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Assessing Urban Sprawl and Agricultural Land Loss: A 40-Year Remote Sensing Study in Çanakkale

[1] **Emre Özelkan**, *[2] **Esra Eren**

[1] Department of City and Regional Planning, Faculty of Architecture and Design, Çanakkale Onsekiz Mart University, Çanakkale, Türkiye
[1] Risk Management of Natural Disasters Program, Graduate School of Education, Çanakkale Onsekiz Mart University, Türkiye
[2] Department of Landscape Architecture, Graduate School of Education, Çanakkale Onsekiz Mart University, Türkiye
[1] E-mail: emreozelkan@comu.edu.tr, [2] E-mail: esraa.eeren@gmail.com

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ABSTRACT

This study investigates the spatial expansion of rapid urbanization and its pressure on agricultural and natural lands within a socio-economic framework. Covering a 40-year period from 1984 to 2024, the research focuses on the central district of Çanakkale and employs spatial analysis methods alongside regression models. Findings reveal significant losses in agricultural lands adjacent to the city center due to urbanization, coinciding with rising employment in industrial and service sectors. Land use and cover maps for multiple years were produced from remote sensing data, achieving classification accuracy above 85% and kappa coefficients exceeding 0.80, ensuring analytical reliability. Regression results indicate a strong negative correlation between employment in the service sector and agricultural land ($r = -0.82$, $p < 0.05$), highlighting the role of economic transformation in rural land use change. The study demonstrates that urbanization should be understood not only as physical growth but as a process intertwined with economic restructuring and social change. By integrating spatial transformations with socio-economic dynamics, it offers insights into balancing development with the protection of productive land. The findings contribute to contemporary debates on inclusive, resilient, and sustainable urban environments, enriching the academic literature on the socio-economic dimensions of urban transformation.

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Highlights:	Contribution to the field statement:
- Urban sprawl significantly alters agricultural and natural land, leading to irreversible land use transformations. - Expansion into rural areas disrupts traditional livelihoods and triggers socio-economic shifts at the local level. - Spatial analysis reveals the role of urban development in fragmenting ecological and productive landscapes. - Understanding the socio-ecological consequences of sprawl is critical for guiding sustainable urban planning.	This study contributes to the field by providing four decades of remote sensing evidence on urban sprawl and agricultural land loss in Çanakkale, Türkiye. By integrating spatial and socio-economic perspectives, it advances understanding of land-use change dynamics and offers insights for sustainable urban planning and land management policies.

* **Corresponding Author:** Esra Eren
Department of City and Regional Planning, Faculty of Architecture and Design, Çanakkale Onsekiz Mart University, Çanakkale, Türkiye
Email address: esraa.eeren@gmail.com

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1. Introduction

Since the Industrial Revolution, cities have become centers of economic production and resource consumption, leading to rapid, often unplanned and uncontrolled urbanization (Kraus et al., 2022). This increase in urban populations has resulted in the expansion of settlements beyond core urban centers, often in a low-density, fragmented, and dispersed manner (Lu et al., 2023). This phenomenon is widely defined in literature as urban sprawl and is particularly associated with inefficient land use patterns that extend beyond metropolitan boundaries (Ewing, 1997). Globally, this form of expansion has placed considerable pressure on natural and productive land resources, particularly agricultural areas. Extensive research conducted in different geographical contexts has revealed that urban sprawl has resulted in significant losses of agricultural land, biodiversity (Imbrenda et al., 2021; Yussif et al., 2023) and that these losses will continue in the future (Bose & Chowdhury, 2020; Chen et al., 2020; Li et al., 2022; Mohammadyari et al., 2023; Ren et al., 2023; Simkin et al., 2022;).

1.1. Types of Urban Sprawl

Urban sprawl is a complex phenomenon that manifests in various typologies and spatial forms. Harvey and Clark (1965) were the first to systematically classify this phenomenon, identifying three basic types of sprawls: continuous development, ribbon development, and leapfrog development. Continuous development refers to low-density, unplanned horizontal growth originating from the city center. This type of sprawl typically involves the systematic conversion of agricultural lands and natural areas into urbanized zones. Ribbon development describes a linear settlement pattern that emerges along major transportation corridors. This form often results in unequal access to infrastructure services and increased dependence on transportation. Leapfrog development refers to new constructions that are spatially disconnected from the existing urban fabric, occurring in low-density areas and lacking spatial continuity (Glockmann et al., 2022). This form of development creates fragmented landscapes and spatial segregations, posing significant threats to ecological integrity (Rizkiya et al., 2023).

Harvey and Clark’s framework has been expanded over time to include additional dimensions. For instance, Wilson et al. (2003) categorizes urban growth into three main forms: infill, edge expansion, and dispersed development. Infill refers to the urbanization of vacant parcels within the existing urban fabric and is, in some literature, considered outside the scope of urban sprawl. In contrast, edge expansion denotes a continuous form of growth that extends beyond existing urban boundaries. Dispersed development consists of irregular settlements in low-density, fragmented, and poorly accessible areas. This form is frequently criticized in planning literature for increasing public service delivery costs, prolonging travel times, and contributing to the fragmentation of natural areas (Lovera, 2015).

The different forms of urban sprawl not only pose significant challenges for spatial planning but also generate complex environmental and socioeconomic effects. Unplanned development complicates the effective and sustainable provision of infrastructure services, leads to the irreversible loss of agricultural land, and reduces open natural areas and biodiversity (Gumma et al., 2017; Halder et al., 2021; de Sousa et al., 2023). Furthermore, increased surface runoff raises the risk of water pollution and threatens water quality (Tu et al., 2007). Spatially dispersed and extensive development intensifies dependency on private vehicle use, resulting in increased greenhouse gas emissions and air pollution; the expansion of impervious surfaces heightens flood risks and exacerbates the urban heat island effect (Moazzam et al., 2022; Yuan et al., 2018) In addition, longer travel distances significantly increase energy consumption (Obregón-Biosca et al., 2016). Beyond these environmental impacts, urban sprawl deepens the spatial segregation of urban populations, exacerbates social inequalities, and leads to changes in lifestyles and spatial justice issues. Therefore, urban sprawl should be examined not merely as a physical phenomenon but also in relation to its broader socioeconomic contexts (Oyalowo, 2022).

1.2. Socio-Spatial Impacts of Urban Sprawl

Although urban sprawl is primarily associated with economic factors, it is also shaped by numerous variables such as demographic dynamics, spatial planning policies, physical geography, environmental features, and transportation infrastructure (Magidi & Ahmed, 2019; Zhang et al., 2025; Wu et al., 2021). In developed countries, factors such as globalization, market economy, the dominance of capitalist ideology, and the declining livability of inner-city areas have accelerated the process of urban sprawl (Scott, 2017). Conversely, in developing countries, the main driving forces behind urban sprawl include informal settlements on public lands, rural to urban migration, inadequate planning practices, and the efforts of low- and middle-income households to find affordable housing on urban peripheries (Deng & Huang, 2004; Festus et al., 2020). In this context, urban sprawl emerges as a multilayered phenomenon shaped by both internal (country-specific) and external (global) dynamics, driven by a wide array of interacting forces.

In low-density residential areas, the establishment of infrastructure and the delivery of public services require high costs and reduce service efficiency (Hajilou et al., 2023). This situation may lead to the economic and social decline of city centers over time and deteriorate the quality of public spaces (Maryati & Humaira, 2015). The spatial dispersion that emerges with the process of urban sprawl weakens social relations at the neighborhood scale; the erosion of neighborly ties and decreased interaction undermines community identity and the sense of belonging. This becomes particularly evident in suburban areas, where social isolation tends to increase.

Moreover, the promotion of a lifestyle dependent on automobile use reduces physical activity, thereby negatively impacting public health. In areas with low walkability and fragmented spatial integrity, individuals' active participation in daily life diminishes, which adversely affects both physical and mental well-being (Genovese et al., 2023). In unplanned and rapidly developing suburban zones, ensuring public safety and order becomes increasingly difficult, potentially resulting in rising crime rates and weakened social control. On the other hand, traffic congestion and prolonged travel times lower the quality of daily life and lead to significant delays in accessing work or education (Cruz-Sandoval et al., 2025).

All these processes not only reduce individual quality of life but also deepen social inequalities. The spatial segregation of different socio-economic groups increases urban polarization and creates injustices in access to resources, services, and opportunities. In this context, urban sprawl is seen to fuel socio-spatial polarization and reproduce income disparities on a spatial scale (Scheba et al., 2021). Therefore, urban sprawl should be addressed not merely as a physical phenomenon but also as an urbanization issue directly related to social justice, equity, and quality of life.

