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ANALYSIS OF URBAN GROWTH EFFECTS ON LAND SURFACE TEMPERATURE (LST) INCREASE USING GIS: A CASE STUDY OF CHELGHOUM EL AÏD CITY (1984–2024)

Abstract: The city of Chelghoum El Aïd has experienced rapid urban growth, primarily driven by a major urbanization event. This expansion has prioritized the development of natural and undeveloped spaces, rather than investing in urban infrastructure. As a result, there has been a significant transformation of open areas, leading to a considerable reduction in green and natural spaces. In addition to the environmental impact, the urban expansion of Chelghoum El Aïd has become more pronounced from a morphological perspective. This is characterized by the densification of existing urban fabric and the gradual transformation of its original structure. The city continues to expand beyond its initial boundaries, gradually integrating previously undeveloped areas. This study analyzes the urban growth of Chelghoum El Aïd (Wilaya of Mila, Algeria) from a morphological perspective the city's growth has predominantly followed a linear and compact pattern along National Road No. 5 to highlight the role of urban form in the emergence of urban heat islands. The research employs across-evaluation of Land Surface Temperature (LST) and the Normalized Difference Vegetation Index (NDVI), utilizing satellite imagery spanning the period from 1984 to 2024. The analysis is based on data from Land sat sensors 5, 8, and 9, processed using ArcGIS 3.2.0 software. The correlation results indicate an inverse relationship between LST and NDVI indices. The year 1984 showed the strongest negative correlation (R^2 = 0.3466) and the steepest regression slope (-42.33) demonstrating that the decrease in vegetation cover has significantly contributed to the rise in temperatures within Chelghoum El Aïd, Since the beginning of the study period, temperatures have risen by approximately three degrees Celsius. This study benefits key stakeholders, including ministries (environment, ag-

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riculture, energy), universities and research centers, municipalities, environmental organizations, and the private sector. These entities use the findings to enhance urban planning, resource management, and sustainable development.

Keywords: urban growth, Geographic Information Systems, LST, NDVI, Chelghoum El Aïd City, Heat Islands

Introduction

Urban growth is a global phenomenon characterized by the continuous expansion of urban areas driven by population increase and socio-economic development This expansion significantly impacts the morphological structure of cities, altering their growth patterns and influencing the distribution of buildings, streets, green spaces, and infrastructure since the increase in private car ownership correlates with a higher rate of urban growth (Benhenni & Alkama, 2023).

At the same time, local climate conditions within cities arise from complex interactions between physical components and human activities, leading to the formation of urban heat islands. Studies have shown that cities tend to be warmer than surrounding rural areas (Guechi et all., 2022; Benoumeldjadj et all., 2023), which poses numerous challenges. These include increased energy consumption and resource demand, economic burdens, and adverse effects on residents' thermal comfort, ultimately threatening the overall quality of life in urban environments.

In the United States alone, extreme urban heat contributes to the deaths of over 1,000 people annually, highlighting the urgent need for sustainable urban planning and climate adaptation strategies (Changnon et all., 1995).

Studying and addressing this environmental and climatic aspect through effective planning, development, and strategic programming has become a necessity in today's world. With rapid technological advancements and easier access to information through advanced tools, ensuring the sustainability of the urban system requires a data-driven approach. This can be achieved by analyzing key indicators that reflect the state of the local climate, such as land surface temperature (LST), the normalized difference vegetation index (NDVI), and building density.

In this context, this research paper presents a descriptive, analytical, and chronological study of the morphological evolution of urban growth in the city of Chelghoum El Aïd. The study examines the city's development from its inception to the present day, focusing on its environmental impacts. The analysis is conducted by evaluating the NDVI to assess vegetation cover and LST to measure temperature variations. Furthermore, the relationship between these two indicators is explored using regression analysis and Pearson's correlation coefficient to better understand the interplay between urban expansion and climate change because studying the spatiotemporal variation patterns of LST and its spatial coupling relationship with NDVI can effectively reflect the trend of ecological environment change in the study area (Afrasiabi Gorgani et all., 2013; Liangyan et all., 2024).

The city of Chelghoum El Aïd was selected for this study due to its status as a medium-sized city within the Algerian urban network. It is strategically located in the Mila province in eastern Algeria, positioned between longitudes 6°8' and 6°12' east and latitudes 36°7' and 36°11' north. The city is traversed by National Road No. 05 and is situated 54 km from

Constantine, 76 km from Sétif, and 55 km from Mila, making it a central hub within these key provinces.

Chelghoum El Aïd lies on a flat, easily accessible plain that is part of the Upper Constantine Plains, covering an area of 254.4 km². This topography makes the city susceptible to the dry Sirocco winds during the summer, occurring for an average of 9.7 days per year (Zawi, 2015), which contribute to elevated land and atmospheric temperatures.

The city has a total population of 102,854, with a population density of 404 people per km², making it the most populous municipality in the Mila province. The urban area itself accommodates 87,883 residents (Department of Programming and Budget Monitoring, 2023) within a built-up area of 935 hectares (author's calculation using satellite imagery and Arcgis, 2024) The concentration of this population within the city's urban perimeter, which spans approximately ten square kilometers, has led to various environmental, social, and economic repercussions.

