



A GIS-BASED ASSESSMENT OF LAND USE DYNAMICS AND CLIMATE VARIABILITY IN CONSTANTINE PROVINCE, ALGERIA

Meriem BOURECHEROUCHE^{1*}

¹ Centre de Recherche en Aménagement du Territoire (CRAT), Campus Zouaghi Slimane,
Route de Aïn El Bey, 25000 Constantine, Algérie

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Abstract: *Understanding the interaction between land use dynamics and climate variability is essential for effective environmental monitoring and sustainable land management. This study presents a spatio-temporal geospatial assessment of land use dynamics in Constantine Province, Algeria, and examines their relationship with key climatic variables, namely annual precipitation and maximum temperature. Land use data for 1990, 2000, 2010, and 2022 were analysed using Geographic Information Systems to identify spatial patterns and temporal changes among the main land use classes. The analysis focused on detecting changes in land cover distribution, evaluating land transformation trends, and comparing these changes with climatic variations across the study area.*

The results showed that cropland remained the dominant land use class throughout the study period, although it decreased slightly from 191,887.00 ha in 1990 to 188,248.00 ha in 2022. In contrast, impervious surfaces increased strongly from 3,098.10 ha to 11,095.70 ha, reflecting clear urban expansion and infrastructure development. Forest areas decreased from 19,994.30 ha to 12,978.60 ha, while shrubland, grassland, sparse vegetation, and bare areas increased, indicating a progressive transformation of the landscape toward more open land cover types and a possible reduction of dense vegetation cover. The climatic analysis revealed a general increase in maximum temperature intensity, whereas precipitation showed irregular variability, with drier conditions particularly observed in 2000 and 2022.

These findings highlight the combined influence of human activities and climatic variability on land use dynamics in Constantine Province. The study confirms the usefulness of geospatial approaches for monitoring environmental change and provides relevant information to support sustainable land management, environmental monitoring, and regional planning.

Keywords: *Land Use Change; Geospatial Analysis; Climate Variability; GIS; Environmental Monitoring; Constantine Province.*

1. Introduction

Land use and land cover dynamics have become a major topic in environmental and geographical research because they reflect the continuous transformation of the Earth's surface under the combined influence of natural processes and human activities. Land use refers to the way humans utilize land for agriculture, settlements, transport infrastructure, industry, and urban development, whereas land cover describes the physical characteristics of the land surface, such as vegetation, forests, water bodies, bare soil, and built-up areas. Therefore, the analysis of land use and land cover change is essential for understanding environmental degradation, ecosystem disturbance, resource availability, and sustainable territorial planning [1].

In recent decades, land use and land cover changes have accelerated worldwide due to population growth, agricultural intensification, urban expansion, infrastructure development, and deforestation. These transformations may lead to the reduction of agricultural land, the fragmentation of natural vegetation, the decline of forest cover, and the expansion of impervious surfaces. Such changes can strongly affect soil quality, biodiversity, hydrological processes, and local climatic conditions, especially in semi-arid and Mediterranean environments where ecosystems are highly sensitive to environmental stress [1].

* Corresponding author: Meriem Bourecherouche, Centre de Recherche en Aménagement du Territoire (CRAT), Campus Zouaghi Slimane, meriem.bourecherouche@crat.dz

The development of Geographic Information Systems and remote sensing technologies has greatly improved the ability to monitor and assess land use dynamics over large areas and long periods. Multi-temporal satellite images allow researchers to detect land cover transitions, map spatial patterns of change, and quantify the magnitude of land transformation. Change detection techniques based on satellite imagery and Geographic Information Systems are widely used because they provide consistent spatial information that supports environmental monitoring and decision-making [2]. Recent studies also confirm that geospatial approaches are effective for analysing complex land transformations and for supporting sustainable land management [3].

In Algeria, and more broadly in the Mediterranean region, land use dynamics are influenced by both anthropogenic pressure and climatic variability. Several studies have reported important changes in land cover, including forest regression, urban expansion, and fluctuations in agricultural areas. These changes are generally associated with population growth, land degradation, agricultural pressure, and the development of built-up areas [4]. In northern Algeria, such transformations are particularly important because many regions are characterized by agricultural dominance, ecological sensitivity, and increasing pressure on natural resources.

Climate variability represents another major factor influencing land use and environmental conditions. It is commonly expressed through changes in climatic variables such as precipitation and temperature. In North Africa, climate variability is associated with irregular precipitation, increasing temperatures, recurrent drought conditions, and growing pressure on water resources and vegetation cover [5]. These climatic changes may affect soil moisture, crop productivity, vegetation density, and ecosystem stability. As a result, climate variability can contribute to the transformation of land cover and increase the vulnerability of agricultural and natural landscapes.

The relationship between land use dynamics and climate variability is complex and reciprocal. On the one hand, climatic conditions influence land cover by affecting vegetation growth, water availability, soil moisture, and agricultural productivity. On the other hand, land use change can modify local environmental and climatic conditions by altering surface albedo, evapotranspiration, soil permeability, and heat storage. For example, the expansion of impervious surfaces, such as roads, buildings, and paved areas, can increase surface temperature because these materials absorb and retain more heat than vegetated surfaces. This process may contribute to the intensification of urban heat island effects [6, 7].

