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Urban Development Process and Land Use Change in Atakum District (Samsun, Türkiye) Using Remote Sensing Techniques

Uzaktan algılama teknikleri kullanarak Atakum ilçesinde (Samsun, Türkiye) kentsel gelişim süreci ve arazi kullanım değişimi

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Makale Bilgisi

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Atakum

Öz

Bu çalışmada Türkiye'nin Karadeniz kıyısında yer alan Atakum ilçesinde 23 yılda (2000-2023) nüfus artışına bağlı olarak meydana gelen kentsel gelişim ve bu süreçteki arazi kullanım değişimi incelenmiştir. İlçenin son 23 yıllık gelişimi incelenerek nüfus ve arazi kullanım projeksiyonunun oluşturulması amaçlanmıştır. Arazi kullanımındaki değişiklikleri tespit etmek amacıyla çalışmada 2000 yılına ait Landsat 7 ETM görüntüleri ile 2013 ve 2023 yılına ait Landsat 8 OLI/TIRS görüntüleri kullanılmıştır. Landsat görüntülerinden elde edilen sonuçlar, 2017-2023 yılları arasında Sentinel-2 uydu görüntüleri kullanılarak elde edilen arazi kullanım verileriyle karşılaştırılmıştır. Kentsel gelişim, arazi kullanımı ve nüfus projeksiyonu sonuçlarının haritalandırılması için Coğrafi Bilgi Sistemleri kullanılmıştır. Arazi kullanım projeksiyonuna göre 2033 yılına kadar ilçedeki orman alanlarının azalacağı, yerleşim alanlarının yaklaşık %3 oranında artacağı ve nüfusun yaklaşık iki katına çıkacağı öngörülmektedir. Sürdürülebilir kentsel gelişme ve arazi kullanımı için tarımsal verimliliği düşük olan plato alanları yerleşim yeri olarak tercih edilmeli, orman arazileri korunmalı ve verimli topraklar tarımsal üretimde kullanılmalıdır.

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Abstract

In this study, urban development and land use changes over 23 years (2000-2023) due to population growth in the Atakum district, located on the Black Sea coast of Türkiye, were examined. The aim was to create a population and land use projection through examining the development of the district in the last 23 years. To determine the changes in land use, Landsat 7 ETM images of 2000 and Landsat 8 OLI/TIRS images of 2013 and 2023 were used in the study. The results obtained from Landsat images were compared with the land use data obtained using Sentinel-2 satellite images, between 2017 and 2023. Geographic Information Systems were used to map urban development, land use, and population projection results. According to land use projections, forest areas in the district will decrease, residential areas will increase by approximately 3%, and the population will approximately double by 2033. For sustainable urban development and land use, plateau areas with low agricultural productivity should be preferred as settlement areas, forest lands should be protected, and fertile lands should be used in agricultural production.

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1. Introduction

Land use and management are among the most critical geographical issues today. In particular, the utilisation and management of the natural environment are crucial for sustainability (Huang et al., 2024; Taelman et al., 2016). In an era where the world's population has exceeded 8 billion, the use, planning, and balanced distribution of both productive and unproductive agricultural lands are vital for future generations. Alongside population growth, changing climate conditions, water scarcity, and erosional processes contribute to the shrinkage of natural land use areas. Rapidly growing cities not only lead to the expansion of artificial land use areas but also result in the inappropriate use of agricultural lands. Despite the fixed spatial dimension of the land of the world, the escalating population and its needs necessitate the utilisation of various methods to achieve maximum efficiency in agricultural activities.

Indeed, land use change studies employing different methods are conducted in various parts of the world . The rapid increase in the world's population, especially in the 20th century, has restricted the areas available for human use leading to the use of previously unused areas. At this point, various models are used to determine how to benefit from such areas, ensuring land productivity and sustainable use (Bahadır, 2013a; McNee, 1970). Some of these studies focus on changes in land cover, while others aim to test the accuracy of the method (Ayalke and Şişman, 2024). In fact, some studies address various topics, such as urban development, improper land use, appropriate site selection, and the relationship between climate change and land use (Bibi, 2022; Chen et al., 2015; Hara et al., 2005; Jiang et al., 2023; Randolph, 2003; Rashid et al., 2022; Rogan and Chen, 2004; Rwanga et al., 2017; Song and Deng, 2017; Turoğlu, 1998; Zhang et al., 2010). In many studies where spatial analyses are conducted for land use, it is common to detect improper land uses and present recommendations for addressing these issues. In recent studies, Geographic Information Systems (GIS) technologies have been widely utilised while ,since the 2010s, studies based on Remote Sensing (RS) techniques focusing on the temporal changes in land use have come to the forefront (Bağcı and Bahadır, 2019; Bahadır, 2013a; Göztepe et al., 2022; Hatipoğlu and Uzun, 2020; Kaçmaz and Döker, 2021; Özşahin and Eroğlu, 2018).

In such studies, the answer to the question 'How should it be in the future?' should be sought, rather than just assessing the current situation. When the planned watershed area adheres to economic functions, the regional boundary becomes crucial for existing interactions and holds significant value. The positive aspects of using one or more hydrological (physical), managerial (political), or societal (social) parameters in determining this value have been emphasised (Magrath and Doolette, 1990). In this context, Randolph (2003) has addressed the questions of "how to determine land use in a given area" and "how to benefit from Remote Sensing and Geographic Information Systems in this regard" in his work titled "Environmental Land Use Planning and Management?". He emphasises the importance of identifying and analysing the significance of each element in the natural environment, highlighting the need for individual planning for each element (Randolph, 2003). In today's land use studies, merely assessing the current situation is not sufficient. Identifying future land use issues and planning for their resolution are especially crucial (Chen and Wang, 2010; Coulter et al., 2016; Hiew et al., 2019; Huang and Ge, 2010; Islam et al., 2018; Liu et al., 2019).

The study area is part of Türkiye, characterized by rapid development and a continuously increasing population density (Şenol, 2020). Atakum district is established on three main morphological units: coastal plain areas where urbanisation has developed, sloping terrains, and plateau surfaces. The urban area and social structures currently occupy the productive coastal plain. The establishment of Ondokuz Mayıs University at the western end of the city in 1975 has contributed to increased investments in the district, making it a substantial attraction. Atakum, which was a small town in 1975, has experienced rapid population growth, particularly since the 2000s, increasing its population fourfold in 20 years (Şenol, 2020). The rapidly expanding urban area has developed its infrastructure, transportation network and social areas. However, the expansion has consistently been towards Class I agricultural lands. In light of these reasons, the study focuses on the relationship between urban development and land use in Atakum, a district of Samsun province located in the Black Sea Region of Türkiye (Fig. 1). In this context, the temporal and spatial changes in land use in Atakum district have been identified, and land use modeling, projection, and planning for the future have been conducted.

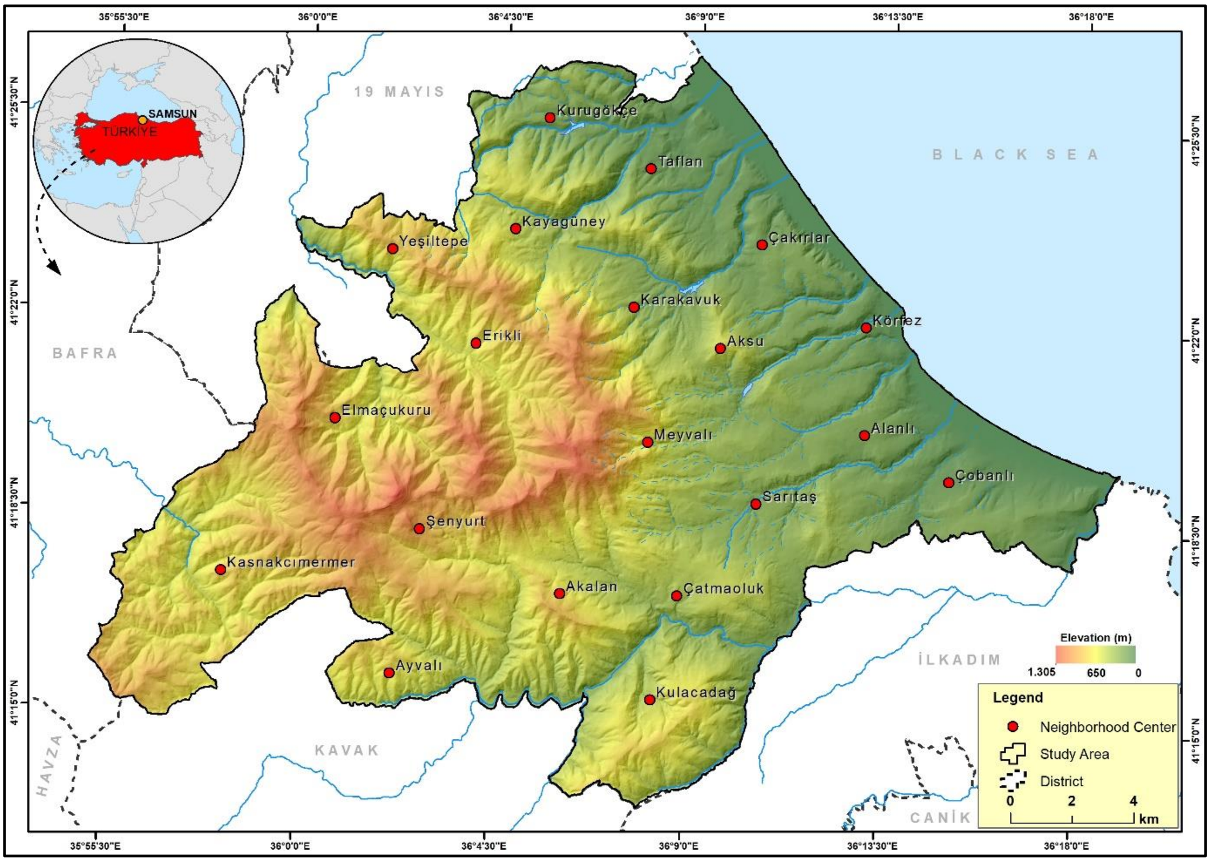


Figure 1. Location map of the study area.

