Artvin Çoruh Üniversitesi
Orman Fakültesi Dergisi
ISSN:2146-1880, e-ISSN: 2146-698X
Yıl: 2023, Cilt: 24, Sayı:1, Sayfa: 64-74

ofd.artvin.edu.tr

Artvin Coruh University
Journal of Forestry Faculty
ISSN:2146-1880, e-ISSN: 2146-698X
Year: 2023, Vol: 24, Issue:1, Pages: 64-74

Determination of carbon storage amounts in above-ground biomass using NDVI based on land use/land cover classes in Bolu

Bolu ili arazi kullanım sınıflarına göre toprak üstü biyokütlede depolanan karbon miktarlarının NDVI ile belirlenmesi

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Eser Bilgisi / *Article Info*
Araştırma makalesi / *Research article*
DOI: 10.17474/artvinofd.1113265
Sorumlu yazar / *Corresponding author*
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e-mail: ahmetdegermenci@duzce.edu.tr
Geliş tarihi / *Received*
09.05.2022
Düzeltme tarihi / *Received in revised form*
17.01.2023
Kabul Tarihi / Accepted
24.01.2023
Elektronik erişim / *Online available*
15.05.2023
Anahtar kelimeler:
Land use/Land cover
Carbon
Above-ground biomass
Landsat
NDVI
Bolu
Keywords:
Arazi kullanım-arazi örtüsü değişimi
Karbon
Toprak üstü biyokütle
Landsat
NDVI
Bolu

Abstract
In this study, the land use/land cover (LULC) class of Bolu province in 1990, 2006, and 2018 and LULC class transitions between periods were examined. In addition, the amount of carbon storage in LULC classes of above-ground biomass (AGB) for the years 1990-2018 was determined through NDVI. CORINE land classification was used to determine the change of LULC classes. Landsat 5 TM and Landsat 8 OLI satellite images were used to determine the carbon storage amounts for the selected periods. There has been an increase of approximately 81.56% (4797.1 ha) in the LULC class of artificial surfaces in 28 years. A total increase of 2.87% (5539.8 ha) has been experienced in agricultural areas in the 28-year period. Forest and semi-natural areas decreased by 1.83% (11745.5 ha) and water bodies have increased approximately 3.4 times in 28 years. In terms of carbon amounts in AGB of the LULC classes, there has been approximately 59.5% carbon accumulation over 28 years. While a total of 1583467.3 tons of carbon was stored in 1990, this amount increased to 2664549.5 tons of carbon in 2018. Of the total carbon stored in 1990, 82.5% was stored in the forest and semi-natural areas, and 17% was stored in agricultural areas. While in 2018, 76.3% of the total carbon was stored in forest and semi-natural areas, and 23% in agricultural areas. In the 28-year period, a total of 1000151.7 tons of carbon has accumulated in the AGBs of the LULC classes that have not been converted to a different class. On the other hand, a total of 80930.6 tons of carbon was transferred from one class to another over the transformed lands. In total, 1081082.3 tons of carbon accumulation occurred between 1990 and 2018.

Özet
Bu çalışmada Bolu ili 1990, 2006 ve 2018 yılları arazi sınıfı durumları ve dönemler arası arazi sınıfı geçişleri incelenmiştir. Ayrıca 1990-2018 yılları için arazi kullanım sınıfları toprak üstü biyokütlelerinde (TÜB) depolanan karbon miktarları NDVI uydu görüntüleri üzerinden belirlenmiştir. Arazi sınıflarının değişimini belirlemek için CORINE arazi sınıflandırması kullanılmıştır. 1990 ve 2018 yıllarında karbon depolama miktarlarını belirlemek için Landsat 5 TM ve Landsat 8 OLI uydu görüntüleri kullanılmıştır. Arazi sınıflarından yapay yüzeylerde 28 yıllık süreçte yaklaşık %81.56'lık artış olmuştur. Tarım alanlarında ise toplamda %2.87 (5539.8 ha) oranında artış yaşanmıştır. Orman ve yarı doğal alanlar ise aynı dönemde %1.83 (11745.5 ha) oranında azalmıştır. 28 yıllık süreçte su kütlesi alanları ise yaklaşık 3.4 kat artmıştır. Arazi sınıfı AGB'deki karbon miktarları bakımından 28 yıllık süreçte yaklaşık %59.5 karbon birikmesi olmuştur. 1990 yılında Arazi sınıfları AGB'sinde toplam 1583467.3 ton karbon depo edilmişken, 2018 yılında bu miktar 2664549.5 ton karbona yükselmiştir. 1990 yılında depolanan toplam karbonun %82.5'i orman alanlarında ve % 17'si de tarım alanlarında depolanmıştır. 2018 yılında ise toplam karbonun %76.3'ü orman ve yarı doğal alanlarda, %23'ü de tarım alanlarında depolanmıştır. Bu 28 yıllık süreçte, farklı bir arazi sınıfına dönüştürülmemiş arazi kullanım/arazi örtüsü sınıflarının TÜB'lerinde toplam 1000151.7 ton karbon birikmiştir. Dönüşüme uğrayan araziler üzerinden de toplam 80930.6 ton karbon bir arazi sınıfından diğerine taşınmıştır. Toplamda 1990-2018 yılları arasında 1081082.3 ton karbon birikimi meydana gelmiştir.

INTRODUCTION

The destruction of natural areas at the global scale brings many problems. With the increase of industrialization and urbanization, natural areas are being destroyed and causing a constant change in LULC classes all over the world. The determination of LULC class situations, which is one of the most dynamic elements on earth, provides important information for the effective use of natural resources and planning studies. There are two different approaches to studies on the LULC classes. The first approach is to determine the current land situation, and the second is to determine the changes that occur through maps or images covering at least two periods.

