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Determining the effects of changes in land use on carbon storage in above-ground biomass with NDVI

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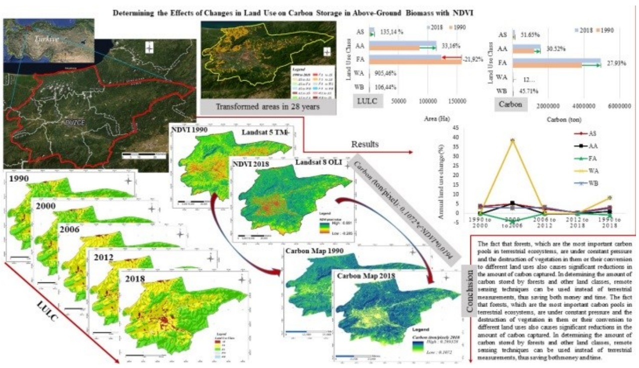
Graphical abstract



Abstract

In terms of sustainable land use management, it is extremely important to reveal the land conditions and the changes that occur on the land in certain periods. In this study, using CORINE data for Düzce province, land use status and transitions between land-use classes over 28 years were investigated. In addition, changes in carbon storage in above-ground biomass were determined for each land-use and land transition using Landsat satellite images for the years 1990 and 2018. 28 years, artificial surfaces increased from 3,852 hectares to 9,058 hectares. While agricultural areas increased by 11.5% to 114,650 hectares, forest and semi-natural areas decreased by 14% to 122,955 hectares. 96.7% of the increase in agricultural areas was land converted from forest areas. While the amount of carbon stored in the forest and semi-natural areas increased by 27.9%, it increased by 30.5% in agricultural areas. With land transitions, 17.8% of the total carbon (14,407 tons) was transferred from one land use to another. In terms of annual land-use change rate between 1990 and 2018, the highest rate of land-use change was in the post-earthquake 2000-2006 period. The information in this study will make important contributions to policymakers in land management and planning.

Keywords: Düzce, land use, above ground biomass, carbon storage, NDVI

1. Introduction

In a world where natural resources are depleted and human needs and desires are unlimited, it is necessary to examine the changes in land use over time and to reveal these changes in certain periods in order to ensure the sustainability of the land and to contribute to the more conscious use of land by people. In recent years, due to the development of industry and population growth, the use of the natural environment in different ways has increased and, especially in economic activities, has gained diversity (Bayar and Karabacak 2017; Özçağlar 1994).

City centers and surrounding areas are the most variables in terms of land use. The expansion of industrial activities or residential areas in these areas by destroying forest areas is one of the most common events. Change in land use should not be considered as an event in itself, and it should not be forgotten that it is also related to objects or phenomena adjacent to these lands. Overuse or misuse of land brings with it problems such as erosion, salinization, deterioration, desertification, soil, water, and air pollution (Başayiğit 2004).

With developing technology, remote sensing techniques are used intensively to determine land use classes and to obtain the fastest and most accurate information about both the past and current situation of the land. Many researchers benefit from using remote sensing (RS) technology and geographic information systems (GIS) to create land use classes (Arslan and Örücü 2019; Chou et al. 2005; Dwivedi et al. 2005; Göksel 1998; Seker et al. 2003; Sönmez et al. 2009; Siyavuş 2021). With the techniques used in these studies and the developing science, RS techniques are also used to determine the CORINE (Coordination of Information on the Environment) land use classes (Sommer et al. 1998).

While revealing the land changes in terrestrial ecosystems, there are also differences in the amount of carbon retained with these changes. In terrestrial ecosystems, the soil and the vegetation on the soil surface sequester carbon. The vegetation cover that can store carbon in its body consists of forests, grassland, pastures, and agricultural areas. The principal factors affecting the amount and duration of carbon retained in terrestrial ecosystems are climate, vegetation type, soil characteristics, erosion, and changes in bedrock and land use (Basaran 2004). Changes in vegetation cover, especially with land use, affect the amount of carbon stored in that land use class positively or negatively during the transition from one land use class to another. By using CORINE basic land use classes, the carbon storage in the aboveground vegetation of these land use classes can be determined through RS techniques and satellite images. NDVI (Normalized Difference Vegetation Index) maps are used extensively, especially in determining the amount of carbon stored in above-ground biomass. Studies have shown that the NDVI is a valuable tool for measuring vegetation biomass and land cover changes (Sellers 1987; Lyon et al. 1998; Boelman et al. 2003; Cutler et al. 2012; Lu et al. 2012). The major limitation of the NDVI approach is that it only allows the estimation of aboveground biomass and thus aboveground carbon. Baniya et al. (2018) measured the carbon dynamics in Nepal forests using NDVI satellite images and a biomass carbon density estimation model, and as a result, they found that carbon amounts tended to increase between 1982 and 2015. Myeong et al. (2006) obtained NDVI images using the time series of Landsat image data from different years (1985–1999) and developed a regression equation to predict urban forest carbon storage using NDVI satellite images. Atak and Tonyalıoğlu (2019) used NDVI satellite images to determine the carbon storage potential of Aydin province between 1990 and 2017.

