Turkish Journal of Agricultural and Natural Sciences 13 (3): 537–551, 2026

https://doi.org/10.30910/turkjans.1917221

TÜRK TARIM ve DOĞA BİLİMLERİ DERGİSİ

TTDB

TURKISH JOURNAL of AGRICULTURAL and NATURAL SCIENCES

www.dergipark.gov.tr/turkjans

Original Article

Determination of the Impact of Land Consolidation on Crop Production Through Satellite Images and NDVI Index

Ömer Faruk Karaca[1]✉, Tuba Albayrak[2]

[1]Department of Biosystems Engineering, Faculty of Engineering- Architecture, Yozgat Bozok University, Yozgat, TÜRKİYE

[2]Department of Agricultural Economics, Faculty of Agriculture, Yozgat Bozok University, Yozgat, TÜRKİYE

[1]http://orcid.org/0000-0002-6302-9738, [2]http://orcid.org/0000-0002-3745-8352

ABSTRACT

The most important issue in terms of protecting the potential of soil and water resources is to determine the current situation and identifying the urgent measures that can be taken for sustainability. This study aims to determine the existing parcel status before (2017) and after (2019-2025) parcel change with the help of satellite images in and around Arifeoğlu Village of Yerköy District of Yozgat Province, where land consolidation studies were completed in 2018. Simultaneously, a survey study was conducted to examine the knowledge and skill levels of the farmers regarding the consolidation process and its results. In 2017, before consolidation, the area covered by stressed plants was higher than that covered by healthy plants. In 2019, consolidation led to an increase in the area covered by healthy plants and a decrease in the area covered by stressed ones. Compared with the previous period, the highest increase occurred in the stressed plant group in 2024 (25.423%) and in the healthy plant group in 2019 (103.592%). The stressed plant group, which indicates that there is no green plant activity, reached its lowest value in 2019 (33.616%) immediately after the consolidation.

Keywords: Land fragmentation, remote sensing, sustainable agriculture, topography, vegetation indices

Uydu Görüntüleri ve NDVI İndeksi Kullanılarak Arazi Toplulaştırmanın Bitkisel Üretim Üzerindeki Etkisinin Belirlenmesi

ÖZ

Toprak ve su kaynaklarının potansiyelini koruma açısından en önemli konu, mevcut durumu belirlemek ve sürdürülebilirlik için acilen alınabilecek önlemleri tespit etmektir. Bu çalışma, 2018 yılında arazi toplulaştırma çalışmaları tamamlanan Yozgat ili Yerköy ilçesi Arifeoğlu köyü ve çevresinde, parsel değişikliğinden önceki (2017) ve sonraki (2019-2025) mevcut parsel durumunu uydu görüntüleri yardımıyla belirlemeyi amaçlamaktadır. Eş zamanlı olarak, çiftçilerin toplulaştırma süreci ve sonuçlarına ilişkin bilgi ve beceri düzeylerini incelemek için bir anket çalışması yapılmıştır. 2017 yılında, toplulaştırmadan önce, stres altındaki bitkilerin kapladığı alan, sağlıklı bitkilerin kapladığı alandan daha fazlaydı. 2019 yılında ise toplulaştırma, sağlıklı bitkilerin kapladığı alanın artmasına ve stres altındaki bitkilerin kapladığı alanın azalmasına yol açmıştır. Önceki döneme kıyasla, en yüksek artış 2024 yılında stres altındaki bitki grubunda (%25.423) ve 2019 yılında sağlıklı bitki grubunda (%103.592) meydana geldi. Yeşil bitki aktivitesinin olmadığı anlamına gelen stres altındaki bitki grubu, toplulaştırmanın hemen ardından 2019 yılında en düşük değerine (%33.616) ulaşmıştır.

Anahtar kelimeler: Arazi parçalanması, bitki örtüsü indeksleri, sürdürülebilir tarım, topografya, uzaktan algılama

INTRODUCTION

Approximately 854 million people, or 14% of the global population, experience chronic malnutrition and hunger, with nearly 50% of this group linked to smallholder farming households and landless rural communities facing production and development inefficiencies (FAO, 2018; Jiang & Shao, 2011; Swaminathan, 2014; Yurui et

al., 2019). It is crucial to urgently address the sustainable management of limited resources and the scarcity of appropriate areas for human habitation.

Land is a finite resource whose loss and degradation are irreversible within a human lifetime. Effective management of agricultural practices concerning water, soil, forests, and wildlife is crucial for achieving sustainable rural development (Gatzweiler et al., 2002; FAO, 2025). Consolidation ensures the continuity of social and cultural life, and living conditions are improved. In addition, it can effectively guarantee the protection of agricultural land and food safety, as well as improve environmental protection and the management of arable land productivity. In addition, thanks to the reorganized rural areas, agricultural lands will be easier to cultivate, their use will be maximized, and the incomes of people engaged in agriculture will increase (Köken & Çay, 2019).

For all these reasons, to use the land properly, the temporal change in land use should be revealed, plans should be made with the results obtained, and a management approach should be adopted accordingly. In this context, geographic information systems (GIS) and remote sensing (RS) systems provide great convenience to researchers (Turan et al., 2021). Combining satellite images obtained with the help of RS with the analysis and interpretation power of GIS is preferred as an easy and reliable method to examine changes in land cover and land use. With the use of GIS technology, data can be stored in a digital environment, its updating is facilitated, and it is possible to develop a standard by creating models with existing data (Duran & Doğan, 2022; Fadhıl, 2022).

Numerous domestic and international studies on land consolidation and remote sensing have been conducted. Akkaya Aslan (2018), in her fragmentation analysis using Januszewski (JI) and Simmons indices (SI) in the land consolidation project of Pınarlar Village in Denizli-Tavas Province, determined that the percentage of farms with a value less than 0.40 before consolidation was 25.5% and 67.90%, respectively, while after consolidation these percentages were 1.08% and 21.20%, respectively. Başayiğit et al. (2016) analyzed the changes in parcel boundaries and land use between 1974 and 2014 in the Isparta Harmanören consolidation area. Their study revealed an increase in the number of parcels to 524, despite a reduction in average parcel size from 13684.10 m² to 6813.68 m², highlighting hidden fragmentation over approximately 40 years. In the Sulucakaçar neighborhood LC project in the Şanlıurfa Bozova district, RS and GIS techniques were used to assess land use changes before and after consolidation. Using Google Earth and Sentinel 2 images digitized with ArcGIS, land use maps were created and area calculations were done. The study found a decrease in rocky and wheat areas and an increase in cotton, corn, and barley areas post-consolidation (Özgültekin, 2019).

Many studies on consolidation include similar evaluations, due diligence, economic benefits, and before-and-after status reports. However, relatively few survey studies have been conducted with farmers, and even fewer have examined changes in product patterns. Therefore, it is believed that the original value of present study is also higher.

In this regard, the aim of this study is to determine the parcel product status before (2017) and the parcel product diversity change after (2019, 2025) the land consolidation works were completed in 2018 in Arifeoğlu Village and its surroundings in the Yerköy District of Yozgat Province, with the help of satellite images. In satellite images, images with dates between 01-15 April and low cloudiness ratios were preferred. Simultaneously, a survey study was conducted to examine the knowledge and skill levels of the farmers regarding the consolidation process and its results. The survey examines how LC practices affected the number of parcels, the sizes of the parcels, and the values that the producers assign to them. In addition, an effort was made to determine producers' perceptions and levels of satisfaction regarding land consolidation application.