Recent geospatial studies have shown that built-up expansion is often associated with increasing land surface temperature, while vegetation cover contributes to thermal regulation through shading and evapotranspiration [6, 8]. The decline of forest and dense vegetation cover may therefore reduce the natural cooling capacity of the landscape and increase vulnerability to heat stress, erosion, and land degradation. In this context, the combined analysis of land use change, maximum temperature, and precipitation provides a useful framework for understanding environmental transformations at the regional scale.

The research problem addressed in this study is based on the need to understand how land use dynamics in Constantine Province have evolved over time and how these changes may be associated with climatic variability. Although Constantine Province is characterized by agricultural dominance, urban growth, and environmental sensitivity, integrated studies combining land use change with precipitation and maximum temperature remain limited at the regional scale. This creates a knowledge gap concerning the spatial relationship between urban expansion, vegetation change, forest decline, precipitation variability, and thermal intensification.

Therefore, this study aims to analyse the spatio-temporal dynamics of land use in Constantine Province between 1990 and 2022 using Geographic Information System techniques, and to explore their relationship with key climatic variables, particularly precipitation and maximum temperature. The study seeks to answer the following main question: how have land use classes changed in Constantine Province during the study period, and to what extent do these changes correspond spatially with variations in precipitation and maximum temperature? By addressing this question, the research contributes to a better understanding of environmental change and provides useful information for sustainable land management, environmental monitoring, and regional planning.

2. Materials and Methods

2.1. Study area

This study focuses on Constantine Province, located in northeastern Algeria. The geographical location of the study area within the national territory, along with its administrative divisions, is illustrated in **Fig. 1**. The region is characterized by a semi-arid Mediterranean climate, with hot and dry summers and relatively

mild and wet winters. The topography includes plateaus, valleys, and mountainous areas, which influence land use distribution and environmental processes.

In recent decades, Constantine Province has experienced rapid urban expansion and increasing anthropogenic pressure, making it a suitable case study for analysing land use dynamics and their relationship with climate variability.