Different methods are used to determine carbon storage in the above-ground biomass. Polat et al. (2011) calculated biomass and carbon storage by using seven different forest enterprises' forest management plan data in approximately 100.500 ha forest area in Tarsus Forest Sub-District Directorate. Tolunay (2011) examined the carbon stocks in the forests of Turkey by using the national forest inventory data for Turkey. In addition, annual carbon accumulations in aboveground and belowground biomass in Turkish forests were investigated according to the gain-loss method. Çömez (2012) and Parajuli and Chang (2012) found and modeled the biomass and carbon storage coefficients developed for different tree species in their studies. The most commonly used method for determining carbon storage in Türkiye is to use stand maps taken from forest management plans and multiply the growing stock values of each forest stand with various transformation coefficients (Sivrikaya et al. 2007; Keleş et al. 2011; Sivrikaya and Bozali 2011; Sivrikaya et al. 2013; Değermenci and Zengin 2018).

This study aimed to determine land use change and the transitions between land use classes, especially in Düzce, where land transformation accelerated with the earthquake and population growth was experienced with industrialization. In addition, the effects of changes in land use on the amount of stored carbon were determined. A systematic examination of these changes and transformations will provide basic information for the roadmap to be prepared for the protection of natural resources and agricultural areas and the determination of the amount of carbon released and stored. For this purpose, according to the CORINE land use types of artificial surfaces (AS), agricultural areas (AA), forest and semi-natural areas (FA), wetland areas (WA) and water bodies (WB) in Düzce, the areal changes in 1990, 2000, 2006, 2012, and 2018 and the transitions between land use classes were examined. In addition, NDVI maps were created for these two periods by using Landsat satellite images for the years 1990 (Landsat-5 TM) and 2018 (Landsat-8 OLI), and they were aimed at determining the carbon amounts in land use classes.

2. Materials and methods

The province of Düzce, which was determined as the study area, is located in the northwest of Turkey, between the metropolises of Istanbul and Ankara. Düzce is geographically located in ED50 UTM Zone 36N, between latitudes 40°53'29" - 41°00'19" N and longitudes 31°16'58" - 31°12'37" E (Figure. 1). Düzce, which is a city built on a plain consisting of first-class alluvial soils and surrounded by mountains to the north and south, is very rich in natural vegetation. The province, where agricultural areas and forest areas are densely distributed, has a coastline and an altitude of up to 1850 m above sea level. In the coastal part, maquis and pseudo-maquis are spread as vegetation. In the mountains behind the coast, deciduous tree species such as hornbeam *(Carpinus betulus),* beech *(Picea orientalis),* chestnut *(Castanea sativa),* and oak *(Quercus* sp*)* are spread. While deciduous tree species are found at lower elevations in the mountains surrounding the Düzce plain, coniferous tree species such as larch *(Pinus nigra*), yellow pine *(Pinus sylvestris)*, and fir *(Abies nordmanniana)* are found at higher elevations. The annual average temperature is 13.0 °C, the average annual total precipitation is 839.4 kg/m², and the average relative humidity is 76% (Kesim 1996).

Figure 1. Location of the study area

2.1. Determination of land use according to CORINE data.

CORINE is a land use classification method that is intended to eliminate negative effects on land cover. This method has been adopted and accepted by many European countries. CORINE, with its environmental policies, aims to collect information on the situation of special environments; the geographical distribution and current situation of natural areas; the quality and quantity of water resources; the condition and structure of the soil; and the level of waste dumped into the environment (CORINE 1997). CORINE data was downloaded in raster format from Copernicus Land Monitoring Service (https://land.copernicus.eu/pan-european/corine-land-cover) and cropped according to Düzce provincial borders. CORINE data was converted into vector data with ArcGIS 10.4™ software and land use classes were determined over the years. The CORINE land cover classification system consists of 5 basic classes and 44 subclasses. In this study, changes in land use classes over 28 years were determined according to 5 basic land use classes (Table 1).

Table 1. CORINE land cover classes used in this study (CORINE 1997)

Land Use	Subclasses determined by CORINE in the study area
1. Artificial surfaces (AS)	Continuous urban fabric, discontinuous urban fabric, industrial or commercial units, road networks and associated land, construction sites, sport and leisure facilities, Construction sites, Mineral extraction sites,
2. Agricultural areas (AA)	Non-irrigated arable land, permanently irrigated land, fruit trees and berry plantations, complex cultivation patterns, Land principally occupied by agriculture, with significant areas of natural vegetation, Pastures
3. Forest and seminatural areas (FA)	Broad-leaved forest, Coniferous forest, Mixed forest, Natural grasslands, Transitional woodland-shrub, Beaches, dunes, sands, Sparsely vegetated areas
4. Wet-lands (WA)	Inland marshes
5.Water bodies (WB)	Water cources, water bodies, Sea and ocean

The following equation developed by Puyravaud (2003) was used to determine the annual rate of change in land use by periods.

$$P = \frac{1}{(t2 - t1)} * Ln(\frac{A2}{A1}) \quad (1)$$

In the equation, t_1 and t_2 show the years, while A_1 and A_2 show the areas of land use classes in the respective years.

