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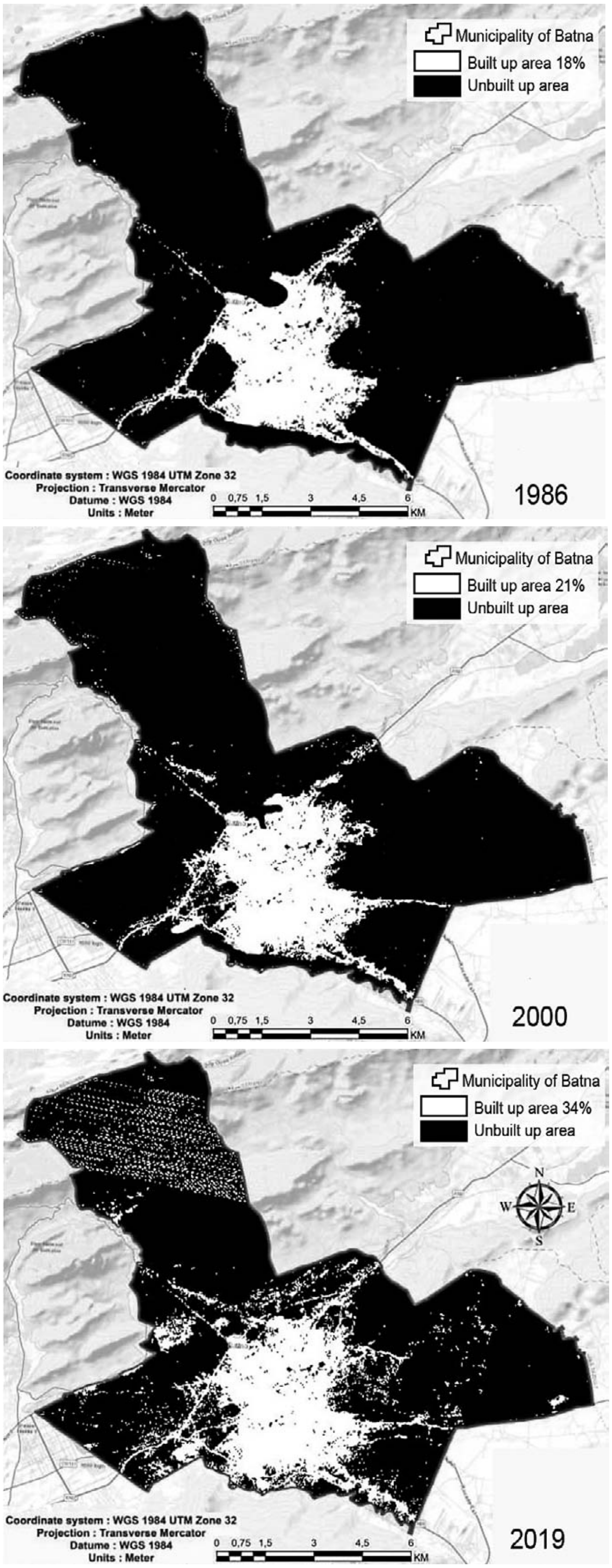
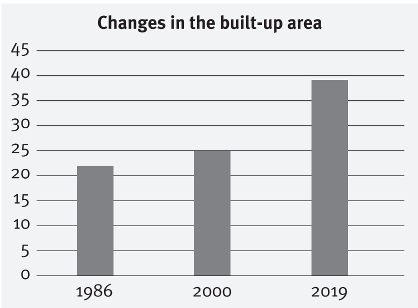


Fig. 1 Urban density and built-up area evolution



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Urban Densification: Effective Sustainability Solution against Urban Sprawl

Batna, Algeria
remote sensing
sustainable development
urban densification
urban sprawl

City densification is typically presented as a strategy to address the challenges of urban sprawl and rapid soil degradation. The aim of this article is to analyze the morphology of the city of Batna, Algeria, using remote sensing and GIS. This approach is part of the prevailing concern over urban sprawl, which is viewed as a troubling phenomenon that increasingly threatens territorial balance. The rate at which natural and agricultural land is being consumed by urban development is accelerating, leading to a gradual and worrying reduction in natural and agricultural land. In the current context, it has become imperative to implement effective strategies to reduce the excessive consumption of bare land. Urban densification appears to be one of the most promising solutions for countering the phenomena of suburbanization and the degradation of natural soils. This perspective seeks to reduce the irrational use of natural and agricultural spaces while ensuring the conservation of resources for future generations, aligning with the principles of sustainable development. The results of this research show that urban densification, which corresponds to optimizing the use of space in urban areas, has the effect of reducing the mineralization of bare soil. This reduction is the result of the city building on itself rather than extensively. The research highlights the decisive impact of urban densification as an effective tool in the fight against urban sprawl. However, this approach to sustainable development is not sufficient on its own; it must be integrated into an overall policy framework for sustainable development, combining different mechanisms for action.

Introduction

Urbanization is a socio-economic phenomenon that continues to grow worldwide. This growth is mainly due to the increase in the number of city dwellers, influenced by migratory movements, both voluntary and involuntary, and the search for better living conditions (Magidi, Ahmed, 2019: 1). However, it has been observed that this rapid urban growth has sometimes led to uncontrolled expansion of urban space. This has led to forms of urban development that are unsustainable in environmental and economic terms (Shao et al., 2020: 241). Unsustainable urban development has reached such a level of concern that it has become a major threat to the achievement of the Sustainable Development Goals (SDGs) through the universal phenomenon of urban sprawl. Considered one of the major human dynamics of our time, this process is the subject of much debate in the fields of urban planning, regional sciences, ecology, economics, and geography. It is a dynamic that represents a major challenge in terms of sustainability, leading to profound transformations in urban lifestyles. Addressing it requires a multidisciplinary approach that involves multiple analytical perspectives and confronts major sustainability issues (Imbrenda et al., 2022: 23). Like many countries around the world, Algeria is faced with the phenomenon of urban sprawl, which emerged as a trend after the Second World War. Since independence, Algerian towns have undergone massive urbanization across the country, leading to the emergence of sprawling, fragmented cities. The phenomenon is constantly evolving and affects all urban areas, including the city of Batna, which will be the subject of our case study.