1.3. Monitoring the Dynamics of Urban Sprawl

Various methods have been developed to identify and monitor urban sprawl. Urban sprawl exerts pressure on agricultural land, forests, pastures, meadows, and wetlands surrounding settlements, resulting in changes in LULC (Antalyn & Weerasinghe, 2020). Therefore, identifying LULC, which is one of the methods used to monitor urban sprawl, is valuable for revealing the negative impacts of urban expansion (AlQadhi et al., 2021; Sharma et al., 2024). Various methods have been developed to identify and monitor urban sprawl. These methods are based on the assessment of indicators such as built-up area growth, land-use mix, land cover change detection, construction density, population density, income level, education level, and GDP, which represent socio-economic conditions, spatial geometry, landscape changes, transportation, and visual measurements, either together or individually (Mosammam et al., 2017). Given the dynamic and spatially dispersed nature of urban sprawl, conventional field-based observation techniques are often insufficient for capturing long-term and large-scale land use changes. Remote sensing, due to its high spatial and temporal resolution, is one of the effective tools for identifying and monitoring urban sprawl (Kaya & Dervisoglu, 2023). Classification methods (supervised, unsupervised, pixel-based, object-based, etc.) (Balha et al., 2021) and tailored indices (normalized difference vegetation index (NDVI) (Yasin et al., 2019), soil-adjusted vegetation index (SAVI), normalized difference water index (NDWI) etc.) are the most commonly used remote sensing methods used to determine LULC (da Silva et al., 2020).

1.4 Problem Statement and Research Gap

Urban sprawl, particularly in unplanned areas, constitutes a significant form of urban growth that exerts pressure on agricultural lands, forests, and natural ecosystems, thereby giving rise to a range of environmental, social, and economic challenges. This process entails not only the transformation of the physical environment but also the reconfiguration of rural production systems, societal lifestyles, and local economic structures (Hussain & Imitiyaz, 2018). Although a substantial body of research has examined the spatial patterns, environmental impacts, and planning needs of urban sprawl in large metropolitan areas, similar transformations in medium-sized cities (with populations ranging from approximately 0.5 to 5 million) have not been explored in sufficient depth (Chettry, 2023). Yet, these cities are critical for understanding contemporary urban change, as they often experience rapid but still manageable transformation phases. This makes them strategic sites for generating transferable policy insights, enabling proactive interventions before reaching unsustainable thresholds.

Medium-sized cities, having not yet reached their full carrying capacities, are poised to undergo more intense spatial transformations in the coming years due to increasing population and investment pressures. Given their current development trajectories, these cities are positioned at a critical juncture in terms of sustainability, resilience, and land management. In Turkey, the impacts of urban sprawl are becoming increasingly visible not only in metropolitan areas but also in medium-sized cities. However, the multifaceted effects of these processes on spatial structures, land use patterns, and local socio-economic systems remain underrepresented in academic literature, particularly in comparative or cross-regional contexts.

In this context, the province of Çanakkale, located in northwestern Turkey, offers a representative and internationally relevant case. Its coastal geography, historical heritage, university-town identity, and ecotourism potential intersect with recent public and private sector investments, generating complex land use pressures. Particularly in the central district, areas that once exhibited rural settlement characteristics have gradually been opened to development. Trends such as the replacement of detached housing with apartment blocks, the increase in impervious surfaces, and the decline of urban agriculture have become prominent. These dynamics reflect broader challenges seen in other coastal and heritage-rich cities worldwide, where economic growth and spatial expansion must be balanced against the protection of agricultural lands and cultural landscapes.

This study aims to quantitatively and qualitatively analyze the land use and land cover (LULC) changes in the central district of Çanakkale between 1984 and 2024 using Landsat satellite imagery and remote sensing techniques, with the goal of capturing the dynamics of urban sprawl over a four-decade period. Furthermore, it seeks to discuss the effects of this spatial transformation on urban–rural interactions, the evolution of agricultural production systems, and the restructuring of the local social fabric. The scarcity of comprehensive studies addressing such multi-layered transformations in similar urban contexts underscores the originality of this research. By combining long-term spatial data with socio-economic interpretation, the study not only advances methodological approaches to LULC change analysis but also enriches the academic literature on the socio-economic dimensions of urban transformation in medium-sized cities.

1.5 Objectives and Hypotheses

The primary objective of this study is to analyze the impacts of urban sprawl on agricultural and natural areas in the city of Çanakkale between 1984 and 2024. To this end, eight different spectral indices were utilized to enhance class separability in satellite imagery. Subsequently, a supervised classification was performed using the Support Vector Machines (SVM) algorithm, and land use/land cover (LULC) maps were generated. These maps aim to reveal the spatial and temporal changes in agricultural and natural areas under urban growth pressure.

In the second phase of the study, the relationship between changes in agricultural land and various socio-economic and demographic indicators was examined. These indicators include total in-migration and out-migration, migration by educational level (primary, undergraduate, master's, and doctoral), agricultural population, number of tractors and trees, neighborhood-level population changes, and employment rates in the agricultural, industrial, and service sectors. The overarching goal is to understand the socio-economic dynamics influencing agricultural land transformation and to uncover the links between urban expansion, demographic mobility, and rural restructuring.
Within this framework, the following hypotheses are tested:

- **H1:** Between 1984 and 2024, agricultural lands surrounding the urban center of Çanakkale have significantly declined due to the impacts of urban sprawl.
- **H2:** There is a statistically significant correlation between the net migration rates of neighborhoods affected by urban expansion and the loss of agricultural land.
- **H3:** A negative correlation exists between the reduction in agricultural land and the agricultural population, number of tractors, and number of trees.
- **H4:** Migration by educational attainment (particularly higher education) and sectoral employment shifts (from agriculture to industry and services) are associated with land use changes and the urban transformation of rural areas.

By integrating spatial analyses with socio-economic indicators, this study seeks to examine the effects of urban growth on rural and peri-urban areas from a multi-dimensional perspective, thereby contributing to the literature on land systems and urban-rural interactions.

1.6 Significance and Structure of the Paper

This study is significant in that it adopts a multidisciplinary approach to examine the spatial and socio-economic impacts of urban sprawl in Çanakkale, a medium-sized city. While remote sensing techniques are employed to reveal the pressure of land use changes on agricultural areas, the study also explores the social implications of these changes through demographic and socio-economic data. In doing so, it provides a more comprehensive understanding of the transformations and lifestyle shifts occurring in rural areas as a result of urban growth processes. The findings offer valuable insights that can inform sustainable urban planning and rural development policies.
The article is structured in fifth steps as follows:
1: Firstly, literature review is presented on the conceptual framework of urban sprawl and its socio-economic impacts.
2: This is followed by a detailed explanation of the research problem, objectives, and hypotheses.
3: The third section describes the methods used for analyzing remote sensing and socio-economic data.
4: In the fourth section, the land use changes and related socio-economic findings from the case of Çanakkale are discussed.
5: Finally, the paper concludes with a summary of key findings, policy recommendations, and suggestions for future research.

2. Materials and Methods

This study investigates the relationship between urban sprawl and changes in agricultural land, forests, and grassland (including pasture and meadows) in the city of Çanakkale over the period from 1984 to 2024, utilizing remote sensing data and geospatial analysis methods. The methodological workflow adopted in this study is illustrated in Figure 1.

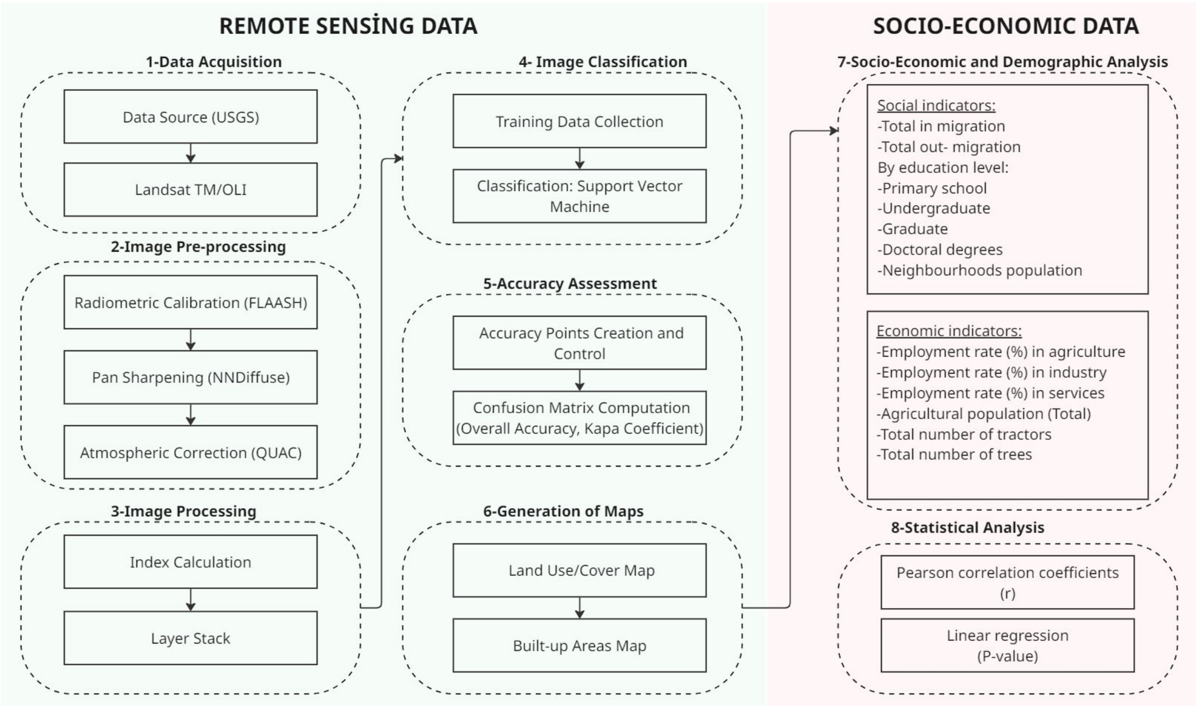

Figure 1. Workflow Diagram Illustrating the Step-by-Step Process of Inserting Subjects.