ArcGIS 10.4™ software was used to transform and record land use data for each period and also to determine the spatial and areal distributions between land use classes by periods.

2.2. Preparation of landsat satellite images for analysis

In addition to the spatial changes in Düzce province according to the main land use classes, it was aimed to analyze and evaluate the temporal variation of the carbon amount stored in each land use class and at the transitions between land use classes. For this purpose, Landsat 5 (TM) and Landsat 8 (OLI) satellite images for 1990 and 2018 for Düzce province were used. Landsat Level I images of May, when vegetation is visible and cloudiness is low, were used for both years. The images used were downloaded online free of charge from the United States Geological Survey (USGS 2021). Landsat 8 OLI satellite entered orbit in February 2013 and It collects spatial resolution data of 30 m in multispectral (Band1-7, Band 9) and Thermal Infrared Sensor (TIRS) (Band 10, Band 11) bands and 15 m in a panchromatic band (Band 8). Landsat 5 TM has 6 bands (Band1-5 and Band 7) with a resolution of 30 m in the visible NIR and SWIR and a Thermal Band (Band 6) with a resolution of 120 m (USGS 2021). Landsat satellite image raw data was saved as DN (Digital Number). The necessary radiometric corrections were made for these DN values using ENVI 5.3 software. Radiometric corrections were made according to the method used by Canty (2014). Atmospheric corrections of the radiometrically corrected satellite images were made using the QUAC (Quick Atmospheric Correction) module in the ENVI 5.3 software.

In the study, NDVI images were used to determine the carbon storage potential in land use classes. To obtain NDVI images, bands 3 (red) and 4 (near-infrared) of the Landsat 5 satellite image and band 4 (red) and band 5 (near-infrared) bands of the Landsat 8 satellite image were used (eq. 2).

$$NDVI = \frac{NIR - R}{NIR + R} \quad (2)$$

In the equation: NDVI=normalized difference vegetation index, NIR = near-infrared band, R=red band.

NDVI values vary between (-1) and (+1), and as the index value approaches (+1), it indicates more green vegetation, while an NDVI value close to (0) indicates openness and low vegetation cover. In the case of cloudiness, water, and snow on the satellite image, the NDVI value is close to (-1). The NDVI images produced by using Landsat satellite images of the study area from 1990 and 2018 are given below (Figure 2).

2.3. Determination of carbon storage above-ground biomass

In this study, NDVI satellite images were used to determine the carbon storage in the above-ground biomass according to the CORINE basic land use classes. For this purpose, the method developed by Myeong et al. (2006) was utilized. With this method, the amount of carbon stored in the above-ground biomass in very large areas can be determined quickly and effectively.

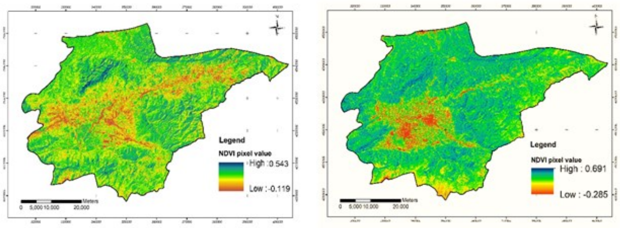


Figure 2. NDVI satellite image of 1990 was obtained from Landsat 5 satellite image (left) and the NDVI satellite image of 2018 was obtained from Landsat 8 satellite image (right)

The temporal and spatial changes can be determined quickly on the satellite image, and the amount of carbon stored by each pixel in the satellite image can be determined. The following relationship was used to determine the amount of carbon stored in each pixel (Myeong et al. 2006).

$$Carbon\left(tons\,/\,pixel\right) = 0.1072 * e^{NDVI*0.0194} \quad (3)$$

After determining the amount of carbon stored in each pixel using the relationship in Equation 3, the total carbon amounts for the main land use classes were calculated using the ArcGIS zonal statistics tool. The creation of maps and various registration processes were also carried out using ArcGIS 10.4^{TM} software.

3. Results

Changes in land use status for five periods (1990, 2000, 2006, 2012, 2018) and land transitions are primarily discussed. Along with the areal change, the carbon amounts stored in the above-ground biomass are given under separate headings for two periods (1990, 2018).

3.1. Land uses by periods

The changes in land use for five periods according to the basic land conditions were examined. While AS covered 1.55% (3,852 ha) of Düzce's total surface area in 1990, they increased in every period and increased to 3.65% (9,058 ha) in 2018. There was an increase of approximately 135% in AS in the 28 years. While AA covered approximately 34% (86,097 ha) of the entire area in 1990 and 2000, an increase of approximately 11.5% occurred in AA in 2006. Thus, 46% (116,265 ha) of Düzce's total surface area was covered with AA. AA increased by 33.1% in the 28 years. FA constitutes the highest land use type in Düzce. While approximately 64% (157,482 ha) of the entire area was covered with FA in 1990 and 2000, a decrease of approximately 22% occurred as of 2006. In the 28 years, approximately 49% (122,955 ha) of the entire area was composed of FA (Figure 3). There was an approximately 10-fold increase in the WA from 1990 to 2018. These areas, which correspond to approximately 2 per thousand (40 ha) of the entire area, increased tremendously, increasing to approximately 2% (408 ha) in 28 years. There was also an increase in WB in all years, and the rate, which was 1.5% (379 ha) in 1990, increased in other periods as well, reaching 3.2% (782 ha) in 2018 (Table 2).