In recent decades, Batna has experienced more pronounced and significant spatial expansion (Dridi et al., 2015: 212), with urban areas constantly expanding, increasingly impacting urban life, and posing a threat to the natural environment. In order to consider effective and sustainable urban planning for the future, it is essential to start with a comprehensive understanding of the phenomenon of urban sprawl.

Today, urban sprawl is an important and topical issue, as urban agglomerations are growing, expanding and spreading worldwide (Sharma et al., 2024: 1-2; Lounis et al., 2024: 405). This excess of land use and occupation resulting from urban sprawl represents a major challenge for the sustainable development and resilience of cities (Nuissl, Siedentop, 2021: 91-92).

The aim of this article is to analyze this phenomenon using morphological indicators based on remote sensing and GIS over the period 1986-2019, in order to quantify and map the spatiotemporal evolution of the urban sprawl and its impact on the natural environment, while examining the role of urban densification as a relevant strategic approach in the fight against urban sprawl. Remote sensing is a method that makes it possible to closely monitor spatiotemporal changes in urban and natural areas using satellite imagery, which offers the possibility of regularly updating the state of land occupation and use in the studied areas (Dechaicha, Alkama, 2020: 44; Chetara, 2023: 122-123).

This remote sensing approach remains a crucial method for monitoring changes in urbanization and ensuring effective planning for the future of cities as part of sustainable urban development.

- **The process of urban sprawl** – Today's cities, driven by economic and technological progress, are expanding and developing remarkably. This urban growth often results in urban sprawl, a growing phenomenon of urbanization marked by the outward expansion of cities into peripheral and rural areas, moving away from the city center (Antoni, Youssoufi, 2007: 3; Muchelo et al., 2024: 1), often to the detriment of agricultural or natural lands. This development model is now a classic and universal concept in geography, urban planning, and environmental studies (Simard, 2014: 332) and represents a complex process manifested by the city's expansion into the surrounding rural areas. It cannot be simply defined as a static phenomenon, as it involves a set of constantly evolving dynamics. It is primarily characterized by horizontal expansion and significant fragmentation, marked by an extensive road network, fragmented plots, and low-density construction due to new residential, commercial, and industrial infrastructures built outside the traditional city limits, resulting in very loose urban fabrics (Le Néchet, 2015).

Urban sprawl is characterized by the expansion of urbanized areas, the dispersal of homes and jobs over greater distances, and an increasing reliance on cars for commuting. It can lead to land fragmentation, the loss of agricultural land and natural spaces, air and water pollution, traffic congestion, alteration of microclimate, destruction of aesthetics, increasing crime wave, pollution and waste management problems (Aniekwe, Igu, 2019: 15) and other environmental and socio-economic issues. According to Aguejdad (2009): "Urban sprawl presents a significant challenge to sustainable development. It accelerates the consumption of land designated for farming in peri-urban areas, leads to socio-spatial segregation, incurs economic costs, and notably contributes to environmental problems."

• **Forms of urban sprawl** – Urban sprawl can take several forms depending on various artificial or natural constraints:

– Concentric sprawl, often described as an oil spot pattern, occurs when urban expansion develops around a central core, typically featuring the urban center, leading to the emergence of secondary centers in the peripheral areas.

– Linear urban sprawl is referred to as a 'glove finger' sprawl when urbanization follows transport axes, and fragmentation results in more dispersed urban forms.

– Dispersed urban sprawl is an extension that does not conform to any of the aforementioned types, often due to the terrain's relief or a lack of communication networks.

– Parallel urban sprawl occurs when a new city is created adjacent to an existing older city, meaning two urban entities are situated parallel to each other.

• **Causes of urban sprawl** – This phenomenon is often the result of factors such as population growth, increased demand for housing, the availability of inexpensive land on the outskirts of cities, and preferences for a suburban lifestyle (Table I).

• **The consequences of urban sprawl** – Urban sprawl can have significant repercussions on land use and land cover, infrastructure, mobility, the environment, and the quality of life for residents. Urban planning and land management often aim to regulate and limit urban sprawl to promote the sustainable development of cities through strategies of urban densification (Table II).

Urban Densification as a Sustainable Urban Planning Strategy (Concept and Principles of Urban Densification)

• **The impact of urban densification on urban sprawl** – Before addressing urban densification, which has been a key objective of urban policies since the 1970s, it is important to define the concept of urban density, which has recently sparked intense debate among experts, becoming a current topic with major implications for sustainable urban development, environmental preservation, climate challenges, and issues related to urban sprawl.

Goal 11 of the Sustainable Development Goals (SDGs), adopted by the United Nations in 2015, aims to promote more sustainable urbanization. This ambition aims to address the ample criticism directed at urban sprawl.

Internally, urban sprawl weakens city centers and distances people from their homes and workplaces, leading to longer commute times, increased social and territorial inequalities, and higher costs for local authorities, particularly in terms of infrastructure and services. It also contributes to the saturation of car traffic.

Outside urban areas, sprawl has major environmental consequences: it consumes a lot of energy, increases greenhouse gas emissions, weakens biodiversity, and leads to excessive consumption of land and natural resources. This evolution of ideas and concepts has had a profound influence on urban development approaches. Today, the focus is on controlling urban sprawl and seeking more sustainable urban forms. In this perspective, density has become a central indicator of the sustainable city. It is closely linked to the model of the compact city, often presented as a relevant solution to the excesses of the dispersed city (Breuillé et al., 2019: 346).

According to Touati (2015), the term "density" has a multidisciplinary meaning. It is often used vaguely in the fields of urban planning, urban economics, and geography. Urban density represents a theoretical ratio between a given quantity (such as the number of inhabitants, jobs, housing units, or even floor area in square meters) and the space it occupies (in terms of gross or net land area).