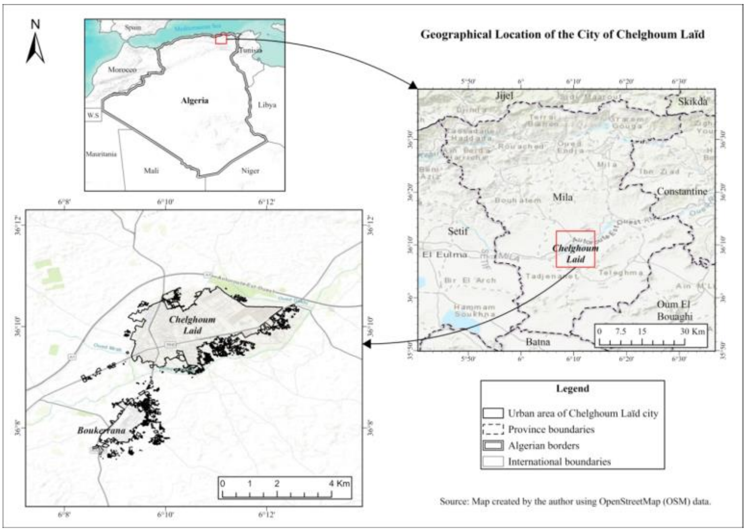

Fig. 1. Geographic Location of the City of Chelghoum Laid (Source: Prepared by the researchers using OSM and ArcGIS Pro 3.2.0 software)

From a morphological perspective, the study examines the stages of urban development that the city has undergone, with particular emphasis on the political, social, and economic factors that have influenced its growth at both urban and demographic levels.

The research employs spatial analysis to assess land consumption patterns from the city's inception to the present day. To highlight the environmental consequences of this expansion, special attention is given to the depletion of agricultural land due to urban sprawl and its impact on the urban climate. This is achieved through the analysis of key indicators such as the Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), which serve as essential tools for evaluating the effects of urban growth on the local climate and green spaces. To ensure a comprehensive and accurate understanding of these phenomena, the study utilizes advanced remote sensing and Geographic Information Systems (GIS), which is an effective tool for constructing environmental models, provides advanced capabilities for data storage, management, analysis, and precise and efficient visualization (Mokhtari et al., 2024).

Methodology and Tools

Morphological Study: To analyze the development of the urban fabric of Chelghoum El Aïd, we utilized ArcGIS Pro to create six maps illustrating the city's expansion from its inception to the present day. This analysis was based on data obtained from various relevant administrative bodies, archival records, municipal development, and construction plans, as well as aerial imagery sourced from Google Earth.

Using Geographic Information Systems (GIS), we calculated the expansion area at each stage and delineated the city's perimeter to derive key indicators, including:

- Average annual growth rate: This indicator helps determine the period during which urban expansion was most significant, providing insights into patterns of land consumption and development trends over time (Hama & Djaffal, 2024).
- Miller's I index to determine the morphological form of city development. (Bendjoudi & Hubert, 2002).
- Gravilius K index to determine the intensity of expansion (Bendjoudi & Hubert, 2002), the space consumed was finally compared to demographic growth.

At the local level, a chronological analysis was conducted focusing on two key indicators, the USGS website (https://earthexplorer.usgs.gov) provided the satellite data needed for this study the spatial resolution of the used wavebands were 30 m for the NDVI and 100 m/ 120 m for the LST indicator (table 01), which was appropriate to achieve the objectives of the study, the satellite images were acquired at a 10-year interval and during the same month:

Table 1. Description of Land sat data from different sensors

Satellite sensor	UTM Zone	Date of acquisition (NDVI)	Resolution (NDVI)	Date of acquisition (LST)	Resolution (LST)
Land sat 5 TM	32	17/03/1984	30 m	16/07/1984	120 m
Land sat 5 TM	32	18/03/1994	30 m	28/07/1994	120 m
Land sat 5 TM	32	26/03/2004	30 m	28/07/2004	120 m
Land sat 8 OLI	32	17/03/2014	30 m	19/07/2014	100 m
Land sat 8 OLI / Land sat 9	32	17/03/2024	30 m	30/07/2024	100 m

Source: Prepared by the researchers, 2024

- Vegetation Cover Index (NDVI) indicator: This index provides valuable insights into the state of vegetation cover, the degree of greenness, and the changes occurring over time. It is based on the interaction between Red and near-infrared (NIR) radiation, where healthy vegetation reflects more NIR and absorbs more red light. The obtained results effectively indicate the health and condition of plant life within the study area.

By analyzing these indicators over different periods, the study aims to assess the impact of urban expansion on green spaces and the overall environmental quality of the city (Al-Sa'ih & Saleheen, 2024).

Based on land sat satellite remote sensing techniques 5 for the years 1984, 1994, and 2004 and 8,9 satellites for the years 2014 and 2024 through the geographic systems program Arcgis pro 3.2.0. Then we compared the images captured in March of the five years

1984-1994-2004-2014-2024, based on the equation for calculating the NDVI index (Ghodieh, 2024).

$$\text{NDVI}=\frac{\text{Nir}-\text{Red}}{\text{Nir}+\text{Red}} \qquad (1)$$

Where: NIR (Near-Infrared Reflectance): This refers to the reflectance of vegetation in the near-infrared spectrum, typically around 700–1300 nm. Healthy vegetation strongly reflects NIR due to the internal structure of plant leaves.

RED (Red Reflectance): This corresponds to the reflectance in the red spectral band, usually in the range of 600–700 nm, which is where chlorophyll absorbs the most light for photosynthesis (Rouse et al., 1974).