2. Method

The data sources in the study were from public institutions and organisations. Climate data for the study were sourced from the Turkish State Meteorological Service (MGM), population data from the Turkish Statistical Institute (TÜİK), raster data from the General Directorate of Maps (HGM), and soil data from the Ministry of Agriculture and Forestry's digital datasets. Satellite images were acquired from open-access addresses (https://earthexplorer.usgs.gov/).

Within the scope of the study, fieldwork was conducted by the project team at regular intervals for two years. Fieldwork was carried out at different times of the year (May, August, October) to examine changes related to seasonal variations. Drone images were captured in the field, providing visuals of urban areas, social facilities, and natural land use areas.

Field-specific maps were produced using GIS techniques. In particular, the ArcGIS for Desktop Advanced program was used for analysis. Both ArcGIS for Desktop Advanced and the ENVI program were used for Remote Sensing techniques. A supervised classification technique was employed in the analysis of satellite images (Fig. 2). Supervised classification operates on the same logic as unsupervised classification. In this method, the determination of which classes the image will be divided into or the desired classes from the image is predetermined. Selecting control areas for the predefined classes from the image is necessary.. Field verification may be necessary for this selection. In this study, ground truthing was performed at 60 different points in the field to check the accuracy of location and land use. This was done to ensure more reliable and accurate analyses.

The selection of control areas is a stage that influences the accuracy of classification. In practice, a commonly encountered issue is class overlap. One of the reasons for class overlap is errors in measuring control areas. The supervised classification method yields more positive results compared to the unsupervised because it uses a training dataset. Therefore, supervised classification is the most preferred method (Kavzoğlu and Çölkesen, 2010). In the supervised classification method, a sufficient number of sample regions (test areas), defining surface features in the study area, are used to create feature files containing spectral characteristics for each object to be classified. By applying the feature files sampled from the control areas to the image data, each image element (pixel) is assigned to the class to which it is most similar based on the calculated probability values. In this classification process, three approaches are used: parallel faces, nearest distance, and highest likelihood classification methods (Oruç, 2003). When all these processes are performed, the accuracy of the analysis, reliability of the map, and soundness of the results are confirmed. In this study, the calculated kappa value varied each year, but the average kappa value was 0.9270 with an accuracy of 97%. A kappa coefficient above 80% indicates that the classification is accurate and reliable (Güney and Polat, 2015).

Currently, various methods are employed to monitor both urban and land use changes, with Remote Sensing (RS) and Geographic Information Systems (GIS) techniques being commonly utilised (Döker and Gül, 2019). RS and GIS techniques involve the analysis of satellite images from different years to reveal spatial and temporal changes in a specific location. By examining satellite images from different years, it is possible to determine land use changes in a city, its growth potential, and the direction and rates of development. When spatial changes are considered along with geographical factors that influence the city's development, their identification becomes instrumental in guiding future planning efforts (Döker and Gül, 2019).

In this study, three different time points, namely 2000, 2013, and 2023, were selected for the Atakum district of Samsun province, and satellite images from these years were utilised. The land use changes in Atakum city among the years 2000, 2013, and 2023 were analysed, and land use models for the subsequent years and the expected land use were developed. Landsat 7 ETM and Landsat 8 OLI/TIRS satellite images were chosen for this study due to their free availability and sufficient technical specifications. These images were downloaded from the website provided by the United States Geological Survey (USGS): https://earthexplorer.usgs.gov. Sentinel-2 satellite images obtained from https://dataspace.copernicus.eu/ were also used to analyze 2023 land cover and use changes in more detail and more precisely. The main factor influencing the selection of this time range (2000–2023) in the study is the substantial demographic and anthropogenic changes that Atakum city has undergone in this period.

Images from Landsat 7 ETM and Landsat 8 OLI/TIRS were used (Table 1). Images for each of the three periods were used to cover the entire study area, and those with cloud cover were replaced or atmospherically corrected. Therefore, when selecting satellite images, attention was paid to choosing the summer period when the sky is clearest. The Landsat 7 ETM and the Landsat 8 OLI/TIRS satellite images, used to illustrate the land changes in Atakum city, have different bands and sensors with a spatial resolution ranging from 15 to 100 meters. Both satellite sensors operate in the near-infrared (NIR), shortwave infrared (SIR), and thermal infrared (TIR) spectra. The Landsat 7 ETM satellite image from June 13, 2000, was used as the initial period to illustrate land use in the city of Atakum. Landsat 8 OLI/TIRS images from June 25, 2013, to July 23, 2023, were chosen to show the changes in land use . The spatial resolution of the satellite images used is 30 meters. To reveal land use changes in different years, the shortwave infrared and red bands, which provide the best results for urban studies, were used for band combination. The obtained satellite images with a spatial resolution of 30 meters were orthorectified to ensure accurate spatial positioning. After different band combinations in satellite images were provided, the supervised classification method was used to determine the land use status of Atakum district for three different years, and create a prediction model for the subsequent years. In addition, Sentinel-2 satellite imagery was used to analyze land cover, and use changes for 2023 in a more detailed and precise manner. Sentinel-2 is a high-resolution optical imaging satellite system developed by the European Space Agency (ESA) under the Copernicus Program. Thanks to the collaboration, of Sentinel-2A (2015) and Sentinel-2B (2016) satellites, data can be obtained from the same region with a 5-day revisit cycle. The satellite provides imagery in 13 spectral bands, covering the near-infrared (NIR) and shortwave infrared (SWIR) regions. The spatial resolution varies according to the bands: 10 m (Bands 2, 3, 4, and 8), 20 m (Bands 5, 6, 7, 8A, 11, and 12), and 60 m (Bands 1, 9, and 10). The Sentinel-2 images used in this study were selected from atmospherically corrected Level-2A products. Thanks to its high spectral resolution, the sensor provided high accuracy in identifying vegetation, agricultural areas, and water surfaces, thereby enhancing classification accuracy when used with Landsat 8 OLI/TIRS images. Thus, urban development and land use changes for 2023 were evaluated more reliably.

Table 1. List of image data set used in the study.

Satellite sensor	Temporal coverage	Spectral bands	Spatial resolution	Radiometric Resolution (bits)	Daily image shooting
Landsat 7 ETM	2000, June 13	VNIR, SWIR, TIR	30 MS, 15 PAN	8	250
Landsat 8 OLI/TIRS	2013, June 25 2023, July 23	VNIR, SWIR, TIR	100 T, 30 MS, 15 PAN	12	400
Sentinel-2A/B	2015, June 2016, July	NIR, SWIR	10/20/60 MS	12	290

MS: Multispectral PAN: Panchromatic, T: Thermal

The study focuses on revealing the changes in residential areas in the Atakum district and making predictions for the future. However, another aspect of the study is to identify changes in land use. Therefore, land use classes include wetlands, forests, agriculture, residential areas, and bare land.

The general image classification and change prediction for the study are illustrated in **Fig. 2**. This diagram encompasses the acquisition, the processing, classification of satellite images, and the production of land use change maps, future prediction models, and expected land use model maps, along with the comparison of results. The landuse change map is generated by comparing Landsat 7 ETM, and Landsat 8 OLI/TIRS satellite images.