Especially with the second approach, it is important to reveal the changes in the land cover regularly and in certain periods, to analyze the changes in the LULC classes and plan for the future (Güre et al. 2009). In this sense, it is extremely important to use remote sensing techniques, where analysis and queries are based on a digital base, in determining LULC class situations in large areas quickly and successfully (Gülersoy 2013).

One of the factors that directly or indirectly affect global climate change is land-use changes. The expansion of urban and agricultural areas, especially in parallel with population growth, causes an increase in wrong LULC classes and serious pressure on ecosystems. Climate change has great impacts on natural areas and developing economies (Stern 2006). Countries signed the Kyoto Protocol (1992) to minimize the impact of anthropogenic factors on the environment and made commitments to ensure that greenhouse gas emissions in the atmosphere remain at a level that will not affect climate change. Carbon compounds, which are seen as the main cause of greenhouse gas formations, are also the most important factor determining the trends and changes in global warming (Le Quéré et al. 2015).

Forests are one of the most important carbon sinks in the world and provide many products and services for humans. One of its most important services is to play a vital role in oxygen production and the carbon cycle, which is the source of life for humans and many living things (Le Quéré et al. 2015). Forests consume much more CO_2 than other ecosystems and have an extremely important place in terrestrial ecosystems because they can keep the bound carbon in their bodies for a long time. Watson et al. (2000) stated in their study that forest and semi-natural areas, which are among terrestrial ecosystems, can store and sequester very large amounts of carbon in the atmosphere. The conversion of CO_2 in the air into organic material related to the amount of leaves in plants. Within terrestrial ecosystems, forests have much more leaves than other plant areas and consume significantly more CO_2 than plants in pastures and agricultural areas. Carbon is stored in living biomass consisting of branches, stems, leaves, and roots of trees and in dead biomass consisting of dead cover, soil organic matter, and soil (Zengin 2007).

Different methods are used to determine carbon storage amounts for forest ecosystems. The method in which calculations are made based on the amount of carbon accumulated in the biomass is most commonly used (Backéus et al. 2005, Brown et al. 1996). The most commonly used approach in biomass determination in practice is, based on the inventory data obtained with forest management plans. The biomass, is calculated by using the inventory data, the distribution of forest and semi-natural areas by tree species, and the conversion of this biomass amount to oven-dry density. Above and below-ground biomass is calculated with the coefficients determined for tree species groups (coniferous and broad-leaved). Based on the biomass determined in this way, the total amount of carbon is calculated for different areas with the help of the coefficients determined by the Intergovernmental Panel on Climate Change (IPCC 2006) for countries (Asan 1995, Asan 1999, Asan et al. 2002, Tolunay 2011, Degermenci and Zengin 2016, Yolasığmaz 2004, Keleş and Başkent 2006, Sivrikaya et al. 2007). Especially in recent years, another widely used approach in the determination of carbon accumulation is to determine the amount of carbon stored in the above-ground biomass (AGB) by using remote sensing techniques, in relation to different land-use classes. (Kumar et al. 2012, Li et al. 2019, Zheng et al. 2007, Zheng et al. 2004, Zhu and Liu 2015, Günlü et al. 2014). It is especially common to determine carbon amounts with NDVI obtained by band combinations from Landsat satellite images (Myeong et al. 2006, Hussain and Sarma 2019, Baniya et al. 2018).

In this study, the changes in five basic land-use classes (artificial surfaces, agricultural areas, forest and semi-natural areas, wetlands, and water bodies) according to CORINE LULC classes for the years 1990, 2006, and 2018 in Bolu province were examined. In addition, the changes in the carbon amounts in the above-ground biomass (AGB) according to the LULC classes between 1990 and 2018 were tried to be determined through the NDVIs produced from Landsat 5 TM and Landsat 8 OLI satellite images. A systematic examination of the changes and transformations in LULC classes will provide basic information for the roadmap to be prepared for the protection of natural resources and agricultural lands, and the determination of the amount of released-stored carbon.

MATERIAL AND METHOD

Study Area

The province of Bolu, located in the Western Black Sea region of Turkey, was determined as the study area. The area of Bolu province is 843290 hectares and the majority of it is covered with forests. Karadere, Seben and Aladağ Forests are among the richest forests of Türkiye in terms of biodiversity and wood quality. The dominant tree species are beech, fir, hornbeam, linden, ash, oak, alder, elm, poplar, and Scots pine. Approximately 67% of the forests in Bolu province is productive. The average altitude is 1000 m. The altitude of the central district of Bolu province is 725 m. Geographically, it is between 30°32'00''-32°36'00'' E longitudes and 40°06'00''-41°01'00'' N latitudes (Figure 1).