As the values range between -1 and 1, negative values represent rocks, water, and sand, Built-up areas such as buildings and roads typically exhibit NDVI values close to zero or negative, indicating the absence of vegetation. In contrast, positive NDVI values ranging from 0.1 to 1 represent varying levels of vegetation cover. Values approaching 1 indicate dense and healthy vegetation, such as thick forests, whereas lower values between 0.2 and 0.4 correspond to grasslands and areas covered with small shrubs (Al-Sa'ih & Saleheen, 2024). This index is crucial for monitoring changes in vegetation cover over time and assessing the impact of urban expansion on green spaces.

- Land Surface Temperature (LST) indicator, refers to the temperature of the Earth's surface at the interface between the ground and the atmosphere, essentially representing the temperature at ground level (depth zero) (Al-Mahi, 2007).

Land Surface Temperature (LST) fluctuates depending on the type of land, soil properties, and the nature of the surface cover (Ghodieh, 2024; Muhammed et all., 2024). Naturally, the temperature of vegetated land differs from that of concrete, snow, or desert surfaces. The ability of each surface to absorb radiation varies based on its composition, and this can be assessed using satellite sensors. In our study, we utilized data from Landsat 5 and Landsat 8 satellites, which provide free coverage from 1984 to the present. Examining Earth's surface temperature is crucial for predicting local climate changes and tracking the development of urban heat islands in cities (Milad, 2022).

The problem of climate change is considered a danger that is reflected on several levels related to the tangible environment, human health, and the deterioration of the quality of life in cities (Quwam, 2023). The results also enable us to know the distribution of temperatures within the urban fabric (Kadhim & Hameed, 2024). To deduce the LST, we downloaded visuals from July of each year, and then the sequence of formulas and rates published on the USGS page was used (https://earthexplorer.usgs.gov). They are as follows:

- Convert the values to spectral radiation using the equation: TOA=ML*Qca1+AL

Where: TOA spectral radiation, ML Multiplication factor from metadata (visual information file), Qca1 Pixel values that correspond to the range1, AL Metadata Scale Factor (File Data)

- Convert TOA to brightness BT using the following equation:

$$BT = \frac{\text{K2}}{\text{In}\left(\frac{\text{K1}}{\text{L}}+1\right)} - 273.152 \qquad (2)$$

K1 and K2 are the first and second thermal conversion constants (we get them from the visual identification data)

- NDVI vegetation index according to the equation mentioned above.
- Derivation of the percentage of vegetation (PV)

$$PV = \frac{(NDVI - NDVImin)^2}{(NDVImax - NDVImin)} \quad (3)$$

- spectral emissivity values E (Emissivity) = 0.004*PV+0.986
- Calculate the ground surface temperature LST

$$LST = \frac{BT}{\frac{1+(0.00115*BT)}{1.4388*Ln(E)}} \quad (4)$$

Following the completion of these mathematical operations and utilizing ArcGIS Pro 3.2.0, the results were visualized in Figure 05, which illustrates the vegetation index for the Chelghoum El Aïd area, and Figure 06, which depicts the land surface temperature for the specified years.

Once the results were obtained, the relationship between the two indicators was analyzed using ArcGIS Pro by overlaying the NDVI and LST layers for each year and calculating the regression coefficient based on 50 randomly selected points from the visual data. Additionally, Pearson's correlation coefficient was computed using Excel to validate the findings.

Results and Discussion

Morphology

Slow urban growth during the colonial period

The city of Chelghoum El Aïd has undergone a long history of transformations that align with the broader urban development of the region. According to the author Lionel Balout, in his book “Algeria in Prehistory,” fossils and human skeletal here remains were discovered at the Mechta El Arabi site, located south of the city (Lionel, 2005), highlighting the deep historical roots of the Amazigh community in the region dating back to about 20,000 years BC (Marc, 1981). In the Roman era, discoveries in the Oued Segane region indicate the presence of a strategic Roman settlement, reflecting the geographical importance of the site due to the fertile and flat lands (El ayadi, 2009).

During the Turkish era, tribal systems dominated the region, with the Ouled Abdel Nour tribe being one of the most prominent in the area. Following French colonization, the region was renamed "Châteaudun," and a colonial settlement was established per a government decree issued on July 11, 1874. The urban layout followed a structured, grid-based organization that reflected the morphological planning approach favored by the colonizers. They prioritized the construction of individual residences for settlers while incorporating essential facilities such as an administrative tower and a church (El ayadi, 2009).This colonial urban expansion aimed to control the strategically located area between Constantine, Setif, And a mile, this colonial nucleus was inhabited by about 100 people distributed over 25 dwellings (Lamri, 2021).

In spatial terms, the city's urban developments indicate a slow expansion at first, with a population of 6,934 in 1926 (Zawi, 2015). However, the city benefited from a housing program under the Constantine Plan before independence, which led to the development of a range of social housing and infrastructure such as a stadium and a health center.