MATERIALS AND METHODS

The consolidation project is a large study covering a total of six districts (Çiçekdağı, Merkez, Sorgun, Şefaatli, Yenifakılı, and Yerköy) and 43 villages. Initially, it was aimed to be completed in February 2015, but it was finally completed in September 2018 with the addition of time. The districts and villages where the project was carried out are listed in Table 1. Fig. 1 shows the land status after consolidation of the Arifeoğlu village and its surroundings.

The study area primarily features xerosols, specifically calcic xerosols, which possess a calcic horizon at 125 cm depth and lack an argillic B horizon above it. Additionally, luvic xerosols contain an argillic B horizon with a calcic or gypsum horizon below it. These soils dominate Central Asia's vast desert steppes and its outer desert regions, where agricultural activities are largely confined to river valleys due to limited water availability (FAO/UNESCO, 2025).

Sentinel-2 is a satellite designed to support Copernicus services, equipped with multi-spectral imaging technology for monitoring land, ocean, and the atmosphere. It delivers high-resolution optical images useful for land monitoring, emergency response, and security. The satellite features a multispectral imager with 12 spectral

bands, including visible, near-infrared, and shortwave infrared, covering latitudes from 56°S to 84°N. Applications include land cover mapping, land change detection, vegetation monitoring, and assessment of burned areas.

Table 1. Districts and villages where the consolidation project is located

	Project Districts					
No	Çiçekdağı	Merkez	Sorgun	Şefaatli	Yenifakılı	Yerköy
1	Köseli	Özlüce	Gedikhasanlı	Kızılyar	Eskiören	Yamuklar
2	Haydarlı	Sarınınören		Koç	Zafer	Karacaahmetli
3	Küçükteflek	Battal		İbrahimhacılı	Yazlak	Kumluca
4	Tatbekirli	Esenli		İnceşehir	Yenifakılı	Göçerli
5	Büyükteflek	Bayatören		Hasanpaşa	Altındağ	Arifeoğlu
6	Safalı	Gelingüllü		Paşaköy	Başağa	Kömüşören
7	Tepecik			Hallaçlı	Fehimli	Buruncuk
8				Saçlı	Cankurtaran	
9				Yenicami	Camikebir	
10				Armağan	Bektaşlı	
11					Yenicami	
12					Mehmet Akif	



Figure 1. Land parcel status after consolidation in the Arifeoğlu Village sub-project (2018)

Satellite images with dates between 2018-04-01 and 2018-04-15 and a low cloudiness ratio were preferred. Because the LC was completed on September 24, 2018, Sentinel-2 L2A satellite images from 2017 (pre-project) and between 2019 and beween 2020-2025 (project) were used. Resolution values range between 10 and 60 m. Each satellite image obtained consists of nine separate bands. The general features of the satellite images are presented in Table 2 (Sentinelhub, 2025).

Table 2. Properties of Satellite Images

Year	2017	2019	2020	2021	2022	2023	2024	2025
	2017/05/10	2019/04/30	2020/04/28	2021/04/28	2022/04/23	2023/04/18	2024/04/22	2025/05/24
Data Supply	2025/07/22	2025/07/22	2025/07/22	2025/07/22	2025/07/22	2025/07/22	2025/07/22	2025/07/22
Cloud Ratio	1.09%	11.73%	1.09%	1.09%	1.09%	1.09%	1.09%	1.09%
Resolution	10 - 60 m	10 - 60 m	10 - 60 m	10 - 60 m	10 - 60 m	10 - 60 m	10 - 60 m	10 - 60 m
Total Number of Bands	9	9	9	9	9	9	9	9

In the Arifeoğlu Village of the Yerköy District, the sample size of the study was determined to be 137 producers registered in the farmer registration system of the Provincial Directorate of Agriculture and Forestry. Various statistical methods were used in the analysis of the questionnaires with the JAMOVI 2.7.28 Package Program, an open source code analysis program.

A simple random sampling method for a finite universe was used to calculate the sample size. The formula used is as follow in Equation 1:

$$\boldsymbol{n = \frac{N.p.q.t^2}{d^2.(N-1)+t^2.p.q}} \quad \textbf{(}1\text{)}$$

Where;
N: Universe (Number of farmers registered in ÇKS-2025)
n: Sample
p: The frequency of the characteristic we are interested in within the universe,
q: The frequency of not seeing the feature we are interested in within the universe,
t = Standard value according to the confidence level (1.645 for 90% confidence interval) and
d = Represents the tolerable margin of error (0.10).

In this population, the sample size was determined as 46 at 10% error and 90% confidence limits, and the studies were completed by conducting surveys with 52 producers that could be reached. In addition, farmers' satisfaction levels were revealed using percentage frequency tables. The filling of the questionnaire forms was started on 2025-04-11 and completed on 2025-04-28. By reaching out to 52 producers whose land was consolidated in the region, we attempted to determine their opinions on the subject. The aim was to obtain the most accurate data in line with the answers provided by the producers.

The Wilcoxon Rank Test, a non-parametric comparison tool, was used to assess differences in data before and after LC, determining whether a significant difference exists between two data sets without assuming a specific data distribution.

In this study, ArcGIS 10.x software was used for image preprocessing and classification. The satellite image was subjected to geographic-geometric correction in ArcGIS software according to the Universal Transverse Mercator (UTM) projection coordinate and WGS84 North Zone 35 system, and the nearest neighbour, which had the least error, was used as the sampling method. After geometric correction, the boundaries of the study area were arranged to include the boundary of the study area.

There are many surface interpolation methods in GIS raster data analysis, such as the Thiessen polygon (nearest neighbour, NN), local average (fixed radius), inverse distance weighting (IDW), kriging, and spline. Each method has its own advantages and disadvantages, and it has not been proven that one method is the best method. In this study, the IDW method in the Interpolation subheading of the Geostatistical Analyst tab was used to create point density maps (Bolstad, 2005).

Digital elevation model (DEM) data with a resolution of 1 arc second (30 m) according to the WGS84 coordinate system were obtained from the ASTER DEM address. Slope and aspect maps of the land were created from the DEM map with the spatial analysis>surface auxiliary tool in ArcGIS 10.8 software. By overlapping these maps with the points where the analysis was performed, we attempted to determine the changes or effects depending on the altitude, slope, and aspect degree.

The base shape (.shp) maps determining the provincial borders to be used in the study were obtained from the General Directorate of Mapping. All data used in the study were converted to the WGS84-UTM-Zone-35 datum projection system and then used in the analyses. All produced raster and vector maps were saved in databases in the form of folders (HGM, 2025).

Land use and land cover data were obtained from the data produced within the scope of Sentinelhub (2025).

The large soil groups map was obtained by extracting the province of Yozgat from the world soil classification map created by (FAO/UNESCO, 2025).

NDVI analysis results are used in studies such as monitoring drought with the help of various bands of satellite images, estimating agricultural productivity, determining whether plants are sick, or determining the destruction of vegetation in fire zones. A healthy plant absorbs visible light and reflects a large portion of near-infrared light. In addition, an unhealthy plant reflects more visible rays and fewer near-infrared rays. The formula used for NDVI calculation is shown in Equation 2 (Rouse Jr et al., 1974; Karaca, 2025). The obtained NDVI values were arranged into 4 classes according to the class ranges shown in Table 3, as suggested by Auravant (2026).

$$NDVI = \frac{(NIR-RED)}{(NIR+RED)} = \frac{(B8-B4)}{(B8+B4)} \quad (2)$$

In the equation;

NIR: Near infrared band value (band=4 for Landsat 4-7, band=5 for Landsat 8-9)

RED: Red band value (band=3 for Landsat 4-7, (band=4 for Landsat 8-9)

Table 3. NDVI class ranges (Auravant, 2026)

Class Range	Description
-1-0	Dead Plants or Inanimate Objects
0-0.33	Diseased Plants
0.33-0.66	Moderately Healthy Plants
0.66-1	Very Healthy Plants

RESULTS AND DISCUSSION

Results

Surveys

The aspect of LC that satisfies the producers the most is the consolidation of fragmented lands, with a rate of 94%. The answer to the consolidation of fragmented lands is followed by a 75% rate of decrease in expenses, a 69% rate of separation from shareholders, a 60% rate of increase in land value, and a 50% rate of infrastructure services performed with LC. The Wilcoxon rank test showed that $P<0.05$, indicating a significant difference (decrease) in the number of parcels after LC compared to the number of parcels before LC.