2.1 Study Area and Time Frame

This study was conducted within the administrative boundaries of Çanakkale, Türkiye. Çanakkale is situated in the northwest of Türkiye, to the south of the Marmara Region and the north of the Aegean Region (Figure 2). Çanakkale is in the subtropical Mediterranean climate zone with a regional Marmara climate characterized by transitional effects from both Mediterranean and Black Sea climates, characterized by mild winters and very hot and dry summers. The total population of the study area is 204454 people.

The temporal scope covers a 40-year period from 1984 to 2024, selected to capture long-term patterns of urban expansion and its impacts on agricultural and natural land. The availability of consistent Landsat satellite imagery for this period supported this selection.

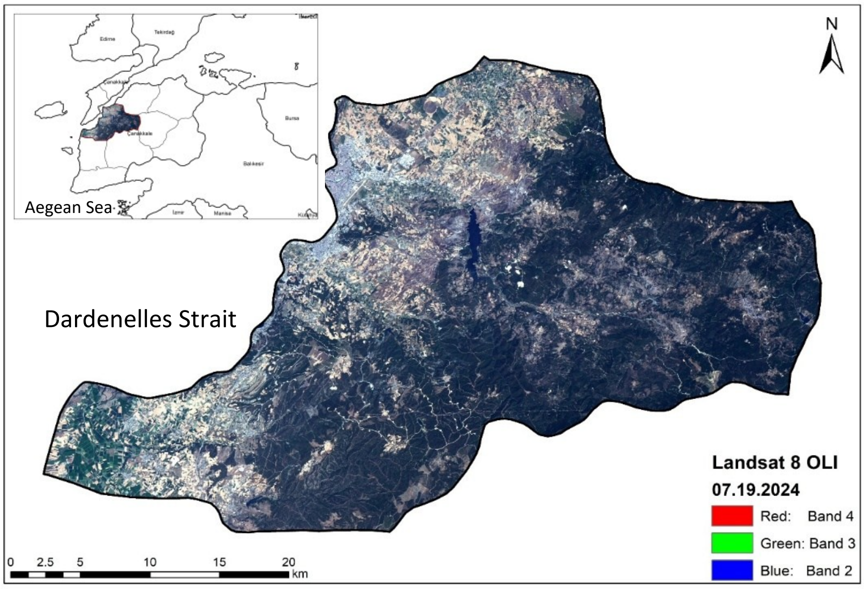

Figure 2. Location Map of the Study Area within the Boundaries of Çanakkale Province, Türkiye.

2.2 Remote Sensing Data and Pre-processing

Multitemporal satellite imagery was acquired from the United States Geological Survey (USGS), including Landsat Thematic Mapper (TM) and Operational Land Imager (OLI) sensors. These images provide medium-resolution (30 m) multispectral data suitable for land cover analysis. Images were selected based on minimal cloud cover and seasonal consistency. In this study, five Landsat TM/OLI images were used to produce LULC maps (Table 1). Pre-processing steps were applied to the images for further processing. First, radiometric correction was performed using the FLAASH algorithm. For Landsat 8 OLI images, radiometric correction was applied to the multispectral bands first, followed by the panchromatic band. Second, the 15 m spatial resolution panchromatic band of Landsat 8 OLI was used to enhance the resolution of the 30 m multispectral bands to 15 meters through pan-sharpening (using the NNDiffuse algorithm). Since Landsat 5 TM images do not have a panchromatic band, they were used with a 30 m spatial resolution. Third, atmospheric correction was performed on all images using the Quick Atmospheric Correction (QUAC) algorithm. Finally, the raw image reflectance values, which were initially provided as scaled integers, were converted to actual physical reflectance values, making all images ready for processing.

Table 1: Specifications of Landsat TM/OLI Images.

Satellites	Acquisition Date	Sensor	Spatial Resolution
Landsat 8	07/19/2024	OLI	15 m
Landsat 8	07/08/2014	OLI	15 m
Landsat 5	07/12/2004	TM	30 m
Landsat 5	07/01/1994	TM	30 m
Landsat 5	07/21/1984	TM	30 m

2.3 Image Processing

To obtain the LULC maps, index calculations were first performed to highlight specific features in the images. In In this study, a total of eight indices including brightness, greenness and wetness layers of Tasseled Cap Transformations (TCT), NDVI, normalized difference built-up index (NDBI), normalized difference moisture index (NDMI), soil adjusted vegetation index (SAVI), and modified soil adjusted vegetation index (MSAVI) were used for LULC classification. Table 2, the "intended use" of each index in assisting the image classification process is provided. For some classes, such as grassland, multiple indices were used. The reason for this is that the NDVI index performs better in identifying areas with higher vegetation density, while the MSAVI index is more successful in areas with lower vegetation density and soil influence. As a result of the trials, a total of eight indices were used in the production of LULC maps in this study, including three tasseled cap transformation components (Crist & Cicone, 2007), NDVI (Singh et al., 2016), NDBI (Zha et al., 2003), SAVI (Huete, 1988), and MSAVI (Qi et al., 1994) (Table 2). All index layers were stacked into a composite image to be used as input for classification.

Table 2: Indexes Used in LULC Classification and Their Descriptions.

Index	Area of use	Intended Use	Formula
TCT-Brightness	Soil reflectivity	Built-up, bare/burnt Land	0.3029 * Blue + 0.2786 * Green + 0.4733 * Red + 0.5599 * NIR + 0.5080 * SWIR1 + 0.1872 * SWIR2
TCT-Greenness	Presence and density of vegetation	Agricultural land, forest	-0.2941 * Blue - 0.2430 * Green - 0.5424 * Red + 0.7276 * NIR + 0.0713 * SWIR1- 0.1608 * SWIR2
TCT-Wetness	Moisture content in plants and soil	Water, forest, and agricultural land	0.1511 * Blue + 0.1973 * Green + 0.3283 * Red + 0.3407 * NIR - 0.7117 * SWIR1 - 0.4559 * SWIR2
NDVI	Vegetation density	Forest, grassland, agricultural land	(NIR - Red) / (NIR + Red)
NDBI	Urban area	Built-up	(SWIR - NIR) / (SWIR + NIR)
NDMI	Moisture analysis	Forest, grassland	(NIR - SWIR1) / (NIR + SWIR1)
SAVI	Vegetation (reduces soil impact)	Agricultural land, forest	((NIR - Red) / (NIR + Red + L)) * (1 + L)
MSAVI	Low vegetation areas	Grassland	0.5 * [2 * NIR + 1 - sqrt((2 * NIR + 1)^2 - 8 * (NIR - Red))]

2.4 Image Classification

After all the indices were calculated, all layers were merged to create a single 8-layer image for classification. For all years (1984, 1994, 2004, 2014, and 2024), training data for six classes (built-up, agricultural land, grassland, bare/burnt area, forest, water) were collected. In this study, eight spectral indices were utilized for regional land cover classification. The grassland and pasture categories were merged due to their high spectral similarity and the fact that they are frequently treated as a single category in municipal reports. This approach ensured both spectral consistency and administrative coherence. Finally, the images were classified through supervised classification using the Support Vector Machine (SVM) algorithm, a widely used non-parametric classifier.

SVM identifies the optimal decision boundary that best separates the data into two classes, aiming to maximize the margin between them (Vapnik, 1999). The classification process of SVM is based on four fundamental principles: (a) if the data are linearly separable, SVM identifies the hyperplane that provides the widest possible margin between the two classes; (b) the data points closest to this hyperplane, known as support vectors, are used to define the decision boundary; (c) the hyperplane is selected to maximize the distance to these support vectors; and (d) if the data are not linearly separable, kernel methods are employed to project the data into a higher-dimensional space where linear separation is feasible (Burges, 1998).