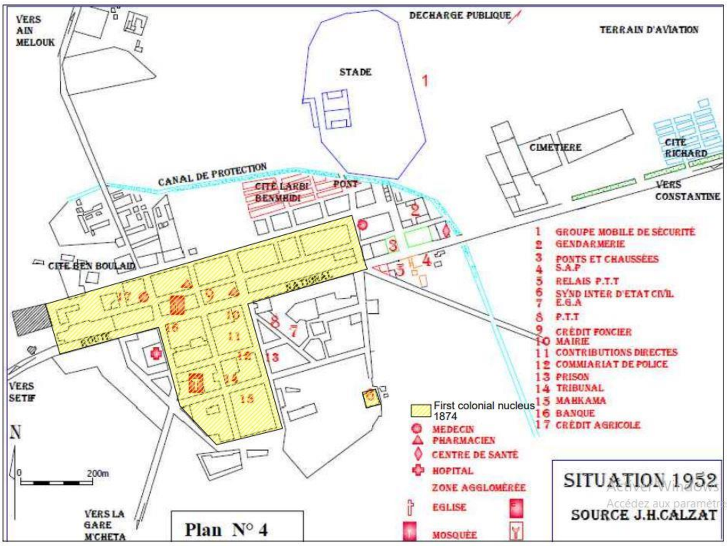

Fig. 2. Expansion Plan of the City of Chelghoum Laid in 1952(Source: Archive of the Technical Services of the Municipality of Chelghoum Laid)

After independence, growth was achieved by condensing the colonial nucleus and then horizontal expansion along the national road:

1962-1984 Weak urban growth: The name was changed to Chalghum Al-Eid, about the martyr Shalghum Al-Eid, who was originally from the village of Ayoun Al-Ajaiz. In Tlaghma The stage did not witness a significant growth movement until 1974, as the population exploited the houses left by the settlers by intensifying the colonial nucleus while continuing French laws and programs.

1984-1994 Significant growth: The region witnessed significant urbanization due to the new administrative division in 1984, which transferred the territory of the municipality of Chelghoum El Aid from Constantine to the state of Mila and promoted it to the district of these political decisions certainly had an impact on the change in the area and urban expansion, concerning housing and equipment. The city also obtained its industrial zone during this period in addition to the ZHUN program. At this stage, the secondary cluster of Bouguerana appeared, which is considered a neighborhood administratively affiliated to the city under the name of the neighborhood of the Lakhdar Mosque (Master plan, 2008).

Population: 62 % of the population of the urban area was 29,896 people, but the Bouguerana community witnessed a very large increase, as the population increased from 1,194 to 4,986 between 1977 and 1997, with a growth rate of 12.25 % due to the availability of jobs in the industrial zone. The population preferred to move closer to the city by moving to the Al-Jami' Lakhdar neighborhood for those who were not lucky enough to obtain housing within the urban area of the city.

1994-2004 A period of security and economic stagnation: Several neighborhoods in the city, such as Ben Bou El Eid and Bourni Brothers, experienced densification during this period. Unlike previous phases, however, urban growth was not as pronounced, largely due to the economic and security crises that the country faced. During this stage, expansion was concentrated in the northern and northeastern areas, with the urban population reaching 38,000 by the end of 1994, including 6,140 residents in the Lakhdar Mosque neighborhood. The early 1990s saw a notable population increase across many Algerian cities, driven primarily by the liberalization of the real estate market and the availability of real estate development loans to private individuals (Djaffal, 2018).After that, the city benefited from a rich housing and equipment program in the northern and northwestern regions and the south, in addition to many residential allocations. The real estate area consumed in ten years was 177.05 hectares.

2004-2014 The period of the greatest consumption in the history of the city: the urbanization rate reached 63 % with 47,933 people in 2005 and 54,431 in 2008. In three years, we notice a significant increase in the number of urban residents (Master plan, 2008), and 11,413 live in the secondary cluster of Bouguerana, representing 15 percent, and 14,263 in 2008. Spatially, the consumption of the area was also great, estimated at 183.26 hectares, with the expansion of the city center and the extension on its outskirts, as shown in (Figure 3) of the city's development.

2014-2024 Population explosion and weak real estate consumption: In the most recent period, according to the data provided, the city has experienced a significant urban population surge. Between 2018 and 2023, the population increased by 19,629 people, marking the largest growth in the city's history. In terms of land, this population growth consumed only 125.17 hectares.

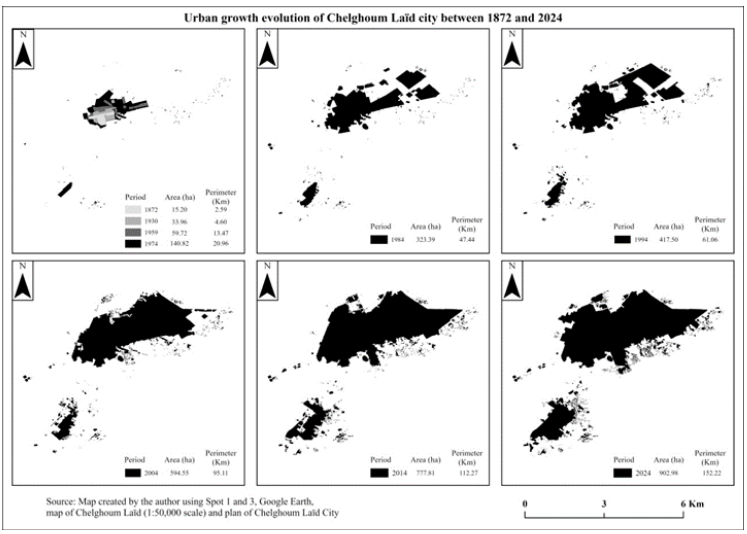

Fig. 3. Development of the Urban Area of Chelghoum Laid (1874-2024) (Source: Prepared by the researchers based on spot 1 and 3 from Google Earth and maps provided by the Directorate of Land Surveying for the Wilaya of Mila (ArcGIS Pro).