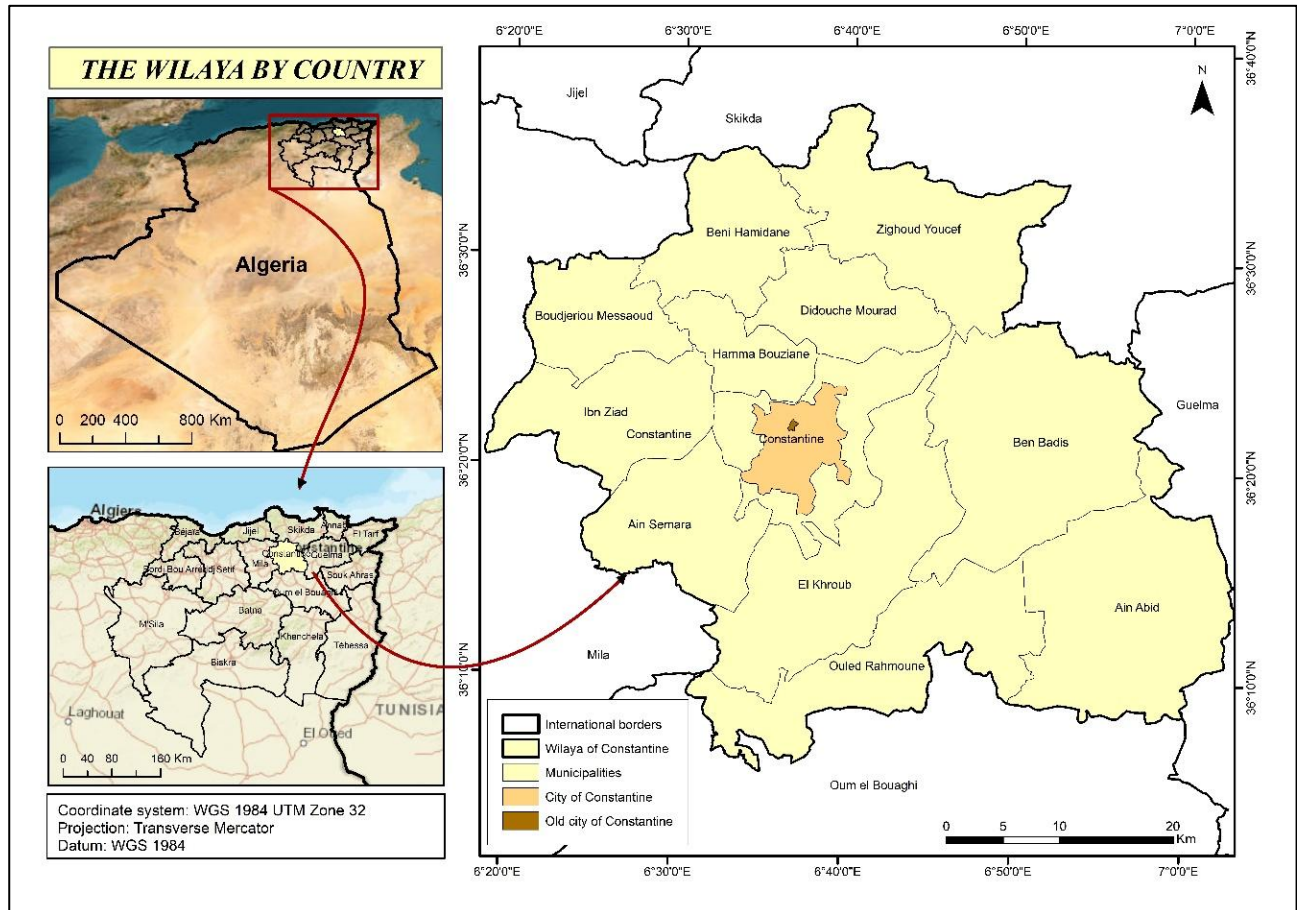


Fig. 1. Location of Constantine Province within Algeria showing administrative boundaries and municipalities.

2.2. Data sources

Land Use Data

Land use and land cover (LULC) data were derived from multi-temporal Landsat satellite imagery acquired for the years 1990, 2000, 2010, and 2022. Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI images were used due to their medium spatial resolution (30 m), long-term availability, and suitability for monitoring land use and land cover changes over extended periods.

Examples of the satellite imagery used as input data are presented in Fig. 2. Figure 2a shows an RGB composite Landsat 5 TM image representing the historical period, while Fig. 2b presents an RGB composite Landsat 8 OLI image representing the most recent observation period. These images were used for visual interpretation, training sample selection, and land use classification.

Prior to analysis, all satellite images underwent standard preprocessing procedures, including geometric correction, radiometric calibration, and atmospheric correction, to ensure data consistency, spatial accuracy, and comparability among the different acquisition dates.

Climate Data

Climatic data, including annual precipitation and maximum temperature, were derived from sixteen virtual climatic stations distributed across Constantine Province. These virtual stations were selected to ensure spatial coverage of the study area and to represent climatic variability within the province. The extracted climatic values were then processed using GIS tools and interpolated using the Kriging method to generate continuous spatial distribution maps of precipitation and maximum temperature for the selected years.

