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Research Article

Monitoring and Mapping Temporal and Spatial Land Use/Land Cover Change: A Case Study from Inebolu, Türkiye

Döndü Demirel * and Fatih Sivrikaya

Kastamonu University, Faculty of Forestry, Department of Forest Engineering, 37150, Kastamonu/Türkiye
* Correspondence: ddemirel@kastamonu.edu.tr

Abstract: Land use/land cover (LULC) change affects forest ecosystem health and ecosystem services, and therefore, identifying and monitoring LULC is essential for ecosystem continuity. This study aims to determine the temporal and spatial changes in land use/land cover between 1999 and 2011 in the Inebolu Forest Enterprise located in the Western Black Sea Region and to reveal the reasons for these changes using Geographic Information Systems. The results showed that the forest area increased by 9362.6 ha, and the productive forest area increased by 15333.4 ha between 1999 and 2011. It was predicted that the main reason for the increase in forest area was afforestation activities and population decrease due to migration from villages to cities. Rehabilitation studies can be recognized as a significant contribution to expanding productive forest areas. Additionally, it was determined that 2039.0 ha and 3607.2 ha of agricultural land were converted into Conifer Forest and Broadleaf Forest, respectively.

Keywords: geographic information systems; land cover/land use; deforestation; agriculture; urbanization; land degradation; landscape

Arazi Kullanımı/Arazi Örtüsünün Zamansal ve Mekânsal Değişiminin İzlenmesi ve Haritalanması: İnebolu Örneği, Türkiye

Öz: Arazi kullanımı/arazi örtüsü (LULC) değişikliği orman ekosistemi sağlığını ve ekosistem hizmetlerini etkilemektedir ve bu nedenle LULC'nin tanımlanması ve izlenmesi ekosistemin devamlılığı için gereklidir. Bu çalışma, Batı Karadeniz Bölgesi'nde yer alan İnebolu Orman İşletmesi Müdürlüğü'nde 1999-2011 yılları arasında arazi kullanımı/arazi örtüsündeki zamansal ve konumsal değişimleri tespit etmeyi ve bu değişimlerin nedenlerini Coğrafi Bilgi Sistemleri kullanarak ortaya koymayı amaçlamaktadır. Sonuçlar, 1999-2011 yılları arasında orman alanının 9362.6 hektar, verim-li orman alanının ise 15333.4 hektar arttığını göstermiştir. Orman alanındaki artışın ana nedeninin ağaçlandırma faaliyetleri ve köylerden şehirlere göç nedeniyle nüfus azalması olduğu tahmin edilmektedir. Bununla birlikte rehabilitasyon çalışmalarının verimli orman alanlarının artışı üzerinde önemli bir katkısı olduğu düşünülmektedir. Ayrıca ziraat alanlarından sırasıyla 2039.0 ha ve 3607.2 ha alanın ibreli ve yapraklı ormanlara dönüştüğü belirlenmiştir.

Anahtar Kelimeler: coğrafi bilgi sistemleri; arazi örtüsü/arazi kullanımı; ormansızlaşma; tarım; kentleşme; arazi bozulması; peyzaj

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1. Introduction

Every year, there is a noticeable growth in the global population, accompanied by technological advancements. This trend is accompanied by an increase in the requirements of society while simultaneously witnessing a decline in the availability of raw materials. The inevitability of Earth's transformation is evident, mainly due to the processes of urbanization, industrialization, and migration to metropolitan areas [1]–[3]. Human activities significantly impact approximately 83% of the Earth's ecosystems, both directly and indirectly [4]. Based on figures from the United Nations (UN), the global population reached 6 billion in 1999 and 8 billion in 2022. However, the "2023 State of the World Population Report" published by the United Nations Population Fund (UNFPA) indicates that the current population exceeds 8 billion (UNFPA, 2023). The conversion of natural ecosystems into controlled regions is well recognized as one of the significant effects of human activity on the environment [5], [6]. Land use/land cover (LULC) change has become a significant global concern [7], [8]. Human land use has drastically affected around 30-50% of the global land cover [9].