While 55.8% of the participants in the survey believe that there was an increase in yield after the LC application, 30.8% were undecided on this issue. The percentage of those who do not agree that there was an increase in yield after LC is 13.5%. Additionally, 46% of the farmers stated that land consolidation works and procedures took a very long time. Overall, 76.90% of the producers are satisfied with the LC activities. Notably, reductions in the number of parcels at a rate of 71.39%, increases in land value at 57%, and the benefits of easier transportation and fuel savings are viewed as satisfactory by the producers.

DEM Maps

The DEM map of the study area is shown in Fig. 2, and the area it covers on the map and the percentage values are shown in Table 4. It has been determined that the area has an altitude varying between 716 m and 828 m. When Table 4 is examined, it is determined that a large part of the area, such as 63.10%, has values varying between 0-750 m. In terms of slope, approximately 60% of the area varies between 1-5°. Regions with a slope of 0-5 cover 92.07% of the total area.

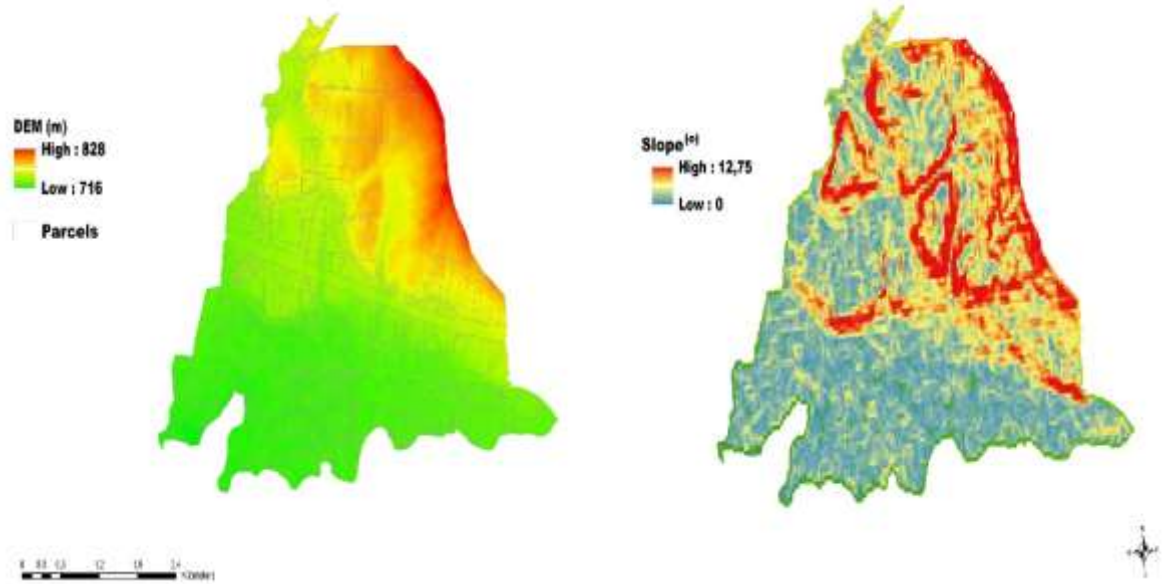


Figure 2. Study area DEM and slope maps

Table 4. Study area and percentages covered by DEM and slope map

DEM (m)			Slope (°)		
Range	Percent	Area (m^2)	Range	Percent	Area (m^2)
0-750 m	63.10	10253678.35	0-1	32.48	5277478.45
750-800 m	34.09	5540238.84	1-5	59.59	9684459.78
800-828 m	2.79	453714.68	5-10	7.70	1251967.04
			10-12.75	0.25	40154.73

Aspect Maps

The aspect map of the study area is shown in Fig. 3, and the area and percentage values covered by the aspect map are shown in Table 5. In terms of aspect, it has been determined that the south (23.33%) is in the first place and the southwest (24.14%) directions are in the second place in the project area. Southern directions cover 56.91% of the total area, while northern directions cover 20.25%. From this, it has been determined that a large part of the area consists of lands with a southern direction tendency.

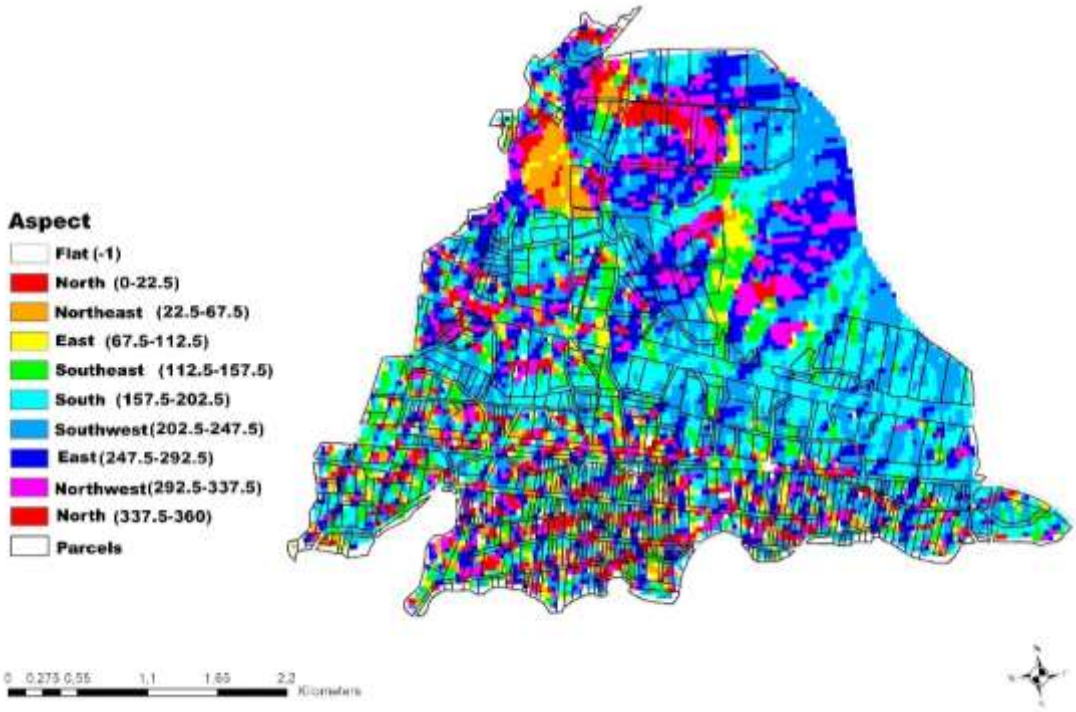


Figure 3. Aspect map of the study area

Table 5. Aspect map area and percentages

Description	Percentage	Area (m^2)
Flat (-1)	2.96	481503.23
North (0-22.5)	2.04	331033.47
Northeast (22.5-67.5)	5.25	852661.97
East (67.5-112.5)	4.88	792474.07
Southeast (112.5-157.5)	9.44	1534791.55
South (157.5-202.5)	23.33	3791837.94
Southwest (202.5-247.5)	24.14	3922245.06
West (247.5-292.5)	15.00	2437610.10
Northwest (292.5-337.5)	10.00	1625073.40
North (337.5-360)	2.96	481503.23

Land Cover Land Usage Maps

The land cover-land use map of the study area, obtained within the scope of the project, is shown in Fig. 4, and the area and percentage values covered by the map are shown in Table 6. According to the results of Table 6, it has been determined that the study area consists of mixed agricultural lands (53.25%) in the first place and non-irrigated arable lands (32.61%) in the second place. Agricultural areas with natural vegetation, plant change areas and sparse vegetation areas consist of places with less than 1% area (Sentinelhub, 2025).