Table I Factors of urban sprawl

Factors of urban sprawl
– Population growth affects both urban and rural areas. When a city experiences an increase in its population, residents tend to migrate to peripheral areas in search of more space and affordable housing.
– The development of the automobile plays a significant role in promoting urban sprawl, enabling residents to live at a distance from their workplaces and amenities.
– Rural exodus is observed in many regions of the world, particularly in the poorest areas or those undergoing industrial growth, whereby rural inhabitants migrate to cities in search of better employment opportunities.
– In wealthy countries, there is an urban exodus towards the outskirts, driven by the high cost of property in city centers, increased accessibility for cars, and the rise of remote work.
– Land policies and property development often promote the construction of new housing on cheaper land, primarily on the outskirts of cities, thereby contributing to urban sprawl.

Table II Repercussions of urban sprawl

The repercussions of urban sprawl	
Environmental stakes	– A reduction in biodiversity and the destruction of ecosystems due to the conversion of agricultural land into urban areas. – Air pollution related to vehicles. – Artificialization and mineralization of soils. – The destruction of rural landscapes.
Social stakes	– A decline in the quality of life for residents, linked to the reduction of activities and services available in the city center.
Economic stakes	– An increasing consumption of energy and resources, along with a rise in greenhouse gas emissions. – An increase in transportation costs for residents living far from their workplace or commercial centers. – Increased costs for water, electricity, road maintenance and waste collection due to population dispersion. – Downtown businesses disappear as commercial activities move to more accessible outlying areas. – Increase in the number of vacant housing units in downtown areas, while residents prefer to move to the suburbs.

Urban density is not a monolithic concept but rather a composite notion that varies depending on the field of application. Here are some categories of density: building density or built density, a concept generally used by architects and urban planners; population density, a term frequently used in geography; traffic density; equipment density; activity density. The calculation of these densities refers to the chosen density domain, each type having its own mathematical formula.

However, in the present research, we refer to the field of urban planning, which practically pertains to built density, providing information on the proportions occupied by constructions and their relationship with undeveloped areas.

In this context, the principle of densification consists of preserving the natural environment while limiting ecological impact, which today constitutes one of the major concerns of sustainable urban planning (Robert, 2016). It is the result of a public policy aimed at combating urban sprawl and the problem of increasing built-up areas within the boundaries of existing cities. The fundamental objective is no longer to extend urbanized areas onto new land, but to densify already built-up areas by using available plots or renovating some of them (Maréchal, 2015), which is what is now called urban recycling.

Urban densification is therefore a process of increasing the concentration of population, buildings, and economic activities in existing urban areas. This process involves several perspectives:

- **Urban perspective** – Kaur et al. (2020), stress that the concept of urban densification has come to the fore as an alternative to the phenomenon of urban sprawl, because the latter implies rational and intensive consumption of land through vertical densification reflected in the construction of taller buildings, a reduction in the distance between buildings, workplaces, services and public spaces, and also optimizing the use of existing urban infrastructure. The overriding objective is to limit the consumption of space while offering a high-quality living environment.

- **Environmental perspective** – The environmental dimension consists of directing urban densification towards ecological ends. It is establishing itself as a virtuous model associated with sustainable development (AUCAM, 2015: 1) by limiting the ecological impact through preserving natural areas, this way of controlling the urban area ecologically involves decreasing dependence on the car by encouraging public transport, cycling and walking, which considerably reduces greenhouse gas emissions. It also aims to reduce the harmful consequences of urban heat islands (UHIs) by improving the growth of green and permeable areas, and by reintegrating urban ecology into the urban environment.

- **Social perspective** – Urban densification has a crucial social dimension, impacting residents' quality of life, access to services, social diversity, and community cohesion. Well-planned densification can stimulate neighborhood vitality by offering a range of accessible amenities and services while promoting sustainable lifestyles.

With regard to the social dimension, Lermoyer (2023: 13) indicates that urban densification ensures both the concept of social and functional mix, the first of which refers to the cohabitation of various social groups in a single area with a set of functions necessary for urban life, namely: various residential, economic, political, administrative, mobility and leisure facilities and services.

- **The contribution of remote sensing in detecting changes in urban sprawl** – To achieve the objectives defined by sustainable urban development (SUD), it is now essential to mobilize different disciplines and areas of expertise. These include remote sensing and geographic information systems (GIS), which play a fundamental role in the planning and management of sustainable and resilient cities (Biłozor et al., 2024: 16).

The advent of remote sensing and GIS techniques has made it possible to collect information without physical contact and to extract relevant information in digital form using remote measurements. This has enabled researchers, planners, resource managers, and policymakers to gain a historical perspective of the land and detect changes in urban land use (Magidi, Ahmed, 2019: 2).

Other contributions of remote sensing and GIS in international and local research include studies on large forest fires, cloud tracking for weather forecasting, and monitoring urban sprawl using temporal data (Sonde et al., 2020; Shao et al., 2020; Bennasr, 2003; Dechaicha, Alkama, 2021; Slimani, Raham, 2023; Bentekhici, Yousfi, 2013). These papers have focused on the role of remote sensing and geographic information systems (GIS) in the analysis, detection, and monitoring of urban expansion, with particular emphasis on how the results contribute to recommendations for future sustainable planning.

In this paper, remote sensing is used as an investigative method to characterize and analyze spatio-temporal changes in urban sprawl in the city of Batna.

Materials and Methods

• **Study area** – The study was carried out in Batna, a city in the northeastern Algeria area defined by coordinates between 35° and 36° North latitude and 4° and 7° East longitude. About 425 km southeast of Algiers, the capital of Algeria. It is nestled within a valley that stretches between two distinct mountain ranges: the Tellian Atlas and the Saharan Atlas. This geographical location endows the city with a fundamental topographic uniqueness that significantly influences its climatic characteristics and living conditions.

Batna is situated on a specific geographic site characterized by a relatively flat basin-like topography in the center, which gradually slopes as one moves away from this central point, particularly towards the south. This topographic feature has considerably facilitated its spatial expansion, a phenomenon highlighted in the study. The area of the wilaya of Batna spans 12,038.76 km², ranking it fifth in the hierarchy of Algerian urban centers (Fig. 2).