As shown in the previous figure, the city's morphological expansion initially occurred through the densification of the colonial core, followed by a longitudinal stretch along National Road No. 05, giving the city a more rectangular shape. In recent years, however, real estate consumption has slowed, despite the large population, indicating a shift toward vertical expansion. To calculate the annual rate of urban growth and the area of land consumed for real estate, we applied the following mathematical operation:

$$-1a = \frac{1}{T}\left(\frac{St}{S0}\right) \tag{5}$$

Where:

a: average annual growth rate
St: value/measurement of land consumed at time t, t+1, t+2t, t+1, t+2t, t+1, t+2
S0: value/measurement of land consumed at time 000
T: interval (in number of years) between the two measurements

Table 2. Represents the evolution of the average annual growth rate of the city of Chelghoum Laid from its establishment to the present day

Periods	Consumed area (hectar)	Average annual (ā) %. Growth rate of consumed land
1872-1930	33,96	3.5
1930-1959	59.72	2.3
1959-1974	140.82	6.1
1974-1984	323.39	8.8
1984-1994	417.50	2.5
1994-2004	594.55	3.6
2004-2014	777.81	2.6
2014-2024	902.98	1.49

Source: Prepared by the researchers, 2024

The results from calculating the average annual growth rate show that during the colonial period, growth was slow due to colonial policies that controlled property in favor of French settlers and focused on establishing infrastructure for military purposes. Between 1974 and 1984, however, the growth rate increased significantly, reaching 8.8%, the highest in the city's history, as the city benefited from an important housing program under the Constantine Plan before independence. This growth was further spurred by national political changes in the late 1970s, with the introduction of ZHUN housing programs and the establishment of a large industrial zone covering 235.04 hectares.

Following this period, growth rates declined at a steady pace until the early 2000s, when real estate consumption rose again due to the population's preference for individual construction. However, in recent years, growth has slowed as the city has shifted toward vertical expansion, driven by collective housing programs such as LPA and AADL social housing projects, particularly in the northwest near the highway, on agricultural land.

To interpret these ratios, we calculated the Gravilélus Index (K) using the following equation:

$$K = \frac{P}{2\sqrt{\pi S}} = 0.28\frac{P}{\sqrt{S}} \tag{6}$$

Where: S represents the area of the city and P represents the perimeter of the city.

The Miller index provides us with the shape of this expansion compared to the circle. The closer its value is to 1, the more circular the shape becomes. Then we compared the results across the periods and with the threshold determined by (Gilles Malignant) through the following equation:

$$I\ miller = \frac{4\pi S}{P^2} \quad (7)$$

Where: S = area and P = perimeter.

Tab. 3. Calculation of the Gravilélus and Miller Indices for the City of Chelghoum Laid.

Years	K	I Miller
1872	1.86	0.28
1930	2.21	0.20
1959	4.88	0.041
1974	4.94	0.0402
1984	7.38	0.018
1994	8.36	0.014
2004	10.92	0.008
2014	11.27	0.007
2024	14.18	0.004
Threshold of Maignant	1.20	0

Source: Prepared by the researchers, 2024

Based on the results obtained after calculating the indicators, we note that compared to the threshold of 1.2 and 0, the city has been dense since its inception, and with its expansion over the periods shown in the table, its density and compression increase over time, especially in the current period, as the indicator 14.18 is very high, which explains the weakness of the average annual growth in the period between 2014-2024 calculated previously. As we previously indicated, the city's policy is directed towards vertical expansion and urban densification, as the population density within the city limits in 2023 reached 9,732 people/km². We also note that the morphological form of the city's circular expansion is very weak according to the results of the Miller index, which is very close to zero, as the city is expanding along National Road No. 5 longitudinally.

Demographic growth and land exploitation

Population growth is a very important factor in urban growth. It is impossible to imagine cities growing and expanding rapidly without population development. Therefore, it is necessary to track population growth in the city, which is fueled by natural increase and the factor of heavy migration from rural areas and neighboring municipalities. The natural increase in 2018 in the municipality of Chelghoum El Aid was estimated at 2.38, the largest among the municipalities of the state (DPBM, 2023). According to the data, the municipality is also considered the first in the number of marriages, with an increase of 161 cases between 2017 and 2018 alone. The development of built-up areas is directly proportional to population growth, according to the following graph:

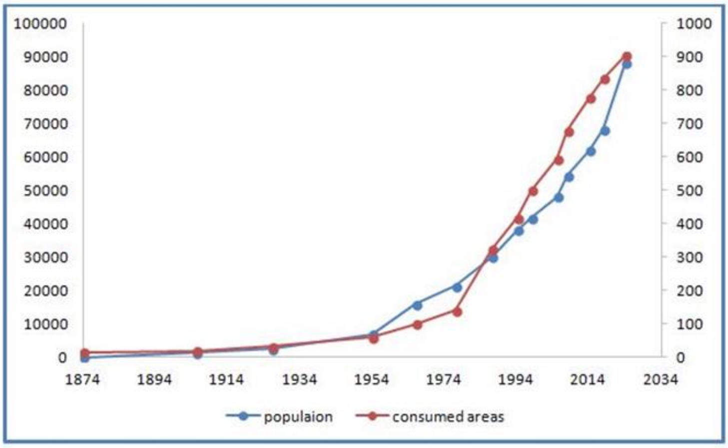

Fig. 4. A graph illustrating the population growth of Chelghoum Laid city and the consumed area development (Source: Prepared by the researchers based on the data from the Master Plan for Urban Planning and Development and the Report of the DPBM for the Wilaya of Mila, 2018, 2023)