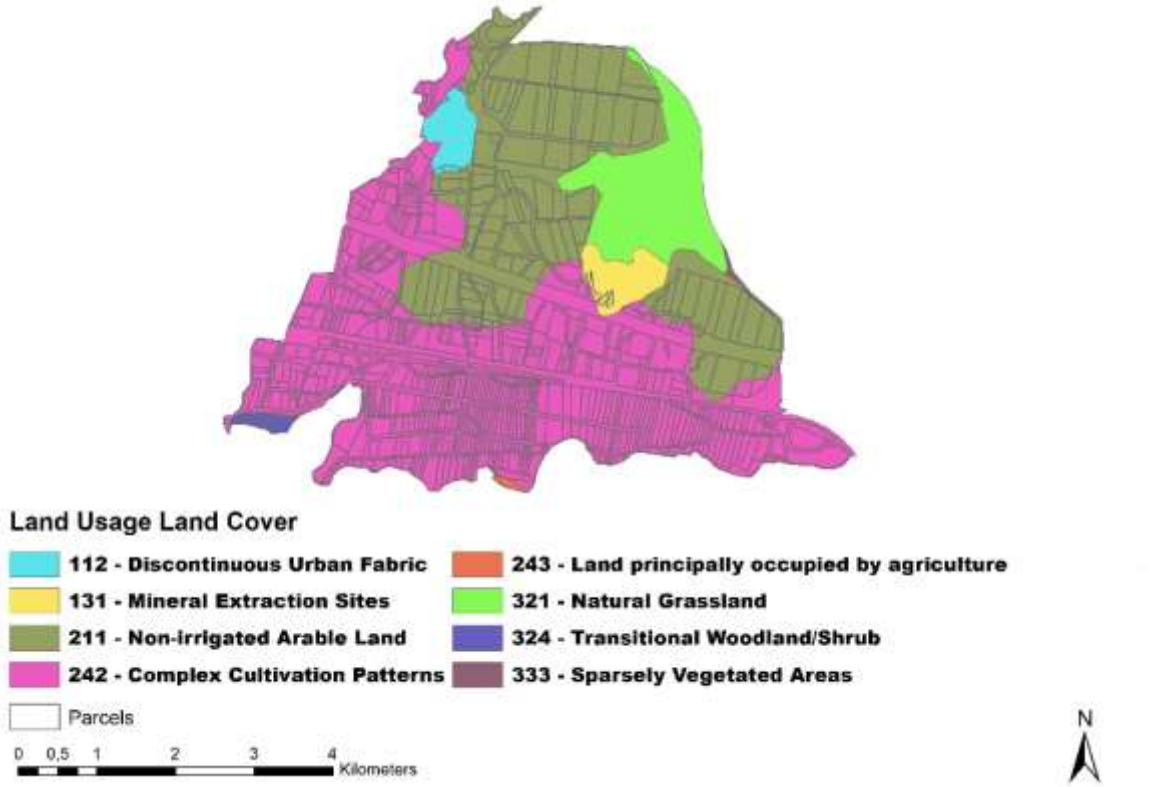


Figure 4. Land cover land use map of the study area

Table 6. Area and percentages of land cover in the land use map

No	Corine Code	Description	Area (m^2)	Area (ha)	Percent
1	112	Discontinuous urban fabric	303354.12	30.34	1.86
2	131	Mineral extraction sites	369626.82	36.96	2.26
3	211	Non-irrigated arable land	5328844.65	532.88	32.61
4	242	Mixed farming areas	8701143.38	870.11	53.25
5	243	Agricultural areas with natural vegetation	22519.01	2.25	0.14
6	321	Natural grassland	1496962.01	149.70	9.16
7	324	Areas of vegetation change	1699.33	0.17	0.01
8	333	Sparse vegetation areas	26584.69	2.66	0.16

NDVI Maps

Different NDVI results for each year derived from the Sentinel-2 L2A satellite using the NDVI formula in Equation 2 are shown in Table 7, and density maps are shown in Fig. 5. When the percentage values in Table 7 are carefully examined, it has been determined that the amount of stressed vegetation is approximately 3 times more than healthy vegetation in 2017, when consolidation has not yet started. In contrast, in 2019, in the post-consolidation period, the amount of stressed vegetation showed a decreasing trend of 33.616%. The value of healthy plants doubled and covered approximately 50% of the total area. This situation revealed that consolidation had a positive effect. However, due to the extreme drought seen in 2020-2021, the effect of consolidation began to disappear. 2021 was the year with the most extreme events, with 1024 extreme weather events recorded. In the same report, when looking at monthly temperature differences, it was stated that the temperatures of all months except March, September and October were above normal. As a result of this situation, it has been determined that the level of stressed vegetation is higher than the level of healthy vegetation every year, especially between 2020-2024. In contrast, starting from 2025, the level of healthy vegetation began to be determined more than the level of stressed vegetation, in contrast to previous years. Similarly, when looking at the rates of change compared with the previous year, it has been determined that the levels of stressed vegetation are gradually decreasing, while the levels of healthy vegetation are gradually increasing.

Table 7. Area percentages of density maps for 2017 and 2019-2025

Year	Range	Percentage	Area (m^2)	Area (ha)	Change (ha)
2017	Stressed plant	75.50	12337411.46	1233.74	-
	Healthy plant	24.50	4003530.87	400.35	-
2019	Stressed plant	50.12	8190080.29	819.01	-33.616
	Healthy plant	49.88	8150862.03	815.09	103.592
2020	Stressed plant	64.90	10605271.57	1060.53	29.489
	Healthy plant	35.10	5735670.76	573.57	-29.631
2021	Stressed plant	78.58	12840712.48	1284.07	21.079
	Healthy plant	21.42	3500229.85	350.02	-38.974
2022	Stressed plant	76.18	12448529.87	1244.85	-3.054
	Healthy plant	23.82	3892412.46	389.24	11.204
2023	Stressed plant	56.21	9185243.68	918.52	-26.214
	Healthy plant	43.79	7155698.65	715.57	83.837
2024	Stressed plant	70.50	11520364.34	1152.04	25.423
	Healthy plant	29.50	4820577.99	482.06	-32.633
2025	Stressed plant	47.17	7708022.50	770.80	-33.092
	Healthy plant	52.83	8632919.83	863.29	79.085