The wilaya of Batna is bordered by several wilayas. To the north, it is bordered by the wilaya of Mila, while to the East; it is adjacent to the wilaya of Khenchela. In the West, it shares a boundary with the wilaya of M'sila. To the south, it is bordered by the wilaya of Biskra. In the Northwest, it is contiguous with the wilaya of Setif, and to the northeast, it shares limits with the wilaya of Oum El Bouaghi.

It is worth noting that the city of Batna, located in the northeastern part of the wilaya of Batna, holds a historically recognized position as the capital of the Aures region. This city, which simultaneously serves as the administrative center of both the wilaya and the municipality of Batna, covers a total area of 11641 hectares. Additionally, its average altitude is 1058 meters above sea level (Fig. 3).

• **Population density** – At the end of 2019 the population of the wilaya of Batna is estimated at 1,377,000 inhabitants, whereby the municipality of Batna with 350,000 inhabitants is by far the most populous. The average population density of the province at the end of 2019 is 114 inhabitants per km².

• **Data collection** – In the context of this study, two methodologies were combined, each providing specific insights into the understanding of the phenomenon under investigation (Fig. 4). The first methodological approach consists of a remote sensing study. This approach aims to characterize the spatiotemporal changes of the urban area of Batna over a period of 30 years, from 1986 to 2019. Secondly, a morphological approach was employed, using two morphological indicators to quantify urban sprawl in the city of Batna for the three selected periods.

To achieve the desired results, this process was carried out in stages:

– To achieve the target results, this process was completed in stages;

– Collection of satellite data and images for the periods 1986, 2000 and 2019;

– Classification of satellite images through supervised classification;

– The acquisition of data required by a Geographic Information System (GIS) for the calculation of the two morphological parameters, namely density and compactness.

• **Data and Image Preprocessing** – The data used in this study consist of a series of time-series images acquired by the Landsat 5 TM and Landsat 8 OLI/TIRS sensors. These images are freely available on the NASA and United States Geological Survey (USGS) websites. The images have a spatial resolution of 30 m for the visible and near-infrared (NIR) bands, 120 m for the thermal bands of Landsat 5 TM, and 100 m for the thermal bands of Landsat 8 OLI/TIRS. The images cover key dates between 1986 and 2019, selected approximately every 15 years to ensure temporal consistency. These scenes were chosen based on the similarity of atmospheric and phenological conditions to minimize seasonal variations (Table III).

The remote sensing data were analyzed using a Geographical Information System (GIS), specifically ArcGIS software. This phase of image processing is crucial as it facilitates the development of Land Use and Land Cover (LULC) maps. In the context of this study, the main objective of this study is to map and

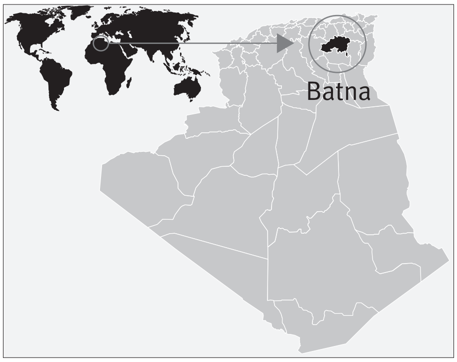


Fig. 2 Geographical location of the settlement of Batna on the map of Algeria

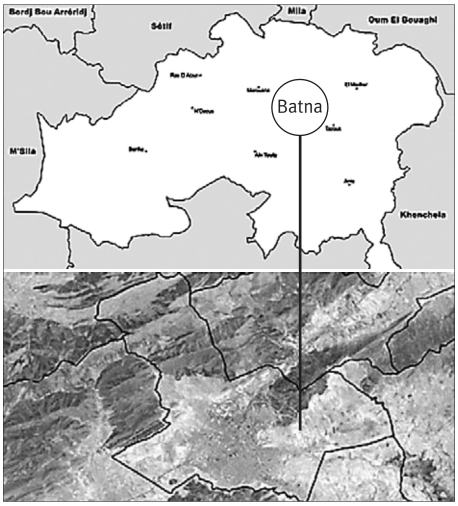


Fig. 3 Administrative boundaries of the wilaya of Batna

Fig. 4 Structure of the study

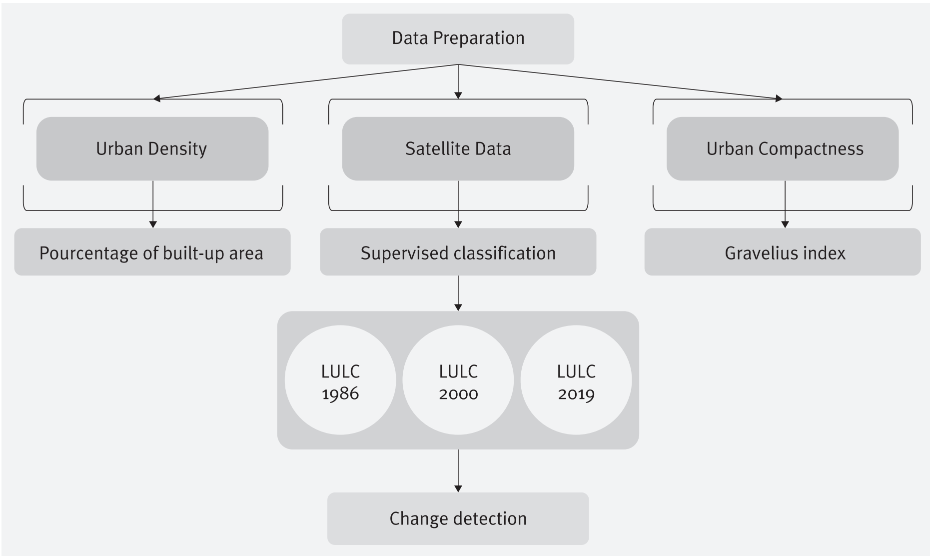
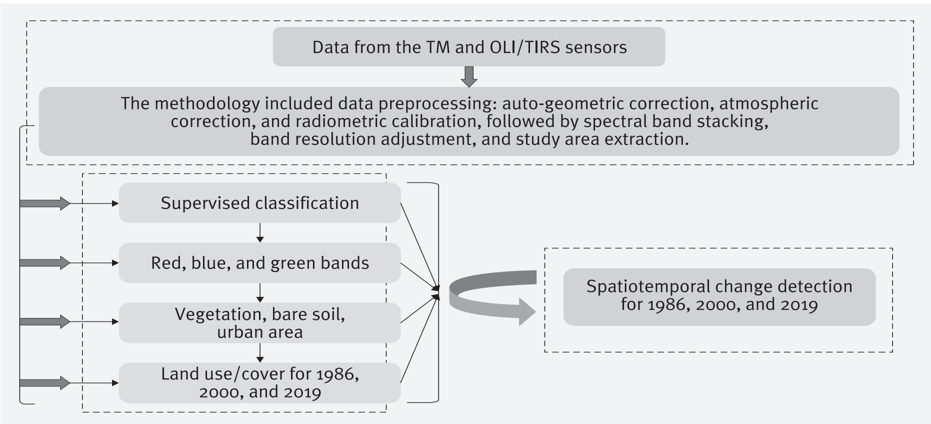


