

TeMA

Journal of
Land Use, Mobility and Environment

print ISSN 1970-9889 e-ISSN 1970-9870
FedOA press - University of Naples Federico II

DOAJ

 Rivista scientifica
di classe A - 08/F1

Scopus WEB OF SCIENCE



NEW CHALLENGES FOR CITIES IN THE TWENTY-FIRST CENTURY

Regenerative Design - Climate Adaptation & Mitigation
Circular Economy - Citizen Agency - Urban Livability

Vol.19 n.1
April 2026

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- Urban Livability

1 (2026)

Published by

Laboratory of Land Use, Mobility and Environment
DICEA - Department of Civil, Building and Environmental Engineering
University of Naples Federico II, Italy

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Editor-in-Chief: Rocco Papa
print ISSN 1970-9889 | online ISSN 1970-9870
Licence: Cancelleria del Tribunale di Napoli, n°6 of 29/01/2008

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TeMA 1 (2026) 117-136

print ISSN 1970-9889, e-ISSN 1970-9870

DOI: 10.6093/1970-9870/12803

Received 7th November 2025, Accepted 16th April 2026, Available online 30th April 2026

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Examining the temporal and spatial change of current land cover types in Demre District using machine learning

GeoAI - Object-based controlled classification

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Abstract

The study, conducted to analyze the temporal and spatial changes in current land use types in Demre district of Antalya Province and to establish a foundation for future land management studies, was supported by multispectral satellite images obtained from the Landsat 5- Thematic Mapper (TM) and Landsat 8- Operational Land Imager (OLI) remote sensing satellites. Land use maps showing the spatial distribution of land cover changes were prepared using composite images compiled for the years 2004, 2014, and 2024. The Support Vector Machines (SVM) algorithm was used as the classifier model. High classification performance was achieved for all three images ($\kappa = 0.90, 0.89, 0.87$, overall accuracy = 90.7%, 90.3%, 87.9%). Following the classification process, land use change maps were created for each decade, and statistical analyses related to land cover change were conducted. Over the past 20 years, according to the land use types in Demre district, quarry and mining areas ($\uparrow 227.49\%$) and settlement and greenhouse areas ($\uparrow 72.88\%$) have increased significantly, while scrubland ($\downarrow 41.21\%$), agricultural land ($\downarrow 9.45\%$), and forest areas ($\downarrow 8.89\%$) have decreased significantly. In addition, sparse maquis areas, dune areas, and water surfaces areas have declined, indicating a situation that is detrimental to the region's natural areas. In conclusion, the study provides an overview of how land use types have changed in the region and reveals the current state of land use preferences in the district.

Keywords

Demre district (Antalya); Land cover; Land use; Machine learning; Remote sensing; Temporal and spatial change

How to cite item in APA format

Akten, S., Dündar, H.B. & Gül, A. (2025). Examining the temporal and spatial change of current land cover types in Demre District using machine learning. *TeMA - Journal of Land Use, Mobility and Environment*, 19 (1), 117-136. <http://dx.doi.org/10.6093/1970-9870/12803>

1. Introduction

With the increase in urban population worldwide, the demand and intensity of land use in urban areas and their surroundings have been steadily rising. Consequently, rapid changes have occurred in various land cover types, particularly in productive agricultural lands, forests, pastures, and settlement areas. Rapid population growth and the resulting uncontrolled urban expansion have intensified pressures on agricultural lands and urban ecosystems in many countries (Lambin et al., 2003; Manley et al., 2022). The goal of sustainable development is an essential priority for all nations, and it is imperative that cities are planned and managed in an environmentally, economically, and socially balanced, livable, and future-oriented manner (Murray, 2001).

Urban development is a process in which communities and cities control the emergence of a city (Bhatta, 2010). Most urban development problems in cities are indicative of land use planning and policies (Dutta, 2012). Sustainable urban development aims to strike a balance between the efficient use of resources, the protection of the natural environment, and the well-being of society. In order to establish appropriate land use policies that can promote sustainable urban development, it is necessary to determine priorities that will help identify the most suitable spatial pattern for deciding future land use, to use decision support tools, and to monitor urban growth (Meyer & Turner, 1992). On the other hand, understanding landscape dynamics and sustainable management decision-making processes requires knowledge of the current state of land cover and use (Jamal & Ahmad, 2020).

Monitoring and evaluating urban growth serves as an essential tool for the planning and efficient management of natural resources in the near future. Identifying and interpreting land use changes within a given region is crucial for understanding the relationships and interactions between human activities and natural processes, as well as for mitigating environmental and socio-economic challenges (Arfanuzzaman & Dahiya, 2019; Huang et al., 2020; Wang et al., 2021). To observe global-scale changes and maintain sustainable development, the application of change detection methods is required. In remote sensing, change detection aims to identify alterations on the Earth's surface by analyzing multi-temporal images acquired from the same geographical area at different time periods (Bolat & Doğan, 2022). These alterations are primarily referred to as land use and land cover changes.

Land use and land cover changes are an indicator representing natural and economic processes. Identifying and modeling changes in land cover and land use types facilitates the interpretation of the causes and consequences of land use dynamics and supports policymakers' decisions. Therefore, the identification of land cover types and land use changes is important for natural resource management, environmental assessment, regional and urban planning, and agricultural production management (Wang et al., 2022).

Accurate information on land cover is crucial for environmental research, monitoring the impacts of climate change, resource management, and disaster risk reduction. To assess the effects of land cover transformations on natural environments, these changes must be detected accurately and in a timely manner. Multi-year time series of land cover characteristics provide a broader perspective on land dynamics. Temporal change analysis captures both gradual and abrupt transformations (Lambin et al., 2003). Accurate and up-to-date land cover maps are of critical importance, serving both as inputs for modeling systems (e.g., flood and fire spread models) and as decision-support tools for policymakers (Feddema et al., 2005). Researchers have utilized time-series data in various applications, including forest degradation (Kennedy et al., 2010), land use change (Fallati et al., 2017; Kharazmi et al., 2018; Zhu et al., 2020), ecological alterations (Pasquarella et al., 2016), agricultural intensification (Galford et al., 2008), and forest condition assessments (Arvor et al., 2012). Therefore, conducting detailed, up-to-date, and accurate assessments of changes in urban land use is a fundamental prerequisite for sustainable management and effective urban planning.

Efficient monitoring of land use status and the accurate assessment of land cover changes primarily rely on the use of Remote Sensing (RS) and Geographic Information Systems (GIS) (Rogan & Chen, 2004). With the

advancement of RS and GIS technologies, the evaluation and monitoring of natural resource management and spatial planning processes have gained a new dimension (Ghosh et al., 2017). The acquisition of high-resolution imagery through satellite data has facilitated the application of advanced algorithms for land cover monitoring (Ghosh et al., 2017; Alam et al., 2020).

Additionally, these tools are more cost-effective and less time-consuming than traditional methods, offering several advantages such as free access to satellite imagery, enhanced computational capabilities, and user-friendly interfaces. Due to their ability to map vulnerabilities on a larger scale during disaster events, they have attracted considerable attention from both governments and the public (Parthasarathy & Deka, 2019). However, certain limitations in data processing still hinder the effective monitoring of land use changes at the regional scale.