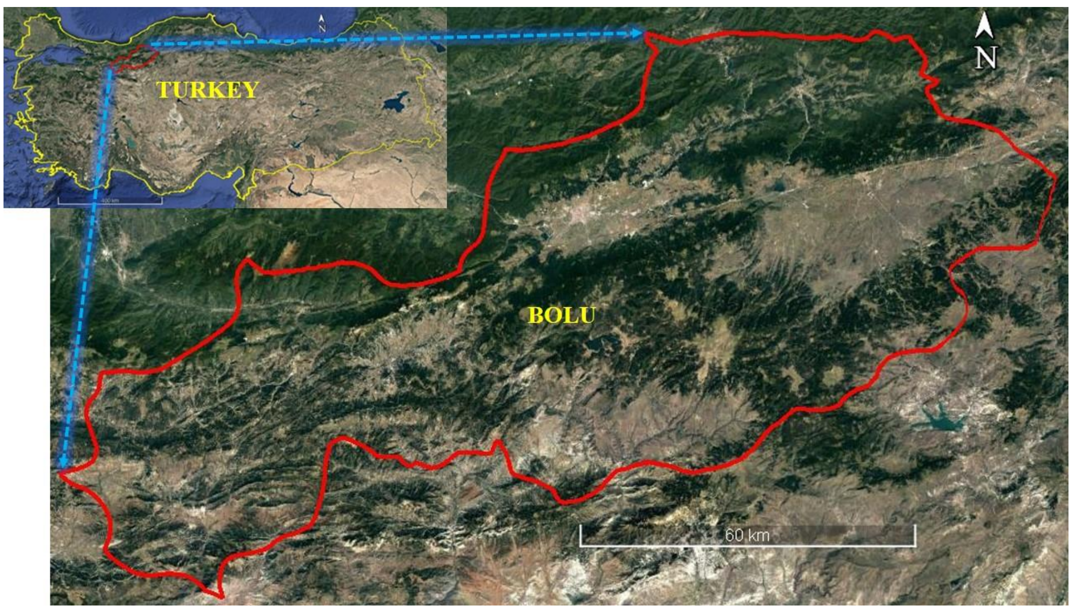

Figure 1. Location of the study area

Bolu is located in the continental climate zone. Especially as you go to the inner regions, the climate becomes continental with the effect of the mountains extending parallel to the coast. While beech, oak, fir, and Scots pine species are common in Bolu province, Anatolian black pine and oak forests are seen in the inner parts and high mountains. According to the data for the last 52 years, the average daily sunshine duration is 5.4 hours, the annual precipitation is 551.2 mm and the annual average number of rainy days is 131 (MGM 2021). The population of Bolu province is 320.014 and 75.29% of this population lives in the city center (TUIK 2021). While the number of people per km^2 in Bolu is 38 in the general area, this number increases to 135 in the central district. The annual population growth rate in the province is 1.66%.

Determination of LULC Classes Using CORINE Data

CORINE (Coordination of Information on the Environment) data were used to determine the LULC classes of Bolu province. CORINE LULC classes determined by the European Environment Agency (EEA) is produced using remote sensing techniques over satellite images (https://land.copernicus.eu/pan-european/corine-land-cover). The EEA aimed to determine the changes in LULC classes, obtain rational information on natural resources, and establish a standard database with a similar structure for all countries in all EEA member countries, based on some criteria determined by the EEA. (CORINE 1997). According to the CORINE data, classifications are made over 44 subclasses, under 5 base classes.

Within the scope of this study, both areal changes and carbon storage amounts were determined for the years 1990-2018 based on the base LULC classes at Level 1 of the CORINE LULC classes. ArcGIS Desktop 10.8^{TM} program was used for creating maps and various overlay processes. ArcGIS Desktop 10.8^{TM} program was used to reveal the spatial changes and calculate the amount of carbon stored in the AGB according to the LULC classes. The total carbon amounts were calculated for 5 base LULC classes using the ArcGIS zonal statistics tool.

Preparation of Landsat Images for Analysis

It aims to analyze and evaluate the temporal changes in the amount of carbon stored in each LULC class, as well as the spatial change of Bolu province according to the main LULC classes. For this purpose, Landsat-5 (TM) of 1990 and Landsat 8 (OLI) satellite images of 2018 were used. Images of May, when vegetation can be observed were used for both periods. Landsat images were obtained online from the United States Geological Survey Science Board (USGS 2021), and Earth Explorer (EE). Landsat satellite images contain raw data DN (Digital Number) and necessary radiometric and atmospheric corrections should be made to these raw data. The ENVI 5.3 software was used to make the radiometric corrections. The method by Canty (2014) was used for radiometric corrections. Atmospheric corrections of the radiometrically corrected satellite images were also made via the QUAC (Quick Atmospheric Correction) module in the ENVI 5.3 software. In this study, band 3 (Red) and band 4 (Near-infrared) of the Landsat 5 TM satellite image were used, while band 4 (Red) and band 5 (Near-infrared) of the Landsat 8 OLI satellite image were used.

Generating NDVI and Preparing for Analysis

Many plant vegetation indices can be produced with various band combinations on Landsat satellite images. Although different vegetation indices are used especially in studies related to vegetation, the most widely used vegetation index is the Normalized Difference Vegetation Index (NDVI). The NDVI was first developed by Tucker (Tucker 979). NDVI can be produced not only from Landsat satellite images but also from all satellites with near-infrared and red bands (Aygün et al. 2016). Evaluations are made on pixel values in NDVI satellite images, and if the pixel brightness is high, it means that the healthy vegetation rate is high. NDVI pixel values are distributed between (-1) and (+1), and as the index value approaches (+1), green vegetation is more and pixel values close to (0) indicate an open area or less vegetation cover. In the case of negative factors such as cloudiness, water, and snow on the satellite images, the NDVI pixel value approaches (-1). Within the scope of this study, NDVI images were produced using the following formula (Eq. 1).

$$NDVI = \frac{NIR-Red}{NIR+Red} \qquad (1)$$

In the equation; NDVI: normalized vegetation index, NIR: near-infrared band, Red: the red band. The NDVI images used in the study are given below (Figure 2).