Table III Acquisition dates and characteristics of image data used

Satellite	Acquisition dates	Time	Number of bands	Resolution	Cloud- cover	Azmuth	Sun elevation	WRS/Path
Landsat 5 TM	15/07/1986	09 :30 :05	7	30 m	0.00	108.96	58.77	193
	12/07/2000	09 :50 :28	7	30 m	0.00	112.36	61.70	194
Landsat 8 OLI/TIRS	17/07/2019	10 :13 :27	11	30 m	0.00	121.05	65.44	194

Fig. 5 The land use mapping process



monitor the evolution of the urban area of Batna (Fig. 5).

For this purpose, we used Level 1 Terrain Precision (L1TP) imagery, which are geometrically corrected and georeferenced to the WGS84 datum and projected in the Universal Transverse Mercator (UTM) coordinate system by the USGS (Soto et al., 2024: 98).

The delimitation of the study area was based on the current administrative boundaries, extracted from a shapefile obtained via DIVA-GIS, a free software for mapping and geospatial analysis.

Finally, the Landsat images, provided in digital numbers (DN) corresponding to radiance, were radiometrically calibrated. This involves the application of a TOA (Top of Atmosphere) correction (Slimani, Raham, 2023: 21) as well as the use of the DOS1 (Dark Object Subtraction) model, which reduces the effect of dark noise in the image.

- **Supervised Classification** – The supervised classification method allows for the creation of land cover maps. This approach relies on the identification of information classes for various types of surfaces, which are then used to define the spectral classes representing them through the maximum likelihood algorithm (MLA) (Soto et al., 2024: 98), which calculates the probability of a pixel belonging to each class in order to determine the digital “signature” of each class. Furthermore, the analysis of urban evolution at the scale of the city of Batna was strengthened through a morphological approach, using morphological indices, particularly urban density (represented by the ratio between built and non-built areas) and urban compactness, measured using the Gravelius index. These calculations were carried out after acquiring the necessary data for their evaluation. These indices mainly allow for measuring the urban patch and understanding its spatial configuration.

The morphological shape indices can be calculated using mathematical formulas. In the two equations of these two indices, (S) represents the surface area of the shape, (A) represents the built-up area, and (P) denotes the perimeter. The data necessary to calculate these two indices are obtained using geographic information systems (GIS).

These two methodological approaches allow for a better understanding of the evolution of the urban sprawl of Batna. It allows for the quantification and analysis of spatiotemporal variations within the city, thus providing essential information for urban planning and management.

Results and Discussion

- **Study of changes in LULC 1986-2019** – The evolution of urban land use was selected as a determining factor to study the phenomenon of urban sprawl. A supervised classification method, involving the Maximum Likelihood algorithm (specified in the “Supervised Classification” section), was implemented using the ArcGIS platform to analyze the spatiotemporal evolution of land use. In the context of the classification, three distinct categories of land use were identified (Table IV):

– Urban Area: Shown by white areas, signifying built-up areas.

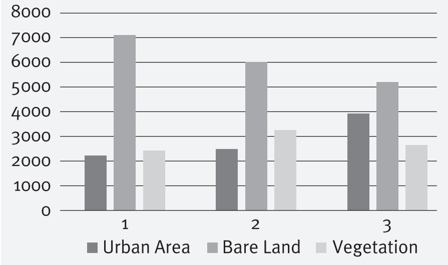
– Bare land: Brown areas indicate unbuilt land.

– Vegetation: Found in green areas.

The built-up area has increased according to the Fig. 1. With an increase of +273.61 ha, it went from 2212.11 ha in 1986 to 2485.71 ha in 2000; between 2000 and 2019, it also increased by +1429.83 ha. However, the category of bare soils has decreased in area, estimated at -1111.77 ha between 1986 and 2000, and at -793.21 ha between 2000 and 2019. The other classes convert the lost part. Vegetation thus recorded a projected surface gain of +838.26 ha between 1986 and 2000 and a loss of -631.62 ha between 2000 and 2019; the land use/land cover maps for the years 1986, 2000, and 2019 are presented on Fig. 6. Allow the observation of changes in the different categories of land use and land cover (LULC) over time (Fig. 6).

Table IV Changes in the land cover in the city of Batna, between 1986 and 2019

Land use class	Area (Ha)			Change (Ha) (+/-)	
	1986	2000	2019	1986 to 2000	2000 to 2019
Urban area	2212.11	2485.71	3915.54	+273.61	+1429.83
Bare land	7083.18	5971.41	5178.42	-1111.77	-793.21
Vegetation	2418.30	3256.47	2624.85	+838.26	-631.62



The data presented in Fig. 1 and the maps in Fig. 6 suggest that the period from 1986 to 2000 was marked by rampant urbanization and the spread of illegal housing, reflecting a chaotic expansion in all directions. The significant migratory influx observed in the city during the so-called “dark decade” in Algeria, combined with the concentration of economic and industrial sectors, contributed to the exacerbation of this situation.