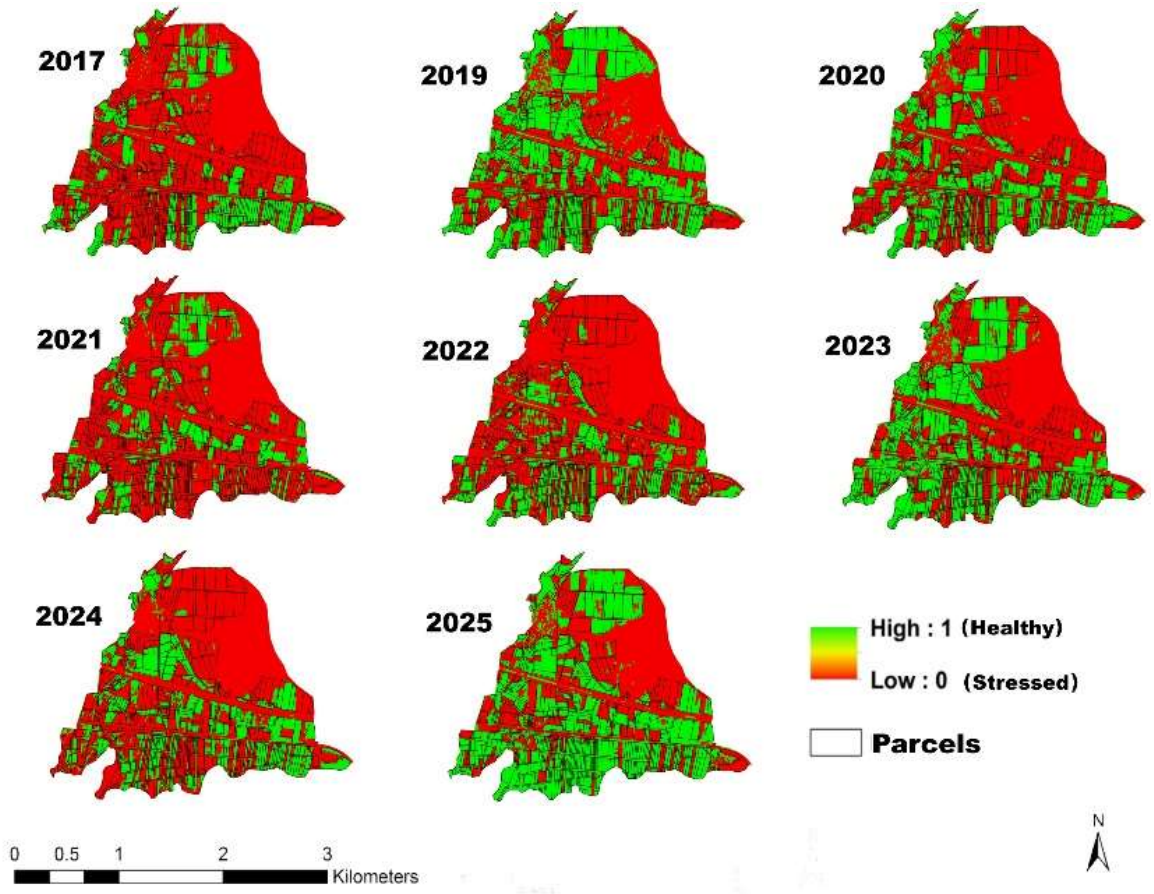


Figure 5. Density maps for 2017 and 2019-2025

Fig. 6 shows the change graph of the areas covered by healthy and stressed plants obtained as a result of NDVI analysis for different years. As can be seen in the figure, the amount of area covered by stressed plants in 2017 before consolidation is greater than that of healthy plants. In 2019, it was determined that there was an increase in the amount of area covered by healthy vegetation and a decrease in the amount of stressed vegetation, depending on consolidation. However, after this year, the positive effect of consolidation could not become very clear due to the extreme drought seen especially in 2020-2021.

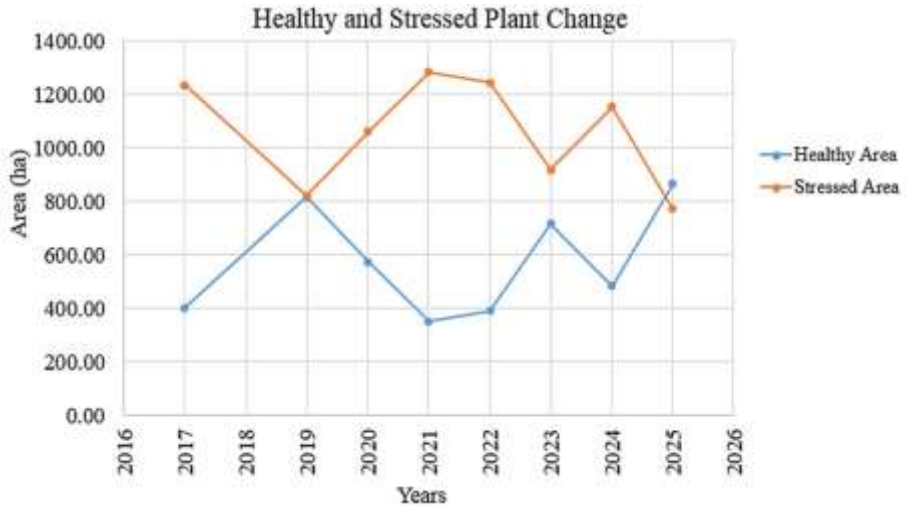


Figure 6. Spatial changes in healthy and stressed plants by year

Discussion

A common issue in agriculture within developing countries is land fragmentation, which negatively impacts agricultural profitability and population income levels. It results in reduced arable land and increased labor needed to manage small, irregular land parcels (Ertunç & Uyan, 2022; Janus et al., 2023).

In the studied area, 97.19% of the area falls within an elevation range of 0 to 800 m, which is linked to lower economic productivity in mountainous regions. Fragmented agricultural lands and topographical challenges elevate production costs and diminish net profitability, raising concerns among policymakers. Fragmentation incurs higher operating costs, as it extends travel time between parcels and limits machinery use. Evidence suggests that small, scattered plots lead to inefficiency and improper allocation of production inputs (Schultz, 1953; Kawasaki, 2010; Yucer et al., 2016; Deininger et al., 2017; Heider et al., 2018; Looga et al., 2018; Li & Li, 2019; Wang et al., 2020).

Farmer attitudes significantly influence the adoption of land consolidation projects in Turkey, with a survey indicating that 74.57% of agricultural stakeholders recognize land fragmentation as an issue, especially prevalent in the Marmara and Central Anatolia regions (Fig. 7). The majority of farmers (94%) expressed satisfaction with the consolidation of fragmented lands, followed by 75% satisfaction regarding cost reductions, 69% about separation from shareholders, 60% for increased land value, and 50% for improved infrastructure services. Overall, 76.9% of respondents were satisfied with LC activities, while only 5.8% were dissatisfied (Yucer et al., 2016).

Evidence from Japan and India indicates that the lack of LC leads to increased cultivation costs due to spatial fragmentation, highlighting the importance of LC projects in cost reduction for rice farming (Kawasaki, 2010; Deininger et al., 2017).

In Turkey, a significant issue is the concentration of agricultural enterprises, with 25.9% operating in the 20-49 decare size group. Most of the land is held by enterprises in the 200-499 decare group, comprising 24.5%. Additionally, 80.7% of agricultural enterprises are classified as small, with less than 100 decares, accounting for 29.1% of the total land held (TUİK, 2016).

The average number of parcels per farm in Turkey rose from 4.1 in 2001 to 5.9 in 2002, as per the 2001 General Agricultural Census. By 2011, the average parcel size reached 6.81 hectares. Despite this, the total average farm size decreased from 7.7 hectares in the 1950s to 6.1 hectares in the 2000s, before slightly increasing to 6.8 hectares in 2011 due to social agricultural policies. In 2020, the average agricultural farm size was reported as 5.9 hectares (Yucer et al., 2016; TUİK, 2020).