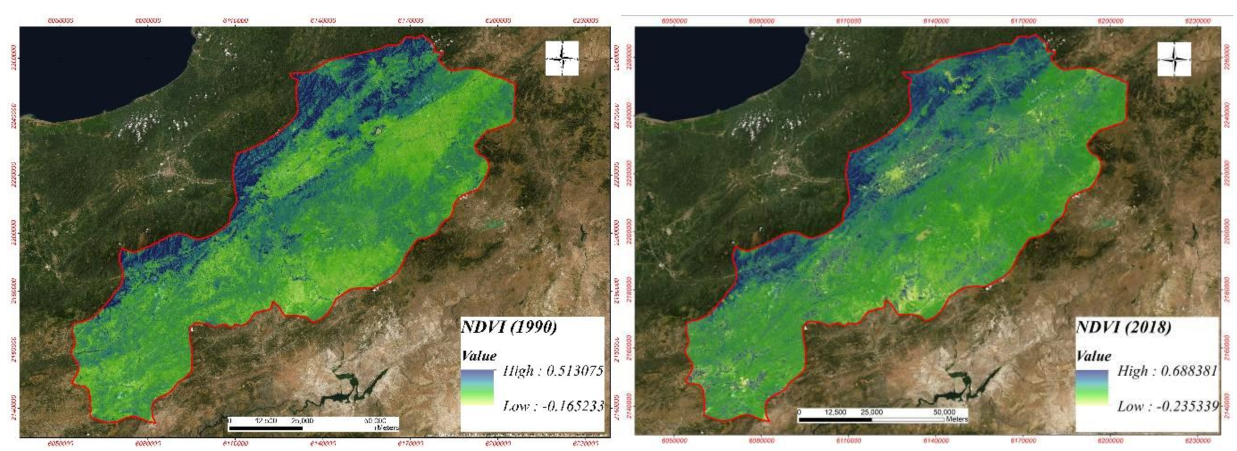

Figure 2. NDVI satellite image of 1990 (Landsat 5 TM) (left) and NDVI satellite image of 2018 (Landsat 8 OLI) (right)

Calculation of Carbon Storage

In determining the carbon storage capacity according to LULC classes with NDVI satellite images, the method developed by Myeong et al. (2006) was used. With this method, the amount of carbon stored in the AGB in very large areas can be determined quickly and effectively in a short time. The following formula (Eq. 2) was used to determine the amount of carbon stored in each pixel on the NDVI satellite image (Myeong et al. 2006).

$$Carbon\ (ton) = 0.1072 * e^{NDVI * 0.0194} \quad (2)$$

RESULTS

First of all, the changes in the LULC classes for 3 periods (1990-2006, 2006-2018 and 1990-2018) were examined, and in the second step, the carbon amounts stored in the AGB of the LULC classes were revealed for the years 1990 and 2018.

Results of Changes in LULC Classes

When the changes in the LULC classes for in 1990, 2006, and 2018 periods in the study area are examined, the highest increase occurred on artificial surfaces with 48.15% in the 1990-2006 period and 22.55% in the 2006-2018 period. Artificial surfaces, which were 5881.4 hectares in 1990, increased to 8713.6 hectares in 2006 and 10678.5 hectares in 2018. In the 28 years, there has been a total increase of 81.56% in artificial surfaces. While agricultural areas increased by 3.49% (6734.7 ha) in the first period, it decreased by 0.6% (1194.9 ha) in the 2006-2018 period. In the 28 years, there was a total increase of 2.87% (5539.8 ha) in agricultural areas. There has been a decrease in forest and semi-natural areas in each period. There was a 1.52% (9747.1 ha) decrease in the period between 1990 and 2006 and a decrease of 0.32% (1998.5 ha) in the 2006-2018 period. In the 28 years, there was a total decrease of 1.83% (11745.5 ha) in forest and semi-natural areas. The percentages correspond to a very serious decrease based on the area due to a large number of forest and semi-natural areas. Wetlands areas, on the other hand, decreased by 2.93% (10.4 ha) in the first period but increased by 8% (27.5 ha) in the 2006-2018 period. In the 28 years, there has been an increase of 17.1% (4.84 ha) in total. Water bodies, on the other hand, were the land-use class with the highest proportional change. While it increased by 32.36% (190.6 ha) in the 1990-2006 period, it increased by 154.03% (1200.9 ha) in the 2006-2018 period. When the 28 years is evaluated, water bodies have increased approximately 3.4 times (Table 1). This increase is because there are ponds built for irrigation purposes especially in Bolu province in recent years. In addition, the spatial distributions of the changes in LULC classes by periods are also given in Figure 3 below.

Table 1. Changes in LULC classes by periods

LULC classes	Area 1990 (ha)	Change 1990 to 2006 (ha)	Change 1990 to 2006 (%)	Area (ha) 2006	Change 2006 to 2018 (ha)	Change 2006 to 2018 (%)	Area (ha) 2018	Change 1990 to 2018 (ha)	Change 1990 to 2018 (%)
Artificial surfaces	5881.4	2832.2	48.2	8713.6	1964.9	22.6	10678.5	4797.1	81.6
Agricultural areas	193193.0	6734.7	3.5	199927.7	-1194.9	-0.6	198732.8	5539.8	2.9
Forest and semi-natural areas	643272.4	-9747.1	-1.5	633525.3	-1998.5	-0.3	631526.9	-11745.5	-1.8
Wetlands	354.3	-10.4	-2.9	343.9	27.5	8.0	371.4	17.1	4.8
Water bodies	589.0	190.6	32.4	779.6	1200.9	154.0	1980.5	1391.5	236.2
Total	***843290.1***			***843290.1***			***843290.1***		