The rapid increase in population led to a rise in demand for land for housing construction, to the detriment of agricultural and forest lands. This dynamic has favored uncontrolled and unregulated urban growth. Despite the urban planning policies in place, the city of Batna experienced unregulated urban expansion between 2000 and 2019.The urban expansion of the city, which mainly occurred along the main roadways, has led to continuous development of built-up areas along these routes. Unregulated urbanization has caused irreversible consequences on the natural environment, leading to its degradation and the conversion of fertile agricultural lands into urban areas. This transformation has rendered the soils impermeable and mineralized by concrete and asphalt. As a result, the air and surface have experienced an increase in their temperature (Chetara, 2023: 172-173), leading to a worsening of atmospheric and surface pollution.

The findings of this research highlight the widespread and sparse character of the city of Batna, making it potentially vulnerable to the impacts of climate change. These changes can lead to an alteration of its local climate, which results in fluctuations in energy and thermal balance.

- **Urban density calculation** – Urban density is an indicator used to evaluate the evolution of the built-up area in Batna and its densification. In percentage terms, this is the relationship between built area (P) and total city area (A): P/A. This indicator shows the degree of urbanization as well as the percentage of land used for construction. The analysis of this indicator makes it possible to understand the spatial evolution of Batna over time, thus highlighting development trends and the effectiveness of urban planning strategies (Fig. 1). The data shown in Fig. 1 above reveals a clear trend towards growth of built-up area, leading to a significant increase in the urbanization rate of the city of Batna. There is also an increase in the percentage of built-up areas, which reflects a high dependence on agricultural and natural resources.

- **Urban compactness** – Urban compactness was quantified using the morphological index of Gravelius (Maignant, 2005), an index used to evaluate a city’s structural configuration (Honvo, Dossou-Yovo, 2021: 6). It also measures the degree of fragmentation or compactness of the urban fabric. The index reaches high values when fragmentation is pronounced. To calculate this, the perimeter “P” and area “S” of the built area must be

Table V Gravelius index

Year	1986	2000	2019
Built area (km²)	22.1211	24.8571	39.1554
Perimeter (km)	73.737	82.857	130.518
Gravelius index	4.423	4.689	5.885

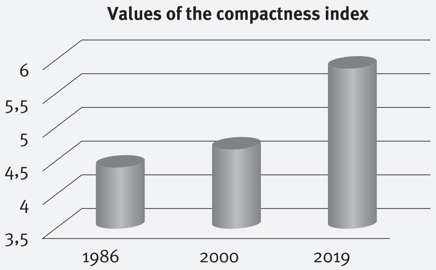
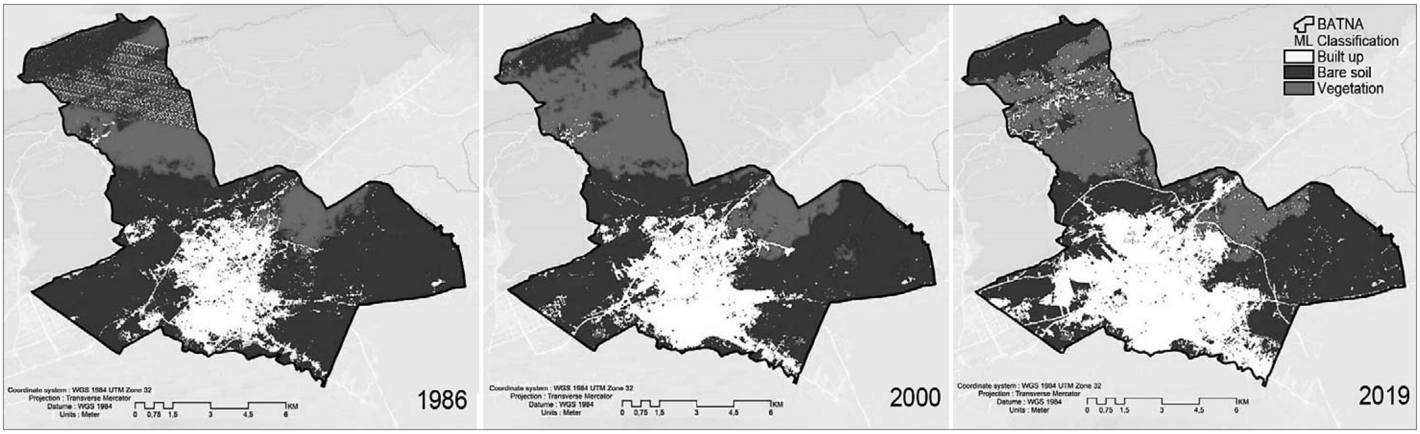


Fig. 6 Spatiotemporal evolution of the city of Batna for the years 1986, 2000, and 2019 (Urban area in white)



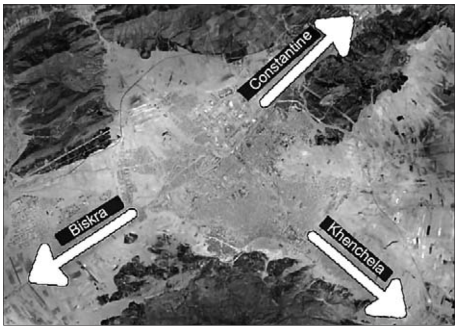


Fig. 7 Urban sprawl directions

known (Saouli et al., 2020: 827). The data required for this calculation are extracted from satellite images combined with geographic information systems (GIS) for the period covering 1986-2019 the entire territory, is formulated as follows:

$$K = \frac{P}{2\sqrt{\pi S}}$$

Where:

– K is the Gravelius index,
– P is the perimeter of the built-up area,
– S is the area of the built-up zone.

The data are presented in Table V.

The analysis of the data in Fig. 1 reveals a significant expansion of the city of Batna over the past decades. This trend is illustrated by a notable increase in the compactness index, which stands at over 1, indicating a sprawling urban form. Indeed, in 1986, the compactness index was 4.42, suggesting a relatively low urban compactness compared to today. However, it should be noted that this value showed an upward trend, reaching 4.68 in 2000 and 5.88 in 2019, respectively. This evolution suggests an increasingly significant expansion of the city of Batna over time.