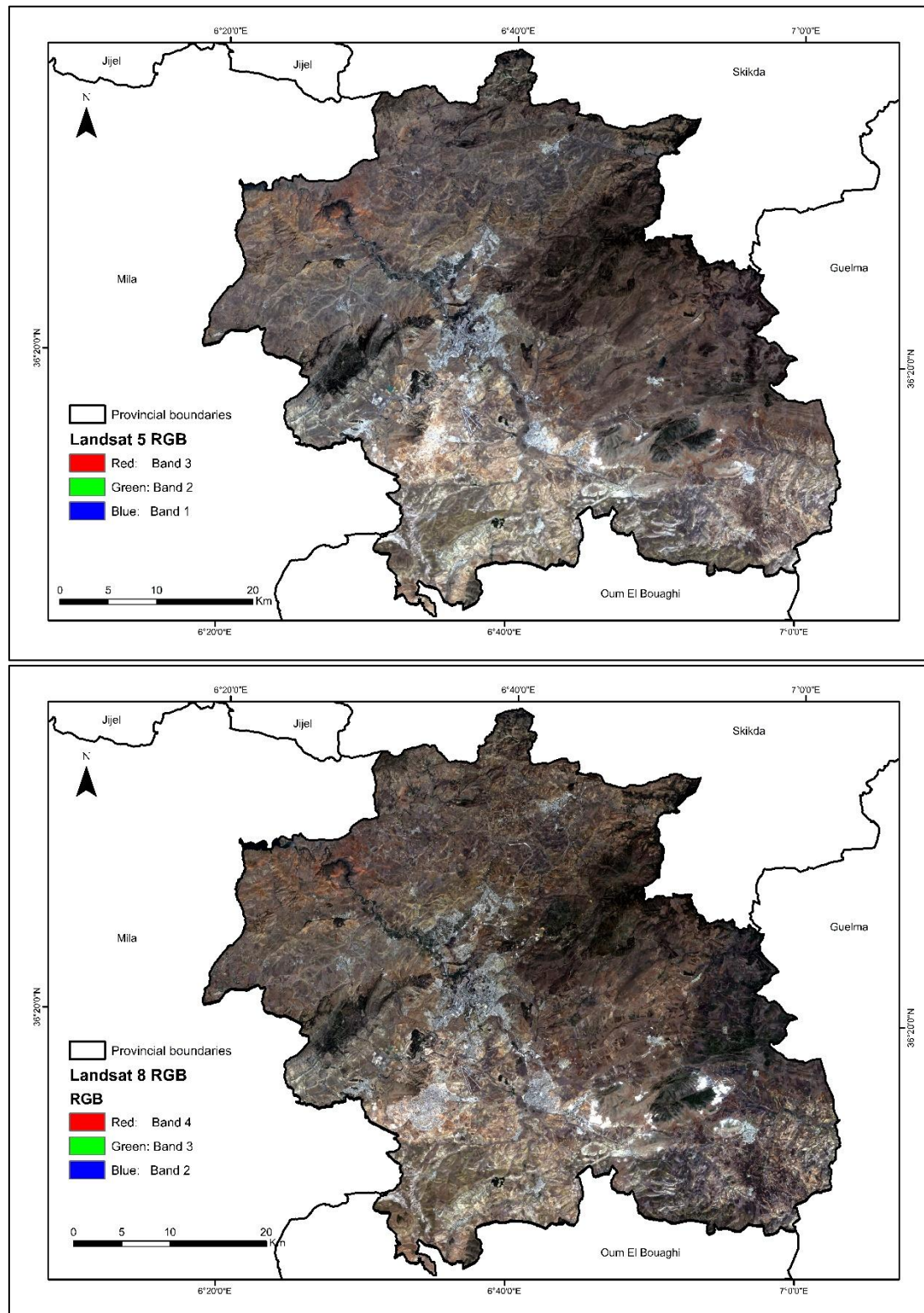


Fig. 2. Examples of Landsat imagery used as input data for land use classification in Constantine Province: (a) RGB composite Landsat 5 TM image; (b) RGB composite Landsat 8 OLI image.

Source: Landsat 5 TM and Landsat 8 OLI imagery processed by the author using Google Earth Engine

2.3. Data Processing and Analysis

Image Classification

Supervised classification was performed using GIS and remote sensing software (ArcGIS or QGIS). Training samples were selected based on visual interpretation of satellite images and ancillary data. The main land use classes identified in the study area included built-up areas, agricultural land, forest and natural

vegetation, bare land, and water bodies. The classified maps were then visually checked and compared with available reference information to ensure consistency in the spatial distribution of land use classes.

Change Detection

Land use changes were analysed using a post-classification comparison approach. This method made it possible to compare classified maps from different years and identify the main changes affecting the study area. The analysis focused on detecting spatial patterns of change, estimating the magnitude of land transformation, and identifying the direction of change between land use categories over time.

Climate Analysis

This study considered both land use and climatic variables to analyse environmental changes in Constantine Province between **nineteen ninety** and **twenty twenty-two**. The land use variables included cropland, forest, shrubland, grassland and sparse vegetation, bare areas, impervious surfaces, and water bodies. These classes were extracted from Landsat satellite images through image classification techniques.

The climatic variables consisted of maximum temperature and precipitation data obtained from climatic stations and spatial interpolation methods. The study also examined the spatial distribution and temporal evolution of these variables in order to identify possible relationships between land use dynamics and climate variability over the study period.

Spatial Relationship Analysis

To investigate the relationship between land use dynamics and climate variability, a comparative spatial analysis was conducted. Land use maps were compared with precipitation and maximum temperature maps in order to identify possible spatial correspondences between land transformation and climatic conditions. This approach allowed the interpretation of the potential links between urban expansion, vegetation change, temperature increase, and precipitation variability.

2.4. Software and Tools

The analysis was carried out using several software and geospatial tools for data processing, spatial analysis, and map production.

- ArcGIS and QGIS: These Geographic Information Systems were used for spatial data management, visualization, thematic map production, raster processing, and spatial analysis. Tools such as raster classification, reclassification, and spatial interpolation were applied during the analysis.
- Google Earth Engine: This remote sensing platform was used for Landsat image processing, visualization, and extraction of land use information from multi-temporal satellite imagery.
- Microsoft Excel: This software was used for organizing climatic and statistical data, calculating land use area values, and preparing tables and graphical summaries used in the study.

3. Results

3.1. Land Use Dynamics between 1990 and 2022

The analysis of the land use maps shows that Constantine Province was largely dominated by agricultural lands throughout the study period. This class occupies a major part of the territory, especially in peripheral and rural municipalities. Therefore, agricultural land represents the main spatial component of the province.

However, a progressive change can be observed between 1990, 2000, 2010, and 2022. Impervious surfaces, including built-up areas and infrastructure, became increasingly visible over time. This expansion is particularly noticeable in the central part of the province, around Constantine city, as well as toward El Khroub, Hamma Bouziane, Didouche Mourad, and areas located near major urban axes.

In 1990, impervious surfaces were relatively limited and mainly concentrated around the main urban core. In 2000, a slight expansion began to appear. By 2010, urbanization became more pronounced, with an increase in built-up areas around neighboring municipalities. In 2022, this trend became even more visible, indicating a progressive artificialization of the territory.

Forest areas and natural vegetation are mainly located in the northern and north-eastern parts of the province. Their distribution appears less continuous than that of agricultural lands. Bare areas and herbaceous or sparse vegetation are also present, but their extent varies depending on the year and location.

Table 1. Land use area changes in Constantine Province between 1990 and 2022 (ha).