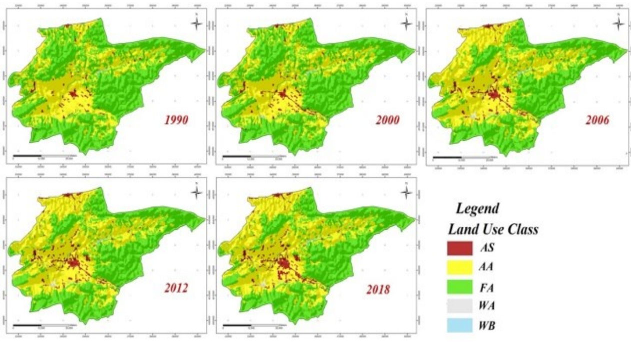


Figure 3. Change of land use classes in Düzce over the years

Table 2. Basic land use by periods

Land Use	1990		2000		2006		2012		2018	
	Area (ha)	Percent %	Area (ha)	Percent %	Area (ha)	Percent %	Area (ha)	Percent %	Area (ha)	Percent %
AS	3852	1.55	5594	2.26	7583	3.06	8798	3.55	9058	3.65
AA	86097	34.74	84360	34.04	116265	46.91	114753	46.3	114650	46.26
FA	157482	63.54	157324	63.48	122962	49.61	123128	49.68	122955	49.61
WA	40	0.02	40	0.02	408	0.16	405	0.16	405	0.16
WB	379	0.15	532	0.21	632	0.26	766	0.31	782	0.32
TOTAL	247851	100	247851	100	247851	100	247851	100	247851	100

3.2. Transitions between land uses by period

The transitions between land use that occurred in five periods were examined. Between 1990 and 2000, 7.1 hectares of AS were converted into AA. There was a land use transition of 1,478.8 hectares of AA to AS, and there was an increase of 45.2% in AS in this period. While there was a very small decrease in agricultural, FA in this period, there was an increase of 40.5% in the WB land use type. The period between 2000 and 2006 was the period with the highest land use class transition. A transition of 142.6 hectares from AS to AA was realized. The appearance of these lands as AA as a result of the removal of building debris in many parts of the city, which was destroyed after the large earthquake that took place towards the end of 1999, was a significant factor. During this period, 312.1 hectares of agricultural land were converted to AS. In particular, those whose houses were destroyed after the earthquake built their houses on different lands and preferred agricultural lands for this, which was effective in the transition of agricultural lands to AS. AS increased by

35.6% in this period. There was a transition of 1099.5 hectares from AA to FA. The Black Sea geographical region, especially uncultivated and empty AA, can be covered with forest vegetation in a short time. There was a transition from AA to WA, 220.4 hectares of which were under water. With this transition, the WA increased approximately 9 times. Declaring the vicinity of Efteni Lake as a wildlife protection area in this period was a factor in this transition. In this period, 366.1 hectares of were transitioned to AS and 34,933.1 hectares to AA. With this transition, FA decreased by 21.8%, while AA increased by 37.8%. In many areas in Düzce, forests are put under pressure for the construction of hazelnut groves and orchards. In this period, especially in the north of Düzce, a large amount of forest was converted into AA. In the 2006–2012 and 2012–2018 periods, there was a total increase of 19.4% in AS. There was an increase of 23.7% in total in the land use class of WB. While there was a very small increase in FA, there was a 1% decrease in other agricultural and WA (Table 3).

Table 3. Changes in land use status by periods

Land Use	1990		2000		2006		2012		2018	
	Area (ha)	Percent %	Area (ha)	Percent %	Area (ha)	Percent %	Area (ha)	Percent %	Area (ha)	Percent %
AS	3852	1.55	5594	2.26	7583	3.06	8798	3.55	9058	3.65
AA	86097	34.74	84360	34.04	116265	46.91	114753	46.3	114650	46.26
FA	157482	63.54	157324	63.48	122962	49.61	123128	49.68	122955	49.61
WA	40	0.02	40	0.02	408	0.16	405	0.16	405	0.16
WB	379	0.15	532	0.21	632	0.26	766	0.31	782	0.32
TOTAL	247851	100	247851	100	247851	100	247851	100	247851	100

When the changes that occurred according to basic land use classes in Düzce in the 28 years between 1990 and 2018 are examined, it is seen that there was an increase of approximately 135.1% (5,205.85 ha) in AS. In this process, the areas subject to the increase in AS were converted from AA at a rate of 86.5% and from the FA at a rate of 13.3%. Especially in recent years, with the increase in urbanization and industrialization due to the increasing population and housing demand, there have been significant transitions from AA to AS. In this period, an area increases of 33.2% (28,552 ha) occurred in AA. While 96.7% of these lands, which were converted into AA, were converted from FA, 3.2% were transitioned from AS to AA. A decrease of approximately 21.9% (34,526 ha) occurred in FA. 96.7% of this decrease in FA was land turned into AA. There was a 10-fold increase in the WA, and 99% of this increase was land converted from agricultural lands. While there was an increase of more than 2 times in the land use class of WB in this period, 48.7% of this increase was land converted from FA, while 50.5% was land converted from AA (Table 4).

