking spaces in the Mzab Valley can be assessed by analysing the occupancy rate and the number of cars parked. Based on the available data, it is estimated that there are approximately 12,495 cars parked in the area. Of these, 55% of cars are parked during the morning period, from 7 a.m. to 1 p.m., while 45% are parked in the evening.

By subtracting the total number of available parking spaces from the estimated demand, as indicated in tables 6 and 7, it becomes evident that there is a significant challenge in providing sufficient parking facilities. The shortfall amounts to approximately 10,497 parking spaces that need to be provided in order to meet the immediate parking needs in the Mzab Valley.

Tab. 7. Demand for parking in the Mzab Vallye

Venue	1st November Road	5th July Road	Talib Muhammad Road	Al-Baraka Square	Other roads	Total
Number of positions	3,377	1,202	1,112	1,020	5,784	12,495

Source: Ghardaia transport plan + field investigation, 2021

To calculate the space required to meet the car parking needs in Ghardaia, the following formula is used: NA= NP * AS, where NA (m²) represents the space required for car parking, NP is the number of car parks (10,497 spaces), and AS is the surface area required to park a car. Considering the range of 20 m² to 24 m² for the minimum and maximum space required to park a car, respectively. Therefore, the minimum space required for car parks in Ghardaia is 209,940 m², and the maximum space required is 251,928 m².

User transport mode

In this section, an analysis was conducted to examine the distribution of trips based on the mode of transport as well as the distribution of trips in terms of purpose and time, considering the integration of the transport system with car parks.

Transport modes

According to the data obtained from the 2009 transport plan for the state of Ghardaia, it is observed that the majority of movements within the area rely on motorised modes of transport. Only a small percentage, approximately 6%, of trips are made on foot, indicating a relatively low level of pedestrian activity.

Among the motorised modes of transport, private cars and taxis account for the largest share, representing 50.08% of the total movements. This suggests a significant reliance on private vehicles for transportation within the study area. Buses contribute to 10.04% of the movements, indicating the presence of a public transportation system serving a portion of the population.

Bicycles and motorbikes contribute to approximately 9.70% of the movements, indicating some usage of non-motorised modes of transport. This suggests that cycling and motorcycle riding are used by a portion of the population as alternative means of transportation.

Finally, there is a category labelled "other automated modes of transport", which accounts for 24.18% of the movements.

Distribution of transports in terms of purpose and time

According to the Ghardaia 2021 State Transport Plan, trip purposes in the area are categorised into compulsory and non-compulsory reasons. Compulsory transport refers to non-optional movements such as commuting from home to work or school, while non-compulsory transport includes optional trips for shopping, family visits, or entertainment.

Analysing the data presented in table 8, it is evident that during the morning period, non-compulsory transport dominates the total number of journeys, accounting for 56.65% of the trips. This indicates that the city of Ghardaia is a hub for health and commercial facilities, attracting people for various non-essential purposes. Additional-

ly, a significant percentage of workers, 40.03%, or 500 workers, commute from home to work in the morning. This highlights the importance of the city as a centre of employment and economic activity.

In contrast, the percentage of trips made for school purposes remains relatively low, representing only 3.32% of the total transports. This suggests that the existing school infrastructure in the area is adequately distributed and covers the educational needs of the population.

During the evening period, non-compulsory reasons for transportation become even more prominent, accounting for 67.58% of all transports. This indicates that people are more likely to engage in leisure activities, social visits, or other non-essential trips in the evenings.

Tab. 8. Distribution of transports in terms of purpose and time

	Morning		Evening	
Mobility in terms of purpose	Number	Percentage(%)	Number	Percentage(%)
Obligarory	541	43.35	432	32.42
Non- Obligatory	707	56.65	900	67.48
Total	1248	100	1332	100

Source: Ghardaia transport plan + field investigation, 2021

The calculation of workers' access to car parks in the Mzab Valley is based on the number of available parking spaces, which is 1998, divided by the number of employees, which is 84,444. This calculation results in a ratio of 0.02, meaning that for every 100 workers, only two have access to the car parks. In other words, approximately 1,689 workers out of the total workforce have access to the car parks. This indicates a low proportion of access to car parks compared to the number of workers in the area.

Administratively, the management and administration of the transport sector, including car parks, in the Mzab Valley are the responsibility of various local authorities and entities. These include the state, the municipality, authorities' directorates, the Directorate of Transport for the state of Ghardaia, unions, the URBAS Studies Office, and the Directorate of Public Works. These entities work together to ensure the efficient operation of the transport system and the proper management of car parks.