Land use class	1990 (ha)	2000 (ha)	2010 (ha)	2022 (ha)
Bare areas	26.66	97.90	122.51	277.02
Cropland	191,887.00	193,611.40	190,913.00	188,248.00
Forest	19,994.30	13,366.47	13,117.60	12,978.60
Grassland, sparse vegetation and mangrove	915.30	1,443.12	1,592.24	1,760.77
Impervious surfaces	3,098.10	7,199.91	9,684.16	11,095.70
Shrubland	8,512.54	8,692.65	8,733.97	9,748.38
Water body and salt marsh	33.84	55.07	302.19	357.59
Total	224,467.74	224,466.51	224,465.67	224,466.06

Source: Author's processing based on land use classification.

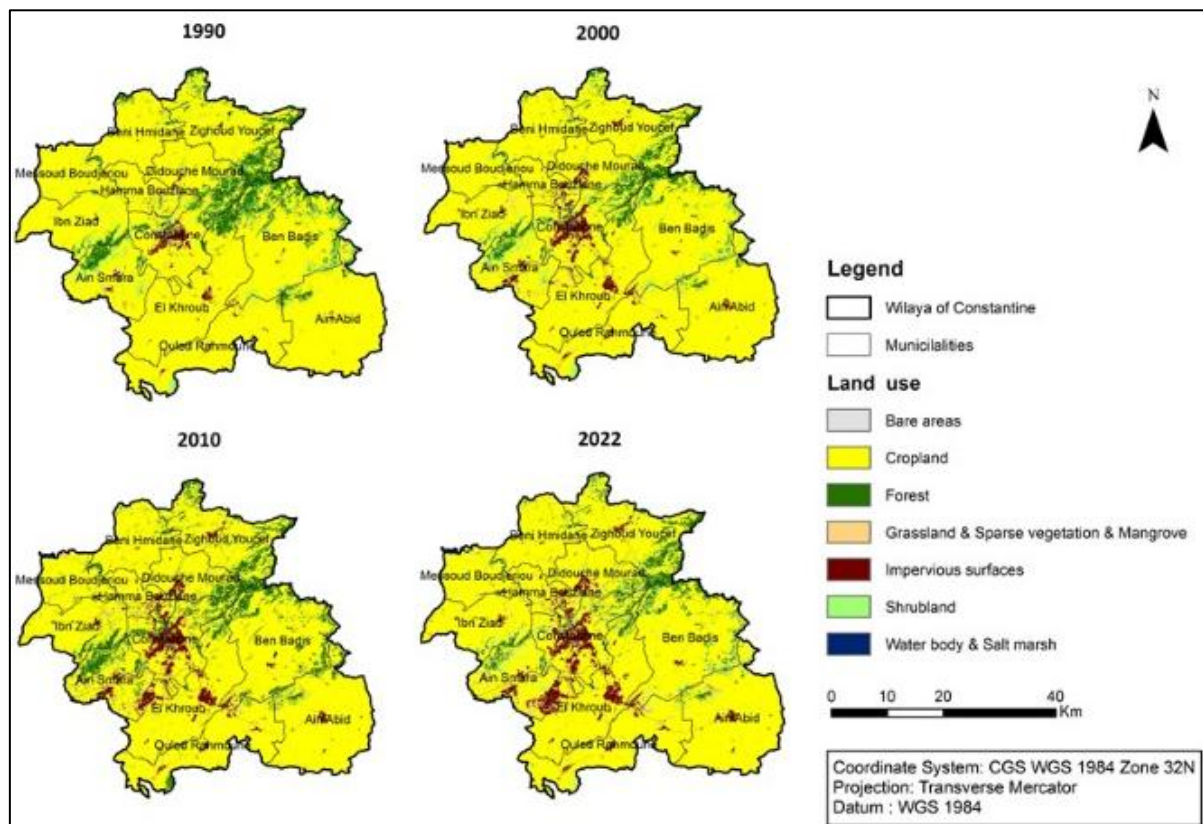


Fig. 3. Land use dynamics in Constantine Province between 1990 and 2022.

3.2. Spatial Evolution of Maximum Temperature

The maximum temperature maps show a progressive increase in thermal intensity in Constantine Province between 1990 and 2022. This evolution is visible through the shift from moderate heat classes toward more intense heat classes.

In 1990, the map mainly showed lower heat classes, with a relatively balanced distribution across the municipalities. High temperatures were already present, but they were less spatially extensive.

In 2000, an increase in thermal intensity can be observed over a large part of the territory. Higher heat classes began to expand, particularly in the central and eastern sectors.

In 2010, the thermal situation became more pronounced. Most of the province was affected by intense heat classes. The areas around Constantine, Ben Badis, Didouche Mourad, and El Khroub showed a more visible intensification.

In 2022, the map shows the highest thermal levels of the study period. Severe, very severe, and extreme heat classes occupied a larger area, especially in the central, eastern, and north-eastern parts of the province. This evolution indicates a general warming trend and an increase in thermal stress.