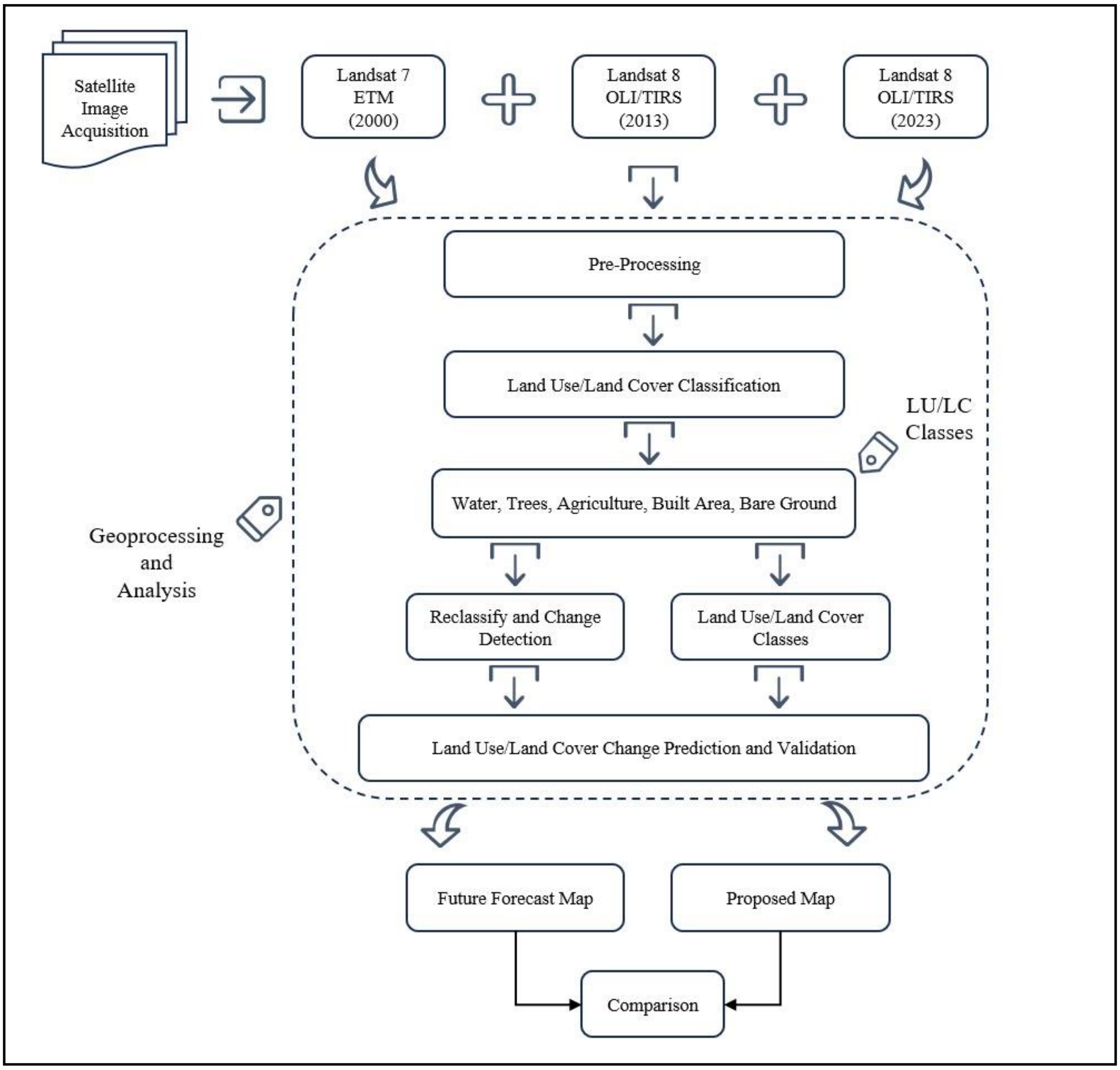


Figure 2. Method and workflow diagram of the study.

3. Findings

3.1. General Geographic Features of the Study Area and Land Use Relationship

When the basic geological features of the Atakum district and its surrounding areas are examined, the majority of the area is composed of Eocene-aged volcano-sedimentary rocks. However, the coastal plain, where urban areas are densely located, is formed by alluvium. These areas exhibit characteristics of Class I agricultural land. Moreover, they are highly susceptible to earthquakes. Nevertheless, the expansion urban areas has always been towards agricultural lands and coastal plains, which are highly sensitive areas in terms of natural hazards, have become urban development areas.

Coastal plains are areas with low slope, high agricultural yield, and fertile soils. In these areas, agricultural production has been replaced by residential areas (Figure 3a). Despite urban development being limited due to the rugged topography and higher infrastructure costs, slope sections still serve as agricultural production areas. Plateau areas are more resistant in terms of soil; they are used as dry farming land. The higher elevations are covered with forests. These areas, which have higher earthquake resistance compared to coastal alluvial soils, have not yet been developed (Figure 3). The shift of settlements to these areas is of critical importance for future land-use planning.

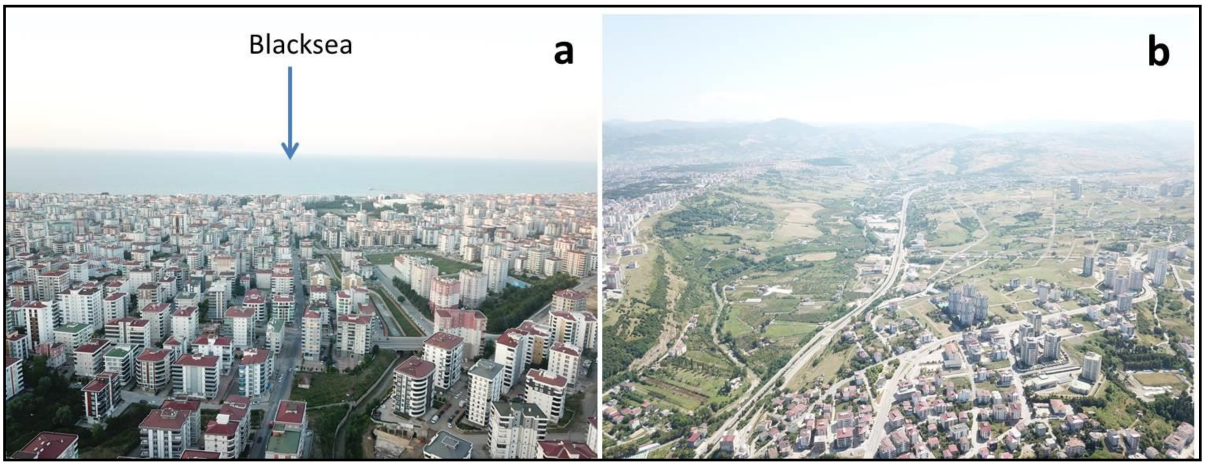


Figure 3: a) The part of the Atakum campus built on the coastal plain. Multi-storey buildings are constructed on alluvial soil. b) Plateau areas. These areas are composed of volcanic-sedimentary soils and are durable.

When examining the climatic characteristics of the region, the region exhibits a climate type with hot and humid summers and mild winters with occasional snowfall. The region does not exhibit a typical Black Sea climate (Bahadır, 2013b; Bahadır, 2014; Bayraktar and Efe, 2022). The annual total precipitation is 718 mm, and the annual average temperature is 14.5°C. The scarcity and irregularity of precipitation are significantly different from the Black Sea climate. Additionally, short-term droughts during the summer season pose a significant challenge for agricultural production. Therefore, dry farming predominates in plateau areas.

The district is home to numerous small streams of various sizes. These streams are intermittent streams and can cause severe flooding with sudden rainfall. The settlement areas located in the coastal plain, especially, are within the impact zone of waters overflowing from the streams originating from the slopes. Therefore, almost every year, one or more floods occur in the Atakum district. These floods result in loss of life and property (Bahadır, 2014). In addition, in many places, rivers that have been channelled and have flood prevention barriers have been transformed into green areas, parks, and walkways for public use (Fig. 4). However, the presence of residences right at the edge of rivers, in flood-prone areas, serves as an example of improper land use despite these precautions.

Figure 4. A flood protection barrier constructed over the river in Yenimahalle, one of the most populous neighbourhoods in Atakum, to safeguard against flooding. Residences are observed right at the edge of the stream.

In the research area, the predominant soil type is brown forest soil, constituting 81.38% (81.38%) of the total (Fig. 6). These soils have mature profiles and exhibit enhanced permeability. They are widespread in the slope and plateau areas of the study site, supporting dry farming and forest cover. However, the areas where these soils are prevalent generally have high slope gradients, leading to an increased amount of surface runoff. Consequently, erosional processes are effective in places with improper land use. Slightly shallower but generally similar soils, known as gray-brown podzolic soils, also have a substantial distribution (15.65%) in the area. These soils are mainly used for cereal farming. In the higher southern regions, forest cover is the primary land use type. Coastal plains, on the other hand, feature alluvial soils (Fig. 6). Although alluvial soils are highly fertile, they have been occupied by settlements (Fig. 5). The multi-storey buildings constructed in these areas pose risks in terms of natural disasters.

Figure 5. Settlement areas established on the coastal plain in Atakum district. The buildings are multi-storey, and begin right from the shoreline.