The transportation sector utilises transportation planning and organising tools supported by a range of legislative laws that define the roles, scope, and powers of each actor involved. Some of these laws include Executive Decree 88-01, which promotes private transport and releases it from state control, and the Distinguished Law of August 7, 2001, which links transport policy to urban development. Additionally, Executive Decree 04-416 specifies the modalities for preparing transport plans, and Law No. 04-16 of 2004 focuses on the regulation and safety of road traffic.

However, the findings of the study conducted in the area emphasise the importance of implementing these efforts on the ground through continuous coordination among the various actors. It is crucial to activate monitoring and control tools to ensure effective management and administration of the transport sector, including car parks. By fostering

collaboration and utilising these tools, the challenges related to parking and transportation can be addressed more efficiently.

Application of SWOT method

This section presents a SWOT analysis applied to the car parks in the Mzab Valley.

Strengths

Strategic Location: The parking spaces in the Mzab Valley are concentrated in a strategic location where residents and facilities are settled, providing convenience and accessibility.

Excellent Accessibility: The parking facilities in the Mzab Valley benefit from excellent accessibility thanks to their location along major roads such as Al-Arabi Ben M'hidi Road and 1st November Road. These roads account for 47.92% of the total road width on both sides, ensuring easy access to the parking spaces.

Well-connected Road Network: The Mzab Valley boasts a well-connected road network, with a connectivity index of 0.52. This high level of connectivity contributes to the overall accessibility of the car parks in the region.

Obligatory Travel: A significant portion (38%) of the total travels in the Mzab Valley are for obligatory reasons, with 56% of these trips occurring in the morning. This is consistent with the fact that a substantial portion of the population (40%) consists of workers, particularly in the administrative sector. The concentration of movements in the morning aligns with the work schedules of the majority of the population.

Multiplicity of Actors: The management of car parks in the Mzab Valley involves multiple actors, including the state, municipality, state authorities and directorates, the Directorate of Transport of Ghardaia, unions, the URBAS Studies Office, and the Directorate of Public Works. This multiplicity of actors allows for collaboration and collective efforts in managing and improving the car parking infrastructure.

Planning and Organisational Tools: The existence of tools for planning and organising transport, such as traffic planners and transport planners, contributes to the effective management and utilisation of the car parks.

Legislative Framework: The car parking sector in the Mzab Valley benefits from a range of legislative laws that define the roles, responsibilities, and powers of various stakeholders. These include Executive Decree 88-01, which promotes private transport and frees it from state control, and the Distinguished Law of August 7, 2001, which links transport policy to urban development. Additionally, Executive Decree 04-416 specifies the modalities for preparing transport plans, and Law No. 04-16 of 2004 regulates road traffic, safety, and security.

Weakness

Insufficient supply: The existing parking offer only covers 9.19% of the total demand for parking lots, indicating a significant shortage.

Critical demand: The problem of high demand is particularly concentrated in the state capital, with 1st November Road being the most demanded street, representing 27% of the total parking needs. The demand exceeds the available supply in these areas.

Scarcity of real estate: There is a scarcity of available land for developing new parking spaces, with an estimated requirement of 209,940 m² to 251,928 m².

User preferences and limited public transportation: A significant portion (62%) of movements in the valley occur for non-compulsory reasons, primarily in the evening. As public transportation services often end by 5 p.m., people rely heavily on private cars for non-compulsory activities like shopping and family visits. Public transportation also fails to provide ideal conditions for these purposes.

Lack of coordination: There is a lack of coordination between the various actors involved in car parking management, which can hinder the effective implementation of strategies and solutions.

Underutilised tools and means: Despite having a multitude of tools and means available for managing car parks, their application on the ground has been lacking, potentially leading to inefficiencies and missed opportunities.

Concentration of facilities and employment: The high concentration of departments and service facilities in the city centre, along with a high rate of employment (73.5% of total jobs in the municipality of Ghardaia), contributes to congestion and parking problems, as everyone tends to be present in the same area simultaneously.

Opportunities

State support for public transport: The state has invested in the completion of 70% of the track section of the southeastern railway, which includes an electrified monorail. This railway, spanning 560 km and passing through the state of Ghardaia, offers high-speed travel capabilities of up to 220 km/h. Additionally, there is a plan to increase the number of transport lines in the Mzab Valley, indicating the state's encouragement of public transportation.

Law on importing old cars and car taxation: The issuance of a law on importing old cars, coupled with the imposition of a tax on cars, can incentivize people to purchase vehicles and reduce their reliance on private cars. This initiative aims to promote alternative modes of transportation and decrease traffic congestion.

Excellent infrastructure for technology utilisation: The presence of a robust infrastructure, including a significant number of internet subscribers (22,637) and fourth-generation (4G) subscribers (6,542), along with a phone density of 9.75, provides an opportunity to leverage information and communication technology. This infrastructure can facilitate services such as reserving parking spaces in advance through mobile devices, accessing information, and disseminating relevant data to enhance parking management.