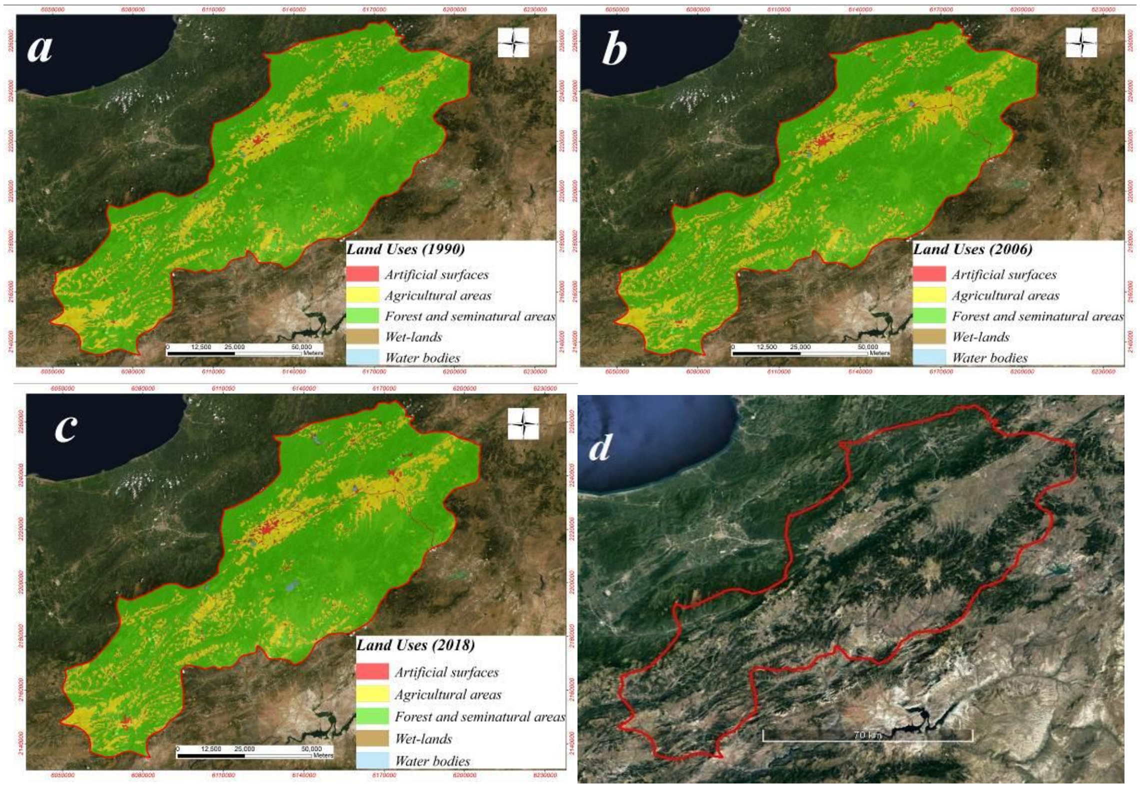

Figure 3. LULC classes for 1990 (a), 2006 (b) and 2018 (c) according to CORINE data and Bolu province 2018 satellite image (d)

When the LULC classes transitions between the periods are examined, it is seen that the largest area transformation was from forest and semi-natural areas to agricultural areas (21949.57 ha) between 1990 and 2006. There was a transition from the forest and semi-natural areas to artificial surfaces in 1829.74 ha. While 14048.27 hectares have been transformed from agricultural areas to forest and semi-natural areas, 3528.82 hectares have been transferred from agricultural areas to artificial surfaces. From the artificial surface, especially after the 1999 earthquake, a total of 2304.3 hectares of land has been transformed to agricultural areas. An area of 222.3 hectares from artificial surfaces has also been transformed into forest and semi-natural areas. In this period, 86.76 ha of agricultural areas and 135.76 ha of forest and semi-natural areas were transformed into wetlands. In addition, 8.85 ha water bodies were also converted to wetlands. During this period, 21.77 ha of agricultural land and 183.63 ha of forest and semi-natural areas were converted to water bodies (Table 2).

Table 2. Transformations of land-use classes between 1990 and 2006

	LULC classes	2006						
		Artificial surfaces (ha)	Agricultural areas (ha)	Forest and semi-natural areas (ha)	Wetlands (ha)	Water bodies (ha)	Total (ha)	%
1990	Artificial surfaces (ha)	3353.77	2304.30	222.31	0.34	0.69	5881.40	***0.70***
	Agricultural areas (ha)	3528.82	175507.3	14048.2	86.76	21.77	193192.9	***22.91***
	Forest and semi-natural areas(ha)	1829.7	21949.5	619173.7	135.76	183.63	643272.4	***76.28***
	Wetlands (ha)	1.18	161.88	73.39	112.19	5.64	354.28	***0.04***
	Water bodies (ha)	0.05	4.57	7.65	8.85	567.92	589.03	***0.07***
	Total (ha)	***8713.56***	***199927.68***	***633525.32***	***343.90***	***779.65***	***843290.11***	***100.0***
	%	***1.03***	***23.71***	***75.13***	***0.04***	***0.09***	***100.0***	

In the period 2006 to 2018, wh ile 7373.8 hectares transitioned from forest and semi natural areas to agricultural areas, there were 7216.1 hectares of transition from agricultural areas to the forest and semi-natural areas. In particular the decrease in the population in rural areas and the lack of cultivation of agricultural lands has led to the emergence of woody vegetation in those areas. In this period, the population of Bolu province increased by about 15% and while 42% (112.479 people) of the total population lived in rural areas in 2006, this rate decreased to 29% (91.536 people) in 2018 (TUIK, 2021). During this period, 1554.5 hectares of agricultural land were converted to artificial surfaces, while 1053.6 hectares of forest and semi-natural areas were converted to artificial surfaces. In addition, in this period, there was a transition of 212.6 ha from agricultural areas and 982 ha from forest and semi natural areas to water bodies, which increased approximately 2.5 times (Table 3).