In recent years, LULC change has had significant implications for climate dynamics. These changes have been observed to impact biodiversity, soil integrity, water availability and purity, and greenhouse gas emissions. It is important to note that these effects extend beyond simple modifications in the physical appearance of land, exerting a global influence. This observation suggests that when a civilization makes decisions regarding land utilization, it concurrently determines several elements that have significant implications for the worldwide community, particularly climate change [1].

According to many researchers [2], [10], [11], forest regions would undergo noticeable transformations through the stages of economic growth, industrialization, and urbanization. There has been a significant decline in global forest area, and subsequent efforts to restore forest areas are anticipated to be challenging [12], [13]. According to the Food and Agriculture Organization (FAO), the per capita agricultural area is 0.6 ha. Furthermore, it is observed that this per capita has experienced a decline of 30% between the years 1990 and 2019. This scenario demonstrates the efficacy of agricultural land utilization in the face of a growing population. According to the FAO, in 2019, there was a 4% decline in the worldwide forest area for 29 years, resulting in a total of 4.1 billion hectares [14]. Türkiye is currently experiencing a significant invasion of individuals migrating from rural regions to urban centers, primarily driven by economic and social factors. According to Yılmaz (2015), in 1950, the rural population accounted for 75% of the total population [15]. However, starting from 1985, the urban population has surpassed the rural population. According to the Turkish Statistical Institute [16], 19848 hectares of agricultural land in Türkiye was reduced from 2000 to 2010. There was a notable expansion of the forested area, amounting to an increase of 2.3 million hectares over 22 years, from 1999 to 2021 [17].

The function of the ecosystem is greatly influenced by forest structure and dynamics. Nevertheless, comprehending the historical dynamics of forests and assisting in developing future forest management strategies and environmental regulations for a nation becomes challenging without a comprehensive explanation of the manner and degree to which LULC changes over time, as well as the reasons for these changes and resulting impacts. Moreover, the analysis of changes in land utilization holds an essential place in the context of promoting sustainable forestry practices [18]–[22]. In this context, studies have been carried out to determine the temporal and spatial changes occurring in the forest ecosystem in Türkiye using Geographic Information System (GIS) and remote sensing techniques [3], [8], [18], [23]–[32].

The objective of this study was to analyze the LULCC in the Inebolu Forest Enterprise (FE), situated along the coast of the Kastamonu Regional Directorate of Forestry (RDF), for the years 1999 and 2011. This was achieved using forest cover-type maps and GIS techniques. The study aimed to identify the temporal and spatial changes over the 12 years under investigation.

2. Material and Methods

2.1. Study Area

Inebolu FE was chosen as the study area. The study site is in the Kastamonu province, located in the northwestern region of Türkiye. According to the UTM coordinate system (WGS 84 Datum, 36 Zone), the FE is situated within the geographical boundaries of 527000-577300 eastern longitudes and 4628000-4652100 northern latitudes (Figure 1). The Inebolu FE encompasses a total area of 66490.2 hectares, with 71% (47180.7 hectares) of this land designated as a forested area. The primary tree species observed within the designated research site include *Pinus nigra*, *Pinus sylvestris*, *Abies nordmanniana*, *Pinus brutia*, *Fagus orientalis*, *Castanea sativa*, *Carpinus orientalis*, and *Quercus* spp. The study area has a climatic pattern characteristic of the Black Sea region. The winter season is characterized by relatively mild temperatures and a significant amount of precipitation, while high temperatures with a notable absence of aridity indicate the summer.