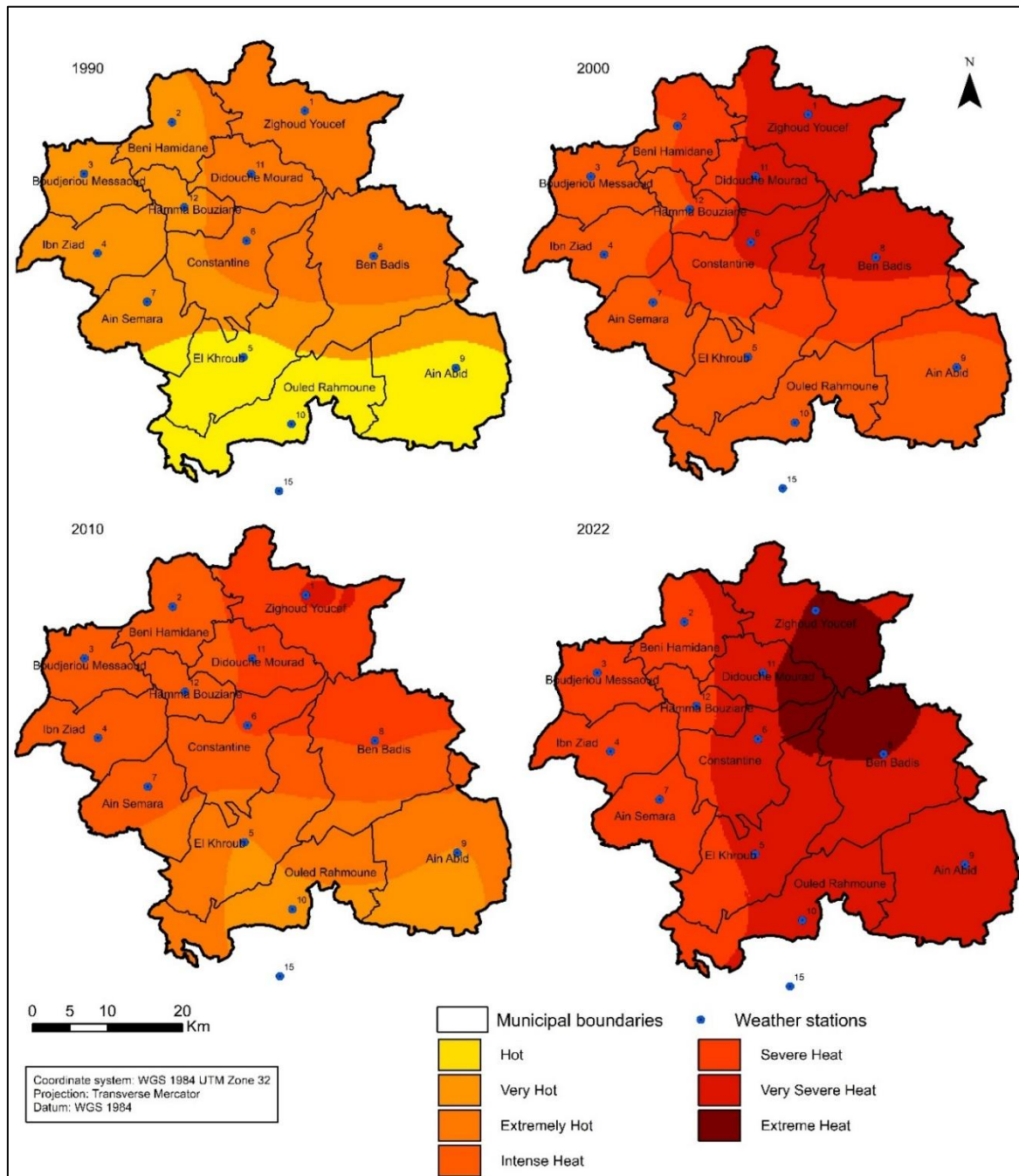


Fig. 4. Spatial evolution of maximum temperature in Constantine Province between 1990 and 2022.

3.3. Spatial Evolution of Precipitation

The precipitation maps reveal significant variability between the different years studied. Unlike temperature, which shows a general increasing trend, precipitation presents more irregular fluctuations.

In 1990, Constantine Province appeared generally wetter. High and very high precipitation classes dominated a large part of the territory. This indicates relatively important precipitation availability during this period.

In 2000, a clear decrease in precipitation was observed. Low precipitation classes became more present, especially in the western, central, and southern parts of the province. This year therefore appears to be characterized by drier conditions.

In 2010, precipitation increased again in several areas. High precipitation classes reappeared, especially in the northern, central, and western parts of the province. However, some southern and south-eastern areas remained characterized by more moderate precipitation levels.

In 2022, the map shows a general decrease in precipitation. Very low and low precipitation classes dominated a large part of the territory. This situation indicates more marked dry conditions, which may have direct effects on water resources, soils, vegetation, and agricultural activities.