The compactness index highlights a built urban expansion in Batna that has been characterized by spatial dispersion in all directions. The trend can be interpreted as a reflection of poor urban planning, characterized by the absence of a coherent spatial development strategy. This situation is due to a shortage of land and the saturation of the central urban fabric, caused by the presence of several artificial obstacles, such as the industrial and military zones, and natural constraints, such as the mountainous terrain and the presence of rivers. This expansion follows three main axes: towards Constantine in the north towards Fésdis, towards Biskra in the south towards the Oued Chaâba, and towards Khenchela in the east towards the Tazoult road. An in-depth analysis of the area in question reveals a predominance of individual dwellings, with the presence of a few collective groups forming a loose and discontinuous fabric (Fig. 7).

Conclusion

Remote sensing technologies and Geographic Information Systems (GIS) are useful tools for obtaining accurate spatial data on land use and occupation characteristics. These data are crucial for making informed and strategic decisions on sustainable urban planning. The present study aims to analyze the spatio-temporal urban growth of the city of Batna, in Algeria, over three different periods from 1986 to 2000-2019. This analysis is part of a methodological approach based on the use of satellite imagery and the application of morphological indices, allowing an in-depth quantitative assessment of the city's evolution.

The diachronic study of the urban evolution of Batna revealed an expansion towards an elongated, less compact form, marked by a fragmented geometric configuration. This has exceeded the initial limits set by the planning documents.

Spatial analysis of land use revealed variations in the rate of urban area spatial growth, which accelerated during the period 2000-2019. The urban growth observed in recent decades is marked by a fragmentation of the territory along transport routes, especially national roads (RN 03 and RN 31). This fragmentation has influenced the current direction of urbanization, with urban extensions developing on the periphery of these axes, far from existing urban centers. This configuration has contributed to the creation of a loose and dispersed urban network. This is due to two main factors. First, the scarcity of available land, combined with the topography of the site, characterized by mountainous exposure and a dense hydrographic network, contributed to the formation of this landscape.

The results obtained also show that densification remains one of the most promising solutions to slow down urban sprawl, as there is a direct and negative link between urban sprawl and densification; the latter allows for a rational use of natural lands while preserving them for future generations by building the city upon itself. Although urban densification has advantages in the fight against urban sprawl to control it rather than stop it, given that it is a natural and logical phenomenon that accompanies population growth, it cannot be considered the only solution. It must be accompanied by other strategies to achieve sustainable development goals. Conversely, urban densification can create significant nuisances within cities, especially if it is poorly managed, such as air pollution, urban heat, noise disturbances, and traffic congestion, among others. In this context, and with the aim of improving urban quality of life, it is essential that various policies be implemented.

Bibliography and sources

1. Aguejdad, R. (2009) Etalement urbain et évaluation de son impact sur la biodiversité, de la reconstitution des trajectoires à la modélisation prospective. Application à une agglomération de taille moyenne: Rennes Métropole. Géographie. Université Rennes 2. https://theses.hal.science/tel-00553665v1
2. Aniekwe, S. and Igu, N.I. (2019) 'A Geographical Analysis of Urban Sprawl in Abuja, Nigeria'. *Journal of Geographical Research*, 2(1), pp. 12-18. https://doi.org/10.30564/jgr.v2i1.344
3. Antoni, J.Ph. and Youssoufi, S. (2007) 'Étalement urbain et consommation d'espace. Étude comparée de Besançon, Belfort et Montbéliard'. *Revue Géographique de l'Est* [En ligne], vol. 47/3. mis en ligne le 18 octobre 2011. http: // journals.openedition.org/rge/1433 ; https: //doi.org/10.4000/rge.1433
4. AUCAM (2015) Qu'en savons-nous? N° 78, Oct.
5. Bennasr, A. (2003) 'L'étalement urbain de Sfax'. *Revue Tunisienne de Géographie,* 36, pp. 49-87 ‹halshs-00588300›.
6. Bentekhici, N. and Yousfi, D. (2013) 'Analyse de l'étalement urbain de la ville de Mostaganem à l'aide des données satellitales multidates'. *Bulletin des sciences géographiques de l'INCT*, 17(1), pp. 51-62. https://www.asjp.cerist.dz/en/article/198415
7. Biłozor, A.; Cieślak, I.; Czyża, S.; Szuniewicz, K. and Bajerowski, T. (2024) 'Land-Use Change Dynamics in Areas Subjected to Direct Urbanization Pressure: A Case Study of the City of Olsztyn'. *Sustainability*, 16(7), p. 2923. https://doi.org/10.3390/su16072923
8. Breuillé, M.L.; Grivault, C.; Le Gallo, J. and Le Goix, R. (2019) 'Impact de la densification sur les coûts des infrastructures et services publics'. *Revue économique*, 70(3), Mai, pp. 345-373. https://doi.org/10.3917/reco.703.0345
9. Chetara, A. (2023) *L'influence de la morphologie urbaine sur les ambiances thermiques extérieures dans les zones semi-arides (Cas de la ville de Batna)*. Thčse de doctorat. Université Mohamed Khider, Biskra, Algérie.
10. Dechaicha, A. and Alkama, D. (2020) 'La détection du changement de l'étalement urbain au bas-sahara algérien : Apport de la télédétection spatiale et des SIG. CAS de la ville de Biskra (Algérie)'. *Revue Française de Photogrammétrie et de Télédétection*, No. 222. ffhal-03091780f. https://doi.org/10.52638/rfpt.2020.486
11. Dechaicha, A. and Alkama, D. (2021) 'Suivi et quantification de l'urbanisation incontrôlée : une approche basée sur l'analyse multitemporelle des images satellitaires Landsat. Cas de la ville de Bou-Saâda (Algérie)'. *Revue Française de Photogrammétrie et de Télédétection*, 223(1). https://doi.org/10.52638/rfpt.2021.595
12. Dridi, H.; Bendib, A. and Kalla, M. (2015) 'Analysis of urban sprawl phenomenon in Batna city (Algeria) by remote sensing technique'.

Analele Universității din Oradea, Seria Geografie. Article no. 252108, pp. 211-220.