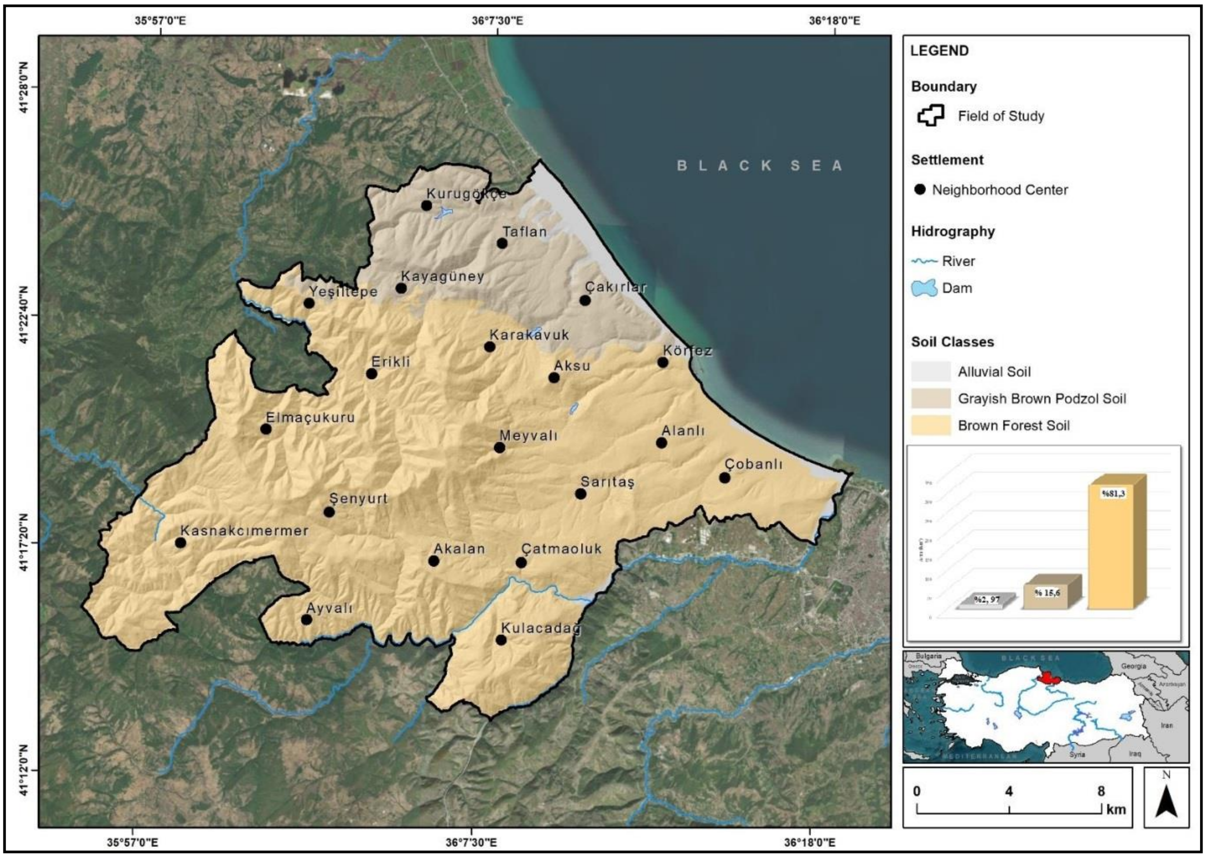


Figure 6. Soil map and spatial distributions of Atakum district.

Approximately 65% of the land in Atakum district is classified as having VI and VII class land capability. These correspond to the rugged areas of slopes and plateaus. The areas suitable for agriculture are located in the coastal plain, accounting for approximately 10% of the total area (Fig. 8). However, these areas have been occupied by settlements, and agricultural production has ceased. These impermeable surfaces prevent water from seeping and lead to direct surface runoff. As part of flood control efforts, streams have been channelized, but due to the high flood protection walls, surface runoff cannot reach the stream bed in some places. Moreover, the walls of the tram line, which cuts across the city from end to end and is perpendicular to the slope, serve as a barrier preventing the flow of water to the sea. During rainy periods, accumulated water on the tram line causes flooding and disruptions in transportation. All these efforts are necessary for the social development and infrastructure of the city. However, incorrect land practices and unplanned construction lead to improper land use.

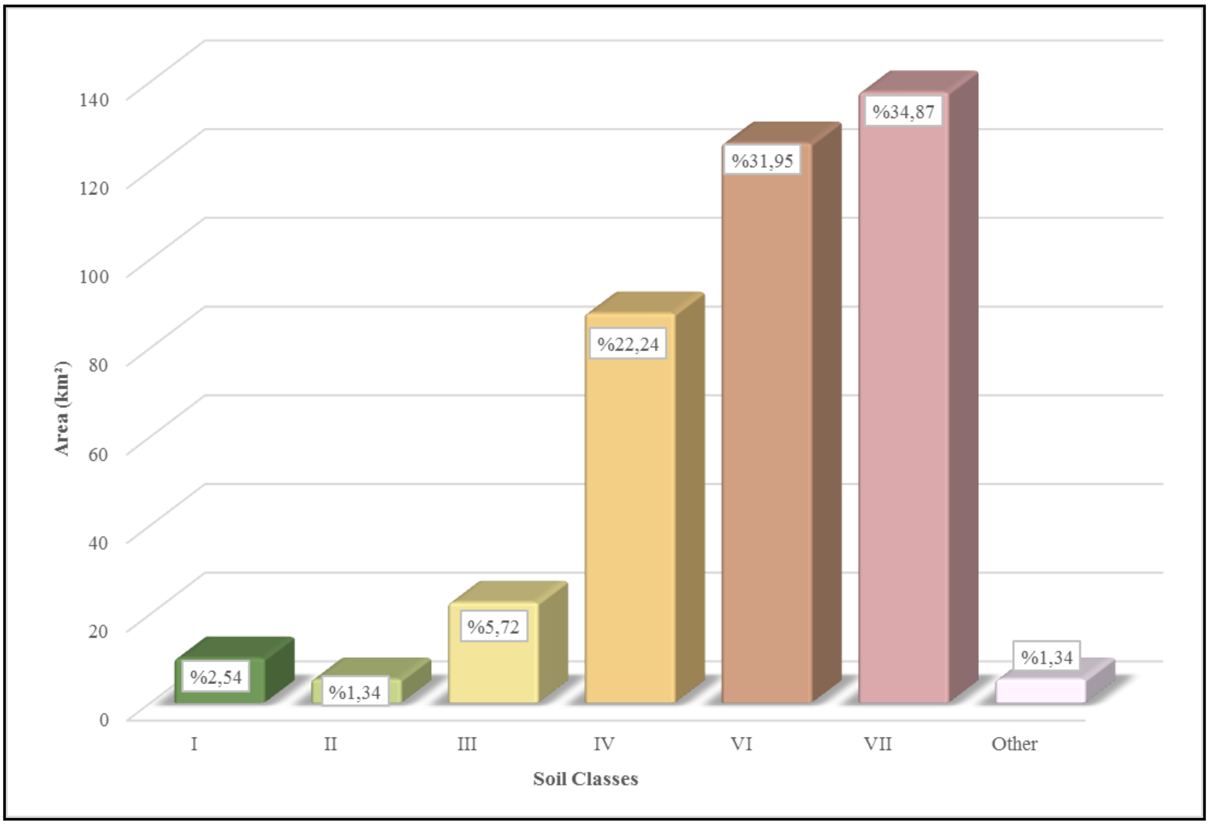


Figure 7. Agricultural suitability status of the soils in Atakum district.

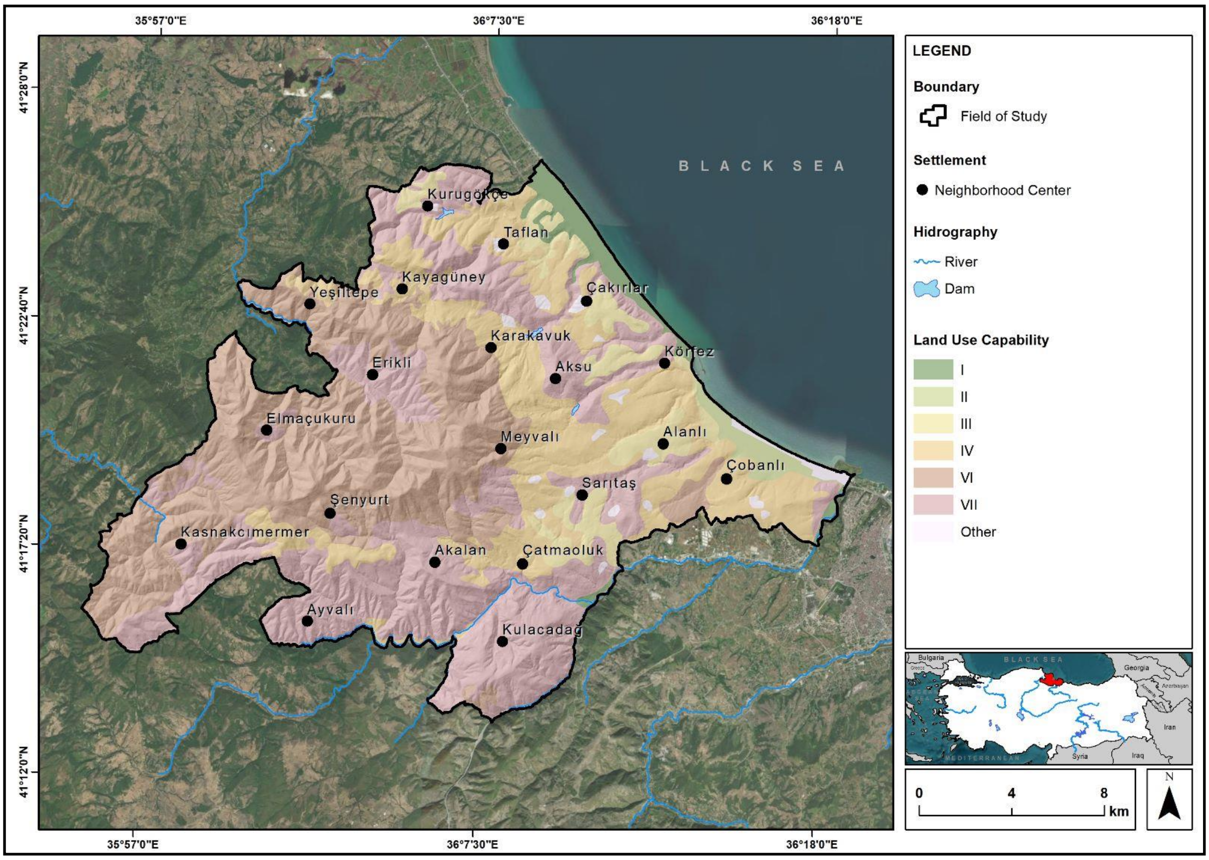


Figure 8. Soil capability status of Atakum district.

3.2 Temporal and Spatial Changes in Land Use in Atakum District

Urban development and land use changes in the study area from 2000 to 2023 have been investigated. Landsat 7 ETM and 8 OLI/TIRS images were used to assess land use changes. For the year 2023, Sentinel-2 satellite images were also analysed alongside Landsat OLI/TIRS, to establish a correlation between the two satellites and to identify potential differences in the 2023 urban development. Within the scope of the study's analysis, five different land use classes (water, trees, agriculture, built area, and bare ground) were identified from satellite images.