Among these limitations, intensive data processing and storage requirements are significant factors (Debella-Gilo & Gjertsen, 2021). There are a limited number of algorithms available for analysis methods such as object-based image analysis and clustering. In particular, the lack of advanced segmentation and clustering algorithms can cause accuracy and precision issues in some analyses (Tamiminia et al., 2020). Despite all these limitations, it is used as an important tool in environmental analyses and sustainable resource management processes (Pettorelli et al., 2014).

Satellite imagery is among the most commonly used sources for environmental analysis. The Earth Resources Technology Satellite (ERTS)-1, launched in 1972, was renamed "Landsat" in 1975. The Landsat program has launched eight satellites, providing nearly 50 years of continuous data. Currently, Landsat 7 and Landsat 8 remain operational. This satellite series has become one of the most important long-term and freely accessible data sources for civilian applications and has been widely used in various fields, including monitoring land cover changes in agricultural areas (Liu & Seto, 2008; Tassi & Vizzari, 2020), mapping urban expansion (Yan et al., 2021), forest cover mapping (Abijith & Saravan, 2022), vegetation analysis (Senf et al., 2017), and hydrological studies (Abijith et al., 2020). Consequently, Landsat provides a deeper understanding of land cover and land use changes, supporting improved decision-making and resource management. Its broad spectral bands and high spatial resolution enable the detection of significant variations in land cover (Abijith et al., 2020).

Demre is located in the coastal region of Antalya, which encompasses the fertile lands of the Mediterranean region. The area has undergone significant transformation in its urban land cover in recent years. Demre's urban population is growing rapidly, leading to heavy traffic and problems with basic resources. The analysis of land cover and land use types is essential for the sustainable planning and development of a new city and is influential in determining the ideal location for various purposes. Land suitability analysis for urban planning and development will reduce the destructive effects of unplanned and uncontrolled urban sprawl on the environment. Land use suitability is a measure of the suitability of a certain amount of land for specific purposes (Marull et al., 2007).

The study involves determining and examining the spatial and temporal changes in urban land cover and land use types in Demre District, Antalya Province, where tourism and agricultural production activities occur simultaneously and where land conflicts and competition exist, using machine learning. Accordingly, the aim of the study is to obtain spatial and temporal change maps of land cover and use types using satellite images from 2004, 2014, and 2024 with machine learning algorithms and various remote sensing indices, and to compare the results of the classification algorithms used and evaluate their performance.

In this context, the study sought to answer the following questions: How has the spatial distribution and change in land cover and land use types in Demre district changed over the years? How do the classification successes of algorithms vary across different land evaluation classes? Identifying and interpreting these changes will play a significant role in guiding the development of spatial planning and policies for Demre district in the future.

2. Materials and methods

2.1 Study area

The study area is the Demre District, which is part of the Antalya Province. The study area is located between 29°59' east longitude and 36°14' north latitude (Fig.1). The total area of the Demre District is approximately 472 km².

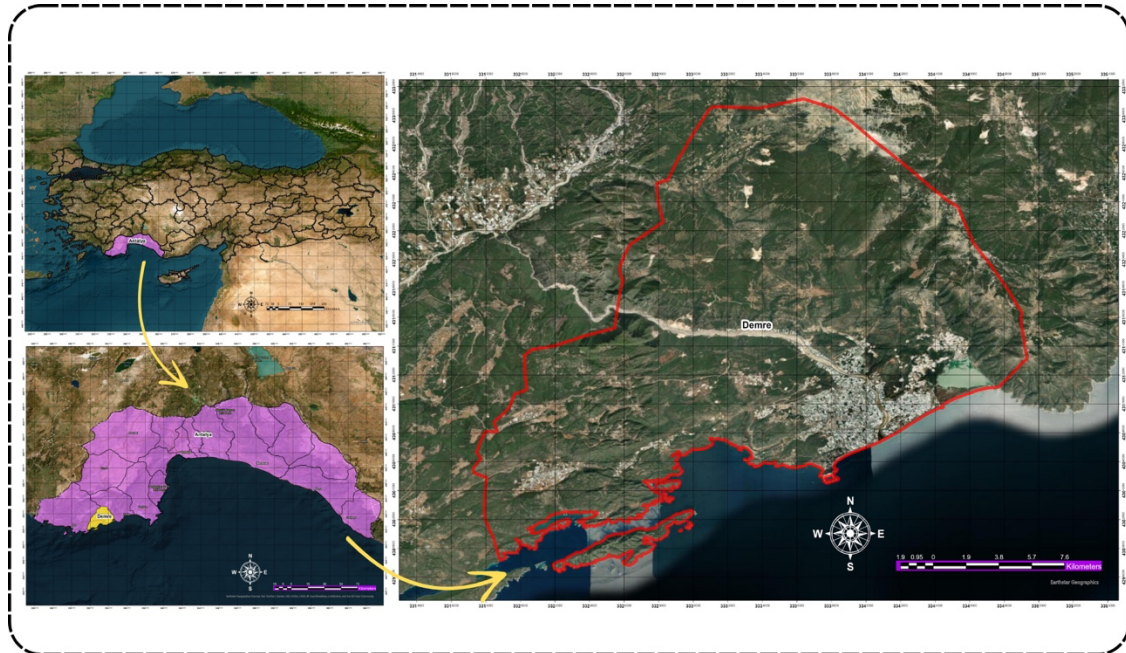


Fig.1 Location of the Demre District

Demre District is located west of Antalya Gulf, south of Teke Peninsula. The district, surrounded by mountains on three sides, was established on Demre Plain, formed by the fertile alluvial soils brought by Demre River. The northern part of the district extends to the foothills of the Taurus Mountains. A significant part of Demre is located on the coastline and has important coastal formations such as the Kekova Gulf. The district has a typical Mediterranean climate, with hot, dry summers and mild, rainy winters. This climate is quite advantageous for agricultural activities. Greenhouse cultivation and citrus production are widespread in the region. However, rapid urbanization and the growth of tourism areas have led to changes in land cover. This study will provide information on the rates of change in land cover and the land uses where these changes are most concentrated.

2.2 Methodology

In this study, land cover data obtained from Landsat satellite images with a spatial resolution of 30 meters were used specifically for Demre District. The machine learning method diagram is shown in Fig.2.

Landsat 8-OLI and Landsat 5-TM satellite images of Demre District were obtained from the United States Geological Survey (USGS) portal to determine changes in land use and land cover information for Demre District in 10-year intervals between 2004 and 2024 (USGS, 2014, and 2024, were obtained from the United States Geological Survey (USGS) portal to detect changes in ten-year intervals (USGS, 2025). The reason for selecting 10-year image intervals is that images prior to 2004 did not show reliable results for sample selection in the study area, and land use changes are more clearly observable within this period.

Additionally, the Scan Line Corrector (SLC) in the Landsat 7 ETM+ sensor malfunctioned on May 31, 2003. After this date, the satellite continued to collect data in SLC off mode, but a 22% data gap was observed in the obtained data. This situation has been another critical factor considered in the selection of satellite images

within the scope of this study (USGS, 2025). Around the time the satellite images were selected, the bands of the selected satellite images were Band 7 (SWIR 2), Band 6 (SWIR 1), Band 4 (Red), and for Landsat 5-TM, Band 7 (SWIR 2), Band 5 (SWIR 1), Band 3 (Red), C2L1 level raster data (Tab.1). This is because the SWIR1, SWIR2, and RED bands have been found to provide the most effective results for urban development and vegetation change in order to detect changes in land cover (urban sprawl, vegetation change) as a result of machine learning (Butler, 2013; Kaçmaz & Döker, 2021).