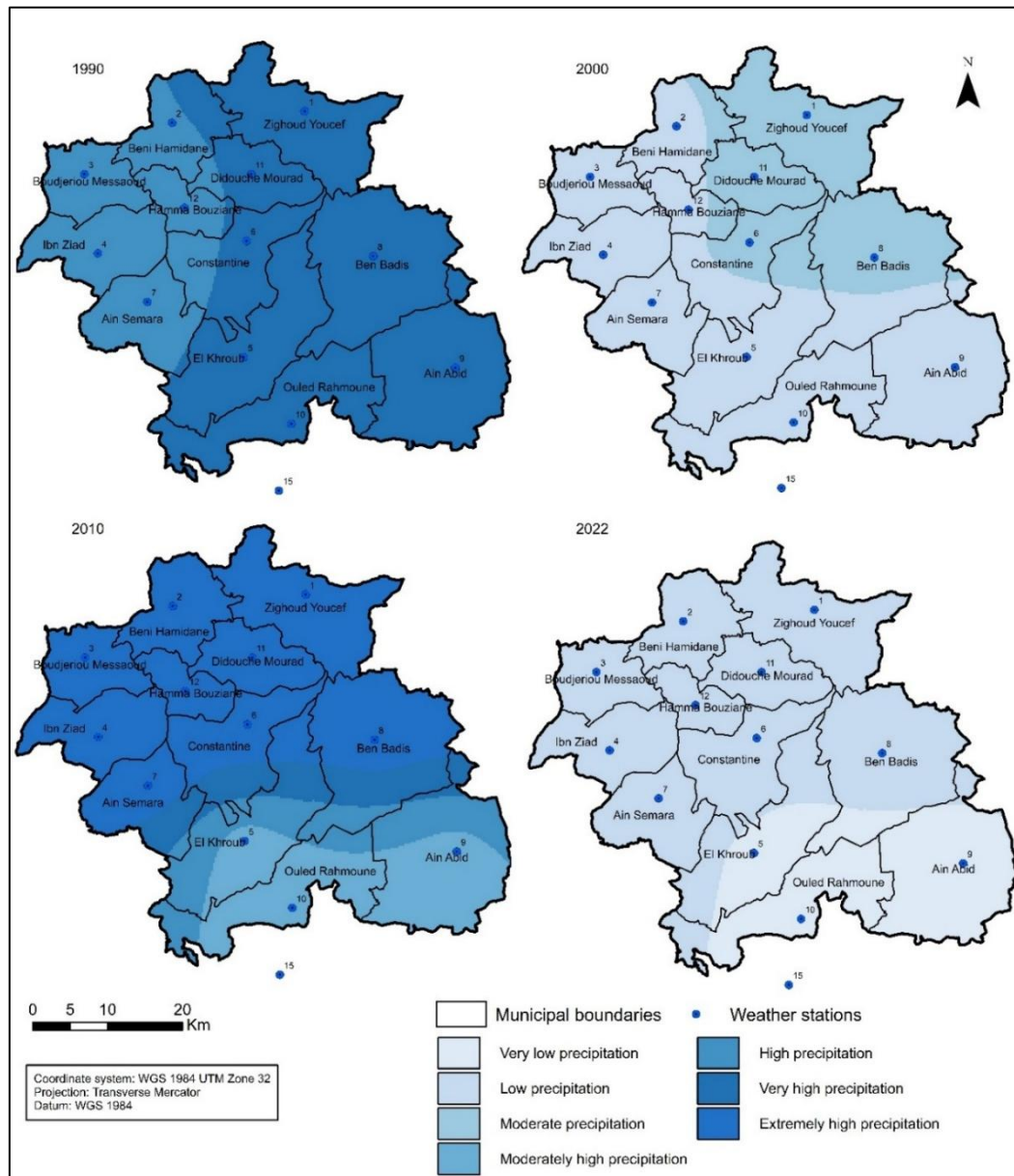


Fig. 5. Spatial evolution of precipitation in Constantine Province between 1990 and 2022

4. Discussion

The results showed that Constantine Province experienced important land use transformations between 1990 and 2022. Although cropland remained the dominant land use class during the whole study period, its area decreased slightly from 191,887 ha in 1990 to 188,248 ha in 2022. This decline was not very large compared with the total area of the province, but it indicates a progressive pressure on agricultural land. This evolution can be explained by the expansion of urban areas, infrastructure development, and the gradual conversion of some cultivated surfaces into built-up or semi-natural land cover classes. Similar studies have confirmed that land use and land cover change is mainly driven by urban expansion, agricultural transformation, and increasing human pressure on natural resources [3].

The most remarkable change was the strong increase in impervious surfaces, which expanded from 3,098.10 ha in 1990 to 11,095.70 ha in 2022. This increase reflects the growth of built-up areas, roads, housing, industrial zones, and other infrastructure. The expansion of impervious surfaces is an important indicator of urbanization because it modifies the physical properties of the land surface. Built-up areas usually reduce soil permeability, limit water infiltration, increase runoff, and store more heat than vegetated surfaces. Recent research has shown that urban sprawl and built-up expansion are strongly associated with increasing land surface temperature and the intensification of urban heat island effects [6]. Therefore, the increase in impervious surfaces observed in Constantine Province may partly explain the rise in maximum temperature shown by the climatic maps.