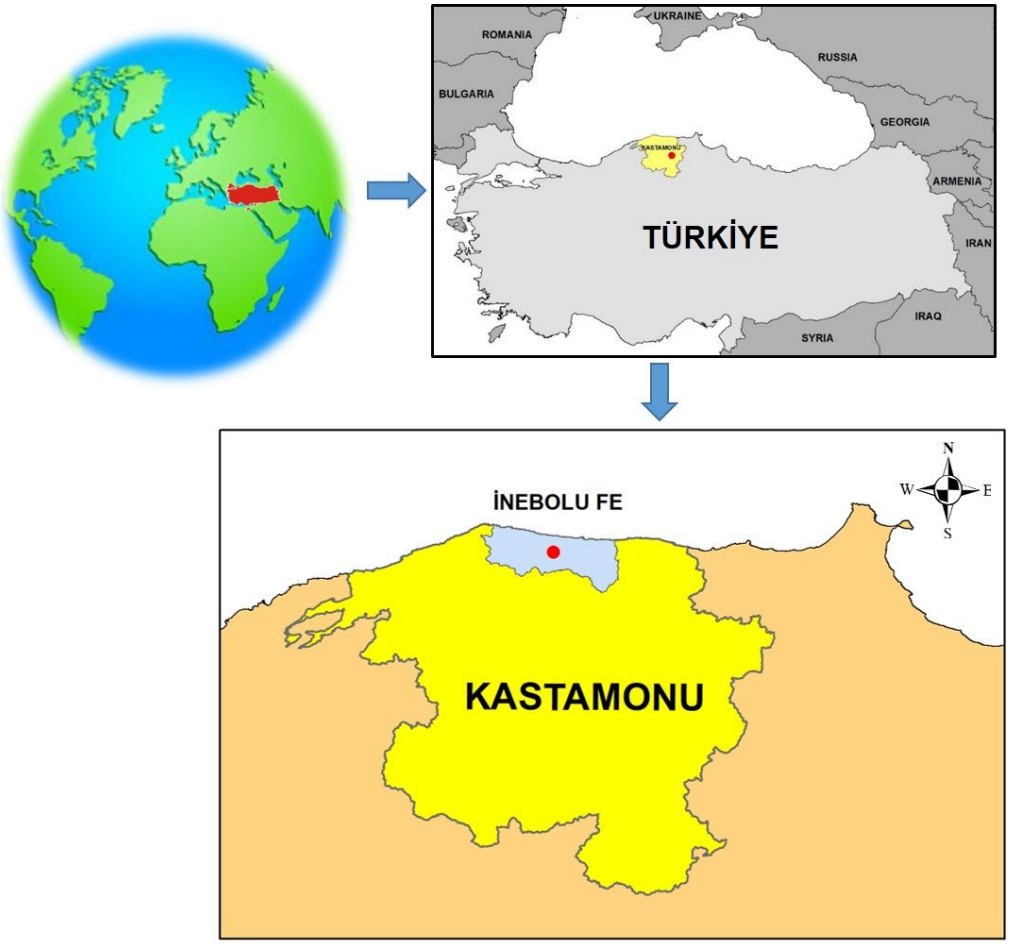

Figure 1. The study area.

2.2. Database Development

The study utilized digital forest cover-type maps from the years 1999 and 2011 to assess both temporal and spatial variations within the Inebolu FE. The digital forest cover-type maps were acquired from the Kastamonu RDF. The present study examines various LULC categories, including Conifer Forest (CF), Broadleaf Forest (BF), Mixed Forest (MF), Degraded Forest (DF), Forest Openings (FO), Agriculture (AG), Settlements (ST), and Other (OH) (Table 1). The LULC classes determined were entered into the forest cover-type map database with ArcGIS 10.6 software, resulting in the creation of LULC maps for 1999 and

2011. The generation of transition matrices involved utilizing the overlay function to ascertain the transition between different LULC categories. Furthermore, the annual rate of deforestation/afforestation was determined by employing Equation 1 [33].

$$P = \frac{100}{t_2 - t_1} \ln \frac{A_2}{A_1} \quad (1)$$

Where; P= percentage of forest loss/gain per year, and percentage of forest loss/gain per year, and A_1 and A_2 = amount of forest cover at time t_1 and t_2, respectively.

Table 1. Descriptions of LULC categories.