Due to its high accuracy and low training data requirements, SVM is a widely preferred method for the classification of satellite imagery such as Landsat (Fragou et al., 2020), Sentinel (Kavzoglu et al., 2020), and MODIS (Sheykhmousa et al., 2020). SVM was selected for this study because of its strong performance in distinguishing spectrally similar classes in complex datasets, its effectiveness with limited training data, its ability to separate non-linear boundaries through kernel functions, and its robustness against overfitting.

Support Vector Machine (SVM) with a Radial Basis Function (RBF) kernel was employed for the classification. The SVM parameters were determined through experimental trials, with a gamma value of 0.2 and a penalty parameter (C) set to 500. For each class, approximately 20 to 50 training samples were selected using a trial-and-error approach to ensure adequate representation of spectral variability, and a total of approximately 250 samples were collected.

2.5 Classification Accuracy Assessment

Accuracy assessment was conducted using the Spatial Analyst Tools module in ArcGIS, specifically the “Segmentation and Classification” tools. A total of 120 validation points were generated using the stratified random method to ensure balanced spatial representation. This method was chosen to improve the evaluation of user accuracy, particularly for underrepresented classes such as water surfaces. The validation points were converted to KML format and visually interpreted in Google Earth using high-resolution imagery. Subsequently, these points were used as attribute data in ArcGIS, and a confusion matrix was computed to derive overall accuracy, producer’s accuracy, user’s accuracy, and the Kappa coefficient.

2.6 Generation of Land Use/Cover Maps

Land Use/Land Cover (LULC) maps were generated for multiple time points (1984, 1994, 2004, 2014, and 2024) to capture the spatiotemporal dynamics of urban expansion and its impact on agricultural and natural areas. The classified images resulting from the SVM algorithm were post-processed to refine class boundaries and eliminate isolated misclassified pixels through majority filtering. The LULC classification schema included five primary land cover categories: urban/built-up areas, agricultural land, forest and natural vegetation, water bodies, and barren land.

Each LULC map was visually inspected and validated using high-resolution imagery and available ancillary data (such as CORINE land cover maps, historical records, and local knowledge where applicable) to ensure thematic consistency across the years.

The resulting LULC maps served as the foundation for subsequent spatial and statistical analyses, particularly in assessing the socio-economic drivers of land transformation and quantifying the extent of urban encroachment into non-urban land uses.

2.7 Socio-Economic and Demographic Analysis

In the second stage of the study, a socio-economic and demographic analysis was conducted to investigate the underlying factors contributing to the transformation of agricultural lands, particularly in relation to urban expansion. This stage aimed to evaluate the associations between land use change and a range of human-induced variables that reflect demographic mobility, rural restructuring, and shifts in economic activity.

The analysis utilized neighborhood-level indicators, including total in- and out-migration, migration by education level (primary school, undergraduate, graduate, and doctoral degrees), the number of agricultural workers, the quantity of registered tractors and fruit-bearing trees, population changes at the neighborhood scale, and employment distributions across the agriculture, industry, and service sectors (Turkish Statistical Institute, n.d.).

To quantitatively assess the relationships between these variables and changes in agricultural land, two complementary statistical methods were employed. First, Pearson correlation analysis was used to determine the strength and direction of bivariate associations between agricultural land change and individual socio-economic indicators, with correlation coefficients (r) interpreted according to conventional thresholds. Second, linear regression analysis was conducted to identify the extent to which selected variables explained variance in land cover change. Since R^2 is simply the square of the correlation coefficient in simple linear relationships, we reported only the correlation coefficient (r) and p-values to evaluate the strength and significance of the relationships. These analyses provided empirical evidence on the socio-economic dynamics driving land conversion processes. By integrating spatial and statistical methods, the study offered a nuanced understanding of how urban growth intersects with demographic trends and agricultural transitions in the context of Çanakkale's peri-urban landscape.

3. Results

3.1 Classification Accuracy Assessment

The overall accuracy of the LULC maps produced as a result of classification is between 86% and 90% (Table 3). The LULC maps produced in this study reveal the spatial changes in the analyzed region between 1984 and 2024 (Figure 3). The classification was performed across six main classes: built-up areas, agricultural land, meadow and pasture areas, forested areas, bare and burnt areas, and water bodies. In this classification, meadow and pasture areas were considered as a single class name with grassland. When the time series of maps was analyzed, a significant increase in built-up areas was observed. Urbanization appears to have concentrated around urban centers, and this process has exerted pressure on agricultural land. The observed reduction in agricultural land is seen as a direct consequence of the pressure of urbanization on the outskirts. On the other hand, an increase in water surfaces was detected in some areas due to the construction of dam reservoirs. When examining forested areas, fire-related losses over the years stand out. The map for 2024 clearly shows this change. A vast forest area is observed to have transformed into burnt land, which is a direct result of the large-scale forest fires that occurred in July and August 2023. This situation serves as a striking example of the impact of natural disasters on land cover.

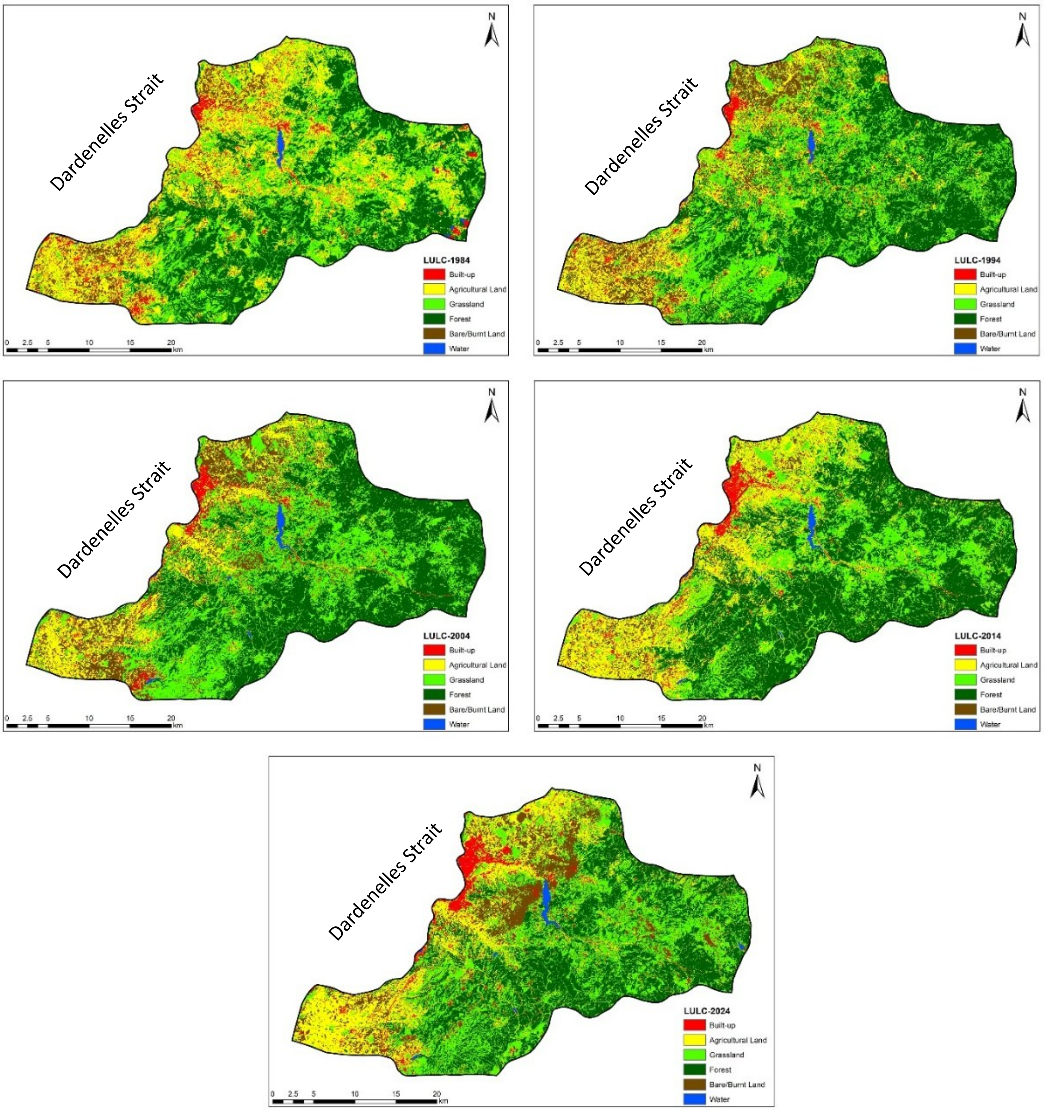

Figure 3. The LULC Maps Produced in this Study between 1984 and 2024.

Table 3: Accuracy Assessment of LULC Maps.