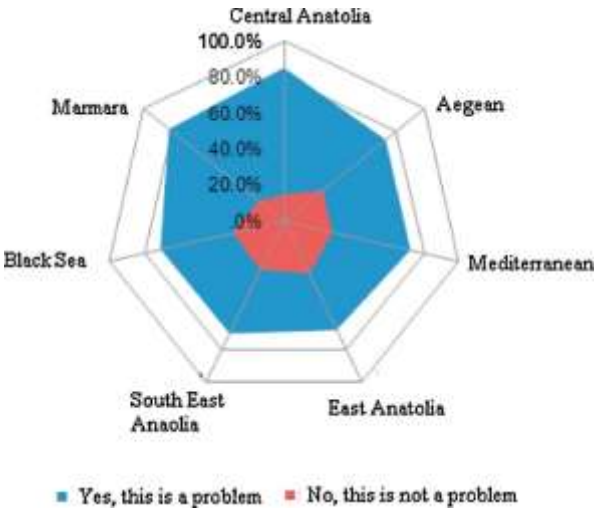


Figure 7. Fragmentation of agricultural lands is seen as a problem by stakeholders in different regions of Turkey (Yucer et al., 2016)

In 2020, the EU had 9.1 million agricultural holdings, with 63.8% being under 5 hectares (Fig. 8), playing a vital role in reducing rural poverty and supporting incomes. In contrast, 7.5% of farms, occupying 50 hectares or more, managed 68.2% of the agricultural area, while the average holding size was 17.4 hectares, with only 18% of farms reaching that size (Eurostat, 2022).

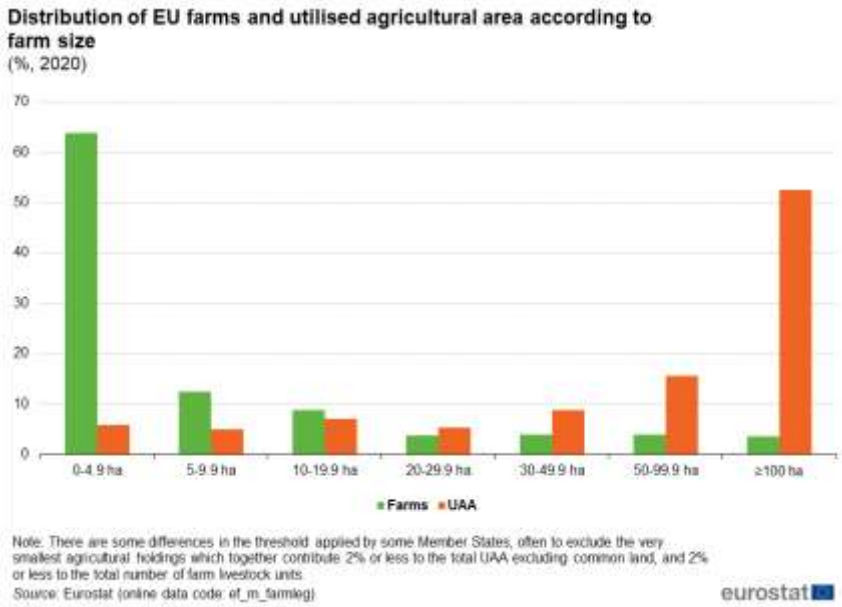


Figure 8. Distribution of EU farms and utilized agricultural area by farm size (%, 2020) (Eurostat, 2022)

As of 2024, the USA has 1.88 million farms, reflecting an 8% decrease from the 2.04 million reported in 2017. Additionally, farm land assets have declined to 876 million acres, a 3% fall from 900 million acres in 2017. The average land size per farm is 46.6 hectares (Fig. 9) (USDA, 2025).

In South China, the average land size is less than 0.64 hectares, notably smaller than the typical 1-4 hectares found in the EU and USA. Rapid urbanization and industrialization in the 21st century have caused a decline in the rural population and labor force, leading to abandoned houses and fields, which restrict effective land use (Sirami et al., 2019; Zou et al., 2024).

A study found that fragmentation in southwestern China's mountains is more severe than in other regions, with a Simpson index of 0.63. On average, 6.06 mu (1 mu = 666.67 m^2 or 1 mu = 1/15 ha) of cultivated land is divided into 6.16 parcels, requiring about 45 minutes for a round-trip from the farm to all parcels. They also stated that a one standard deviation increase in the number of parcels, the Simpson index, or the total minimum round trip time would lead to a 7.1%, 15.1%, and 12.2% increase in costs, respectively, when other conditions remain constant (Wang et al., 2020).

The overall consolidation rate for land consolidation projects in Turkey stands at 42.4%. Specific projects in Aşlama, Çarıklı, Çayırlı, and Karatlı villages within the Misli Plain of Niğde province showed varying rates of 54.18%, 23.08%, 35.72%, and 37.70%, respectively. These findings align with previous research indicating an average consolidation rate of 48% across 507 projects in 33 provinces of Turkey (Yağanoğlu et al., 2000; Başayiğit et al., 2016; Kuzu et al., 2018).

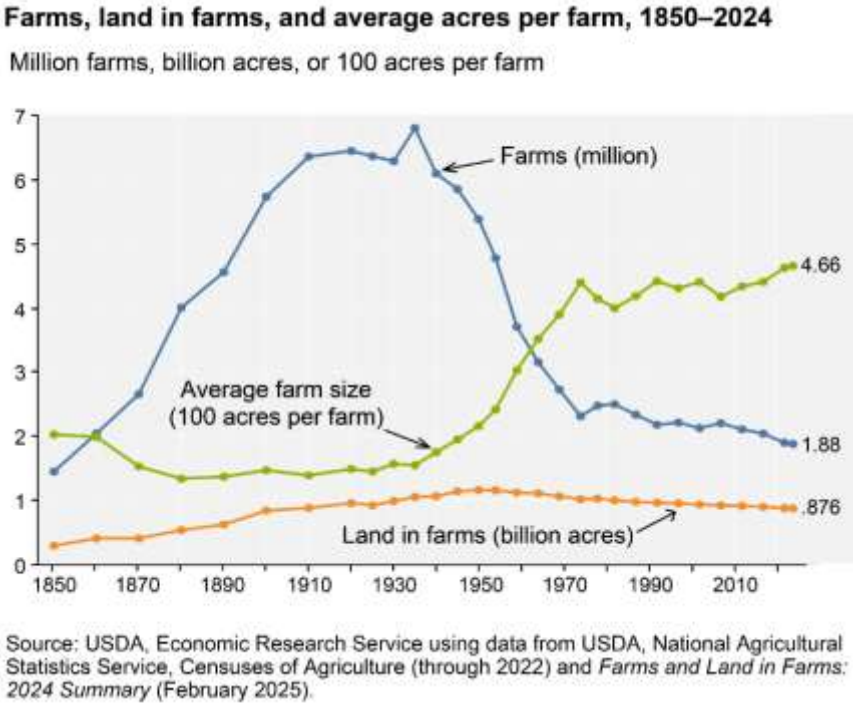


Figure 9. Farms, land in farms, and average area per farm, 1850-2024 (USDA, 2025)

In this study, it was found that the average number of parcels decreased from 11.71 to 3.35 after land consolidation (LC), reflecting a 71.39% reduction. Generally, consolidation projects in Turkey lead to a decrease in parcel numbers by over 50%, with some cases exceeding 80%. Other studies showed a 30.79% change in average parcel size in Beyazaltın Village and a 70.15% change in Yenipazar Plain. Additionally, one report indicated a reduction in parcels from 661 to 542, indicating an 18% consolidation rate, while another analyzed eight projects in Tavas Plain, with an average consolidation rate of 35.5% (Çay & Iscan, 2011; Uyan et al., 2013; Sönmezyıldız & Çakmak, 2013; Peker & Dağdelen, 2016; Tunalı & Dağdelen, 2018; Arslan & Değirmenci, 2026).