When the land use in the study area for the year 2000 is examined, approximately 58% of the total area is covered by agriculture, 35% by forest, and about 5% by residential areas (Fig. 9, Fig. 12). The remaining approximately 2% of the area consists of bare rocky areas, coastal zones, and water surfaces. The most notable characteristic of this period, as evident from the land use status, is its rural appearance. Residential areas are situated mainly along roadsides (Fig. 12).

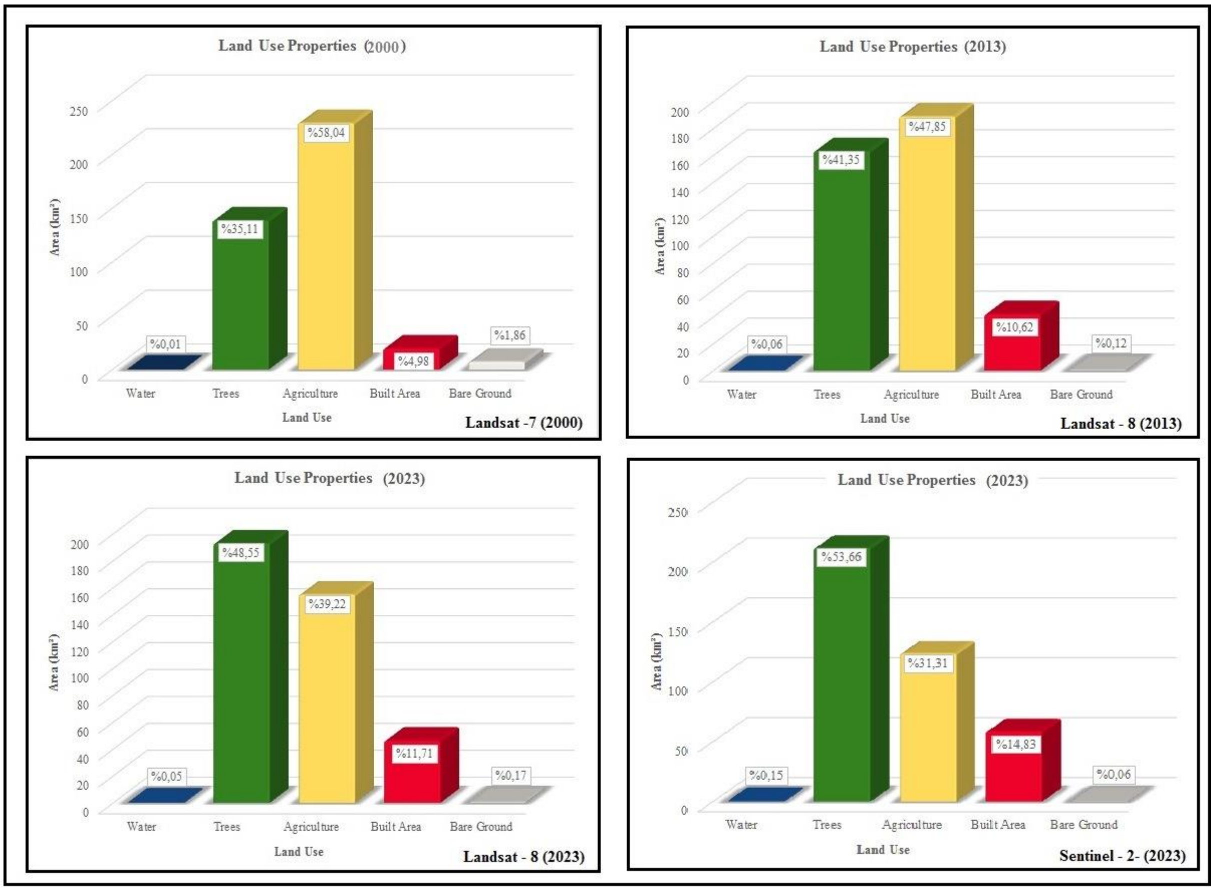


Figure 9. Changes in land use in Atakum district in different periods.

In the 2013 land use situation, significant changes are observed. While forest areas increased, agricultural lands, with a loss of about 10%, covered approximately 48% of the total area (Fig. 9; Fig. 12). The decrease in agricultural lands resulted in an increase in forest and residential areas. Residential areas doubled from 5% to 10% of the total area. This situation indicates that the district is rapidly developing and expanding as an urban area. The population of the district, which was 73,846 in the year 2000, increased to 149,226 in 2013. The population doubled, social facilities increased, roads expanded, and construction activities intensified. However, this rapidly developing urban area has taken on an irregular appearance due to improper planning. Particularly, in the urban area, buildings of 4, 6, 8, and 10 stories have been constructed on the same street. A 10-storey building has risen in front of a 4-storey building, blocking the sea views of residential buildings (Fig. 10).

Figure 10. Multi-storey residences built on the ridges in the southern part of Atakum district. These areas are highly susceptible to landslides, and such events occasionally occur.

By 2023, forest areas have once again increased, covering 48% of the total area. Agricultural areas have decreased again, shrinking to 31% (Figure 9; 12c). While the population grew during this period, settlements continued to develop on the alluvial ground close to the coast. The ratio of residential areas to the total area of the district has reached 12%. In this period, not only buildings with horizontal architecture but also those with 20-30 floors have been constructed, due to the enacted zoning laws. Thus, urban areas have expanded both horizontally and vertically (Figure 11).

Figure 11. Atakum city has developed both horizontally along the coastline and vertically due to the decrease in available land. However, horizontal expansion negatively affects agricultural lands, while vertical growth poses serious challenges, especially in the face of natural disasters such as earthquakes and landslides.

In the 2023 land use analysis conducted using Sentinel-2 satellite imagery, at a 10 m spatial resolution, forest areas have increased further (53%), while agricultural areas have decreased to a lesser extent (31%). Settlement areas, on the other hand, appear to constitute a greater proportion of the total area when analyzed using Landsat 8 OLI/TIRS imagery, amounting to approximately 15% (Fig. 9, Fig. 12, Fig. 13). Undoubtedly, this discrepancy is related to the resolution of the satellite images.

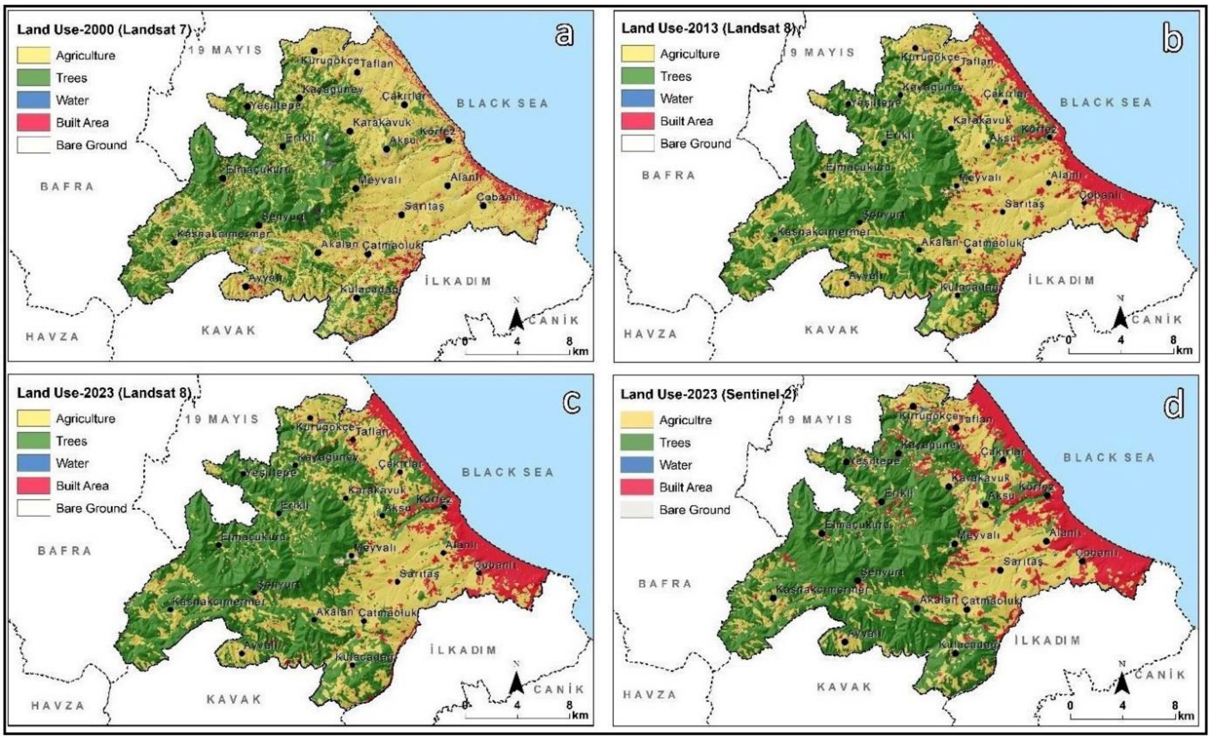


Figure 12. Changes in the spatial distribution of land use in different periods in the Atakum district.