Table 4. Transitions in the land use situation over the 28 years

Land Use		2018 Area (ha)											
		AS	%	AA	%	FA	%	WA	%	WB	%	Total	%
1990 Area (ha)	AS	2656.87	69.0	1155.70	30.0	35.01	0.9	0.00	0.0	4.47	0.1	3852.05	1.6
	%	*29.3*		*1.0*		*0.0*		*0.0*		*0.6*			
	AA	5539.3	6.4	78763.4	91.5	1211.26	1.4	368.18	0.4	215.08	0.2	86097.3	34.7
	%	*61.2*		*68.7*		*1.0*		*90.9*		*27.5*			
	FA	853.19	0.5	34713.5	22.0	121707.5	77.3	0.53	0.0	207.11	0.1	157481.9	63.5
	%	*9.4*		*30.3*		*99.0*		*0.1*		*26.5*			
	WA	0.00	0.0	3.82	9.5	0.00	0.0	36.51	90.5	0.00	0.0	40.33	0.0
	%	*0.0*		*0.0*		*0.0*		*9.0*		*0.0*			
	WB	8.47	2.2	13.22	3.5	1.64	0.4		0.0	355.57	93.8	378.90	0.2
	%	*0.1*		*0.0*		*0.0*		*0.0*		*45.5*			
	Total	9057.9		114649.7		122955.4		405.22		782.22		247850.5	100.0
	%	3.7		46.3		49.6		0.2		0.3			

In these 28 years in Düzce province, while the AA, AS, WA, and WB land use classes increased, there was a decrease in FA (Figure 4). Between 1990 and 2018, 17.8% (44,330.5 ha) of the entire Düzce area was transformed and transitioned from one land use class to another (Figure 5). The percentage of the areas that were unchanged in the 28 years was 82.2% (203,519.9 ha). As of 2018, 46.3% of the entire area consists of agricultural lands, 49.6% consists of FA, while 3.7% of the remaining 4.2% consists of AS. 0.5% of Düzce's area is covered by the land use classes of WA and WB.

When the percentages of changes in land use by periods are analyzed, it is seen that there were significant increases in the percentages of change in land use, especially in the period immediately following the large earthquake (1999, M:7.2), 2000-2006. It was determined that the highest percentages of change were observed in all land use classes in this period. New houses were built on agricultural fields in Düzce province, which was especially destroyed by the earthquake. FA was also converted into AA in large quantities during this period. Such factors caused the highest percentage of change to occur in this period. While a negative 4.1% annual change occurred in FA, it was determined that there were positive changes in other land use classes. While percentages of change of approximately 5% per year were observed in AS and AA in this period, a percentage of change of 2.9% was found in the land use class of WB. In the 2000-2006 period, the highest rate of increase occurred in wetlands. The percentage of change increased, especially in 2005, when Efteni Lake and the surrounding AA were declared wildlife protection areas. When evaluated as a 28-year process, while there was a negative annual change of approximately 1% in FA, other land uses had a positive annual change. Annual land change percentages were found to be 8% in WA, 3% in AS, 1% in AA, and 2.5% in water body land use types (Figure 6).

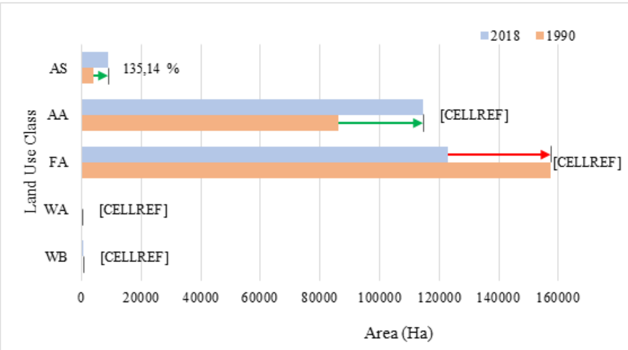


Figure 4. Land use gains and losses of Düzce from 1990 to 2018

3.3. Carbon stored by land use classes in the 28 years

In the province of Düzce, changes occurred in many areas according to the basic land use classes in the 28 years. While there was a decrease in FA, there were increases in other land use classes. In this period, when transitions were experienced at various rates between land use classes, changes also occurred in the amount of carbon stored in the above-ground biomass. There are different pixel reflectance values on satellite images depending on the type of vegetation cover. Normalized difference vegetation index (NDVI) maps were produced for two periods using Landsat satellite images, and the average carbon amounts of each pixel were determined spatially by using the relationship obtained from the previous study (Myeong et al. 2006) on these maps. In the obtained NDVI maps, while light colors indicate low carbon amounts, dark colors indicate high carbon amounts (Figure 7).