Table 3. Transformations of LULC classes between 2006 and 2018

	LULC classes	2018 Artificial surfaces (ha)	Agricultural areas (ha)	Forest and semi-natural areas (ha)	Wetlands (ha)	Water bodies (ha)	*Total (ha)*	*%*
2006	Artificial surfaces (ha)	8068.5	428.4	184.5	1.5	30.7	***8713.6***	***1.0***
	Agricultural areas (ha)	1554.5	190909.6	7216.1	34.9	212.6	***199927.7***	***23.7***
	Forest and semi-natural areas (ha)	1053.6	7373.8	624110.3	5.6	982.0	***633525.3***	***75.1***
	Wetlands (ha)	0.3	12.1	3.9	323.6	4.0	***343.9***	***0.0***
	Water bodies (ha)	1.6	8.8	12.1	5.8	751.3	***779.6***	***0.1***
	Total (ha)	***10678.5***	***198732.8***	***631526.9***	***371.4***	***1980.5***	***843290.1***	***100.0***
	%	***1.3***	***23.6***	***74.9***	***0.0***	***0.2***	***100.0***	

When the changes in LULC classes are analyzed in the 28 years between 1990 and 2018, it is seen that 42.3% of the total area of artificial surfaces has been transformed from agricultural areas and 25.62% from forest and semi-natural areas. In agricultural areas, there are areas transformed from the forest and semi-natural areas at a rate of 11.74% and artificial surfaces at a rate of 1.12%. In forest and semi natural areas, there is an area of 2.43% gained from agricultural areas in these 28 years. While the wetland areas were converted from forest and semi natural areas at a rate of 37.04%, the rate of 29.54% was gained from agricultural areas. Water bodies were converted from forest and semi-natural areas at a rate of 61.61%, and from agricultural areas at a rate of 9.57% (Table 4). When the transitions in LULC classes are examined in the 28 years, it is seen that the artificial surfaces have passed to agricultural areas at a rate of 37.7% and forest and semi-natural areas at a rate of 4.1%. As for agricultural areas, 2.34% turned to artificial surfaces and 7.95% to the forest and semi-natural areas. There was a transition from the forest and semi-natural areas to agricultural areas at a rate of 3.63% and artificial surfaces at a rate of 0.43%. Of the areas converted to wetlands, 45.34% are agricultural areas, 21.27% are forest and semi-natural areas. In the water body LULC class, 1.02% was converted to agricultural areas and 1.7% to wetlands (Table 4).

Table 4. Transformations of LULC classes between 1990 and 2018

	LULC classes	2018 Artificial surfaces (ha)	*%*	Agricultural areas (ha)	*%*	Forest and semi-natural areas (ha)	*%*	Wetlands (ha)	*%*	Water bodies (ha)	*%*	Total (ha)	*%*
1990	Artificial surfaces (ha)	3420.1	***58.2***	2221.4	***37.7***	239.6	***4.1***	0.2	***0.0***	0.0	***0.0***	5881.4	***0.7***
	%	***32.0***		***1.1***		***0.0***		***0.1***		***0.0***			
	Agricultural areas (ha)	4520.8	***2.3***	173017.8	***89.6***	15355.1	***7.9***	109.7	***0.1***	189.5	***0.1***	193193.0	***22.9***
	%	***42.3***		***87.1***		***2.4***		***29.5***		***9.6***			
	Forest and semi-natural areas (ha)	2735.7	***0.4***	23327.0	***3.6***	615852.0	***95.7***	137.6	***0.0***	1220.2	***0.2***	643272.4	***76.3***
	%	***25.6***		***11.7***		***97.5***		***37.0***		***61.6***			
	Wetlands (ha)	0.8	***0.2***	160.6	***45.3***	75.3	***21.3***	113.6	***32.1***	3.9	***1.1***	354.3	***0.0***
	%	***0.0***		***0.1***		***0.0***		***30.6***		***0.2***			
	Water bodies (ha)	1.0	***0.2***	6.0	***1.0***	4.8	***0.8***	10.3	***1.7***	567.0	***96.3***	589.0	***0.1***
		0.0		0.0		0.0		2.8		28.6			
	Total (ha)	***10678.5***		***198732.8***		***631526.9***		***371.4***		***1980.5***		***843290.1***	***100***
	%	***1.3***		***23.6***		***74.9***		***0.0***		***0.2***		***100***	

Between 1990 and 2018, 2461.3 ha from artificial surfaces, 20175.2 ha from agricultural areas, 27420.5 ha from the forest and semi-natural areas, 240.64 ha from wetlands, and 22.08 ha from water bodies were transformed into a different LULC class. The areas that have been transformed in the 28 years and the spatial distribution of which LULC class those have transitioned to are given in Figure 4.