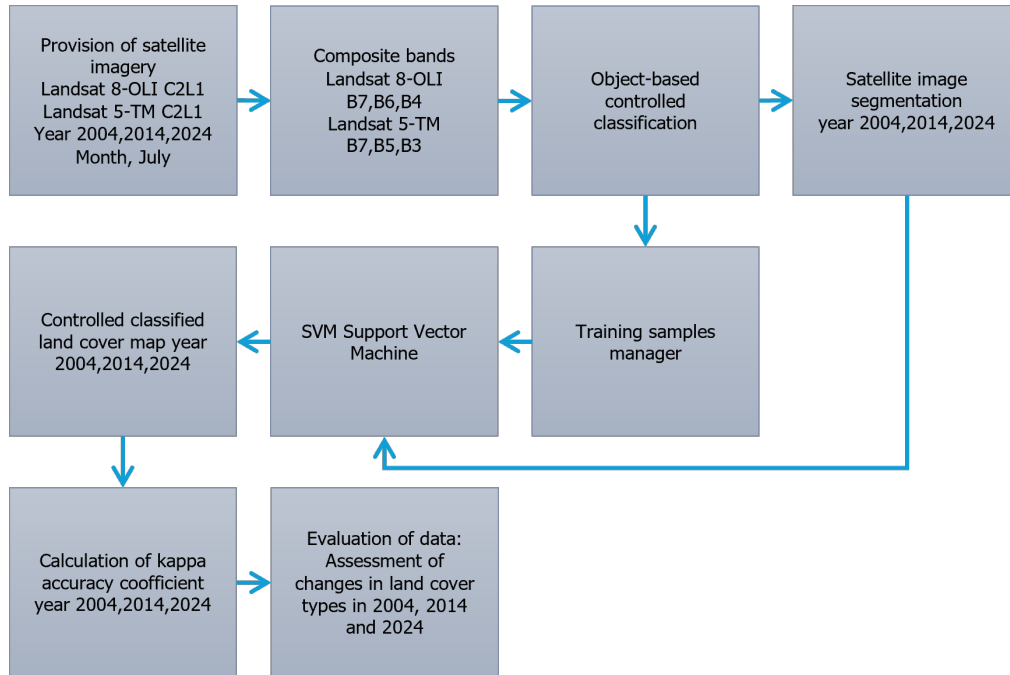


Fig.2 Study process and its application in the Demre District

Date	Sensor Type	Path	Row	Resolution	Cloud cover	Bands
23 July 2004	Landsat-5 TM	178	035	30 m	0	7,5,3 (False Color,Urban)
3 July 2014	Landsat-8 OLI-TIRS	178	035	30 m	0	7,6,4 (False Color,Urban)
30 July 2024	Landsat-8 OLI-TIRS	178	035	30 m	0	7,6,4 (False Color,Urban)

Tab.1 Satellite images used and band characteristics

C2L1 level data are suitable for time series analysis and provide the highest quality Level-1 Terrestrial Precision (L1TP) data, maintaining consistent geographic registration within a <12 m RMSE tolerance (USGS, 2020). Reflectance values for the selected bands are provided in Tab.2.

Landsat-8 OLI-TIRS	Micrometers [µm]	Landsat-5 TM	Micrometers [µm]
Band 4	0.64-0.67 µm	Band 3	0.63-0.69
Band 6	1.57-1.65 µm	Band 5	1.55-1.75
Band 7	2.11-2.29 µm	Band 7	2.08-2.35

Tab.2 Wavelength ranges of Landsat-5 TM and Landsat-8 OLI-TIRS bands used

These single-band raster data have been converted into multi-band RGB (composite) images within the working software. The resulting RGB images were cropped (extract by mask) based on the working area boundary. Following these steps, the data set was prepared for the production of result maps by proceeding to the object-based supervised classification stage for the examination of spatial and temporal change. The process leading to the final maps consists of two stages. In the image classification process, segmentation plays an important role in object-based classification approaches using support vector machines (SVM). Using

segmentation techniques, pixels with similar spectral (pixel reflectance values) and spatial characteristics (volume, shape, and proximity) are classified to obtain meaningful segments. There are three key elements in image segmentation. These are "spectral detail," "spatial detail," and "minimum segment size."

The parameters to be determined vary depending on the resolution, size, and spectral band characteristics of the image. These parameters play a decisive role in determining the classification results (Kaçmaz & Döker, 2021). Accordingly, within the main focus of the study, ten different land use classifications were performed. These classes were defined as "Forest Area," "Water Bodies," "Settlement and Greenhouse Area," "Quarry and Mining Area," "Agricultural Area," "Bare Surface (Rock and Gravel, Bedrock)", "Scrubland", "Sparse Maquis Formation," "Dune Area," and "Wetland-Reed Area".

After the classes were determined, a sufficient number of samples were collected from the study area to create the training dataset. The training data and image segmentation serve as inputs for object-based supervised classification. In this study, the SVM (Support Vector Machine) classifier was employed for object-based supervised classification. The SVM classifier is well-suited for segmented rasters and is an effective supervised classification method for multi-band imagery. The classification process was initiated using the outputs containing meaningful segments obtained through image segmentation, together with a sufficient number of training samples generated using the "Train Sample Manager."

The final outputs include controlled land cover classification maps for the years 2000, 2014, and 2024. The final process following the classification map is the calculation of the classification's accuracy. In ArcGIS Pro 3.5, a total of 1,000 validation points were generated for each year, and the software automatically distributed these points to the relevant classes in proportion to the spatial size of the classes. A total of 1,000 points were retained each year to create an error matrix; from this, overall accuracy, user/producer accuracies, and the Kappa statistic were calculated. The land cover types corresponding to these points were calculated using reference images (HGM Küre application, orthophotos obtained from Demre Municipality, Google Earth application, and Demre district forest map) to determine the Overall Accuracy (OA) and Kappa Coefficient of the results.

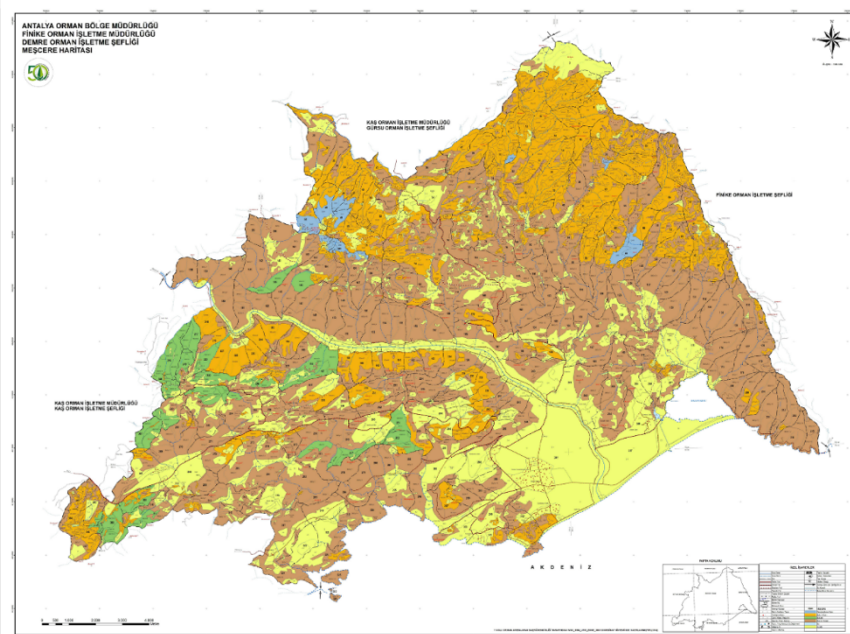


Fig.3 Forestry map of Demre District

To best observe the land cover, satellite images from July, when sunlight is high and cloud cover is low, were selected. The cloud cover ratio is zero in the satellite images selected for 2004, 2014, and 2024. Additionally, the Demre forest map obtained from the Demre Forest Management Directorate during the study was used

as a reference in the area classification stage of this study (Fig.3). The systematic study process was carried out using ArcGIS Pro 3.5 software.