LULC Classes	Code	Description
Conifer Forest	CF	Pure conifer forests with crown closure higher than 10%
Broadleaf Forest	BF	Pure broadleaf forests with crown closure higher than 10%
Mixed Forest	MF	Mixed (BF-CF, CF-BF) forest areas
Degraded Forest	DF	Forest areas with crown closure less than 10%
Forest Openings	FO	Treeless and open areas are accepted as forest area
Agriculture	AG	Agricultural lands
Settlements	ST	Settlements areas
Other	OH	Pasture lands, rocky areas

3. Results and Discussion

The LULC change of Inebolu FE from 1999 to 2011 is shown in Figure 2, while its spatial distribution is presented in Table 2. The forest area exhibited a notable change over 12 years, from 1999 to 2011. Specifically, the forest area expanded from 37818.1 hectares in 1999 to 47180.7 hectares in 2011, representing a significant increase of 24.8% or 9362.6 hectares. The study reveals a notable increase of roughly 61.3% (equivalent to 15333.4 hectares) in productive forest areas that contain conifer, broadleaf and mixed forests. In contrast, there was a significant decrease of approximately 46.6% (equivalent to 5970.8 hectares) in degraded forest areas. According to the results, significant changes were detected in both productive and degraded forest areas. The analysis revealed a noticeable improvement in the quality and quantity of forested areas. This result demonstrates that forests can enhance their capability to deliver ecological and socio-cultural benefits. The primary factor contributing to the increase in both overall forest coverage and the extent of productive forest areas may be attributed to the afforestation activities implemented over the period spanning from 1999 to 2011. Afforestation activities were conducted in forest clearings and degraded areas. Furthermore, after the adoption of the National Afforestation and Erosion Control Action Plan in 2008, the GDF launched rehabilitation, afforestation, and artificial regeneration efforts in regions that had been degraded, with the primary objective of mitigating erosion (GDF, 2008). Implementing these action plans has resulted in an essential increase in forested areas (Table 2).

Population is an additional significant factor influencing the forest ecosystem's temporal and spatial changes. During this particular event, the inhabitants of Inebolu moved from their rural settlements, situated at a considerable distance from urban areas to the central district of the city. This migration was driven by the pursuit of improved living standards, increased income prospects, and enhanced employment options available in the city. Based on statistics data provided by the Turkish Statistical Institute (TSI), the population of Inebolu was recorded as 26848 individuals in the year 2000, which subsequently reduced to 23098 individuals in 2011. Consequently, a decline of 3750 individuals, equivalent to nearly 14% of the initial population, was observed during this period. The rural population declined from 17362 individuals in 2000 to 13,445 in 2011 [16]. The agricultural area (AG) experienced a decline of 34.5%, equivalent to 8514.9 hectares, while the settlement area (ST) observed a decrease of 20.4%, amounting to 461.5 hectares. Upon evaluating the demographic data, it is evident that the urban and rural populations of Inebolu noticed a decline throughout this period. The observed decrease in AG and ST, coupled with the concurrent expansion of forested areas, can be attributed to population migrations.