13. HONVO, S. and DOSSOU-YOVO, C. (2021) 'Mutations Socio-Spatiales Et Extension Urbaine au Sud du plateau De Sakété (Sud-Est Du Benin)'. *International Journal of Progressive Sciences and Technologies*, 28(1), pp. 1-16. https://ijpsat.org/index.php/ijpsat/article/view/3375
14. IMBRENDA, V.; COLUZZI, R.; BIANCHINI, L.; DI STEFANO, V. and SALVATI, L. (2022) *Urban sprawl: Theory and practice*. In: P. Pereira & C.S.S. Ferreira (Eds.), *Advances in Chemical Pollution, Environmental Management and Protection*, 8(1), pp. 23-46, Elsevier. https://doi.org/10.1016/bs.apmp.2022.10.017
15. KAUR, M.; HEWAGE, K. and SADIQ, R. (2020) 'Investigating the impacts of urban densification on buried water infrastructure through DPSIR framework'. *Journal of Cleaner Production*, Vol. 259. https://doi.org/10.1016/j.jclepro.2020.120897
16. LE NÉCHET, F. (2015) 'De la forme urbaine à la structure métropolitaine : une typologie de la configuration interne des densités pour les principales métropoles européennes de l'Audit Urbain'. *Cybergeo : Revue européenne de géographie / European journal of geography*. https://doi.org/10.4000/cybergeo.26753
17. LERMOYER, C. (2023) *La densification urbaine : Un processus long et complexe, le cas de Venelles*. Sciences de l'Homme et Société. ffdumas-04840176
18. LOUNIS, I.; LEULMI, L.; GHERZOULI, L. and LAZRI, Y. (2024) 'Comparative Spatio-temporal Dynamics of Urban Sprawl in Algerian Cities Skikda and Tébessa (1985-2024) Using Gis and Landsat Imagery'. *Journal of Contemporary Urban Affairs*, 8(2), pp. 404-420. https://doi.org/10.25034/ijcua.2024.v8n2-7
19. MAGIDI, J. and AHMED, F. (2019) 'Assessing urban sprawl using remote sensing and landscape metrics: A case study of City of Tshwane, South Africa (1984-2015)'. *The Egyptian Journal of Remote Sensing and Space Sciences*. https://doi.org/10.1016/j.ejrs.2018.07.003
20. MAIGNANT, G. (2005) "Compacité et forme urbaine, une analyse environnementale dans la perspective d'un développement urbain durable", *Actes du colloque Développement urbain durable, gestion des ressources et gouvernance*, Lausanne.
21. MARÉCHAL, CH. (2015) *État des lieux, mécanismes et enjeux de la densification urbaine en France. L'approche novatrice de la densification verticale*. Sciences de l'Homme et Société. (dumas01254870)
22. MUCHELO, R.O.; BISHOP, T.F.A.; UGBAJE, S.U. and AKPA, S.I.C. (2024) 'Patterns of Urban Sprawl and Agricultural Land Loss in Sub-Saharan Africa: The Cases of the Ugandan Cities of Kampala and Mbarara'. *Land*, 13, p. 1056. https://doi.org/10.3390/land13071056
23. NUISSL, H. and SIEDENTOP, S. (2021) Urbanisation and Land Use Change, pp. 75-99. https://doi.org/10.1007/978-3-030-50841-8_5
24. ROBERT, S. (2016) 'Entre étalement et densification : une approche fine de l'urbanisation littorale sur la Côte bleue, Provence, Cybergeo'. *European Journal of Geography*. https://doi.org/10.4000/cybergeo.27451
25. SAOULI, R.A.; BENHASSINE, N. and OULARBI, A. (2020) 'A spatio-temporal retrospective of the urban sprawl of Annaba (Algeria)'. *Journal of Fundamental and Applied Sciences*, 12(2), pp. 825-844. https://doi.org/10.4314/jfas.v12i2.20
26. SHAO, Z.; SUMARI, N.S.; PORTNOV, A.; UJOH, F.; MUSAKWA, W. and MANDELA, P.J. (2020) 'Urban sprawl and its impact on sustainable urban development: a combination of remote sensing and social media data'. *Geo-Spatial Information Science*, 24(2), pp. 241-255. https://doi.org/10.1080/10095020.2020.178780
27. SHARMA, M.; KUMAR, V. and KUMAR, S. (2024) 'A systematic review of urban sprawl and land use/land cover change studies in India'. *Sustainable Environment*, 10(1), 2331269. https://doi.org/10.1080/27658511.2024.2331269
28. SIMARD, M. (2014) 'Étalement urbain, empreinte écologique et ville durable. Y a-t-il une solution de rechange à la densification?' *Cahiers de géographie du Québec*, 58(165), pp. 331-352. https://doi.org/10.7202/1033008ar
29. SLIMANI, N. and RAHAM, D. (2023) Urban Growth Analysis Using Remote Sensing and Gis Techniques to Support Decision-Making in Algeria – The Case of the City of Setif. *Journal of the Geographical Institute "Jovan Cvijic" SASA*, 73(1), pp. 17-32. https://doi.org/10.2298/IJGI2301017S
30. SONDE, O.; BALAMWAR, S. and OCHAWAR, R.S. (2020) 'Urban sprawl detection and analysis using unsupervised classification of high resolution image data of Jawaharlal Nehru Port Trust area in India'. *Remote Sensing Applications: Society and Environment*, 17, 100282. https://doi.org/10.1016/j.rsase.2019.100282
31. SOTO, S.; HAMOUDA, A. and REBAH, H. (2024) Monitoring and Quantification of Rural Urbanisation. Case of Arris and Theniet Elabed, Algeria. *Bulletin of the Serbian Geographical Society*, *104*(2), pp. 95-108. https://doi.org/10.2298/GSGD2402095S
32. TOUATI, A. (2015) *L'argument de densité, enquête sur l'histoire d'une notion en vogue*. https://www.citego.org/bdf_fiche-document-58_fr.html

SOURCES OF FIGURES AND TABLES

FIG. 1	Authors
FIG. 2	Derived from: https://www.actualitix.com/ (adapted by authors)
FIG. 3	Derived from: https://d-maps.com/ (adapted by Authors)
FIGS. 4-6	Authors, 2021
FIG. 7	Google Earth (adapted by authors, 2021)
TABLES I-V	Authors

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