3. Land use classes and data set creation

The classification of images obtained from remote sensing satellites plays an important role in the context of monitoring land change. Classification is the process of assigning each element in the image to its class characteristics based on the different spectral reflectance values of the objects in the raw satellite images. It is a technique used to convert unprocessed satellite images into interpretable data. Classifying a satellite image involves separating the pixels or image fragments in the image into classes such as forest, agriculture, urban areas, water bodies, and others based on their spectral characteristics and spatial patterns (Nicolau et al., 2024).

Within the main focus of the study, ten different land use classifications were conducted. These classes were defined as "Forest Area," "Water Bodies," "Settlement and Greenhouse Area," "Quarry and Mining Area" "Agricultural Area," "Bare Surface (Rock and Gravel, Bedrock)," "Scrubland," "Sparse Maquis Formation," "Dune Area," and "Wetland-Reed Area." The Overall Accuracy (OA) and Kappa Coefficient were calculated for the classification.

The process of classifying satellite images aims to automatically assign each pixel to land use classes. However, in order to perform supervised image classification, examples related to the relevant land use classes must be provided to the classifier algorithm as training data. Marking the land use classes selected for training on the images is a prerequisite for training supervised classification algorithms (Iban & Sahin, 2022). For this reason, a total of 1000 pixels randomly distributed across the images for each year were labeled. Using these data sources and algorithms, the study created detailed land change maps of Demre and employed advanced algorithms and machine learning methods for classifying satellite images specific to the study area.

Lansat TM satellites typically cover an area approximately 170 km north-south and 183 km east-west with a sensor spatial resolution or pixel size of 30 m for spectral bands other than the sixth band, which is 120 m (Tewelde & Cabral, 2011). In remote sensing, multispectral bands are widely used for various purposes such as land use and land cover change (Chen, 2007; Koomen, 2007; Schowengerdt, 2007). From the satellite images of Demre district for the specified years, the SWIR1, SWIR2, and RED bands provide the most effective results for urban area development and vegetation change (Butler, 2013). The band order for Landsat is B7, B6, B3, while for Landsat 5-TM it is B7, B5, B3. After combining the selected bands, images of the area were obtained. The image segmentation algorithm, run with different parameters, was used to find regions of minimum heterogeneity. Satellite images and trained training examples for each year were used in this analysis. These data were processed using an algorithm called Support Vector Machines (SVM).

Support Vector Machines (SVM) are a supervised classification algorithm and are widely used in remote sensing and geographic information systems (GIS) literature due to their ability to operate with high accuracy, particularly on segmented raster images (Moeller, 2000; Mucher et al., 2000; Weih & Riggan, 2010). However, they can also be effectively applied to multispectral standard images. SVM classifiers offer significant advantages over traditional classification methods, especially when sample data is limited. The tool accepts multispectral raster data of any bit depth as input and performs pixel-based classification based on user-defined training data. This enables classification on both segmented and standard raster images. One of the key features of the SVM classifier is its ability to be used with segmented raster data. When segmented raster data is used, the tool calculates both the index image and the attribute information for each segment from the RGB segmented raster. The quality of segmentation is decisive for the outcome of subsequent classification. Due to the heterogeneous structure of urban areas, such object-based classifiers are important for urban land change studies (Hsu et al., 2003). After the segmentation process was completed, classification

was performed using source-based sample collection and the standard nearest neighbor algorithm. Based on these procedures, land cover maps for 2004, 2014, and 2024 were created.

3.1 Accuracy assessment

Accuracy assessment is an important process in the classification procedure. Accuracy assessment methods are used to produce statistical outputs that can be used to control the quality of classification results. The accuracy analysis of classification has been performed by evaluating error matrices (Wulder & Franklin, 2007). Errors occur due to the misclassification of pixels. If there are a large number of unclassified pixels, the accuracy of the training data sets decreases. Through this matrix, the classes predicted by the classification results are compared with the reference (true) data. The sum of the correctly classified examples in the error matrix is used to calculate the overall accuracy rate.

Overall accuracy is calculated by dividing the total number of pixels in the error matrix by the number of correct pixels (1).

$$\text{Overall Accuracy} = \left(\frac{\sum A}{\sum B} \right) \times 100 \quad (1)$$

In the equation, A represents the total number of pixels assigned to the correct class, while B represents the total number of pixels that actually belong to these classes. The number of correct pixels belonging to a class divided by the total number of pixels in that column yields user accuracy; the total number of pixels in a class divided by the total number of pixels in that row yields producer accuracy (Kaya, 2020). However, since the overall accuracy rate alone is insufficient to express the classification quality, Cohen's (1960) Kappa coefficient was calculated according to the following formula (2) and taken into account to explain the differences and improvements in the classification of images (Cabral et al., 2005).

$$K = \frac{N \sum_{i=1}^r x_{ii} - \sum_{i=1}^r [(x_{i+})x(x+i)]}{N^2 - \sum_{i=1}^r (x_{i+})x(x+i)} \quad (2)$$

In equality; K: Kappa Coefficient, r: Number of rows in the error matrix, x_{ii}: Total sample count in row (i.) and column (i.), x_{i+}: Total value of row i., x_{+i}: Total value of column i., N: Total sample count in the matrix.

The Kappa coefficient is used to determine the degree to which the accuracy obtained from the classification result differs from the accuracy level that could occur by chance. If the overall accuracy rate is above 80% and the Kappa statistic value is greater than 0.8, the accuracy analysis is considered successful, meaning the classification performed is considered correct (Karayol, 2012). The Kappa coefficient accuracy assessment scale ranges from 0 to 1; 1: Perfect agreement (excellent agreement), 0: Agreement at the level of random agreement, <0: Agreement lower than random agreement (disagreement). Table 3 presents the generally accepted accuracy assessment scale for the Kappa coefficient (κ) (Landis & Koch, 1977). This coefficient allows for a more comprehensive assessment of the reliability of the classification and supports the statistical significance of the results (Sim & Wright, 2005).

Kappa Coefficient (κ)	Interpretation
<0	Less than chance agreement
0.0-0.20	Very low agreement
0.21-0.40	Acceptable agreement
0.41-0.60	Moderate reliability
0.61-0.80	Good accuracy
0.81-1.00	Excellent accuracy

Tab.3 Accuracy assessment scale of the Kappa coefficient

The accuracy analysis results of the study were calculated by comparing images classified according to the years of the study with the reference source, and user, producer accuracy, and Kappa ratio were calculated. Since Demre's overall Kappa ratios were 90%, 89%, and 87%, the classification is acceptable.