CONCLUSION

In the 2001-2024 period, there was an increase of approximately 33.64% in the population of Turkey, and the decrease in agricultural land per capita in the same period was 29.46%. Worldwide, the total agricultural area per capita, which was 0.64 ha in 2021, decreased to 0.45 ha in 2024. According to 2021 data, the cultivated agricultural area per capita in the world is 0.18 ha, and in the EU it is 0.22 ha (TUİK, 2025; DATABANK, 2025).

In this study, it was determined that the amount of stressed plants in 2017, when consolidation had not yet started, was approximately 3 times more than healthy plants. In contrast, in 2019, in the post-consolidation period, the amount of stressed plants showed a decrease trend of 33.616%. The healthy plant value doubled and covered approximately 50% of the total area. This situation revealed that consolidation had a positive effect.

As stated, 2021 was the year with the most extreme events, with 1024 extreme weather events recorded. In the same report, when looking at monthly temperature differences, it was stated that the temperatures of all months except March, September and October were above normal. In particular, May became the hottest month in the last 50 years, with a difference of 2.6°C, while January and July became the second-hottest months on record. In this context, during the period up to 2025, the area covered by stressed vegetation began to increase, similar to before consolidation (MGM, 2022).

In the light of all the results and information obtained, policies that can create services such as infrastructure integration and farmer education works need to be developed for a more efficient land consolidation. This is because land consolidation in rural areas aims not only to combine divided parcels, but also

to better manage all related areas such as agricultural, technical, social and cultural areas to improve land ownership standards (Mesci & Karlı, 2018; Pasakarnis & Maliene, 2010; Çay & Uyan, 2013).

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Author Contributions

Ömer Faruk KARACA: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; software; writing-original draft; writing-review and editing.
Tuba ALBAYRAK: Investigation; writing-review and editing.

ORCID

Ömer Faruk KARACA http://orcid.org/0000-0002-6302-9738
Tuba ALBAYRAK http://orcid.org/0000-0002-3745-8352

Article History	
Submission received:	27.03.2026
Revised:	24.06.2026
Accepted:	27.06.2026

REFERENCES

Akkaya Aslan, Ş. T. (2018). Arazi Toplulaştırma Öncesi ve Sonrası Arazi Parçalılık Değişiminin Analizi: Denizli Tavas İlçesi Pınarlar Köyü Örneği. Turkish Journal of Agricultural and Natural Sciences, 5(3), 364-371. https://doi.org/10.30910/turkjans.448399

Arslan, F., & Değirmenci, H. (2026). Geospatial and geostatistical analysis of land fragmentation and parcel shape indicators for sustainable farm structure in land consolidation. *Farming System,* 4, 1. https://doi.org/10.1016/j.farsys.2025.100173

Auravant (2026). Vegetation indices and their interpretation: NDVI, GNDVI, MSAVI2, NDRE, and NDWI. https://www.auravant.com/en/articles/precision-agriculture/vegetation-indices-and-theirinterpretation-ndvi-gndvi-msavi2-ndre-and-ndwi/ (Accessed date: 05.05.2026)

Başayiğit, L., Aydın, M., & Uçar, Y. (2016). Arazi Toplulaştırma Yapılan Alanlarda Yeniden Parçalanmanın Uydu Görüntüleri İle İzlenmesi. In: 6. Uzaktan Algılama-CBS Sempozyumu (UZAL-CBS 2016) 5-7 Ekim, Adana.

Bolstad, P. (2005). GIS Fundamentals - A First Text on Geographic Information Systems. Eider Press, White Bear Lake, MN.

Çay, T., & Iscan, F. (2011). Fuzzy expert system for land reallocation in land consolidation. *Expert Systems with Applications,* 38, 9. https://doi.org/10.1016/j.eswa.2011.02.150

Çay, T., & Uyan, M. (2013). Evaluation of reallocation criteria in land consolidation studies using the Analytic Hierarchy Process (AHP). *Land Use Policy,* 30, 1. https://doi.org/10.1016/j.landusepol.2012.04.023

DATABANK (2025). World Development Indicators https://databank.worldbank.org/source/world-development-indicators/Series/AG.LND.ARBL.HA.PC# (Accessed date: 18.03.2026)

Deininger, K., Monchuk, D., Nagarajan, H., & Singh, S.K. (2017). Does land fragmentation increase the cost of cultivation? Evidence from India. *The Journal of Development Studies,* 53, 1. https://doi.org/10.1080/00220388.2016.1166210

Duran, S., Doğan, M. (2022). Detection and modeling of long-term (1984-2020) land-use change (2035) analysis of Gölcük district. *Journal of Geography,* 44. https://doi.org/10.26650/JGEOG2022-997334.

Ertunç, E., & Uyan, M. (2022). Land valuation with best worst method in land consolidation projects. *Land Use Policy,* 122. https://doi.org/10.1016/j.landusepol.2022.106360

Eurostat (2022). Agriculture - Farms and Farmland in the European Union - Statistics. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Farms_and_farmland_in_the_European_Union_-_statistics (Accessed date: 20.03.2026).

Fadhıl, A.K.T. (2022). Modelling urban sprawl with cellular automata Markov chain method: The case of Kirkuk governorate. *Journal of Geomatics,* 7, 15. https://doi.org/ 10.29128/geomatik.852900

FAO/UNESCO (2025). FAO/UNESCO Soil Map of the World. https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/faounesco-soil-map-of-the-world/en (Accessed date: 20.03.2026)

FAO (2018). The State of Food Security and Nutrition in the World - Building Climate Resilience for Food Security and Nutrition. *FAO IFAD UNICEF WFP and WHO Report*, Rome, Italy.

FAO (2025). FAO Knowledge Repository Beta. https://www.fao.org/3/i4373e/i4373e.pdf (Accessed date: 25.03.2026)

Gatzweiler, F., Judis, R., & Hagedorn, K. (2002). Sustainable agriculture in central and eastern European countries: The Environmental Effects of Transition and Needs for Change. *Shaker Verlag Aachen*, Germany. https://doi.org/10.1016/j.agsy.2004.02.003

Heider, K., Lopez, J.M.R., Aviles, J.M.G., & Balbo, A.L. (2018). Land fragmentation index for drip-irrigated field systems in the Mediterranean: A case study from Ricote (Murcia SE Spain) *Agricultural Systems,* 166. https://doi.org/10.1016/j.agsy.2018.07.006

HGM (2025). Harita Genel Müdürlüğü. https://www.harita.gov.tr/urunler/indirilebilir-verilerdosyalar/13 (Accessed date: 15.03.2026)

Janus, J., Ertunc, E., Muchova, Z., & Tomić, H. (2023). Impact of selected land fragmentation parameters and spatial rural settlement patterns on the competitiveness of agriculture: Examples of selected European and Asian countries. *Habitat International,* 140. https://doi.org/10.1016/j.habitatint.2023.102911

Jiang, N., & Shao, M. (2011). Characteristics of soil and water loss of different slope land uses in small watershed on the Loess Plateau. *Transactions of the Chinese Society of Agricultural Engineering,* 27, 6. http://www.tcsae.org/en/article/id/20110607

Karaca, Ö.F. (2025). Determination of Spatial and temporal changes in NDVI in Yozgat province using satellite images. *Bozok Journal of Agriculture and Natural Sciences (BOJANS),* 3, 2. https://doi.org/10.59128/bojans.1576006

Kawasaki, K. (2010). The costs and benefits of land fragmentation of rice farms in Japan. *Australian Journal of Agricultural and Resource Economics (AJARE),* 54, 4. https://doi.org/10.1111/j.1467-8489.2010.00509.x

Köken, B., & Çay, T. (2019). Effects of the Classification to the Land Reallocations in Land Consolidation Studies: Çaltı-Konya. *Turkish Journal of Agricultural and Natural Sciences*, 6(2), 243-257. https://doi.org/10.30910/turkjans.557105