Years	Overall Accuracy	Kappa Coefficient
1984	86.60%	0.83
1994	90.90%	0.86
2004	89.70%	0.86
2014	90.90%	0.88
2024	87.70%	0.84

3.2 Urban Sprawl and Agricultural Land Conversion

An examination of the urban development process reveals that the city center was initially established in a location close to the coastline (Figure 4). This point of origin determined the direction of settlement and led to the continuation of urban sprawl along the coastal strip. Over time, the construction of a ring road beyond the city center facilitated expansion into new areas, and the space created by this road became a significant corridor for urban growth. Several factors influencing the spatial expansion of the city were identified during this process. In particular, natural geographical features such as the coastline, the development of transportation infrastructure, political decisions to relocate public facilities outside the urban core, and topographical characteristics have all been key elements shaping the direction and form of urban areas. These dynamics demonstrate that urban sprawl is shaped not only by physical geography but also by socio-political and economic decisions.

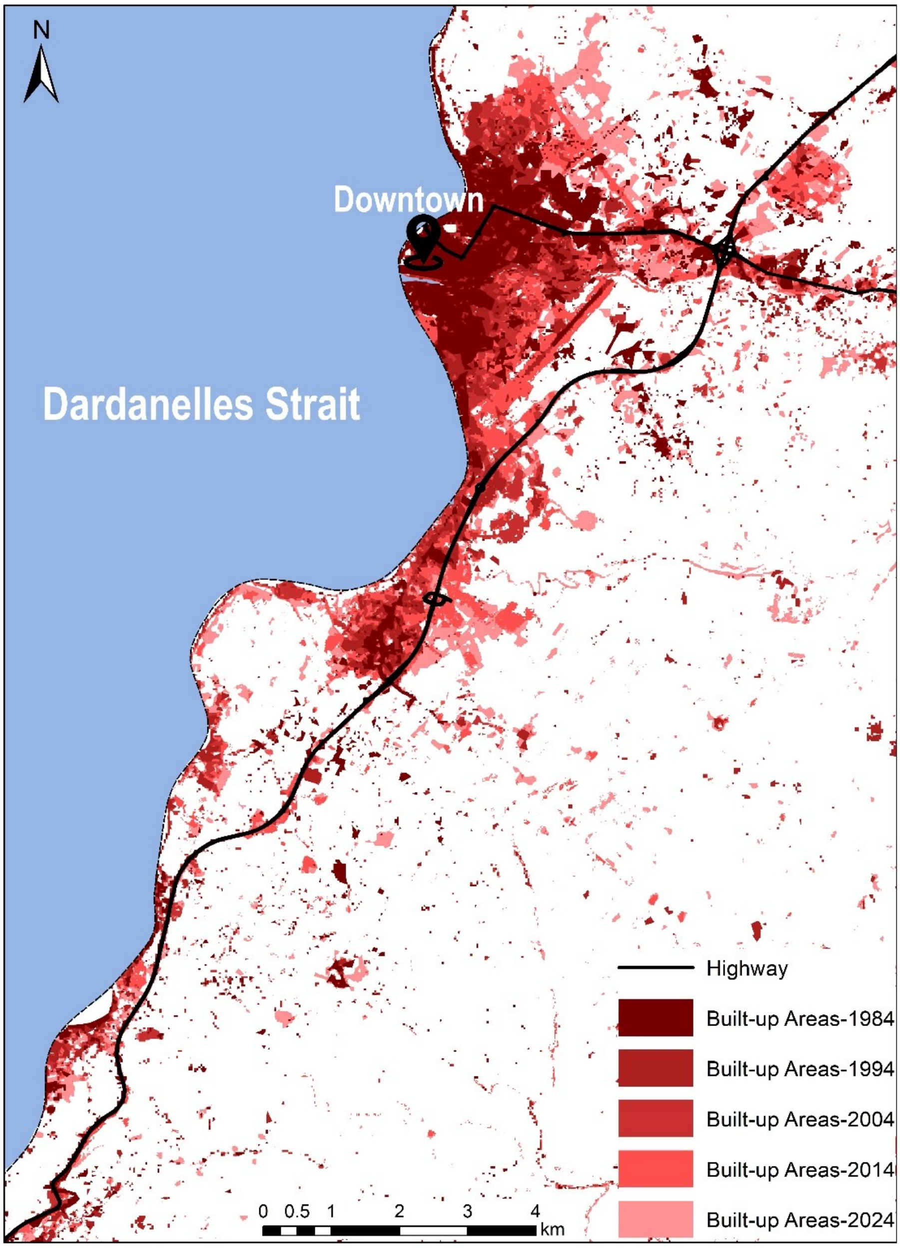

Figure 4. Built-up Areas Change between 1984 and 2024.

Images from Google Earth Pro were used to determine the visible impact of urban sprawl (Google Earth, n.d). However, since the highest resolution image of the oldest date can be obtained in 2006, the first image was acquired in 2006, and the other image was acquired in 2024, following the temporal scope of the study. The first example focuses on the area surrounding the largest settlement closest to the city center (Figure 5). This area is characterized by a flat plain composed of fertile agricultural land. However, over time, unplanned urban development has led to the conversion of these productive agricultural areas into built-up zones, resulting in the loss of natural land cover. This clearly illustrates the negative impact of urban sprawl on agricultural production areas.

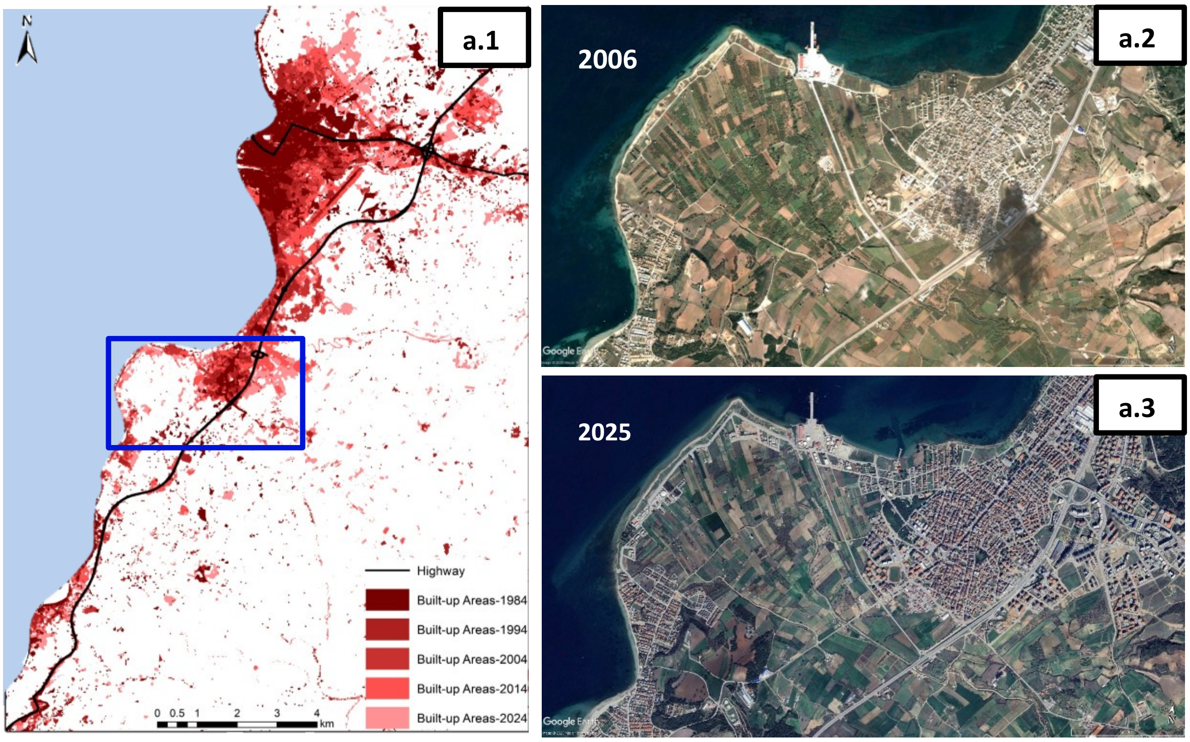

Figure 5. Urban Expansion is over Fertile Agricultural Land Near the City Center. (a.1) Temporal Change of Built-up Areas Produced in this Study, (a.2) Satellite Image of the Area from 2006 (Google Earth, n.d.), (a.3) Satellite Image of the Area from 2024 (Google Earth, n.d.).

The second example includes an image taken directly from the city center (Figure 6). Initially, the airport and ring road were planned outside the urban settlement; however, over time, they became surrounded by the expanding urban fabric and were eventually encompassed within residential areas. This example demonstrates that large-scale infrastructure investments with non-residential functions can also trigger urban sprawl and influence the direction of urban development.