4. Result

Changes in land use occurring in urban areas and their surroundings, when examined and interpreted in relation to space and time, serve as an important guide for local administrators and decision-makers. Assessments of land use changes using GIS and remote sensing techniques with up-to-date and accurate data are an important tool for making environmentally sustainable decisions. To this end, satellite images from 2004, 2014, and 2024 were used to reveal changes in land cover and use over time in the Demre District.

Post-classification comparison is one of the existing change detection methods (Jensen, 1996). In this regard, the classification rules developed for each of the three images were kept the same during classification and classified independently. After the classification results were determined, the areas of change were identified through direct comparison, and the land change distributions were given as percentages. Table 4 shows the land change in 2004, Table 5 shows the land change between 2004 and 2014, and Table 6 shows the land change between 2014 and 2024. Separate maps were also created for the changes in land use classes over the years (Fig.4, Fig.5 and Fig.6).

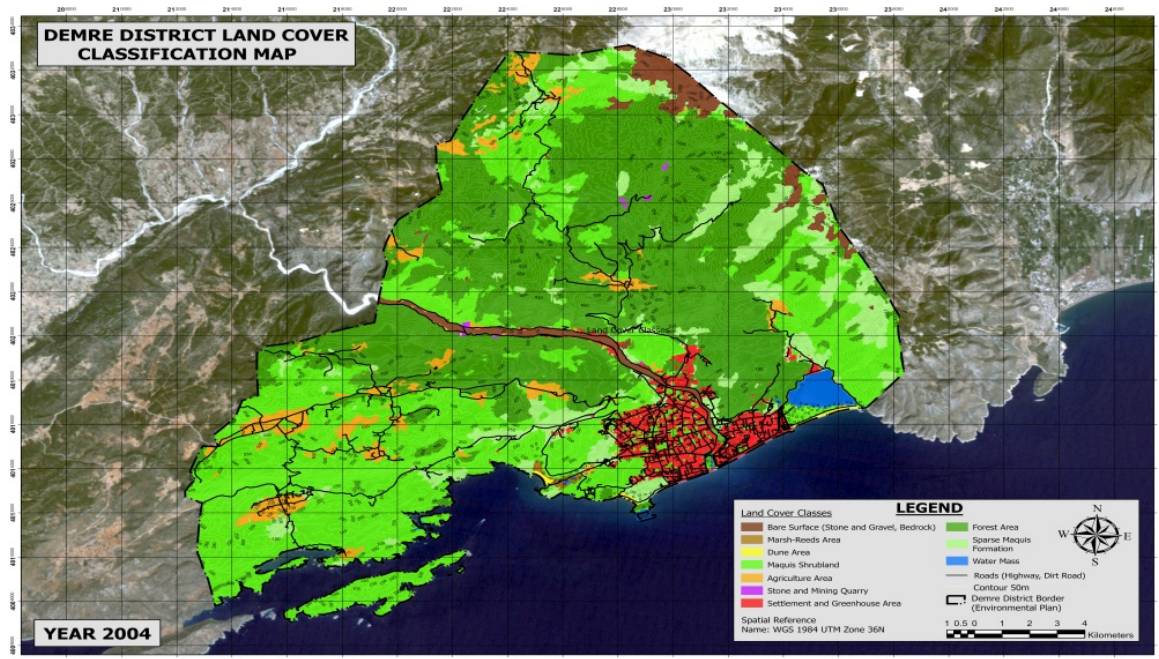


Fig.4 Land cover change map for 2004

Looking at the land use distribution of Demre district in 2004, 41.74% is forest area, 45.08% is scrubland (35.42% + 9.66%), making a total of 86% of the area natural. Settlement and greenhouse areas accounted for 4.27%, agricultural land for 4.49%, bare surface for 3.15%, water bodies for 0.85%, quarries and mines for 0.10%, and dune areas for 0.14% (Tab.4). Geodetic measurement is a three-dimensional measurement that takes into account the curvature of the Earth. This is the fundamental difference between planar measurement and geodetic measurement, as geodetic measurement is suitable for large-scale projects covering areas greater than 250 square kilometers, taking into account the spherical shape of the Earth. The geodetic measurement method was applied to road data within the boundaries of Demre district. Accordingly, the district's road length in 2004 was 412.04 km², and the area it covered was 309.03 ha. The area covered by roads in the district accounts for 0.858% of the total area.

No.	Land Use Types	Area [ha]	
		2004	%
1	Forest Areas	15,030.10	41.74
2	Water Bodies	306.94	0.85
3	Settlement and Greenhouse Area	1,536.11	4.27
4	Quarry and Mining Area	36.19	0.10
5	Agricultural Area	1,617.09	4.49
6	Bare Surface (Rock and Gravel, Bedrock)	1,135.62	3.15
7	Scrubland	12,752.54	35.42
8	Sparse Maquis Formation	3,478.18	9.66
9	Dune Area	63.44	0.18
10	Wetland–Reed Area	48.65	0.14
Total Area [ha]		36,005.28	100.00

Tab.4 Land use change distribution in 2004 [%]