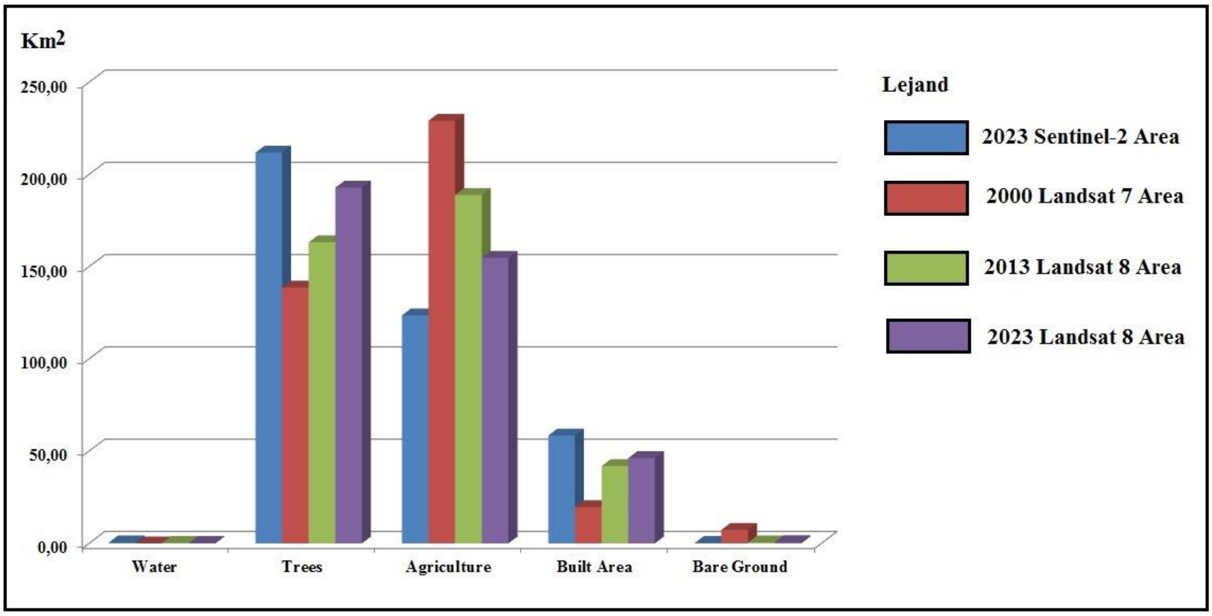
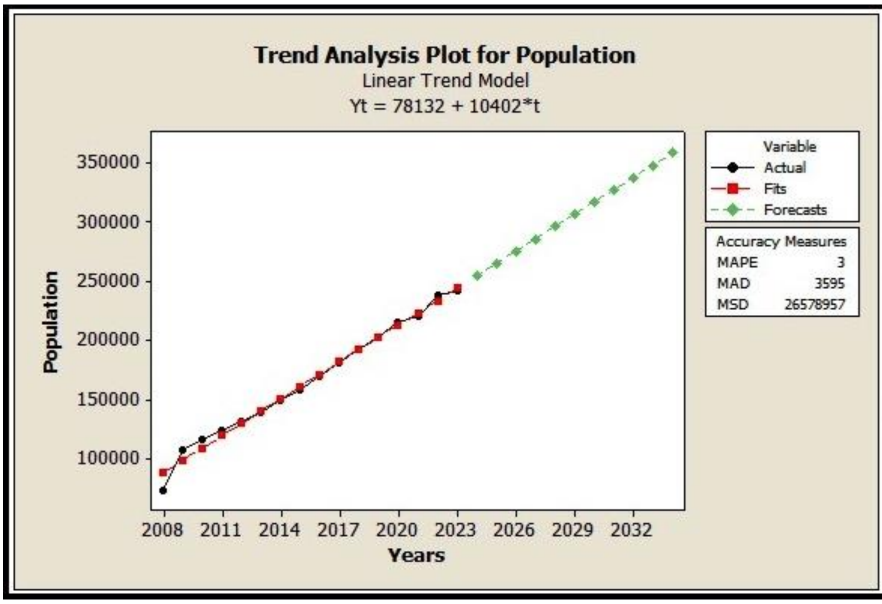


Figure 13. Comparative temporal changes in land use classes.

3.3. Projection of Land Use Status in the Next 10 Years in the Atakum District.

The land use estimation for the Atakum district was examined in conjunction with population growth projections. The range of land use change and population projection intervals was kept the same, and the estimates were made up to 2033. According to the trend analysis, conducted by excluding extraordinary situations for the existing population growth in the district, an increase of approximately

100,000 people is predicted over a 10-year period (Fig. 14). The population, which was 73,846 in the year 2000, increased to 123,904 in 2010, just ten years later. The population of Atakum increased by 15,826 people in just two years. The population, which was 139,730 in 2012, reached 242,171 in 2022. For the estimated year 2033, the population of Atakum district is projected to be 358,992. The district has a structure where investments are made; education, health, and service sectors are rapidly developing; and tourism activities are increasing. All these factors indicate that settlements will continue to grow rapidly in the future. When the population growth in the estimation period was correlated with the population growth figures in the census period, it was found that the population growth had doubled over the past ten years. This is estimated to be around 100,000 currently.



Years Period	Forecast
2023	254970
2024	265372
2025	275774
2026	286177
2027	296579
2028	306981
2029	317383
2030	327785
2031	338188
2032	348590
2033	358992

Figure 14. Population projection for the next 10 years in the Atakum district.

When looking at the spatial distribution of the population in the Atakum district, it is observed to be concentrated in coastal areas. Particularly, 80% of the population lives in settlement areas established on the coastal plain (Fig. 15). The development of the urban area along the coast was influenced by factors such as public investments in these areas, geomorphological conditions that do not pose any difficulties for construction, and the desire to be close to the sea.

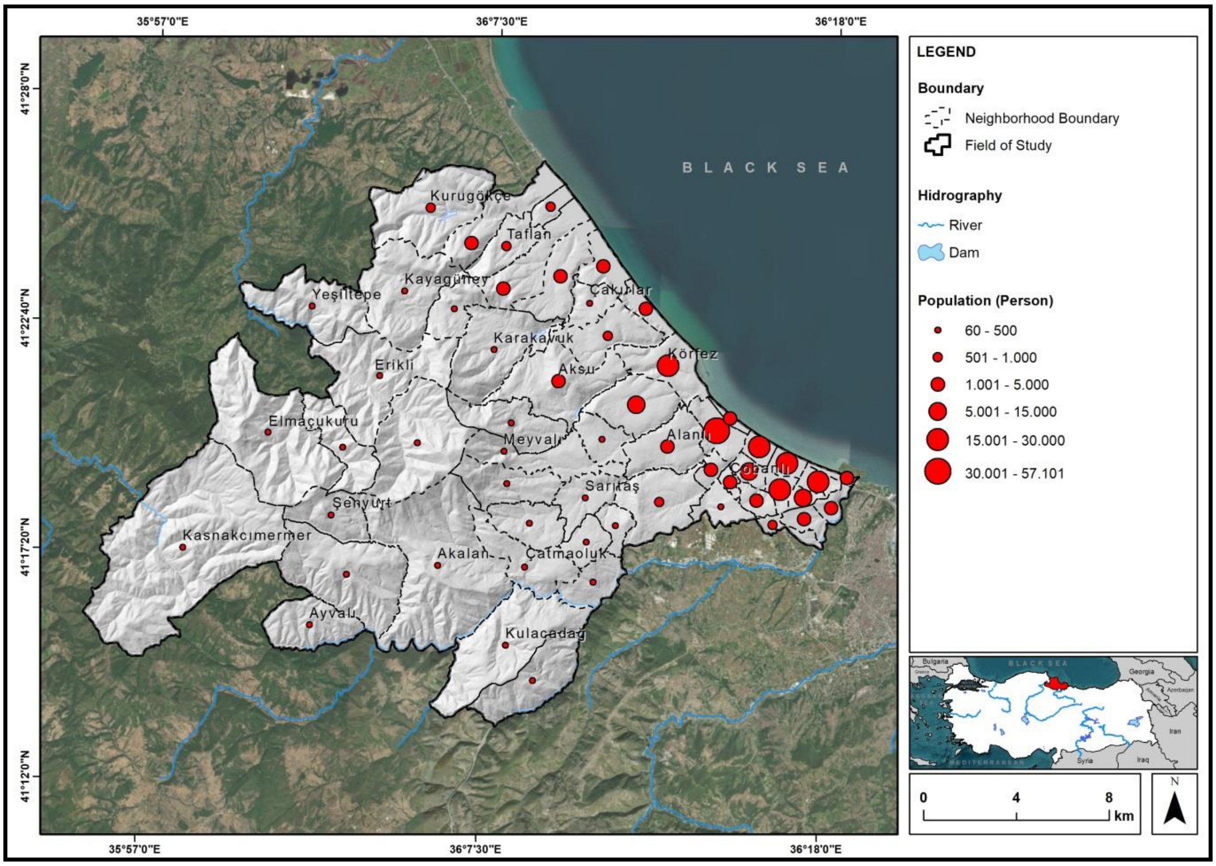


Figure 15. Population distribution by neighbourhoods in the Atakum district. The areas with high population density and concentration are first-class agricultural lands, and the coastal plain. In contrast, the population is low in plateau areas and slopes.

When examining the land use projection for the study area, it is anticipated that urban areas will continue to grow rapidly, shifting towards the sloping hills in the south, while river valleys and slopes will be occupied by settlements. The projections suggest that settlements will completely cover the coastal plains, and green areas within the city, excluding forested areas, will be very limited (Fig. 16). In this context, proper land use planning should designate plateau areas, which are more resilient in terms of soil characteristics and have lower agricultural productivity, as new settlement areas. Establishing main roads perpendicular to the coastline in these areas will facilitate drainage and reduce infrastructure costs due to the direction of the slope. Moreover, it will contribute to the discharge of floodwaters from the slopes into the sea efficiently. Effective land use planning may make it possible to leave future generations with cities that are well-integrated, rich in green spaces, resilient natural hazards, and liveable as a legacy, fostering happiness.