Shift towards sustainable mobility: There is a possibility of promoting sustainable mobility by increasing the proportion of movements conducted through soft modes of transportation. By encouraging more walking, cycling, and the use of public transport buses, the Mzab Valley can improve the sustainability of transportation. Currently, 25.74% of movements occur through these sustainable modes, and this percentage can be further enhanced in the future. Implementing parking management policies, such as pricing strategies tailored to the region's characteristics and the state's capabilities, can contribute to this transition.

Conversion of city centre station into a multi-story car park: The city centre station in the Mzab Valley has the potential to be converted into a multi-story car park. With the upcoming operationalization of a new station in Bouhraoua that meets high technical standards for passenger transportation, the existing city centre station can be repurposed to alleviate parking challenges and provide additional parking spaces.

Threats

Exhaustion of reserve real estate: The availability of suitable land for parking spaces in the valley may become limited over time. This issue can be compounded by natural obstacles that require significant financial resources to overcome, such as the need for land leveling or addressing geological challenges. The exhaustion of available real estate poses a threat to the expansion and development of parking facilities.

Mzab Valley flood: The Mzab Valley is susceptible to flooding, which can adversely affect existing parking lots and infrastructure. Flooding events can damage parking facilities, rendering them unusable and requiring costly repairs or relocations. Such natural disasters pose a threat to the stability and functionality of the car parks in the valley.

Inability to predict individual behaviour: The behaviour of individuals, particularly residents, can be difficult to predict and manage. Residents may resist changes or controls imposed on them regarding parking regulations, especially when they involve eliminating free parking on the streets or in public spaces. This resistance to change can hinder effective parking management strategies and create challenges in implementing necessary policies.

Priority of private cars over housing: Algerian families prioritise owning a private car over housing, according to a study conducted by Media Sance (Kabeesh, 2009). This preference for car ownership as a primary necessity indicates that there may be a strong attachment to private cars within the population. Such preferences can contribute to increased private car usage and a higher demand for parking spaces, potentially exacerbating parking-related issues in the Mzab Valley.

Conclusion

This study focused on mobility and car parks in the Mzab Valley, Algeria, which is known for its historical urban environment consisting of two distinct urban areas. The analysis conducted revealed that the main causes of parking problems in the valley are the lack of parking supply and the mismatch between supply and demand, primarily due to rapid population growth and high car ownership rates.

Residents in the valley have resorted to using roadsides and neighbourhood squares to park their cars due to the shortage of parking spaces. The concentration of administrative facilities in the city centre of Ghardaia has also resulted in heavy traffic and a high percentage of car parks (81%) in that area. The study analysed the road network and found a road saturation coefficient of 57.92% and moderate road connectivity within the valley.

The study identified a significant challenge in providing approximately 10,497 car parks, equivalent to an area of 251,928 square metres, to meet the immediate parking needs in the valley. However, the problem extends beyond the lack of parking supply and

is also attributed to inadequate management practises, including a lack of follow-up, enforcement of laws, coordination among stakeholders, and the underutilization of geoinformatics applications in transport sector management.

The literature review findings emphasised the importance of parking policies in managing transportation demand by promoting measures to reduce private vehicle usage and implementing complementary policies to address various parking problems. Based on these findings, the SWOT method was applied to assess the strengths, weaknesses, opportunities, and threats of car parks in the study area.

Several solutions were proposed to address car parking problems in the valley. Firstly, integrating bicycle parking as an essential element in local car park management (Van der Spek & Scheltema, 2015), particularly within multi-floor and mixed-use parking structures that include bicycle parking on the ground floor, Converting the city centre station into a multi-floor car park was recommended due to limited real estate availability and its strategic location serving densely populated municipalities in the eastern part of the valley, including Ghardaia, Bounoura, and El Atteuf.

Implementing a pricing policy was also suggested, as demonstrated by a study on the impact of pricing policy on parking demand in Nanning, China, where increasing parking prices resulted in a 20% reduction in parking demand and a 10% decrease in waiting time (Mo et al., 2021). Secondly, enhancing the attractiveness of public transport through technological solutions such as intelligent guidance and parking information systems (Shin et al., 2018), advanced traffic management systems, and traveller information systems. These technologies provide real-time information on parking availability, road conditions, and alternative routes.

Thirdly, employing various policies such as job-sharing during the day and utilising public transport, bicycles, and walking to reduce private car usage and alleviate parking issues. While implementing these policies may require time to gain acceptance from employers and residents, they can be implemented in the medium term based on the Mozabite community's inclination towards serving the community rather than the individual.

The findings of this study contribute to a comprehensive understanding of the car parking system in the Mzab Valley and can serve as a foundation for future improvements and planning in terms of car park location, management, and accessibility. This will benefit both users and the surrounding facilities in the region.

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