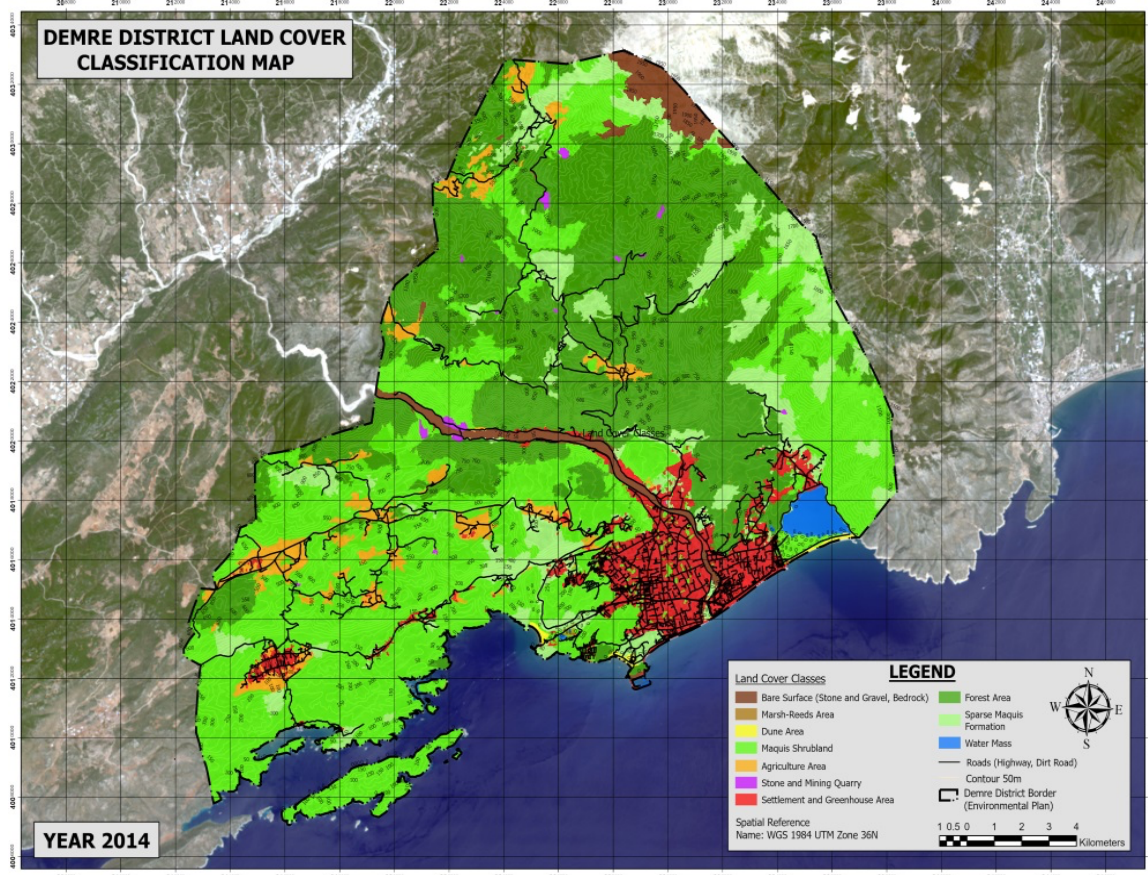


Fig.5 Land cover change map for 2014

Looking at the land use distribution of Demre district in 2014, 35.28% of the total area is forest area, 49.78% (38.86% + 10.92%) is scrubland, making a total of 85.10% natural land. Settlement and greenhouse areas accounted for 6.85%, agricultural land for 4.16%, bare surface for 2.62%, water bodies for 0.80%, quarries and mines for 0.27%, and dune areas for 0.22% (Tab.5).

Furthermore, according to the geodetic measurement method road data within the boundaries of Demre district, the road length in 2014 was 537,06 km and the area covered was 402,80 km². The area covered by roads in the district accounts for 1,119% of the total area.

No.	Land Use Types	Area [ha]	
		2014	%
1	Forest Area	12,700.91	35.28
2	Water Bodies	289.18	0.80
3	Settlement and Greenhouse Area	2,466.10	6.85
4	Quarry and Mining Area	96.05	0.27
5	Agricultural Area	1,497.43	4.16
6	Bare Surface (Rock and Gravel, Bedrock)	944.62	2.62
7	Scrubland	13,991.70	38.86
8	Sparse Maquis Formation	3,930.96	10.92
9	Dune Area	79.70	0.22
10	Wetland–Reed Area	8.62	0.02
Total Area [ha]		36,005.28	100.00

Tab.5 Distribution of land changes between 2004 and 2014 [%]

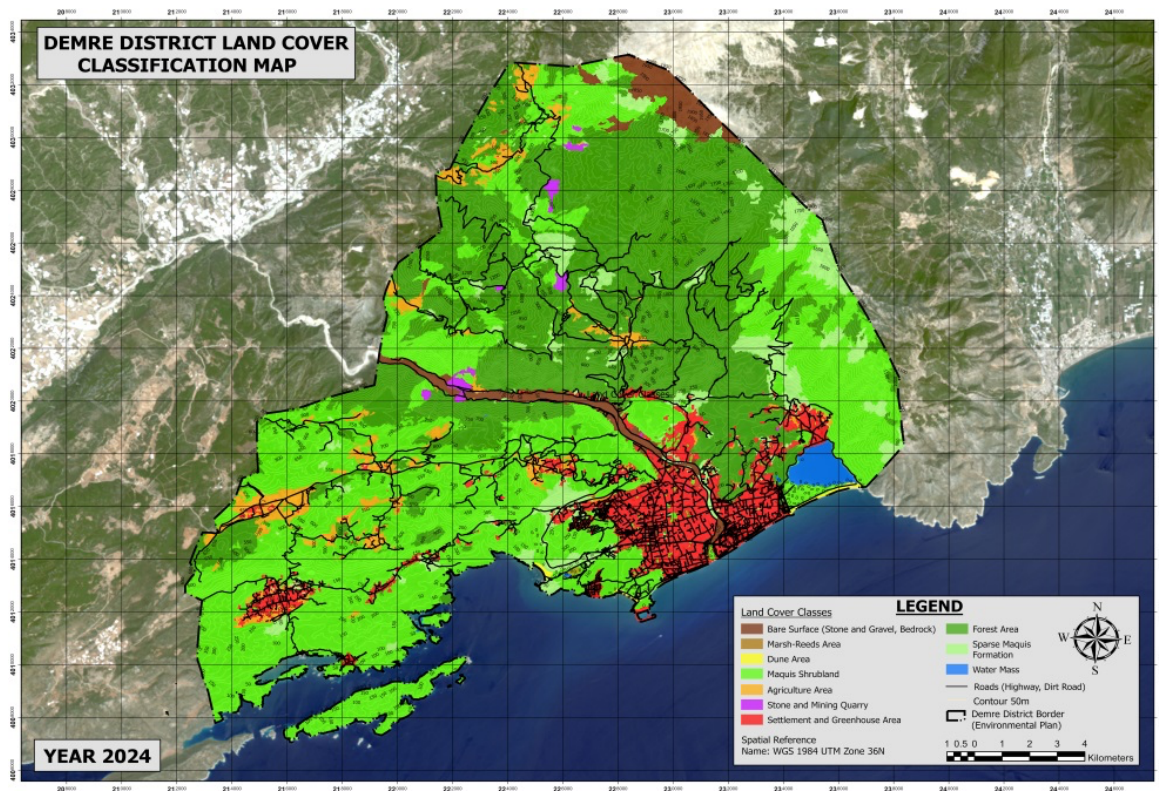


Fig.6 2024 land cover change map

Looking at the land change distribution between 2014 and 2024, 36.06% of Demre district is forest area, 46.71% (41.29% + 6.42%) is scrubland, and 82.77% of the total area is natural land. Settlement and greenhouse areas account for 7.69%, agricultural areas for 4.08%, bare surface for 3.04%, water bodies for 0.78%, quarries and mines for 0.43%, and dune areas for 0.03% (Tab.6).

Road data within the boundaries of Demre district, measured using the geodetic measurement method, shows that the road length in 2024 is 711.51 km and the area covered is 533.63 km². The area covered by roads in the district accounts for 1.482% of the total area.

When examining the land use types of Demre district by year, compared to 2004, in 2014, marshland decreased by 82.28%, bare surface (rock and gravel, bedrock) decreased by 16.82%, forest area decreased by 15.50%, agricultural areas decreased by 7.40%, and water bodies decreased by 5.79%. In contrast, quarry

and mining areas increased by 165.39%, settlement and greenhouse areas by 0.54%, dune areas by 25.62%, and scrub and sparse maquis formations by 22.74% (Tab.7).