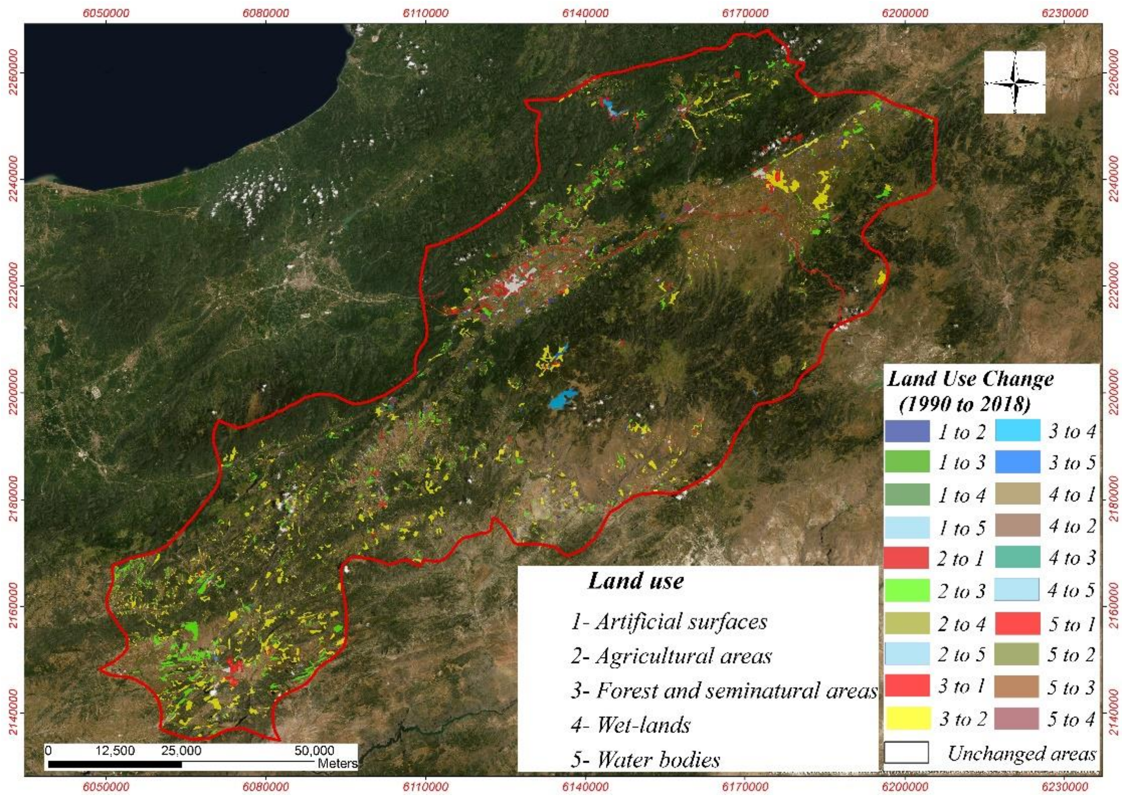

Figure 4. Areas that transitioned to a different LULC class between 1990 and 2018

Results of Carbon Storage

Within the scope of the study, after the LULC class transitions and distributions determined using CORINE data, the carbon amounts stored in the AGB according to the LULC classes in 1990 and 2018 were determined using NDVI image. In the province of Bolu, there has been an increase of approximately 59.5% in the total amount of carbon stored in the AGB according to the LULC classes over 28 years. While a total of 1583467.3 tons of carbon was stored in the AGB in 1990, this amount increased to 2664549.5 tons of carbon in 2018. While 82.5% of the total stored carbon was stored in forest and semi-natural areas in 1990, about 17% was stored in agricultural areas. In 2018, 76.3% of the total stored carbon amount was stored in the forest and semi-natural areas, while 23.0% was stored in agricultural areas. On the artificial surfaces, where 0.5% carbon was stored in 1990, 0.7% carbon was stored in 2018. Although the percentage of wetland and water bodies was low in LULC classes, carbon storage amounts increased (Table 5).

Table 5. Amounts of carbon stored in the AGB of LULC classes in 1990 and 2018

LULC classes	1990 Carbon (ton)	%	2018 Carbon (ton)	%
Artificial surfaces	7785.5	0.5	18638.0	0.7
Agricultural areas	268593.6	17,0	610456.9	23,0
Forest and semi-natural areas	1306170.8	82.5	2032487.1	76.3
Wetlands	870.7	0.05	1122.6	0.04
Water bodies	46.6	0.00	1844.8	0.1
Total	***1583467.3***	***100.0***	***2664549.5***	***100.0***

When the net carbon accumulations occurring in the AGBs of the LULC classes over the 28 years are examined, it has been determined that 1000151.7 tons of carbon are kept in the lands that have not been transformed. 80930.6 tons of carbon was transferred from one LULC class to another over the transformed lands. In total, 1081082.3 tons of carbon have accumulated over 28 years. A total of 4332.4 tons of carbon has been transferred over the areas that have passed from other LULC classes to artificial surfaces. The highest carbon transfer to artificial surfaces was from agricultural areas at 3885.4 tons. A total of 6520.1 tons of carbon has accumulated in green plants or trees on existing artificial surfaces. While a total of 341863.3 tons of carbon accumulated occurred in agricultural areas, 306805.5 of them occurred in existing agricultural areas. A total of 35057.8 tons of carbon has accumulated in different classes previously agriculture areas with 26331.5 tons in forest and semi-natural areas and 8406.9 tons in areas converted from artificial surfaces to agriculture. While a total of 341863.3 tons of carbon accumulated in agricultural areas, 306805.5 of them occurred in existing agricultural areas. While 251.9 tons of carbon accumulated in wetlands, 159.7 of this was gained from areas converted from agricultural lands. A total of 1798.2 tons of carbon accumulation occurred in water bodies, and the majority of this (1731.4 tons) was accumulated from existing water bodies (Table 6).