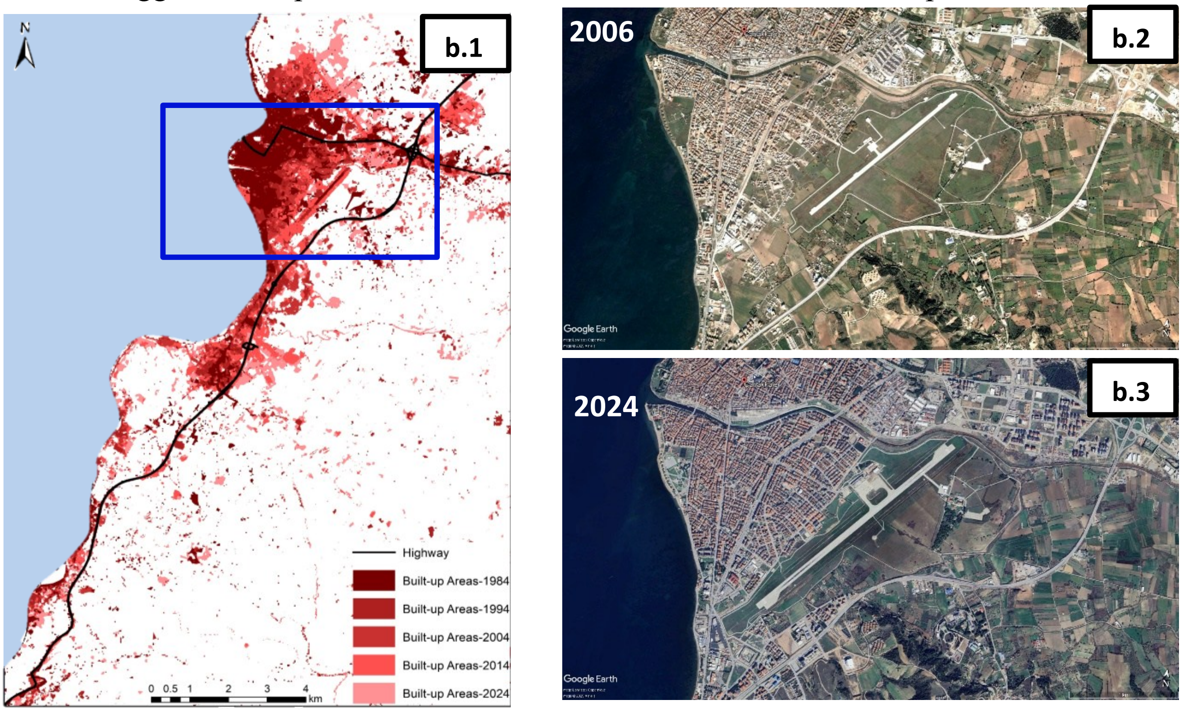

Figure 6. Urban Sprawl Enclosing the Airport and Ring Road was Originally Planned Outside the City. (a.1) Temporal Change of Built-up Areas Produced in this Study, (a.2) Satellite Image of the Area from 2006 (Google Earth, n.d), (a.3) Satellite Image of the Area from 2024 (Google Earth, n.d).

The third example illustrates the impact of the location of public investments on urban sprawl (Figure 7). A hospital complex constructed on the urban periphery has redirected the trajectory of urban growth, leading to the conversion of surrounding agricultural, pasture, and grassland areas into built-up zones. This case highlights that public investments play a strategic role not only in the provision of services but also in guiding spatial development.

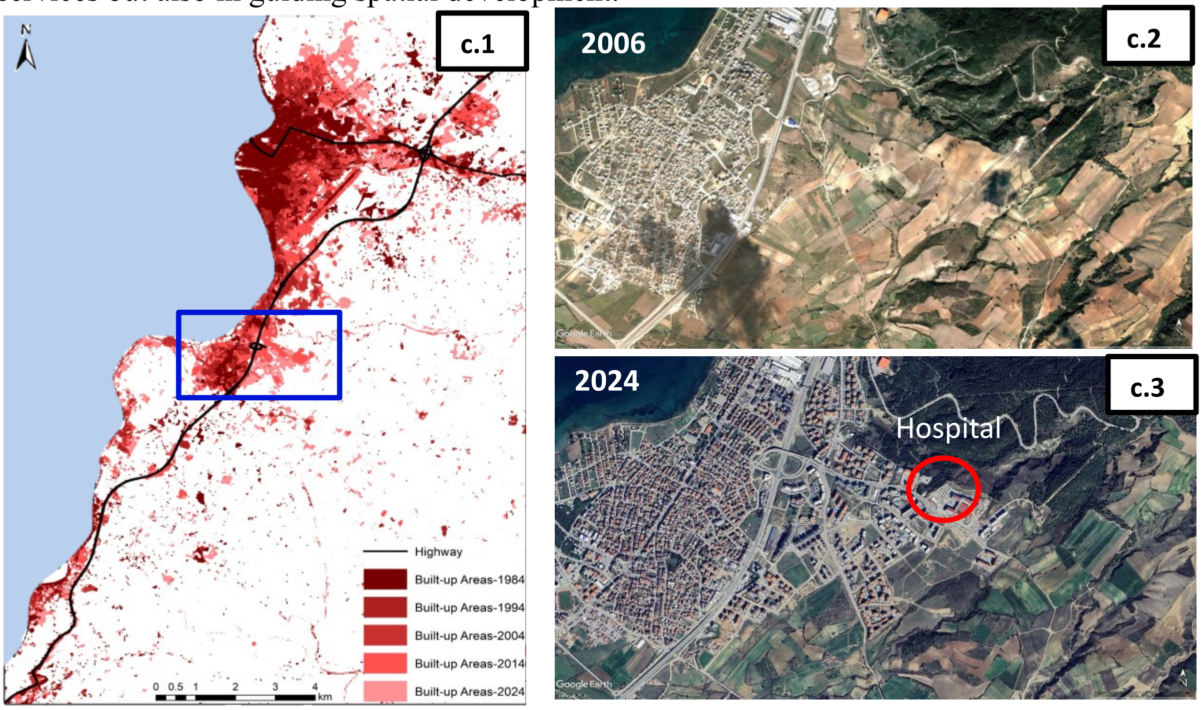

Figure 7. Directional Shift in Urban Growth Due to a Hospital Complex on the City's Edge. (a.1) Temporal Change of Built-up Areas Produced in this Study, (a.2) Satellite Image of the Area from 2006 (Google Earth, n.d), (a.3) Satellite Image of the Area from 2024 (Google Earth Pro); the Hospital is Indicated with a Red Circle.

The final example points to large-scale forest loss resulting from wildfires (Figure 8). It has been determined that the fires were primarily caused by human activities and rapidly spread due to meteorological conditions. In this context, the proximity of residential areas to natural environments places significant pressure on ecosystems and leads to the destruction of habitats. This situation demonstrates that urban sprawl threatens not only land use patterns but also environmental sustainability.