In particular, the future land-use planning for the region has been examined with a 10-year land use projection (Figure 17). When the current growth rate of the city population continues and the development direction of current investments is examined, it can be predicted that residential areas will again be concentrated in the coastal area and its vicinity. It is vital that multi-storey buildings constructed vertically have a solid foundation. Therefore, it is suggested that residential areas be relocated towards eroded surfaces consisting of lithological agglomerates. (Fig. 17). River valleys and existing forested areas along their edges should be preserved to serve as breathing spaces for the urban area. The mapping indicates that in the future, agricultural areas will continue to decrease, forest areas will partially decrease, and in contrast, urban areas will continue to rapidly increase. Proper and sustainable land use requires land planning studies implemented by local authorities.

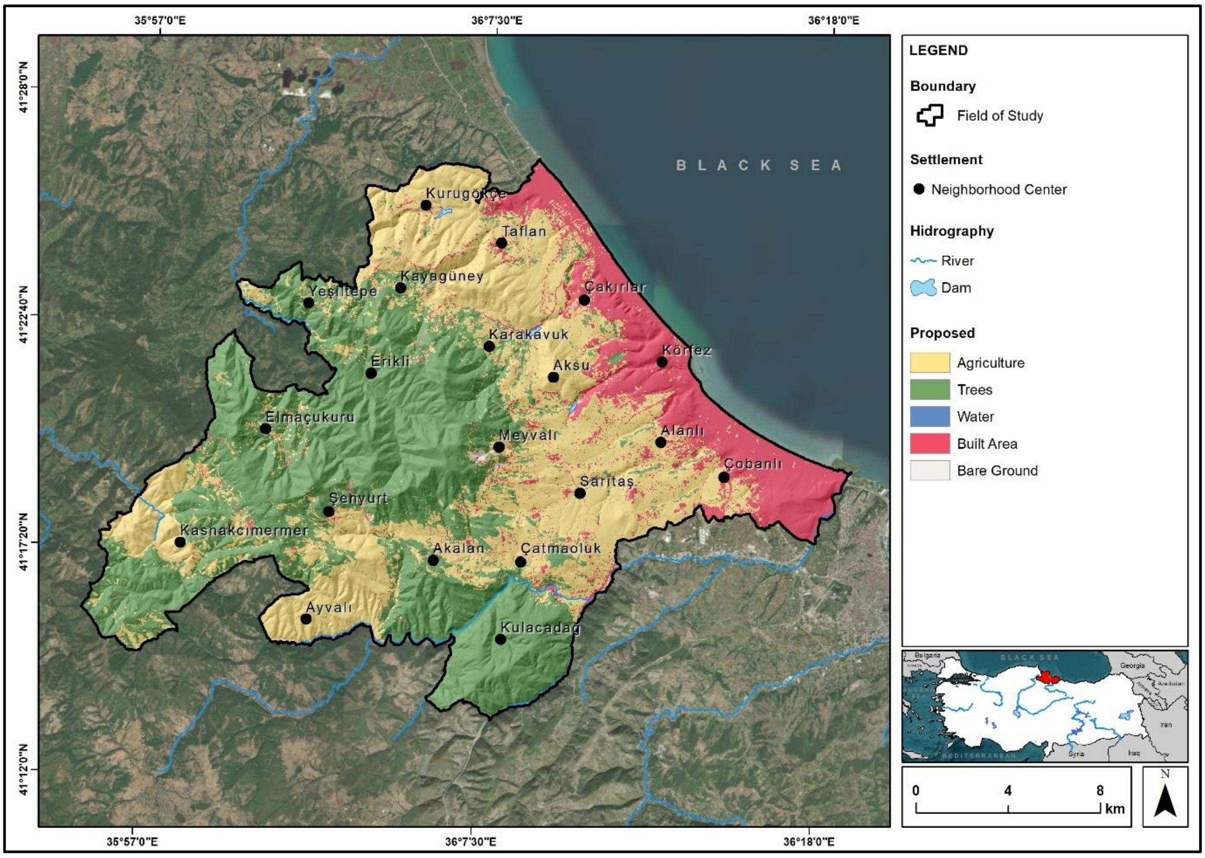


Figure 16. Potential land use situation in Atakum district in 2033.

The modeling process is based on classified land use data from Landsat 7 ETM, Landsat 8 OLI/TIRS, and Sentinel-2 images from 2000, 2010, and 2023. The Cellular Automata-Markov (CA-Markov) based spatial modeling method was applied to temporally analyze land use change trends and predict the future situation. The CA-Markov model calculates the probabilities of each land use class transforming into other classes based on the transformations observed in previous years (Wu et al., 2019). Using these probabilities, a transition probability matrix was created, and using the CA-Markov algorithm, spatial dynamics were added. In the modeling process, geographical factors such as spatial contiguity and slope were also analyzed to determine the possible expansion directions of settlements. The model's accuracy was tested by comparing the projection for the 2000-2023 period with the actual 2023 data. The kappa coefficient obtained in this comparison was 0.9270, and the overall accuracy rate was 97%. In addition, to assess the statistical reliability of the model outputs, prediction confidence intervals were calculated for each land use class at a 95% confidence level (Table 4). These confidence intervals indicate a 95% probability that the area value predicted by the model for a particular class is within this range. The land use amounts predicted by the model for the year 2033 are given with a margin of error of ±5%, and it is considered highly probable that they will remain within these limits. In this context, a gradual decrease of land use is projected, especially in agricultural and forest areas, while horizontal and vertical growth in built-up areas is expected to continue. For proper land use planning, these projections guide local governments in their sustainable urbanization policies. This approach shows that land use projections are numerical estimates supported by a certain degree of uncertainty and statistical confidence.

Table 2. Land use projections for 2033 and confidence intervals.

Land Use Class	Area (km^2)	%	Confidence interval (km^2)	Description
Water	0,09	0,02	0,0855-0,0945	Very low rate
Trees	175,84	44,55	167,05-184,63	Declining trend
Agriculture	159,80	40,48	151,81-167,79	Declining trend
Built area	58,69	14,87	55,75-61,62	Upward trend
Bare ground	0,31	0,08	0,2945-0,3255	Relatively stable

To evaluate the model's accuracy, the projection created using 2000, 2013, and 2023 data was compared with the 2023 classified land use map. As a result of this comparison, an error matrix (confusion matrix) was created, and the classification success was evaluated with the following accuracy criteria (Table 3).

Table 3. Error matrix.

Actual/Estimated	Water	Trees	Agriculture	Built area	Bare ground	Total (Actual)
Water	156	1	1	1	1	160
Trees	1	154	2	1	2	160
Agriculture	1	2	154	1	2	160
Built area	2	1	1	154	2	160
Bare ground	1	2	2	1	154	160
Total (Estimate)	162	159	159	160	160	800

The accuracy rate indicates the performance of the classification process in all classes. It is calculated as the ratio of correctly classified pixels to the total number of pixels (Ben-David, 2008). The overall accuracy rate of 97% obtained in this study shows that the model produces highly reliable results. Such a high accuracy, especially in complex areas where the boundaries between different land use classes are clear, increases the effectiveness of the model and its usability in decision support processes.

Table 4. Accuracy rates obtained from the error matrix.

Land use class	Producer's accuracy (%)	User's accuracy (%)
Water	97,50	96,27
Trees	96,25	96,25
Agriculture	96,25	96,25
Built area	96,25	97,47
Bare ground	96,25	95,65
Overall accuracy (%)	97,00	

A ground truthing process was conducted to test the model's accuracy. In this process, Sentinel-2 images of 2023 and high-resolution Google Earth images were evaluated together, and a total of 800 control points were selected, distributed evenly to represent each class. A random sampling method was used for point selection. This ensured a fair and representative comparison for all classes. Each selected control point was classified based on visual interpretation and land cover characteristics, and then compared with the model output. The error matrix and the above accuracy measures were calculated based on the data obtained from these comparisons.