The carbon maps obtained were overlaid with the main land use classes, and the total pixels in each land use class and the carbon amounts of these pixels were calculated. The carbon amounts of the pixels in each land use class were collected and the carbon amounts were determined according to the land use classes and the transformations that occurred in the land use classes for both periods.

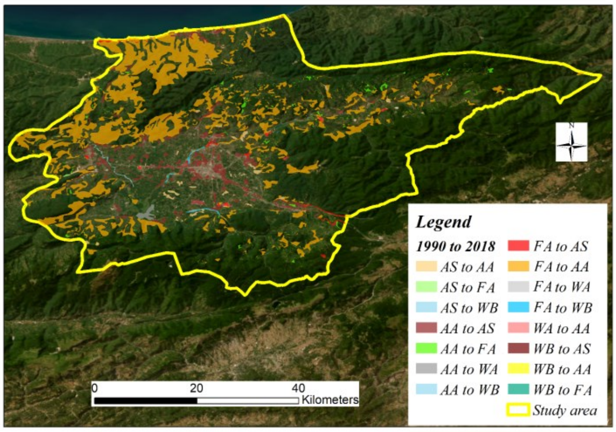


Figure 5. Transitions of land use classes between 1990-2018 in Düzce.

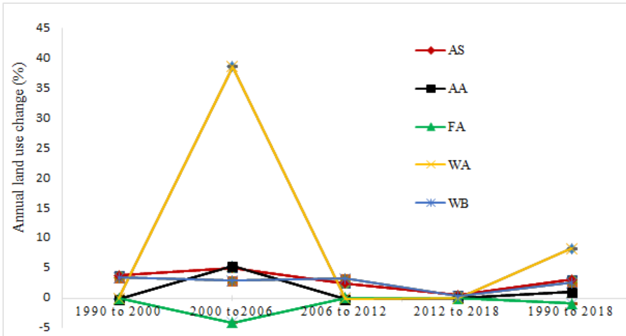


Figure 6. Annual land use change rates by periods

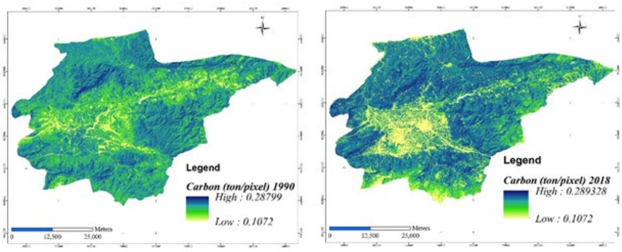


Figure 7. Pixel-based carbon amounts according to the years 1990 (left) and 2018 (right)

When the amount of carbon storage by land use classes is analyzed over this 28-year period, there was an increase of approximately 51.6% in the amount of carbon storage on AS. An increase of 30.5% occurred in the amount of carbon held in AA, in parallel with the increase in AA. Despite the significant decrease in FA, the amount of stored carbon increased by 27.9%. Despite this decrease in FA in 28 years, the increase in the amount of carbon is due to the sustainable forestry practices in forests and especially the increase in thinning operations in forests. Photosynthesis/respiration rate in an unthinned stand is low, which reduces the carbon stored. With the thinning, the amount of light and nutrients per tree in the stand will increase, which will increase the rate of photosynthesis and respiration. Thinning also positively affects the increase in stand volume growth and increases the amount of carbon to be bonded. Özbayram and Çiçek

(2018) conducted a 10-year study to determine the effect of maintenance on stand volume increase and determined that there was an annual volume increase of 15 to 18 m^3 per hectare in two experimental areas. Forests are the most important carbon storage, and they continuously perform this forestry service. Due to the increase in land use in WA, the amount of carbon stored increased by approximately 13 times. There was a 45.7% increase in the amount of carbon stored in WB in this 28 years (Figure 8). In Düzce province, 74.2% of the total carbon stored in the above-ground biomass was stored in FA, and 22.6% in AA. Other land use classes also stored 3.2% of carbon.

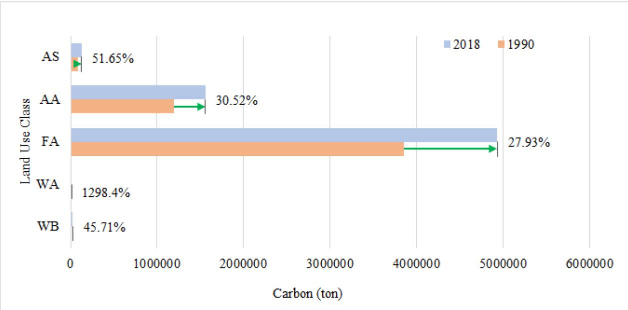


Figure 8. Amounts of carbon stored in above-ground biomass by land use classes in 1990 and 2018

Along with the changes in land use, carbon loss or gain has been observed over the transformed lands. As a result of the transformation from AS to AA and even a very small FA, a total of 48,378.8 tons of carbon was transferred to these lands. However, there was a total loss of 90,572.2 tons of carbon because of the transition from forest and AA to AS, and AS sequestered 90,572.2 tons of carbon. In other words, a total of 90,572.2 tons of carbon was stored in the areas converted to AS. On the other hand, 33,310.5 tons of carbon were stored in the unchanging AS. In particular, according to the CORINE land use classification, it is subclassified as a continuous urban fabric or a discontinuous urban fabric, all of which are considered within AS. It was determined that most of the areas transformed into AS, especially in Düzce province, were in a discontinuous urban fabric. This is one of the most important reasons for carbon storage on AS. Also, in the storage of carbon in areas transformed into AS, the carbon storage of plants such as landscaping, afforestation, parks, community gardens, private yards, and other street trees and shrubs is effective, causing carbon gain on AS.