Results of the development of the vegetation cover index in the city of Chelghoum El Aid (1984-2024)

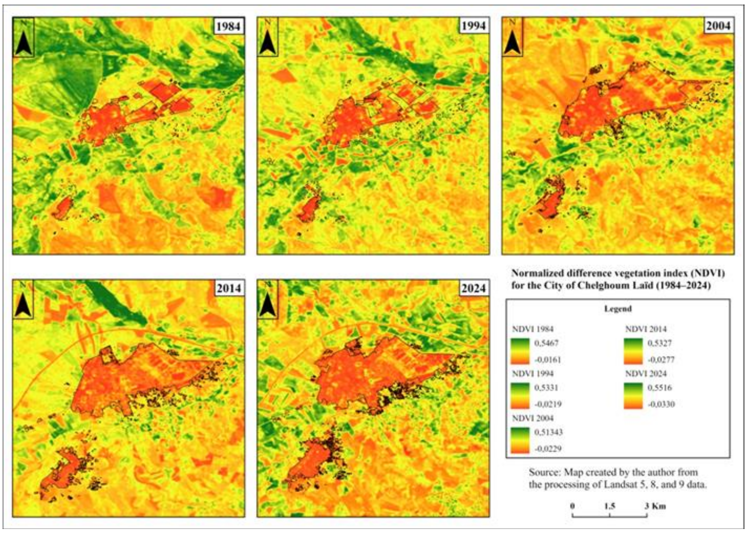

Fig. 5. Vegetation Index of Chelghoum Laid for the years 1984, 1994, 2004, 2014, and 2024(Source: Prepared by the researchers based on ArcGIS Pro 3.2.0 software)

The results indicate that in 1984, the vegetation cover index ranged from -0.0161 to 0.5467, with higher vegetation density observed in the northern, southeastern, and southwestern parts of the study area. Notably, vegetation is more concentrated along the banks of major valleys such as Wadi Dhakri, located north of the main urban cluster, originating from the municipalities of Ben Yahya Abdel Rahman and Bouhatem, and Oued Erremal (Sand Valley) in the southeast, which originates from the Tajnanat municipality. In contrast, the city itself appears in red on the index map, indicating the lowest vegetation values.

In 1994, a noticeable decline in vegetation cover was observed, with index values ranging between 0.5331 and 0.0229. The urban area expanded in all directions, encroaching on the surrounding fertile agricultural lands, particularly near the valleys. The previously high vegetation values recorded in 1984 significantly dropped, turning negative in several areas, especially to the north of the urban zone.

By 2004, the minimum index values represented by red and orange shades, indicating buildings, roads, concrete surfaces, and barren land dominated the landscape. The vegetation cover in the northern part of the city became severely depleted, with only a few small, scattered patches remaining along the valley banks. Overall, the vegetation-covered areas continued to shrink, particularly along the city's periphery.

In 2014, the city recorded the lowest percentage of vegetation cover and the most extensive urban expansion, reaching 183.26 hectares, as indicated by the previously presented urban expansion data. The period from 2004 to 2014 marked the most significant growth phase in the history of Chelghoum El Aid, characterized by rapid urbanization. Additionally, the construction of the East-West Highway, which encircles the city from the north, contributed to the substantial loss of vegetation cover in that area.

In 2024, the highest recorded vegetation index value reached 0.5516, indicating an improvement in vegetation quality and plant health, while the lowest value was -0.033, representing non-vegetated areas. The northeastern and southwestern parts of the region appear covered with a green mantle, likely due to favorable rainfall during the spring period (March) in which the satellite image was captured. The urban expansion during this period was estimated at 125.17 hectares, accompanied by a significant population increase of 26,006 people over ten years. Although the area consumed is relatively small compared to the previous decade, the rapid population growth is alarming, which is further reflected in the high Gravilius index, indicating increased urban density and compaction.

Climatically

Study of the surface temperature of the earth in the city of Chelghoum El Aid (1984-2024)

Over time, the surface temperatures of the Earth have shown an increasing trend, with both maximum and minimum temperatures rising. However, 1984 was an exceptional year, displaying a wide temperature range between 49.56°C and 32.45°C. Lower temperatures were observed along the valley banks due to the dense vegetation cover in these areas. In 1994, the temperature range was between 41.83°C and 24.97°C, marking the lowest recorded values across the studied years. However, regions where vegetation cover had disappeared exhibited higher temperatures, particularly in the northern part of the city, which appeared in red on thermal maps.

Regarding the city's urban fabric, temperatures were relatively moderate due to the elongated expansion pattern. However, by 2004, a noticeable temperature increase was observed within the city's boundaries, especially in the eastern part and the industrial zone. Additionally, areas with sparse vegetation cover, barren lands, and dark-colored surfaces that absorb solar radiation more effectively experienced significant surface temperature increases.

In 2014, the land surface temperature (LST) ranged between 42.98°C and 29.05°C. A notable observation during this period was the highest recorded temperatures within the city's first industrial zone, which is integrated into the urban fabric. This led to the formation of urban heat islands within the area. The industrial zone, the only one in the Mila province, covers an area of 457.4 hectares, with an actual occupied area of 235.04 hectares.