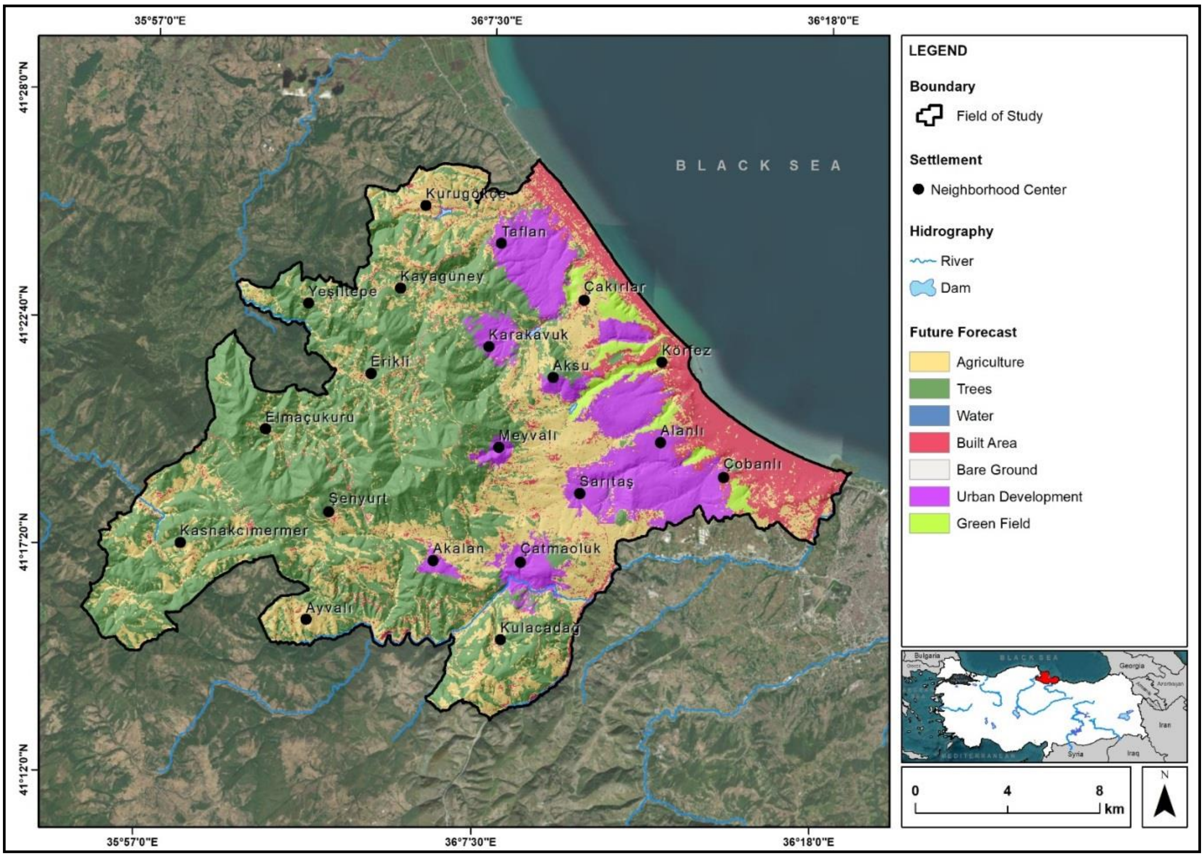


Figure 17. Land use planning proposal for Atakum district in 2033.

Linear trend analysis, one of the statistical prediction models, has been used to calculate the changes in land cover in Atakum district over 10 years. According to this analysis, a 4% decrease in forest areas is predicted compared to the year 2023. Agricultural lands are expected to remain almost the same, while settlement areas are estimated to increase by approximately 3%. This increase is calculated only horizontally. No significant changes are anticipated in other land use types (Fig. 18). However, using different criteria (soil properties, green areas, river valleys, landslide areas, plains and landfill areas), changes have been calculated based on a 10-year land use plan created through a weighted overlay method. With proper planning, land use management can be implemented, allowing for healthy urbanisation and sustainable land management. According to the land use planning map and analyses prepared for Atakum, it is concluded that, by 2033, settlement areas are expected to shift towards plateau areas. This will reduce the risk of natural disasters and alleviate pressure on the coastal plain. In this scenario, the development of new urban areas with 2 to 3-storey detached houses, abundant green spaces, and seismic-resistant structures on suitable grounds will contribute to the formation of a planned urban model. Moreover, it is estimated that the spatial expansion of urban areas will be twice as large as previously anticipated (Fig. 18). However, when the inclined plateau areas with low agricultural yield are opened for settlement, the pressure on land use in the coastal plain, will decrease, and these areas will be primarily allocated for agricultural production. Such small settlement models already exist in Atakum district, forming the most attractive living spaces and focal points of the city.

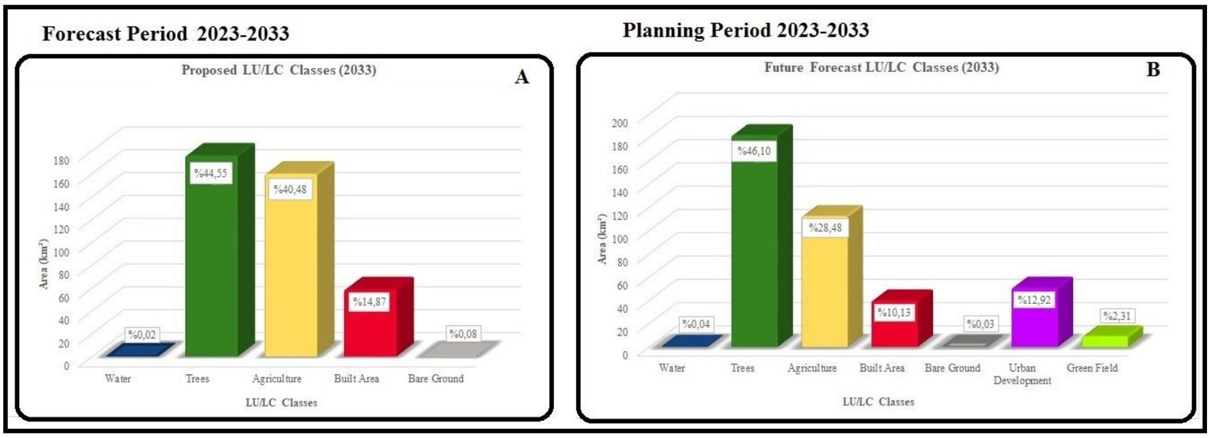


Figure 18. Land use prediction modelling for Atakum district. A) Changes in land use during the prediction period. B) Changes according to the sustainable land use model with planning.

4. Discussion and Conclusion

This study addresses the relationship between land use and urban development in Atakum. Atakum is the fastest growing and most populous district of Samsun, which is the northern province with the highest population in Türkiye's Black Sea Region. In the study, various models have been employed the 20-year period of land use changes and the 10-year projected period have been examined. As a result of the analyses, it is observed that the population of the district has increased rapidly from 2000 to 2023. This situation is related to the migration to the district. The establishment of the campus of Ondokuz Mayıs University, one of the country's prominent universities located in the western part of Türkiye, has significantly attracted people to this district. This has led to rapid urbanisation in the district since the 2000s. The population in the district, which was 73,846 2000, reached 123,904 2010, just 10 years later. The population of Atakum increased by 15,826 people in just two years. The population, which was 139,730 in 2012, reached 242,171 people in 2022. The projected population for the year 2033 in Atakum district is 358,992. This indicates that settlements in the district will continue to grow rapidly.

When considering changes in land use, five land use classes have been identified. These main land use types consist of forests, agriculture, and settlement areas. Water surfaces and bare lands are very limited. When the land use in the study area is examined for the year 2000, approximately 58% of the total area is covered by agriculture, 35% by forests, and about 5% by settlement areas. The remaining approximately 2% of the area consists of bare rocky areas, coastal sections, and water surfaces. Significant changes in the land use situation were observed in 2013. While forest areas increased by 41%, agricultural lands experienced a loss of approximately 10%, with agricultural lands now covering

48% of the total area. The decrease in agricultural lands resulted in an increase in both forested and settlement areas. Settlement areas doubled over a specific period, covering 10% of the total area.

By the year 2023, forest areas have once again increased, covering 48% of the total area. Agricultural lands have decreased again, reaching 31% of the total land area. Settlement areas continue to grow, constituting approximately 12% of the total area.

Images from two different satellites were used to create the land use maps for 2023. When the images were compared, differences were detected in the land use rates produced from the satellite images. This is related to the different resolutions of the satellites. The resulting situation allowed the comparison of satellite images. It was determined that Sentinel-2 images were more sensitive for detecting wooded or forested areas and residential areas, whereas Landsat-8 images had higher accuracy for detecting agricultural areas.

Researchers have stated that seismicity must be taken into consideration when making land use plans in areas where earthquake risk is high due to their proximity to fault lines (Sandıkçıoğlu et al., 2024). Atakum district is also an area under earthquake threat due to its proximity to fault lines and soil characteristics. The majority of the population in Atakum district lives in the coastal neighbourhoods. The neighbourhoods in this area are extremely vulnerable in terms of soil stability, earthquake sensitivity, and risk, being classified as first-degree hazardous zones (Bahadır et al., 2024). Approximately 40 km south of the district, the North Anatolian Fault (NAF), Türkiye's largest and most active fault, passes through the region (Ketin, 1969). Large earthquakes occasionally occur on the NAF. Indeed, one of these earthquakes, the 7.2 Mw magnitude earthquake that occurred in Ladik in 1943, substantially affected the area, causing severe damage to the city centre of Samsun (Arslan, 2020). At that time, the population in the city of Samsun was 73,400 people, and buildings were two to three stories high. Today, the presence of buildings with 10-20 stories, the risk of liquefaction, and the lack of energy release in this segment of the fault for about 80 years pose a serious risk. The extent to which the district will be affected, the level of impact, and damage and loss of life in a potential earthquake disaster depend entirely on land use. Proper use that is appropriate for the land use will reduce both human and property losses.

When considering the necessary steps for a more planned and implementable land use in the district over the next 10 years, it is important to ensure strategic planning. According to the land use planning map and analyses prepared for Atakum, the conclusion is that in 2033, residential areas should shift towards plateau areas. This will reduce the risk of natural disasters and alleviate the pressure on the coastal plain. In this scenario, new urban areas should be directed towards locations with suitable ground structure and earthquake-resistant characteristics, featuring 2-3 story detached houses with ample green spaces, allowing for the development of a well-planned urban model. With accurate planning, land use management can be implemented for sustainability and healthy urban development. When planning land use, a holistic approach is essential, involving local authorities and the community. The local population should take ownership of the situation, and urban planning regulations must be adhered to when constructing buildings. All stakeholders should fulfill their responsibilities for the future.

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