There were significant land transitions from AA to AS, and therefore, a total of 225,679.5 tons of loss occurred, 34,720.8 tons of which was to AS. Despite this loss in AA, it was the land use class that increased the amount of carbon the most. The main reason for this increase is the fact that there was a large amount of land transition, especially from FA, and a 254,939.1 ton carbon gain from these lands. AA gained 289,288.1 tons of carbon from land conversions in total and stored 1,265,604.6 tons of carbon in their unchanged areas. In FA, significant carbon losses were experienced due to the large transitions to AA. A total of 322,553.8 tons of carbon were transferred from FA to other land use classes, 254,939.1 tons of which were on agricultural lands. Since the conversion from other land use classes to FA was low, carbon gain was realized at 197,247.7 tons. A total of 4,735,597.5 tons of carbon were stored in the unchanging FA. There was also a very small increase in carbon amounts in the WA and water body land use classes (Table 5). With land changes, a total of 603,692.5 tons (9.1%) of carbon was displaced between land use classes. 6,043,733.8 tons (90.9%) of carbon were stored in unchanged land use classes.

Table 5. Gains and losses of land use classes by the amount of carbon stored in the above-ground biomass between 1990 and 2018.

	Land Use	**2018 (ton)**					
		AS	**AA**	**FA**	**WA**	**WB**	**Total loss**
1990 (ton)	AS		28988.9	17300.2		2089.7	48378.8
	AA	34720.8		178351.8	6218.4	6388.5	225679.5
	FA	55726.7	254939.1		6466.2	5421.8	322553.8
	WA		192.4				192.4
	WB	124.7	5167.5	1595.7			6887.9
	Total gain	90572.2	289288.0	197247.7	12684.6	13900.0	603692.5
	Carbon stored in unchanged area	33310.5	1265604.7	4735597.5	769.7	8451.4	6043733.8
	Net Carbon Amount (ton)	123882.7	1554892.7	4932845.2	13454.3	22351.4	6647426.3

4. Discussion

In this study, the changes in the basic land use classes of Düzce, which experienced a large earthquake (M: 7.2) in 1999, during five periods (1990, 2000, 2006, 2012, and 2018) were examined. In addition, the changes in the amount of carbon stored in above-ground biomass over the 28 years with the transitions in the basic land use situations were examined. In the determination of carbon amounts, the method developed by Myeong *et al.* (2006) was used, and the carbon amounts stored in the above-ground biomass were calculated from the NDVI maps. In addition to monitoring the temporal and spatial changes in land use, satellite images are both less costly and more convenient in terms of time than terrestrial measurements in determining carbon amounts. Within the scope of this study, the NDVI map was derived from the Landsat-5 TM satellite image taken in the cloudless period of 1990. For 2018, the NDVI map was derived from the Landsat 8 OLI satellite image taken in the cloudless period.

In the 28 years, there was a significant increase in AS in terms of land use status. It was determined that the city center, which was spread out, especially in the Düzce valley, would expand towards AA. There were very significant transitions from agricultural lands to AS in the 5-10 year period after the major earthquake in 1999 and the great destruction it caused. It was understood that new houses were not built in the areas where the houses were destroyed after the earthquake, and that other agricultural lands were preferred for this. It was determined that 86.5% of the increase in AS was converted from AA. This situation is similar to the study conducted by Arslan and Örücü (2019) in their study of land change in the Bodrum district of Muğla, where they found that a very significant increase occurred in AS and that this increase occurred in AA. While there is a serious decrease in AA in the Düzce plain, we see that there is an increase in AA when the whole of Düzce is evaluated. AA, which covered approximately 35% of the entire area of Düzce in 1990, increased to 46% as of 2018. It has been observed that there were large transitions to hazelnut or cultivated areas, especially as a result of pressures on FA. The FA has been transformed into AA, which has been severely damaged, especially in the Akçakoca district to the north of Düzce. Yıldırım and Ortaçeşme (2016) found that while there was a decrease in FA, there was an increase in AA in their study in the Manavgat district of Antalya. In another study, Uyuk et al. (2020) examined the change in Denizli province with 28 years of CORINE data and determined that there was an increase of 2.83% in AA. A similar situation was observed in Düzce, and an increase of approximately 11.5% occurred in AA while a decrease of 13.9% occurred in FA in these 28 years. 96.7% of the increase in AA was land converted from FA. Among the other main land uses, WA, especially the Efteni Lake and its surroundings, were declared as wildlife protection areas in 2005, resulting in an increase of 2 per thousand in this land situation. The presence of WB experienced an increase of 3 per thousand in the 28 years, and this increase was converted from AA and FA.