It accommodates 142 registered companies, of which 79 are operational, alongside an activity zone spanning 31.67 hectares with 90 active companies (DPBM, 2023).

In 2024, the highest surface temperature recorded reached 52.34°C, marking the hottest year in the study period. The most affected areas were those surrounding the urban fabric, particularly in the northwestern and eastern regions near the East-West highway. Although temperatures in the industrial zone remained elevated, they were lower compared to 2014. Comparing the results across the studied years, it is evident that the city's average temperature has risen by approximately three degrees Celsius since the beginning of the study period.

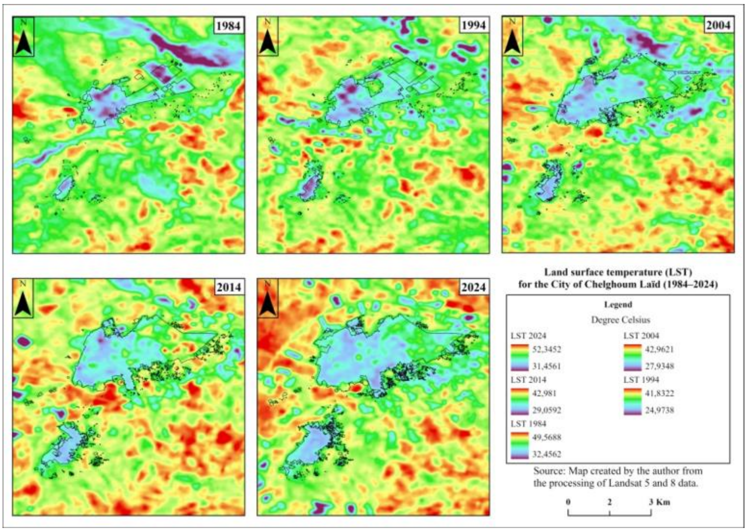

Fig. 6. Land Surface Temperature of Chelghoum El Aïd for the years 1984-1994-2004-2014-2024(Source: Prepared by the researchers based on ArcGIS Pro 3.2.0 software)

Correlation

The relationship between the vegetation index and the surface temperature in Chelghoum El Aid

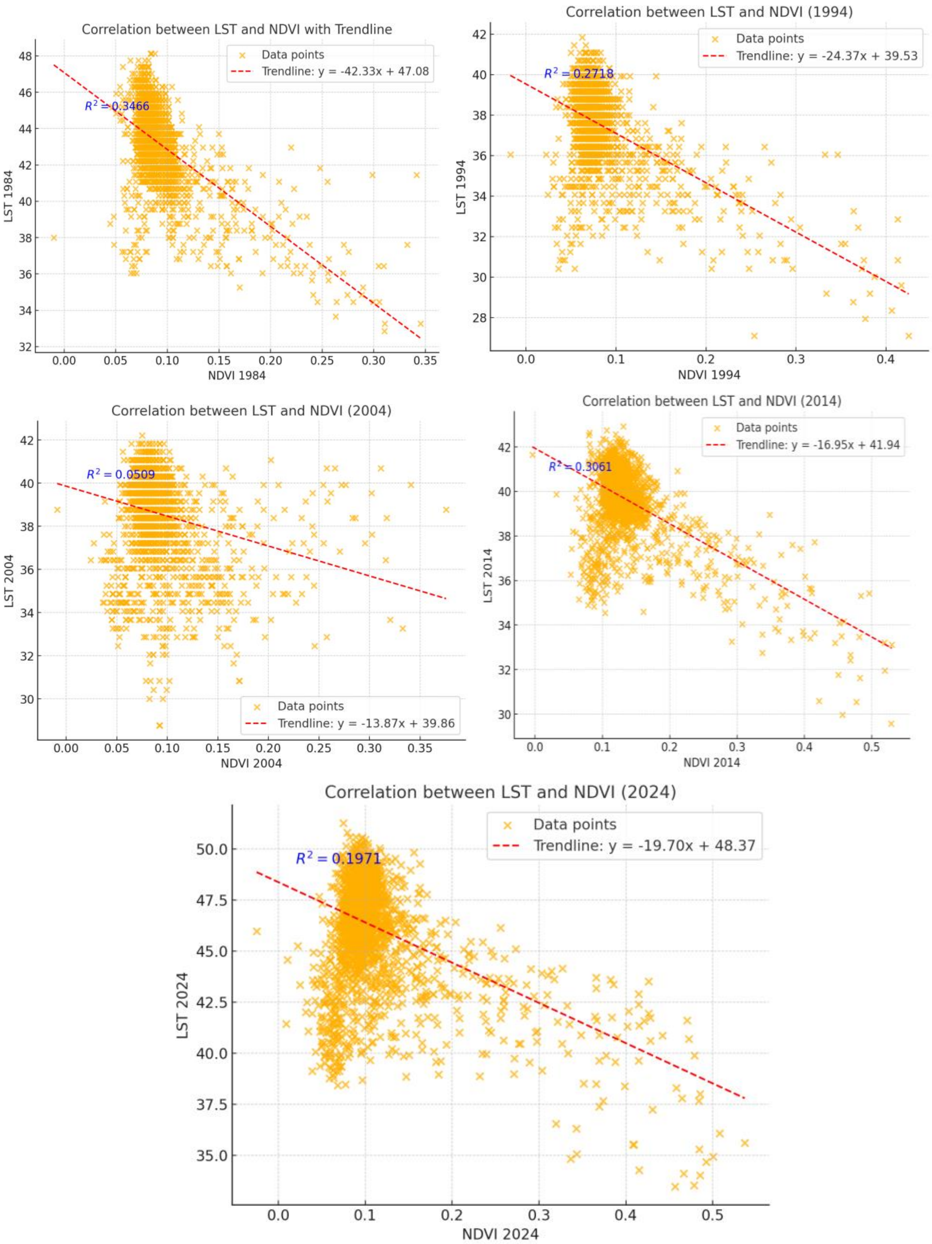

Fig. 7. The correlation between NDVI and LST using the regression line (Trendline) (Source: Prepared by the researchers in 2024, based on imagery data information and Excel software)