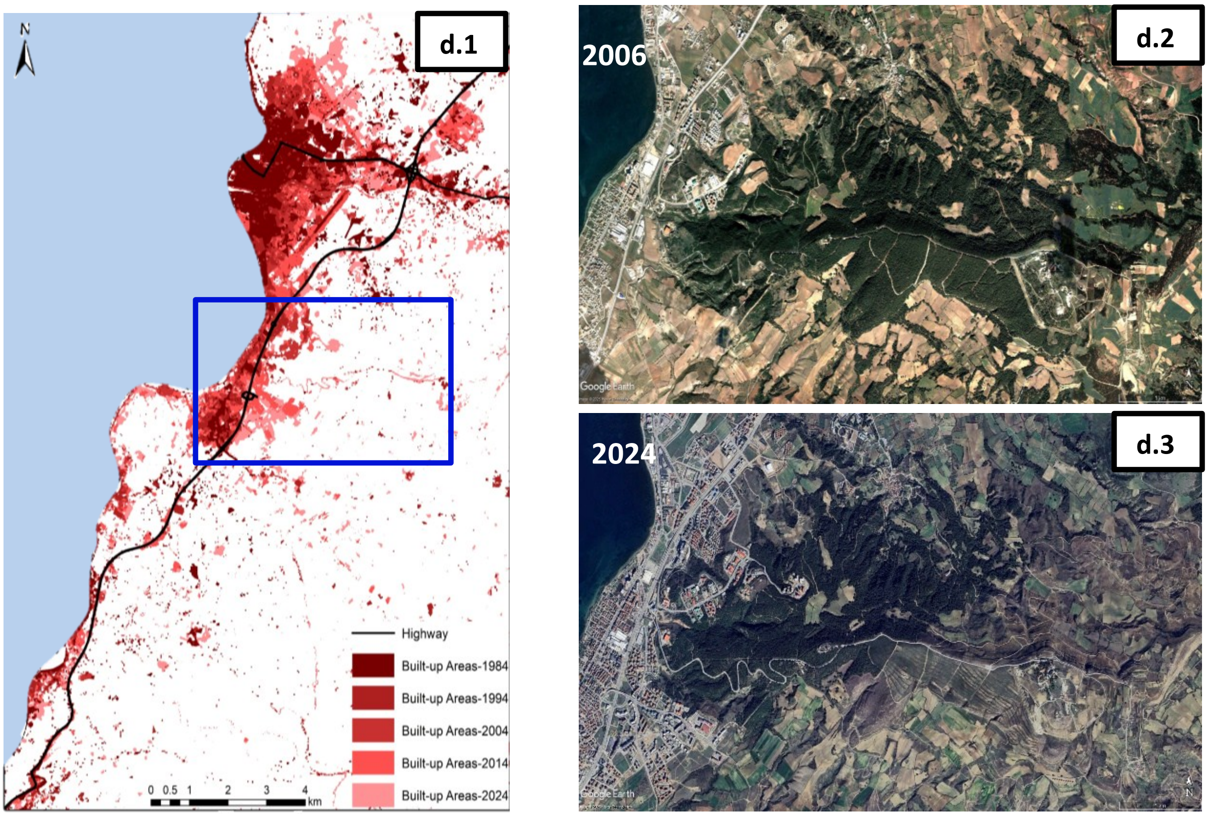

Figure 8. Large-scale Forest Loss Caused by Wildfires Near Residential Areas. (a.1) Temporal Change of Built-up Areas Produced in this Study, (a.2) Satellite Image of the Area from 2006 (Google Earth, n.d.), (a.3) Satellite Image of the Area from 2024 (Google Earth, n.d.).

3.3 Socio-Economic and Demographic Correlates of Agricultural Land Change

In 2024, the total population of Çanakkale province reached 568,966, with 204,454 residents living in the central district alone. Between 1985 and 2024, the central district of Çanakkale experienced a significant increase in population, accompanied by a notable trend toward urbanization. The total population grew from 73,412 in 1985 to 204,454 in 2024, representing an approximate increase of 178% (Figure 9). This demographic expansion was particularly pronounced in urban areas. While the rural population rose from 25,353 in 1984 to 59,260 in 2024, the urban population surged from 48,059 in 1985 to 204,454 in 2024. These figures highlight a substantial shift from rural to urban living, indicating that the majority of population growth has been absorbed by urban settlements rather than rural areas.

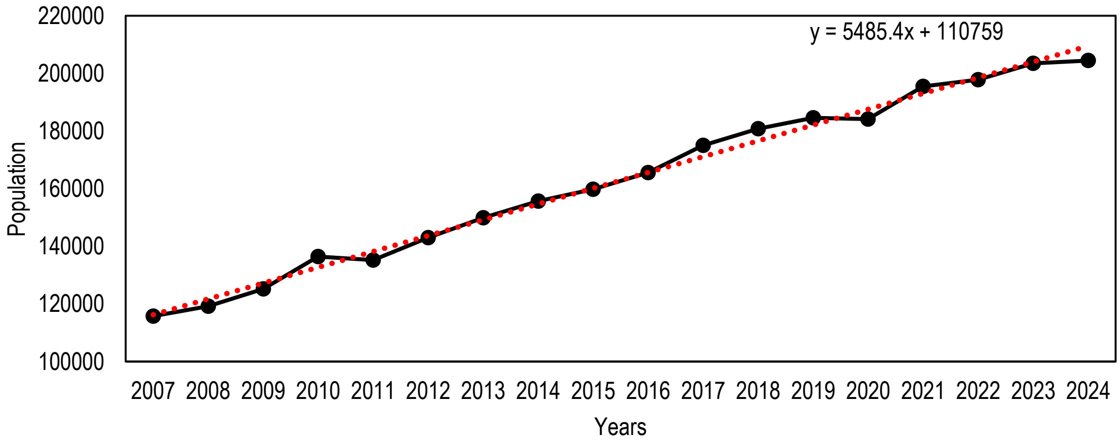

Figure 9. Population Growth of the Study Area (2007-2024) (Turkish Statistical Institute, n.d.).

Statistical analysis of quantitative data from the central district of Çanakkale reveals significant correlations between total agricultural land and various socio-demographic and sectoral indicators (Table 4). In particular, the contraction of agricultural land under the pressure of urban sprawl appears to have a decisive impact on local employment structures and migration dynamics.

A strong positive correlation was found between total agricultural land and the employment rate in the agricultural sector ($r = 0.70$, $p = 0.12$). Similarly, positive relationships were observed with indicators related to agricultural production capacity, such as the total number of trees ($r = 0.30$) and total number of tractors ($r = 0.25$). These findings indicate that the presence of agricultural land is directly associated with production and employment capacity in the agricultural sector.

It was also found that the development of non-agricultural sectors influences agricultural land use. A negative and statistically significant correlation was observed between the employment rate in the service sector and total agricultural land ($r = -0.82$, $p = 0.047$). This suggests that agricultural activities decline in areas where the service sector expands, revealing the transformative effect of urban occupations on rural landscapes. The structural shift from agriculture to services points not only to an economic but also a spatial transformation.

Migration data reveal negative correlations between total agricultural land and the migration of individuals with low educational attainment, particularly primary school graduates (out-migration: $r = -0.57$, $p = 0.02$). This suggests that the reduction in agricultural activities may be prompting low-educated individuals to migrate to urban areas or prevent them from sustaining life in the cities.

There were weaker but positive correlations between agricultural land and the migration behavior of individuals with higher education. For instance, the in-migration of college or university graduates correlated with agricultural land at $r = 0.41$ ($p = 0.12$), while out-migration showed $r = 0.52$ ($p = 0.039$). This implies that the contraction of agricultural land not only affects the rural labor force but also makes urbanizing areas less attractive for highly educated individuals. Master's level out-migration further supports this trend, showing a positive correlation with agricultural land ($r = 0.42$, $p = 0.10$).

Significant and positive correlations were identified between the population of urban neighborhoods [Barbaros ($r = 0.70$, $p = 0.001$), İsmetpaşa ($r = 0.57$, $p = 0.01$), and Hamidiye ($r = 0.60$, $p = 0.02$)] and total agricultural land. These findings indicate that population growth in these neighborhoods has led to the conversion of nearby agricultural areas into built-up land, with urban pressure directly targeting agricultural zones. The particularly high correlation for Barbaros neighborhood suggests it is at the core of this urban expansion.

The analysis of fruit, beverage, and spice crop areas and total number of trees in the central district of Çanakkale revealed a very strong and statistically significant correlation ($r = 0.99$, $p < 0.0001$). This reflects that these crops are largely perennial and tree-based (e.g., olive, cherry, apple), and that such agricultural activities directly affect the increase in tree numbers.

At the spatial level, areas like Kepez Plain which is historically used for fruit cultivation have been increasingly open to urban development, resulting in a noticeable rise in impervious surfaces. Settlements that once had a semi-rural character, with garden houses and detached buildings, have become sites of dense construction over time, limiting opportunities for urban agriculture and contributing to the decline of intra-urban fruit farming.

On a regional scale, the growing demand from metropolitan areas such as Istanbul for products like olives and olive oil has further increased the importance of Çanakkale's fruit-based agriculture. Consequently, agricultural land in the central district appears to have shifted from cereal cultivation toward higher value-added and marketable products such as fruit orchards, a trend particularly observable in rural villages outside the urban core.

These findings illustrate the dual effect of urban sprawl: while exerting pressure on traditional agricultural production areas, it also prompts the spatial reorganization of agricultural activity. Moreover, the results underscore the need for planning policies that account for the spatial sustainability of agricultural production and food security.

Overall, the findings suggest that urban sprawl and associated demographic movements have a determining impact on both the quantity and quality of agricultural land in the central district of

Çanakkale. Notably, neighborhood-level population growth and expansion of the service sector are directly linked to the conversion of agricultural land for urban uses and the dissolution of traditional agricultural practices. This transformation signals not only economic but also social and cultural ruptures within rural areas.

Table 4: Correlation between Total Agricultural Land and Selected Socio-Economic and Demographic Variables.