According to the study by Puyravaud (2003), the annual rate of change in land use classes was calculated. In the 28 years, an annual change rate of 3.05% was found in AS, 1.02% in AA, and 0.8% in FA. An 8% change occurred in the WA and a 2.5% change occurred in the WB. These changes, while there were negative changes in FA, there were positive changes in other land use classes. Periodically, the period with the highest land change is the period of 2000–2006, which coincides with the post-earthquake period. In this period, in a positive direction, there were 5.07% changes in AS, 5.3% in AA, 38.5% in WA, and 2.8% in WB. In FA, there was a negative land change of 4.1%. In their study in the Goga district region, Othow et al. (2017) determined the annual rate of change in FA as 0.085 and in AA as 1.4 in the 1990-2002 period. For the 2002–2017 period, they determined the annual rate of change in FA as -0.030 and for AA as 1.2. In their study in Uganda, Mutesi et al. (2021) examined the annual rate of change according to the LU/LC status for the period 1986–2016 and found a rate of change of 1.18 in FA, 0.13 in AA, and 0.05 in AS in the period 1986–2016. The results obtained are consistent with the results of this study.

Pixel-based average carbon amounts were calculated over the reflectance values of the land cover to determine the amount of stored carbon depending on the changes in the base land situation. NDVI maps were used in the calculations. After the pixel-based carbon amounts were matched with the land use classes for both periods, the total carbon amounts were determined according to the land use classes using ArcGIS software. There was an approximately 3-fold increase in artificial areas in the province of Düzce over the last 28 years, and the amount of carbon stored in this land use class increased by 51.6% (42,193 tons). In 1990, village settlements were established in many areas with agricultural and FA, and these villages were considered AS in the classification in 2018. These villages have trees and AA around them, and the carbon increase in artificial areas is due to this situation. Ariluoma et al. (2021) conducted a study on carbon storage in community gardens and revealed that carbon was stored in these areas. Tang et al. (2016) estimated the C storage and C holding capacity of street trees in Beijing. The results showed that the C density and C sequestration ratio in the urban street trees of Beijing were about 1/3, 1/2 of the corresponding sizes of non-urban forests in China. In other words, AS does not only consist of buildings, and carbon is gained by sequestration in urban green areas. The areal increase in AA caused the amount of stored carbon to increase by 30.5%. Despite the significant decrease in FA, there was an increase of 27.9% in the amount of carbon stored in FA. The Intergovernmental Panel on Climate Change (IPCC) (2003), emphasizing that forests are the most important carbon pools in terrestrial ecosystems, evaluated carbon pools in three separate groups. They state that above and below ground live biomass, dead organic matter and soils are carbon pools. Carbon storage amounts vary according to each plant species, health, and location. According to the report of the Ministry of Environment and Forestry of Türkiye in 2006, while forests are the most important land cover in terms of carbon storage potential, meadow and pasture areas, agricultural areas, wetlands, and green areas in residential areas are ranked after forests in terms of carbon storage capacity. In this study conducted for Düzce province, the amount of carbon stored in the above-ground biomass was calculated, and it was determined that half of the total carbon was retained in FA. In terms of the amount of stored carbon, AA followed FA, and approximately 97.5% of the total carbon was stored in these two main land use classes. In this study, unit area carbon values found in AA (13.6 tons/ha) and FA (40.1 tons/ha) gave results close to the unit area values calculated by terrestrial measurements for the whole of Türkiye (TMAF, 2020). In addition, WB also contributes to carbon storage, although in small quantities. In his research, Skwierawski (2022) determined that an average of 275.5 g of carbon is stored in a lake with a size of about 1 acre. The results obtained to support our study. During the 28 years, 9.1% of the total carbon has been displaced by the transitions in land use classes. The amount of carbon stored in unchanged land constituted 90.9% of the total carbon amount.

5. Conclusion

The dynamic process of land use affected the world in many ways. To reduce CO_2 emissions, which have the most significant share in global warming and have been frequently stated recently, the pressures on FA that store carbon should be reduced. To increase the storage of carbon in AA, it is necessary to use the polyculture production pattern without plowing and to produce crops that are spread throughout the year without leaving fields fallow. The fact that forests, which are the most important carbon pools in terrestrial ecosystems, are under constant pressure and the destruction of vegetation in them or their conversion to different land uses also causes significant reductions in the amount of carbon captured. In determining the amount of carbon stored by forests and other land use classes, remote sensing techniques can be used instead of terrestrial measurements, thus saving both money and time.

In addition, the destruction of productive agricultural areas with urbanization will trigger the food problem, as is the case all over the world. Political measures should be taken to prohibit the construction of buildings in productive forest areas. To reduce both global warming and food shortage, land change and carbon emissions on a global basis should be closely monitored and necessary precautions should be taken.

Ethics approval

Not applicable.

Competing interests

I declare that the authors have no competing interests as defined by Springer, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

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