Table 6. Net carbon accumulations and carbon transfers at LULC class transitions between 1990 and 2018

		2018 (Carbon (ton))						
LULC classes		**Artificial surfaces**	**Agricultural areas**	**Forest and semi-natural areas**	**Wetlands**	**Water bodies**	***Total***	***Transferred Carbon (ton)***
1990	Artificial surfaces	6520.1	3885.44	446.47	0.46	0.03	***10852.5***	***4332.4***
	Agricultural areas	8406.94	306805.46	26331.49	91.19	228.17	***341863.26***	***35057.79***
	Forest and semi-natural areas	3908.43	35211.27	685007.82	166.54	2022.26	***726316.32***	***41308.5***
	Wetlands	1.07	159.73	4.06	86.85	0.25	***251.97***	***165.11***
	Water bodies	2.44	19	12.42	32.93	1731.44	***1798.24***	***66.79***
			Total				***1081082.3***	***80930.6***

DISCUSSION AND CONCLUSION

The changes in LULC classes of Bolu province in 1990, 2006, and 2018 were determined for five base LULC classes by using CORINE data. In addition, for the years 1990 and 2018, the carbon amounts stored according to the LULC classes were calculated by using the NDVI maps. According to the study, there has been an increase of 81.56% in the artificial surfaces of LULC classes in 28 years. Especially in recent years, the increase in the population in the city has caused an increase in artificial surfaces along with the housing problem. In the study conducted by Arslan and Örücü (2019), in the Bodrum district of Muğla, they determined that there was a serious increase in the LULC class of artificial surfaces and that there was a serious transformation from agricultural areas to artificial surfaces. In 28 years, there has been an increase of 2.87% (5539.8 ha) in agricultural areas in the province of Bolu. In particular, the pressure of people on forest and semi-natural areas and the conversion of these areas into agricultural areas is widespread in our country. This situation was also demonstrated in this study. Üyük et al. (2020) examined the change in LULC classes with CORINE data in Denizli and determined that there was an increase of 2.83% in agricultural areas. Forest and semi-natural areas decreased by 1.83% (11745.5 ha) in total between 1990 and 2018. In this study, according to CORINE data, only forest and semi-natural areas decreased among five basic LULC classes. This is due to the intense conversion of forest and semi-natural areas to other land classes. Although the decrease seems low in percentage, there is a serious decrease in forest and semi-natural areas. Yıldırım and Ortaçeşme (2016) obtained similar results in their study in Manavgat, Antalya, and determined that there was a decrease in forest and semi-natural areas and an increase in agricultural areas.

Of these three periods, the 1990-2006 period, which included the year 1999, when the big earthquake was experienced, was more likely to change the land. With the effect of the earthquake, the transitions between agricultural areas and artificial surfaces were excessive in this period. Of the total 7256.5 ha area converted to an artificial surface in 28 years, 62% (4520.8 ha) was made from agricultural lands, and 38% (2735.7 ha) from forest and semi-natural areas. Approximately 91% (23327 ha) of the total 25715 ha area converted to agriculture is from forest and semi-natural areas, and 9% (2221.4 ha) is from artificial surfaces. Water bodies have also increased approximately 2.5 times in this period, especially in the 2010s, due to the construction of ponds for irrigation purposes. 87% of the ponds are built in the forest and semi-natural areas.

According to LULC classes in Bolu province, the total amount of carbon stored in the AGB increased by 59.5% between 1990 and 2018. The most important factor in this increase is the increase in the amount of AGB accumulated in forest and semi-natural areas and the forests are the most important carbon sink. While the total amount of biomass in Bolu province was approximately 40 million ton in 2006, it increased to approximately 55 million ton in 2020 (OGM 2006, OGM 2020). The remaining part of the total carbon is captured by annual and perennial plants in agricultural areas and green areas on artificial surfaces. Green vegetation on artificial surfaces, vineyards, gardens, and trees in parks and roads store carbon. In CORINE LULC classes, artificial surfaces are divided into two as continuous urban structures and discontinuous urban structures. It is normal for carbon to be stored on artificial surfaces, especially since the surrounding residential areas such as the city center and Bolu are intertwined with green vegetation. According to Ariluma et al. (2021), in a study conducted in Helsinki, Finland, revealed that green areas, especially in residential areas, store carbon. Similarly, Tang et al. (2016) also determined that the trees on the streets in Beijing, China store carbon. Green areas, especially on artificial surfaces, contribute to carbon storage (Ariluma et al. 2021, Tang et al. 2016). Water bodies contribute to carbon storage, though to a lesser extent. Especially the materials and organisms carried to the lakes cause the accumulation of carbon in the lakes. Skwierawski (2022), tried in his study in 8 different shallow lakes in Poland, to determine the accumulated carbon in the lake and determined that 275.5 g of carbon was stored in an area of approximately 4047 m2. In net carbon accumulations in AGBs over 28 years, a total of 1000151.7 tons of carbon have accumulated in the unchanged LULC classes. With the changes and transformations in LULC classes, a total of 80930.6 tons of carbon was transferred between LULC classes. In this situation, it is seen that there is carbon loss or carbon gain depending on the transformation in the transformed lands.

It is important that the LULC classes are in a constantly dynamic structure and that the changes are revealed at certain periods, especially in terms of determining their effects on global warming. It is also an important source of information in planning to reduce CO_2, which is one of the most important stakeholders in global warming. Forests are the most important carbon sink among terrestrial ecosystems, and measures should be taken not to reduce the amount of forests and natural areas. The positive or negative results of changes in carbon storage capacities according to LULC classes should be evaluated and plans should be made to increase carbon storage capacity on LULC classes. Studies should be conducted on different plant vegetation indices to determine carbon amounts using satellite images. The number of studies on the NDVI vegetation index should also be increased. Activities that will cause carbon loss in agricultural areas should also be avoided.

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