Kuzu, H., Arslan, F., & Değirmenci, H. (2018). Analysis of roads in land consolidation projects: A Case study of Türkeli village in Şanlıurfa/Turkey. *Journal of Agriculture Faculty (ISUBÜ ZFD), 1st International Congress on Agricultural Structures and Irrigation Special Issue*. https://agris.fao.org/search/ar/records/647481ab425ec3c088f8f8f9

Li, S., Li, X. (2019). The mechanism of farmland marginalization in Chinese mountainous areas: Evidence from cost and return changes. *Journal of Geographical Sciences,* 29. https://doi.org/10.1007/s11442-019-1613-2

Looga, J., Jürgenson, E., Sikk, K., Matveev, E., & Maasikamäe, S. (2018). Land fragmentation and other determinants of agricultural farm productivity: The case of Estonia. *Land Use Policy,* 79. https://doi.org/10.1016/j.landusepol.2018.08.021

Mesci, O., & Karlı, B. (2018). Socio-Economic analysis of farms in the area of land consolidation in Isparta province abstract. *Journal of Agricultural Faculty of Mustafa Kemal University,* 23, 1. https://dergipark.org.tr/tr/download/article-file/487477

MGM (2022). 2021 Yılı İklim Değerlendirmesi. https://www.mgm.gov.tr/FILES/iklim/yillikiklim/2021-iklim-raporu.pdf (Accessed date: 10.03.2026)

Özgültekin, P. (2019). Determination of landuse changes after land consolidation using remote sensing and geographic information system: A case study at the Şanlıurfa Bozova Sulucakaçar example. (Ph.D Thesis). Harran University. Department of Soil Science And Plant Nutrition, Institute of Science, Şanlıurfa, Türkiye. http://acikerisim.harran.edu.tr/8080/xmlui/handle/11513/2372

Pasakarnis, G., & Maliene, V. (2010). Towards sustainable rural development in Central and Eastern Europe: Applying land consolidation. *Land Use Policy* 27, 2. https://doi.org/10.1016/j.landusepol.2009.07.008

Peker, M., & Dağdelen, N. (2016). Effects of land consolidation on land assets in Aydın province. *Journal of Adnan Menderes University Agricultural Faculty,* 13, 1. https://doi.org/10.25308/aduziraat.1461176

Rouse Jr, J.W., Haas, R.H., Schell, J.A., & Deering, D.W. (1974). Monitoring vegetation systems in the great plains with Erts. In: Goddard Space Flight Center 3d ERTS-1 Symp, Vol. 1 Sect. A. Nasa Special Publication. https://ntrs.nasa.gov/api/citations/19740022614/downloads/19740022614.pdf.

Schultz, T. (1953). The Economic Organization of Agriculture. Estados Unidos, Mc Graw Hill Press, New York.

Sentinelhub (2025). Sentinel-2 L2A. https://docs.sentinel-hub.com/api/latest/data/sentinel-2-l2a/#about-sentinel-2-l2a-data (Accessed date: 12.03.2026)

Sirami, C., Gross, N., Baillod, A.B., Bertrand, C., Carrié, R., Hass, A., Henckel, L., Miguet, P., Vuillot, C., Alignier, A., Girard, J., Batáry, P., Clough, Y., Violle, C., Giralt, D., Bota, G., Badenhausser, I., Lefebvre, G., Gauffre, B., Vialatte, A., Calatayud, F., Gil-Tena, A., Tischendorf, L., Mitchell, S., Lindsay, K., Georges, R., Hilaire, S., Recasens, J., Solé-Senan, X.O., Robleño, I., Bosch, J., Barrientos, J.A., Ricarte, A., Marcos-Garcia, M.Á., Miñano, J., Mathevet, R., Gibon, A., Baudry, J., Balent, G., Poulin, B., Burel, F., Tscharntke, T., Bretagnolle, V., Siriwardena, G., Ouin, A., Brotons, L., Martin, J.L., & Fahrig, L. (2019). Increasing crop heterogeneity enhances multitrophic diversity across agricultural regions. *Proceedings of National Academy of Sciences (PNAS),* 116, 33. https://doi.org/10.1073/pnas.1906419116.

Sönmezyıldız, E., & Çakmak, B. (2013). Assessment of irrigation performance in land consolidation area of Eskişehir Beyazaltın village. *Akdeniz University Journal of the Faculty of Agriculture,* 26, 1.

Swaminathan, M. (2014). Zero Hunger. *Science,* 345, 6196. https://doi.org/10.1126/science.1258820

Tunalı, S., & Dağdelen, N. (2018). Evaluation of some land consolidation studies made in Denizli - Tavas Plain. *COMU Journal of Agriculture Faculty,* 6, 2. https://dergipark.org.tr/tr/download/article-file/607343

Turan, İ., Dengiz, O., & Kaya, N. (2021). Determination of land use/land cover changes with multi-temporal landsat satellite images: A Case study of Çarşamba Delta Plain. *COMU Journal of Agriculture Faculty,* 9, 1. https://doi.org/10.33202/comuagri.857787.

TUİK (2016). Agricultural Enterprise Structure Research 2016. https://data.tuik.gov.tr/Bulten/Index?p=Tarimsal--Isletme-Yapi-Arastirmasi-2016-24869 (Accessed date: 20.03.2026)

TUİK (2020). Agricultural Enterprise Structure Research. http://www.tuik.gov.tr (Accessed date: 22.03.2026)

TUİK (2025). Agriculture - Statistical tables - Agricultural areas. https://data.tuik.gov.tr/Kategori/GetKategori?p=Tarim-111 (Accessed date: 14.03.2026)

USDA (2025). Economic Research Service - The number of U.S. Farms Continues Slow Decline. https://www.ers.usda.gov/data-products/chart-gallery/chart-detail?chartId=58268 (Accessed date: 16.03.2026)

Uyan, M., Cay, T., & Akcakaya, O. (2013). A Spatial decision support system design for land reallocation: A case study in Turkey. *Computers and Electronics in Agriculture,* 98. https://doi.org/10.1016/j.compag.2013.07.010.

Wang, Y., Li, X., Lu, D., & Yan, J. (2020). Evaluating the impact of land fragmentation on the cost of agricultural operation in the southwest mountainous areas of China. *Land Use Policy,* 99. https://doi.org/10.1016/j.landusepol.2020.105099

Yağanoğlu, A., Okuroğlu, M., & Hanay, A. (2000). Arazi Toplulaştırması. Atatürk Üniversitesi Ziraat Fakültesi Ders Yayınları, No:159, Erzurum, Türkiye.

Yucer, A., Kan, M., Demirtas, M., & Kalanlar, S. (2016). The importance of creating new inheritance policies and laws that reduce agricultural land fragmentation and its negative impacts in Turkey. *Land Use Policy,* 56. https://doi.org/10.1016/j.landusepol.2016.04.029

Yurui, L., Yi, L., Pengcan, F., & Hualou, L. (2019). Impacts of land consolidation on rural human–environment system in typical watershed of the loess plateau and implications for rural development policy. *Land Use Policy,* 86. https://doi.org/10.1016/j.landusepol.2019.04.026

Zou, Y., Zhao, P., Bianchi, F.J.J.A., Gong, S., Li, L., Li, J., Shi, X., Dainese, M., Liu, Y., & Wanger, T.C. (2024). Relationship between landscape complexity and ecosystem services from the perspective of smallholder agroecosystems in China - A review. *Cell Report Sustainability,* 1, 2. https://doi.org/10.1016/j.crsus.2023.100014