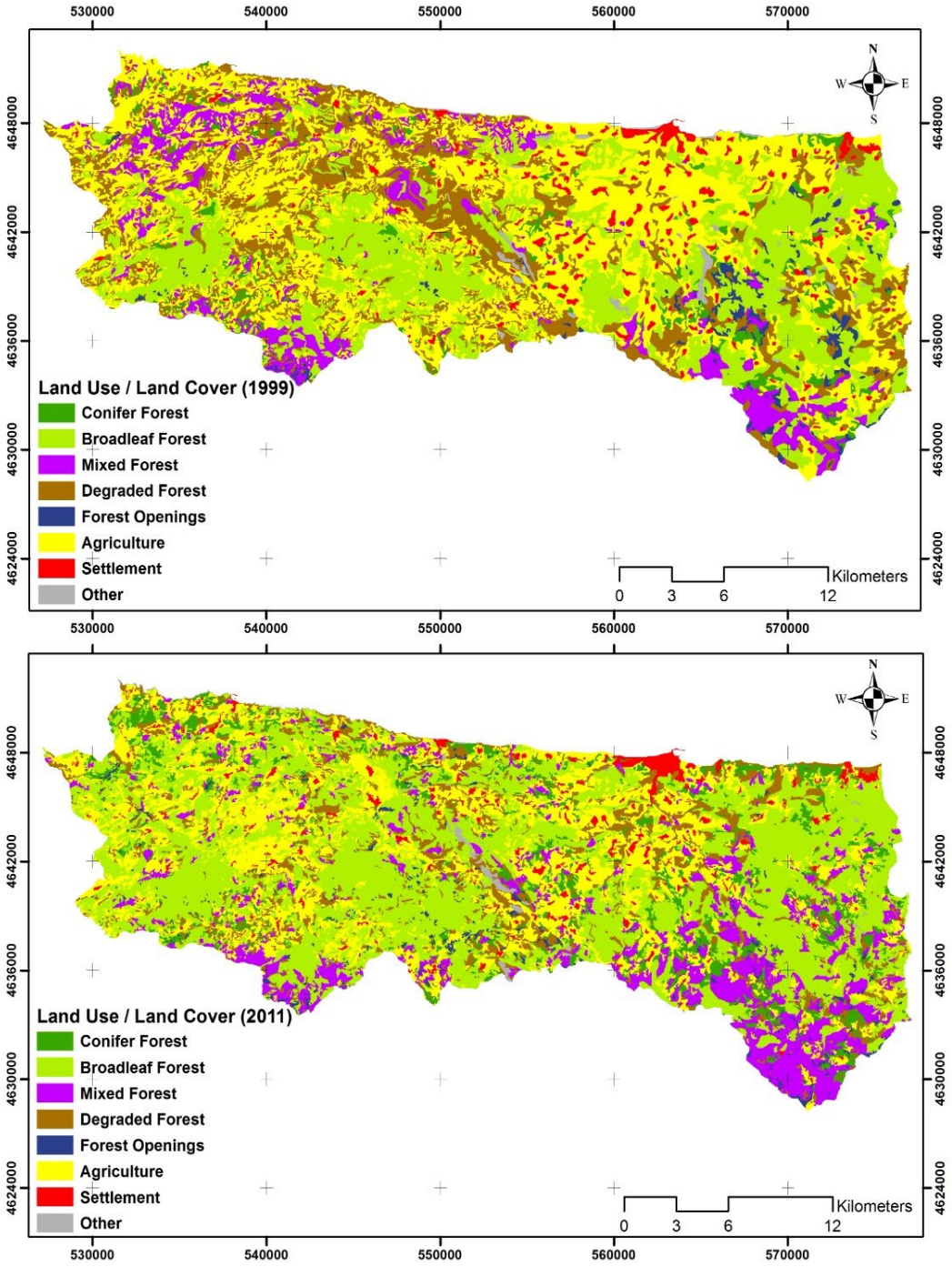

Figure 2. LULC maps in (a) 1999 and (b) 2011.

When analyzing LULC classes, it becomes evident that the most notable change occurs within the BF class, with an increase from 17474.5 hectares in 1991 to 27909.8 hectares in 2011. To clarify, the BF area showed an impressive rise of 59.7%, equivalent to an increase of 10435.3 hectares. Other significant changes occurred in AG and DF. Over 12 years, AG decreased by 8514.9 hectares over 12 years, whereas DF decreased by 5970.8 ha. When examining the spatial distribution of the Inebolu FE in 1999, it is observed that the most significant proportion is comprised of AG, BF, and DF areas, in that order. However, as of 2011, the areal distribution has shifted to BF, AG, MF, and DF, respectively (Table 2). Based on the observed increase of forests over 12 years, it can be determined that the average annual rate of forestation was 1.84%, equivalent to a total of 780.2 hectares per year.

Table 2. Spatial distribution of LULC in 1999 and 2011.