No.	Land Use Types	Area [ha]	
		2024	%
1	Forest Area	12,983.16	36.06
2	Water Bodies	280,20	0.78
3	Settlement and Greenhouse Area	2,770.31	7.69
4	Quarry and Mining Area	155.70	0.43
5	Agricultural Area	1,468.21	4.08
6	Bare Surface (Rock and Gravel, Bedrock)	1,094.98	3.04
7	Scrubland	14,865.32	41.29
8	Sparse Maquis Formation	2,310.93	6.42
9	Dune Area	66.51	0.18
10	Wetland–Reed Area	10.03	0,03
Total Area (ha)		36,005.28	100.00

Tab.6 Distribution of land cover change (%) between 2014 and 2024

No	Land Use Types	Values for 2004	Values for 2014	Difference between 2014 and 2004	Percentage difference between 2014 and 2004	Values for 2024	Difference between 2024 and 2014	Percentage difference between 2024 and 2014
		Area [ha]	Area [ha]	Area [ha]	[%]	Area [ha]	Area [ha]	[%]
1	Forest Area	15,030.10	12,700.91	-2,329.19	-15.50	12,983.16	282.25	2.22
2	Water Bodies	306.94	289.18	-17.76	-5.79	280.20	-8.98	-3.10
3	Settlement and Greenhouse Area	1,536.11	2,466,10	929.99	60.54	2,770.31	304.21	12.34
4	Quarry and Mining Area	36.19	96.05	59.86	165.39	155.70	59.65	62.10
5	Agricultural Area	1,617.09	1,497.43	-119.66	-7.40	1,468.21	-29.22	-1.95
6	Bare Surface (Rock and Gravel, Bedrock)	1,135.62	944.62	-191.00	-16.82	1,094.98	150.36	15.92
7	Scrubland	12,752.54	13,991.70	1,239.16	9.72	14,865.32	873.62	6.24
8	Sparse Maquis Formation	3,478.18	3,930.96	452.79	13.02	2,310.93	-1,620.04	-41.21
9	Dune Area	63.44	79.70	16.26	25.62	66.51	-13.19	-16.56
10	Wetland–Reed Area	48.65	8.62	-40.03	-82.28	10.03	1.41	16.35
Total Area [ha]		36,005.28	36,005.28	0.00	0.00	36,005.28	0.00	0.00

Tab.7 Spatial and percentage change values of land use types in Demre District by year

The total land area of Demre district is 36,005.28 hectares. It has been determined that settlement and greenhouse areas increased by 60.54% in Demre between 2004 and 2014, and by 12.34% between 2014 and 2024, representing an approximate increase of 72.88% over a total of 20 years. Quarries and mines showed rapid growth starting in 2004, increasing by 165.39% in 2014 and 62.10% in 2024, showing a total increase of 227.49% over 20 years.

Land use is defined as the use of land and its resources by people. Change occurs due to both natural and socio-economic factors. While some researchers argue that demographic dynamics contribute to changes in land cover (Mather & Needle, 2000), others draw attention to the effectiveness of economic activities (Lambin et al., 2003; Wubie et al., 2016). Tourism in the district affects all land classes as one of the most important factors triggering urbanization and initiating change and transformation in land use. In Demre, especially in recent years, tourism-oriented accommodation and construction trends have spread and dispersed over agricultural and greenhouse areas, causing a negative impact on the urban environment.

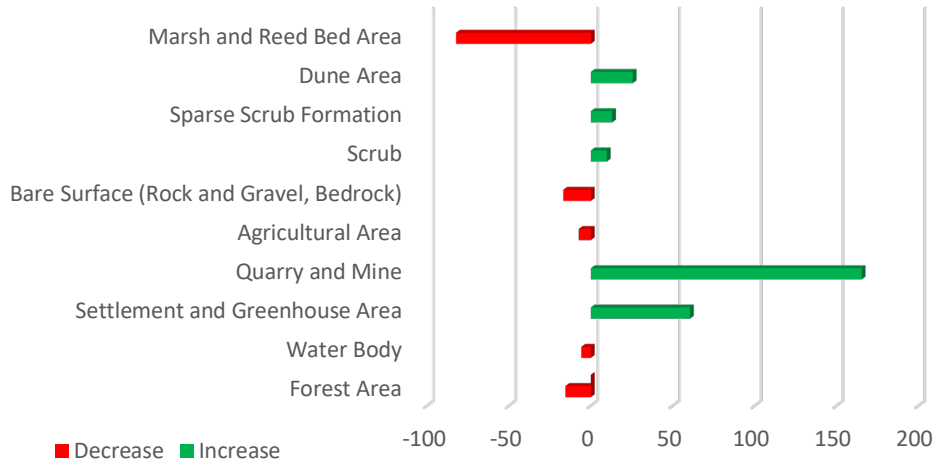


Fig.7 Percentage differences in land use types in Demre district between 2004 and 2014 [%]

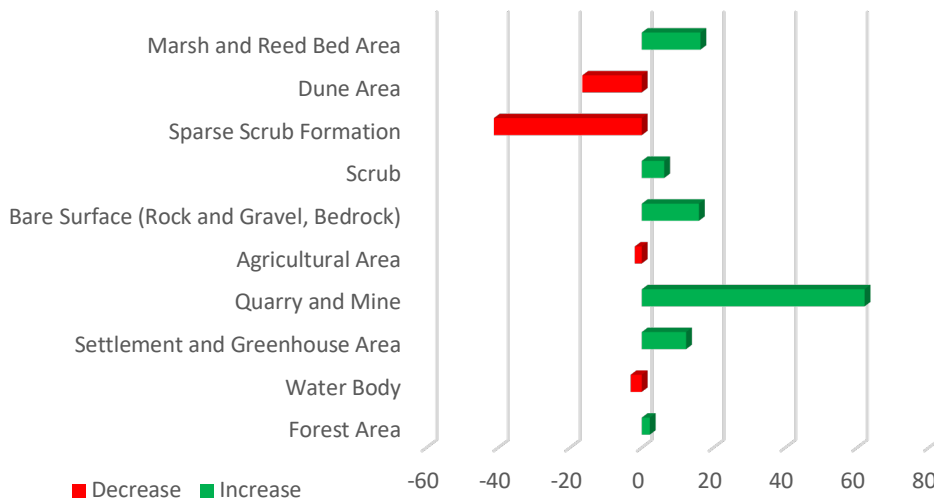


Fig.8 Percentage differences in land use types in Demre district between 2014 and 2024 [%]

The rapid increase in artificial areas and tourism facilities in Demre has led to a decrease in agricultural and forest areas. With the impact of tourism, the development of urban areas has begun to spread, particularly towards agricultural lands. Many studies in the literature addressing changes in land use have found that changes in land use types in cities are particularly associated with an increase in settlement, construction, tourism, and quarry and mine land use (Bahadır & Uzun, 2021; Potapov et al., 2020). Looking at these studies in general, it is concluded that the changes in land use are not as desired and occur in an unplanned manner. This lack of planning has irreversible consequences, especially in fertile agricultural lands, forest areas, and wetlands (Gülersoy, 2013). Therefore, planning land use and determining changes in advance is crucial in preventing improper land use and controlling urbanization.

The areas of Demre district with dense scrub and sparse maquis formations increased by a total of 22.74% between 2004 and 2014. Although there was a 6.24% increase in dense scrub areas in 2024, there was a 41.21% decrease in sparse maquis areas in particular.

Dune areas increased by 25.62% between 2004 and 2014, but decreased by 16.56% in 2024. Marshland areas decreased by 82.28% between 2004 and 2014, while an increase of 16.35% was observed in 2024.

Forest areas decreased by 15.50% between 2004 and 2014, while they increased by 2.22% in 2024. Areas with water bodies decreased by 5.79% between 2004 and 2014 and by 3.10% in 2024, showing a total decrease of 8.89%. Agricultural areas decreased by 7.40% between 2004 and 2014 and by 1.95% in 2024, showing a total decrease of 9.45%.

The results of the classified images for the period 2004-2024 are shown in Fig.7 and Fig.8.