At the same time, forest areas decreased considerably, from 19,994.30 ha in 1990 to 12,978.60 ha in 2022. This reduction represents one of the most important environmental changes observed in the study area. Forests play a key role in soil protection, biodiversity conservation, carbon storage, temperature regulation, and hydrological balance. Their decline may increase the vulnerability of the landscape to erosion, heat stress, and ecological degradation. The increase in shrubland, grassland, sparse vegetation, and bare areas may indicate a transition from dense vegetation cover toward more open or degraded vegetation forms. Similar findings have been reported in northern Algeria, where land use dynamics were associated with forest regression and the expansion of built-up or transformed land cover classes [9].

The increase in shrubland from 8,512.54 ha to 9,748.38 ha, together with the increase in grassland and sparse vegetation from 915.30 ha to 1,760.77 ha, suggests that part of the vegetation cover may have shifted toward less dense formations. This transformation can be linked to both human and climatic pressures. Human activities such as urban expansion, agricultural pressure, grazing, and infrastructure development can contribute to the degradation of natural vegetation. Climatic factors, especially increasing temperature and irregular precipitation, may also reduce vegetation density and favor the expansion of sparse vegetation. Studies using geospatial techniques have shown that changes in vegetation cover, built-up areas, and bare surfaces are closely related to variations in land surface temperature and environmental stress [8].

The climatic results support this interpretation. Maximum temperature increased progressively between 1990 and 2022, with stronger heat classes becoming more visible in the most recent period. This increase may be related to regional climate variability, but it can also be reinforced by land use change. Impervious surfaces absorb and retain heat, while forests and agricultural areas contribute to cooling through evapotranspiration and shading. As a result, the reduction of vegetation cover combined with the expansion of built-up areas may contribute to higher local temperatures. This relationship has been widely discussed in recent studies on land use change and urban heat island dynamics [6, 7, 8].

Precipitation showed a more irregular pattern, with wetter conditions in 1990 and 2010 and drier conditions in 2000 and especially 2022. The decrease in precipitation observed in 2022 may have increased water stress and affected vegetation, soils, and agricultural productivity. In a province where cropland is the dominant class, precipitation variability represents an important environmental factor. Lower precipitation combined with higher maximum temperature can reduce soil moisture, increase crop water demand, and weaken the resilience of agricultural systems. This situation may also contribute to the expansion of bare areas, which increased from 26.66 ha in 1990 to 277.02 ha in 2022 [5].

The combined interpretation of land use and climatic variables shows that Constantine Province is affected by two main pressures: anthropogenic pressure related to urban expansion and environmental pressure related to climate variability. The increase in impervious surfaces, the decline of forests, and the slight reduction of cropland indicate a progressive transformation of the landscape. Similar remote sensing studies have demonstrated the usefulness of spatial monitoring for detecting environmental changes and evaluating the temporal evolution of degraded or transformed areas [10].

Overall, the findings confirm the value of Geographic Information Systems for monitoring land use dynamics and climate variability. GIS makes it possible to detect spatial changes, quantify land cover classes, compare different periods, and identify zones affected by environmental pressure. However, the present analysis remains mainly cartographic and descriptive. Future research should include statistical correlations between impervious surfaces, vegetation cover, temperature, and precipitation. It would also be useful to integrate field validation, high-resolution satellite images, and environmental indicators such as NDVI or land surface temperature. These additional analyses would strengthen the interpretation of the relationship between urbanization, vegetation decline, and climatic variability in Constantine Province [2, 3].

5. Conclusions

This study assessed land use dynamics and climate variability in Constantine Province between 1990 and 2022 using a Geographic Information System-based approach. The results showed that cropland remained the dominant land use class throughout the study period, although it decreased slightly after 2000. In contrast, impervious surfaces increased strongly from 3,098.10 ha in 1990 to 11,095.70 ha in 2022, reflecting clear urban expansion and infrastructure development. Forest areas decreased from 19,994.30 ha to 12,978.60 ha, while shrubland, grassland, sparse vegetation, and bare areas increased, indicating a progressive transformation of the landscape and a possible reduction of dense vegetation cover.

The climatic analysis revealed a general increase in maximum temperature intensity, especially in the most recent period. Precipitation showed irregular variability, with wetter conditions in 1990 and 2010 and drier conditions in 2000 and particularly in 2022. The combination of urban expansion, forest decline,

increasing temperatures, and precipitation variability suggests that Constantine Province is exposed to both anthropogenic and climatic pressures.

The main advantage of this study is its ability to combine land use data with climatic variables in order to provide a broader understanding of environmental change. However, the study remains mainly cartographic and descriptive. Further research should include statistical correlation, field validation, high-resolution satellite images, and additional indicators such as NDVI and land surface temperature.

Overall, the results highlight the importance of sustainable land management in Constantine Province. Protecting agricultural land, conserving forest and vegetation cover, and controlling urban expansion are necessary actions to reduce environmental degradation and support regional planning under changing climatic conditions.

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