The results over the years of study show a strong inverse relationship between the vegetation index (NDVI) and the land surface temperature (LST). As the NDVI increases, the values of LST decrease.

Table 4. Comparaison table

Year	Regression Equation	R^2	Notes
1984	y = -42.33x + 47.08	0.3466	Strong negative correlation, indicating significant influence of vegetation (NDVI) on land surface temperature (LST).
1994	y = -24.37x + 39.53	0.2718	Moderate negative correlation, reflecting a somewhat weaker but still notable vegetation-LST relationship compared to 1984.
2004	y = -13.87x + 39.86	0.0509	Very weak correlation, likely reflecting disruptions in the ecosystem, such as land-use changes or climate anomalies.
2014	y = -16.95x + 41.94	0.3061	Improved correlation compared to 2004, indicating partial recovery of vegetation influence on LST.
2024	y = -19.70x + 48.37	0.1971	Weak-to-moderate correlation, with noticeable improvement compared to 2004 but not as strong as 1984 or 1994.

Source: Prepared by the researchers, 2024

Scientific Observations

Strongest Correlation in 1984: In 1984, the study recorded the strongest negative correlation between vegetation cover (NDVI) and land surface temperature (LST), with an R^2 value of 0.3466 and the steepest regression slope of -42.33. This indicates a significant inverse relationship, emphasizing the crucial role of vegetation in controlling surface temperatures during this period.

Significant Decline in 2004: By 2004, the correlation had weakened considerably, with an R^2 value of 0.0509, suggesting major disturbances in the ecosystem. This decline could be attributed to factors such as rapid urbanization, deforestation, and climatic variations, which diminished the regulatory effect of vegetation on surface temperatures.

Recovery Trend Post-2004: Following the decline, there was a gradual improvement in correlation, with R^2 values increasing to 0.3061 in 2014 and stabilizing at 0.1971 in 2024. This upward trend suggests a partial recovery in vegetation's influence on LST, possibly due to reforestation initiatives, improved land management, or favorable climatic conditions.

Decreasing Slope over the Decades: The regression slope has shown a consistent decline over the study period, decreasing from -42.33 in 1984 to -19.70 in 2024. This trend suggests a weakening response of land surface temperature (LST) to changes in vegetation cover (NDVI), likely driven by increasing anthropogenic pressures and environmental degradation.

Pearson's Correlation Coefficient Trends:

The Pearson's correlation coefficients calculated using Excel for the respective study years were -0.58, -0.52, -0.22, -0.55, and -0.44, reinforcing the overall inverse relationship between NDVI and LST. However, a noticeable weakening of correlation is observed in 2004 (-0.22), which can be attributed to the substantial urban expansion the city underwent during this period, leading to a diminished influence of vegetation on surface temperatures.

Conclusion

In conclusion, urban growth, in both its spatial and demographic dimensions, has significant impacts on the environmental and climatic conditions of cities, making it a pressing issue in contemporary urban planning. As cities expand and populations continue to rise, the demand for land increases, leading to the conversion of vegetated areas into urbanized zones. This transition contributes to the decline of agricultural and forested lands, exacerbating the rise in surface and atmospheric temperatures.

Based on our analysis of morphological, environmental, and climatic variables, the following key findings were identified:

- Urban Expansion Trends: The city's growth has predominantly followed a linear and compact pattern along National Road No. 5, resulting in the depletion of surrounding agricultural lands. Throughout the study period, urban sprawl has consistently replaced vegetation cover, leading to noticeable temperature increases, particularly along the city's periphery. However, within the urban core, despite its density, extreme temperature spikes were primarily observed in areas with concentrated industrial activities.

- NDVI and LST Relationship: A strong inverse correlation between the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) was identified, as confirmed by Pearson's correlation coefficient and trendline analysis. The reduction in vegetation cover was consistently accompanied by an increase in surface temperatures, highlighting the critical role of green spaces in regulating urban climates.

- Emergence of Heat Islands: The industrial zone within Chelghoum El Aïd has become a prominent heat island, posing potential challenges for nearby residential areas. These elevated temperatures could negatively impact thermal comfort, reduce quality of life, and escalate energy consumption for cooling, necessitating strategic urban planning interventions to mitigate these effects.

Therefore, it is crucial to direct urban policies toward the integration of remote sensing technologies and Geographic Information Systems (GIS) at all stages of urban planning. These advanced tools provide accurate and objective data that facilitate the monitoring and analysis of various phenomena, such as urban sprawl. Utilizing such technologies can help identify areas most vulnerable to environmental degradation and support the development of effective strategies to mitigate its adverse effects, ensuring more sustainable urban growth and improved environmental management.

Conflicts of Interest: The authors declare no conflict of interest.

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