Accuracy assessment, an integral part of the image classification process, has been calculated for the accuracy of land use types by year and is presented in Table 8. The accuracy assessment was performed using a high-resolution aerial photograph as a reference. For the three maps, 1,000 random samples were selected, labeled according to the reference data, and the kappa coefficient was calculated. The overall accuracies were determined to be 90.7% for 2004, 90.3% for 2014, and 87.9% for 2024, respectively. It is stated that a minimum accuracy value of 85% is required for effective and reliable land cover change analysis and modeling (Göncüler & Köylü, 2024). The classification obtained in this study meets the accuracy threshold at an almost perfect level of agreement according to the Tab.2 Kappa coefficient accuracy assessment scale.

Land Use Types	2004 [ha]	2014 [ha]	2024 [ha]
Forest Area	117	117	93
Water Bodies	99	112	107
Settlement and Greenhouse Area	95	96	115
Quarry and Mining Area	83	89	91
Agricultural Area	93	83	73
Bare Surface	110	104	90
Scrubland	124	127	151
Sparse Maquis Formation	99	86	106
Dune Area	101	84	68
Wetland-Reed Area	79	102	106
Total Sample	1,000	1,000	1,000
Correct Sample	907	903	880
Overall Accuracy	90.7	90.3	87.9
Kappa values	0.90	0.89	0.87

Tab. 8 Accuracy assessment of land use types using the Kappa coefficient

5. Discussion

The observed changes in land use types indicate a progressive loss of agricultural land and environmentally sensitive areas, accompanied by an accelerating trend of urban expansion. In particular, construction activities and tourism-related accommodation developments are expected to exert increasing pressure on agricultural production, especially greenhouse farming, which represents the primary source of livelihood in the region. This transformation largely reflects unplanned and poorly regulated land-use changes, which may undermine the long-term sustainability of local agricultural systems.

Similar socio-economic pressures have been reported in other regions. For example, Ziari et al. (2025) and Partheepan et al. (2023) documented comparable dynamics in Batticaloa, while Pultrone (2023) emphasized the role of external development pressures in accelerating urban sprawl. These findings reinforce the argument that rapid urbanization processes are often driven by socio-economic factors rather than comprehensive spatial

planning frameworks. In this context, the present study also demonstrates the importance of geospatial technologies for monitoring land-use transformations and identifying environmental degradation patterns. The policy-oriented recommendations derived from the findings offer practical insights that can support local authorities in managing urban growth and promoting more sustainable land management practices.

The environmental consequences of these transformations are equally significant. The reduction of open and green spaces has eliminated an important ecological resource that previously contributed to temperature regulation, biodiversity conservation, and improved air quality. Their disappearance increases urban heat stress and dust emissions, particularly in areas already facing ecological challenges. Furthermore, the expansion of impermeable urban surfaces increases surface runoff, elevates flood risks, and intensifies pressure on limited water resources. These environmental impacts are consistent with patterns observed in many mid-sized cities located in arid and semi-arid climates, where rapid urban expansion frequently exceeds the adaptive capacity of natural ecosystems.

The dominance of socio-economic drivers over political and cultural influences suggests that Demre's land-use trajectory is currently shaped more by short-term development pressures than by long-term strategic planning. Without stronger governance mechanisms and coordinated land-use policies, continued expansion may exacerbate environmental degradation, social inequalities, and economic vulnerabilities. Therefore, integrated planning approaches are required to protect remaining open and green spaces, regulate urban expansion more effectively, and balance development needs with ecological and social sustainability. Comparable land-use transformations have also been documented in several Turkish cities. Dengiz & Demirağ Turan (2014), in their analysis of land use and land capability classes in Samsun, reported that high-quality agricultural lands (Classes I, II, and III) were increasingly converted into artificial surfaces. Similarly, Aydın & Durduran (2021) identified significant land-use changes in the Konya Ereğli–Bor Lower Basin, including the expansion of artificial surfaces and agricultural lands, alongside reductions in forest areas and wetlands. Çelik & Yakar (2023) examined urbanization pressures in Mersin and reported increases in urban areas and vegetation cover, accompanied by decreases in agricultural lands, barren areas, and water bodies. Earlier research also highlights similar trends. Sönmez (2011) demonstrated that agricultural lands in Adana have declined significantly while urban areas have expanded rapidly. According to the study, the city center and its surrounding areas have experienced intense spatial transformation, raising concerns regarding ecological sustainability and land-use efficiency. The findings emphasize the need to control the expansion of built-up areas and implement protective measures for ecologically valuable land-use types such as forests, water bodies, coastal zones, and pasture lands. In addition to controlling urban expansion, nature-based solutions play an important role in mitigating the environmental impacts of urbanization. Strategies such as soil desealing, urban afforestation, and the expansion of green infrastructure can significantly enhance carbon storage capacity, reduce urban temperatures, and mitigate the effects of heavy rainfall events. These approaches, including the utilization of residual urban spaces for green infrastructure development, have been widely recommended as effective climate adaptation strategies in urban planning (Lai & Zoppi, 2025). Urban green spaces require more than just an increase in quantity; the development of a comprehensive and systematic planning approach suitable for urban land use, a topic often overlooked in planning studies, is of greater importance (Gül et al., 2024). Climate change alters environmental conditions, and therefore, rational use of non-renewable resources, especially land, is crucial to revert to, preserve, or achieve the desired outcome. In this context, increasing green spaces and/or infrastructure, integrating them with natural and agricultural areas, will make a significant contribution to reducing vulnerability to climate change (Zucaro & Morosini, 2018).

6. Conclusion

The land change maps for Demre district for the years 2004, 2014, and 2024 were obtained using an object-oriented approach, and the resulting maps provided new information about the spatiotemporal distribution of

land use types in the region. The results obtained from the classification were validated and used for further change distribution analysis. The nature of urban land cover change was addressed and quantified according to landscape metrics and urban sprawl conditions. Each map provided information about the distribution of land change.

It has been determined that over the past 20 years, there has been a significant increase in quarries and mines, as well as residential and greenhouse areas, in Demre district, based on land use types. The conversion of urban agricultural lands and vegetation cover into residential areas, along with increased construction and tourism investments accompanying urban growth, and the expansion of stone and marble quarry activities, have led to the loss of agricultural lands and a decrease in natural vegetation cover. In particular, areas with sparse maquis, dune areas, and water surfaces are experiencing a decline. This situation is detrimental to the region's natural areas. Land use change is fragmenting natural areas and increasing ecological risks. In particular, it supports the claim that tourism-oriented accommodation and urbanization trends in recent years have spread and dispersed over agricultural and greenhouse areas, causing a negative impact on the urban environment. The results suggest that urban growth will continue to expand in the future and, unless certain measures are taken, will lead to multifaceted negative impacts and risks on land resources.

The appropriate use of land according to its purpose and capacity is the most important component of urban planning and management processes. The incorrect, disorderly, and unconscious use of land leads to the destruction of natural resource values, the emergence of multifaceted environmental, social, and economic problems, the negative effects of climate change, increased carbon emissions, decreased biodiversity, and other issues. In this context, it is crucial to accurately determine the current status of land within and around cities using up-to-date inventory data and to reveal the temporal and spatial changes in land use types from the past to the present in order to ensure future sustainability.

In Demre district, strategic actions and decisions must be made with due consideration to the balance between conservation and use, in accordance with the purpose and capacity of the land. In this context, the protection and sustainability of Demre district's natural and cultural heritage values should be the primary objective. Other types of use should be planned in a manner compatible with conservation. Consequently, it is necessary to raise awareness and consciousness among local administrators, decision-makers, and city residents regarding the improvement of natural environments and ensuring their sustainability.

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