Variables	Total Agricultural Land (decare)	
	r	P-value
Employment Rate (%) in Agriculture	0.70	0.12
Employment Rate (%) in Industry	0.49	0.32
Employment Rate (%) in Services	-0.82	0.047
Agricultural Population (Total)	0.25	0.48
Total Number of Tractors	0.30	0.19
Total Number of Trees	0.18	0.43
Total In-Migration	0.28	0.29
Total Out-Migration	0.42	0.10
Primary School (In-Migration)	-0.40	0.12
Primary School (Out-Migration)	-0.57	0.02
University Graduates (In-Migration)	0.41	0.12
University Graduates (Out-Migration)	0.52	0.039
Master's and Doctorate Degree (In-Migration)	0.35	0.17
Master's and Doctorate Degree (Out-Migration)	0.40	0.12
Barbaros Neighbourhood Population	0.70	0.001
İsmetpaşaNeighbourhood Population	0.57	0.01
Hamidiye Neighbourhood Population	0.60	0.02

4. Discussion

4.1 Interpretation of Key Findings

This study evaluates the environmental and socio-economic impacts of urban sprawl in Çanakkale between 1984 and 2024, focusing on land use and land cover (LULC) changes. The findings reveal a significant increase in built-up areas, accompanied by a notable decline in natural lands. Özelkan et al. (2018), in their study conducted in Çanakkale province, found a strong negative correlation ($r = -0.985$) between urban sprawl and agricultural land, emphasizing that urbanization exerts pressure particularly on agricultural areas adjacent to urban boundaries. Although agricultural lands on the periphery of the urban core have been opened to development, there has been a continuous expansion in agricultural zones in other parts of the province, particularly those associated with fruit cultivation. This dual trend highlights the spatial complexity of urban expansion, emphasizing both the contraction of farmland around the city and the intensification of agricultural production in some rural regions.

The increase in urban construction mirrors the forms of continuous and edge expansion described by Harvey and Clark (1965) as well as Wilson et al. (2003), while also indicating the formation of growth corridors, especially along transportation routes and strategic infrastructure investments. Additionally, other studies have emphasized that public investments (e.g., hospitals, ring roads) made outside city centers tend to accelerate urban sprawl (Kilinc et al., 2023; Pratama et al., 2022). The urban expansion observed along coastal zones and peripheral roads underscores the decisive role of physical geography and socio-political decisions in shaping urban development (Khan et al., 2024). As Sudhira and Ramachandra (2007) and Nemouchi (2023) assert, urban sprawl in our study area has also occurred on the periphery of urban areas, particularly along the highways and arterial roads. This study reveals the direct influence of public investments on urban expansion. Tong et al. (2022), in their study in China, found that public finance factors based on land financing, rather than market-oriented economic drivers, played a more decisive role in shaping urban development. Hantalo and Dube (2023) demonstrate that fringe settlement on unserved public lands is shaped by factors such as population growth, migration, weak land governance, and the influence of socio-political actors, exemplifying how urban sprawl is deeply intertwined with socio-economic dynamics. The unplanned expansion observed in the urban periphery is also consistent with findings in the literature (Daunt et al., 2021).

Moreover, the encroachment of urban areas on agricultural lands aligns with patterns of land use and socio-economic transformation observed in other Turkish cities such as Ankara, Konya, and Samsun (Basara et al., 2022; Gurbuz & Cilek, 2023; Yavuz, 2021). Research conducted in Europe and the Mediterranean basin has similarly demonstrated that agricultural lands are increasingly encroached upon by urban expansion and that environmental pressures are intensifying at urban fringes (Salem et al., 2020). Socio-economic analyses further elucidate the multi-layered impacts of urban sprawl. The strong positive correlation between agricultural land and employment in the agricultural sector reveals the direct relationship between land use and rural livelihoods. However, the inverse and statistically significant relationship between agricultural land and employment in the service sector indicates a spatial transformation of the economic structure. This finding is consistent with literature suggesting that urban economic diversification often leads to a decline in agricultural activities, particularly in peri-urban areas (Mosammam et al., 2017). On the other hand, the study finds that tourism-driven development, rather than demographic variables, plays a more influential role in urban expansion in coastal cities such as the study area (Mihalach & Dumitrașcu, 2025).

Migration data show that individuals with lower levels of education tend to migrate to cities as agricultural land decreases, whereas those with higher levels of education exhibit more complex migration patterns. It is also known that individuals migrating for educational purposes contribute more to urbanization and economic growth compared to those migrating for employment reasons (Liao et al., 2022).

Environmental issues are deeply intertwined with these socio-economic dynamics. The wildfires of 2023 demonstrated the high vulnerability of natural areas surrounding urban zones to both climatic and anthropogenic pressures (Godoy et al., 2022; Guo et al., 2024). This highlights the necessity of integrated urban planning approaches that preserve ecosystem services and reduce disaster risks. The wildfires underscore that urban sprawl poses not only land use challenges but also serious threats to environmental sustainability.

4.2 Strengths and Limitations

This study benefits from a robust methodological framework that combines long-term remote sensing data with socio-demographic and sectoral statistics, allowing for a comprehensive examination of urban sprawl and its impact on agricultural land in Çanakkale's central district over a 40-year period. The use of multiple spectral indices together with Support Vector Machine (SVM) classification contributed to the production of accurate land use and land cover maps, with overall accuracies ranging from 86 percent to 90 percent. Furthermore, integrating spatial analysis with socio-economic indicators provided a nuanced understanding of the complex interactions between urban expansion, migration patterns, and changes in agricultural activity.

However, there are limitations inherent in the remote sensing classification process, particularly due to the spectral similarity among certain land cover classes such as fallow agricultural lands, built-up areas, and burnt areas. This spectral overlap sometimes leads to misclassification or mixing of these classes, which may affect the consistency and reliability of land cover change detection over time. Additionally, the availability and resolution of socio-economic data sometimes limits the precision of correlation analyses because some datasets had missing or aggregated values that could affect detailed spatial interpretations. Remote sensing techniques, while powerful for detecting land cover changes, are less effective in capturing informal land uses and qualitative aspects of land management practices. The impact of sudden events such as the 2023 forest fires also introduces variability that complicates the assessment of long-term trends. Lastly, the study's focus on a single urban district limits the broader applicability of the results, suggesting the need for comparative studies across diverse regions to generalize findings.

4.3 Implications and Future Directions

The findings of this study contribute to a deeper understanding of the impacts of urban sprawl on agricultural lands and local demographic dynamics, offering important insights for both theory and practice. These results highlight the need for sustainable urban development and agricultural land management policies. Local authorities are encouraged to develop strategies that mitigate the negative effects of urban expansion and protect agricultural production areas.

Future research should be conducted across cities of different scales to broaden the applicability of findings. Utilizing more comprehensive socio-economic data, especially detailed information on economic transformations, will enable a better understanding of these processes. Investigating migration patterns both quantitatively and qualitatively at the neighborhood and village levels, and establishing their relationship with spatial urban sprawl, is critical to fully capture the socio-economic implications of urban growth.

Furthermore, developing recommendations for policymakers based on such studies will enhance their practical relevance. Strategies informed by scientific evidence should be formulated to preserve agricultural lands, promote sustainable urban growth, and improve spatial planning. Future research incorporating multidisciplinary approaches and field studies will further deepen the knowledge base, allowing for a more effective examination of the environmental, social, and economic dimensions of urban sprawl.

5. Conclusion

In this study, urban sprawl patterns and land use and land cover changes in the examined region between 1984 and 2024 were mapped and evaluated using satellite imagery and spatial analysis methods. The findings reveal that urban expansion has exerted significant pressure on natural and agricultural areas. In particular, the conversion of agricultural lands around the city into built-up areas has not only resulted in the physical loss of land but has also led to a transformation in rural lifestyles and triggered significant socio-economic changes at the local scale.

The examples discussed in the study show that urban sprawl is not limited to residential areas alone; public investments such as airports, hospitals, and ring roads have also accelerated this process. The spatial orientation of these investments has not only shaped the direction of urban growth but has also intensified the transformation of rural and natural areas into developed land, highlighting the critical role of infrastructure planning in sustainable land management. Additionally, it was found that the loss of forested areas was largely due to wildfires. The large-scale fires that occurred in the summer of 2023 have increased environmental risks due to the expansion of urbanization into natural areas. These findings underline that spatial sprawl threatens not only the built environment but also the ecological integrity of natural systems, a challenge increasingly observed in other medium-sized and coastal cities worldwide.

One of the main limitations of this study is the confusion between classes with similar spectral characteristics (such as fallow agricultural lands, built-up areas, and post-fire zones), which prevents a fully consistent representation of all aspects of land cover change. Nevertheless, the overall classification accuracy remained above 85%, ensuring that the identified trends and patterns are robust and reliable. From a policy perspective, the results highlight the need for stricter protection of agricultural lands, the strategic coordination of public investments with spatial plans, and the implementation of green infrastructure strategies to mitigate wildfire risk and protect ecological corridors. Future research is recommended to include comparative analyses of cities at different scales, the integration of broader socio-economic datasets, and the use of detailed micro-scale data to identify processes of economic transformation. Overall, the study contributes to understanding how rapid urbanization interacts with socio-economic change, providing insights that can support the development of more inclusive, resilient, and sustainable urban environments.

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Conflicts of Interest
The author(s) declare(s) no conflicts of interest.

Data availability statement
The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding author.

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Emre Özelkan: Conceptualization, Methodology, Investigation, Formal analysis, Writing – review & editing, Validation, Supervision, Project administration. Esra Eren: Conceptualization, Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing, Validation. All authors contributed equally to the study, reviewed and approved the final version of the manuscript.

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