LULC	1999		2011	
Class	Area (ha)	%	Area (ha)	%
CF	2161.0	3.3	5136.2	7.7
BF	17474.5	26.3	27909.8	42.0
MF	5376.4	8.1	7299.3	11.0
DF	12806.2	19.3	6835.4	10.3
FO	1138.6	1.7	915.5	1.4
AG	24712.4	37.2	16197.5	24.4
ST	2258.8	3.4	1797.3	2.7
OH	562.3	0.7	399.2	0.5
Total	66490.2	100.0	66490.2	100.0

Transitions between LULC classes were revealed according to the forest cover-type maps of 1999 and 2011. In 12 years, 914.5 ha of FO was transformed into forest areas. 741.9 ha and 172.6 ha converted to productive and degraded forests, respectively (Table 3). The main reason for the transformation of FO, a treeless forest area, to a forest area is afforestation activities. According to Şen and Güngör (2018), the afforestation area in the province of Kastamonu had an annual growth rate of 0.9% during the period spanning from 1999 to 2014. 937.1 ha of the DF converted to CF, 6501.5 ha transformed to DF, and 1593.2 ha turned into MF. 860.5 ha converted from productive forest to DF [34]. The main reason for transforming 9031.8 ha of DF into productive forests is rehabilitation activities. Based on the data provided by TUIK, it can be observed that there has been a conversion of AG and ST areas into FO. Specifically, due to the declining population, 10389.5 hectares of AG and 165.6 hectares of ST were converted to forested areas. Additionally, 531.1 ha formerly designated as AG converted to forested areas, while 552.8 ha of AG have been transformed into settlement areas. As illustrated in Figure 2, there has been a notable transformation of AG areas, particularly in coastal regions, into ST areas. During 12 years, 365.8 hectares of CF were converted to BF, while 544.2 hectares of CF were transformed into MF. Additionally, 462.3 hectares of BF were converted to CF, and a substantial area of 1722.6 hectares of BF was converted into MF. The changes in CF and MF forests are mainly attributed to modifying the objectives pursued by organizations managing these forests, which arise from silvicultural practices on the stands.

Table 3. LULC change in 1999 and 2011.

		2011								
	LULC Class	CF	BF	MF	DF	FO	AG	ST	OH	Total
1999	CF	979.7	365.8	544.2	137.2	10.3	116.9	3.6	3.3	2161.0
	BF	462.3	14268.9	1722.6	549.5	70.8	373.5	12.2	14.7	17474.5
	MF	528.4	2583.2	1802.3	173.8	37.3	244.8	4.1	2.5	5376.4
	DF	937.1	6501.5	1593.2	2144.7	116.4	1249.0	31.1	233.2	12806.2
	FO	132.3	323.1	286.5	172.6	141.4	78.8	0.7	3.2	1138.6
	AG	2039.0	3607.2	1301.9	3441.4	531.1	13196.8	552.8	42.2	24712.4
	ST	28.1	67.6	19.0	50.9	0.1	926.5	1166.5	0.1	2258.8
	OH	29.3	192.5	29.6	165.3	8.1	11.2	26.3	100.0	562.3
	Total	5136.2	27909.8	7299.3	6835.4	915.5	16197.5	1797.3	399.2	66490.2

A broad-level analysis showed that despite implementing forestry activities, population decline, and technological advancements between 1999 and 2011, 50.8% of the total areas (33800.3 ha) remained unchanged. Nonetheless, a notable proportion of the entire region, specifically 3.8%, converted from forested to non-forest areas, while 17.9% experienced a conversion of non-forest areas to forested areas. Approximately 24.2% of the total area has experienced alterations in its stand structure (Figure 3). Forests exhibit a dynamic structure and undergo developmental and transformative processes throughout time. Additionally, silvicultural treatments are known to influence stand structure and organization effectively. The LULC classification for 3.3% of the AG, FO, open OH, and ST areas remained unchanged over 12 years. Upon analyzing the changes in LULC classes, it becomes evident that the most significant change occurred within AG, accounting for 37.0% (22673.4 ha) of the total area. This was closely followed by BF, which had a change of 27.7% (17012.2 ha), and DF, which changed 19.4% (11869.1 ha). Among the various LULC classes, changes have occurred in MF (7.9%, 4848.0 ha), ST (3.6%, 2230.7 ha), CF (%1.9, 1181.3 ha), FO (%1.6; 1006.3 ha) and OH (0.9%, 533.0 ha), respectively (Table 3).

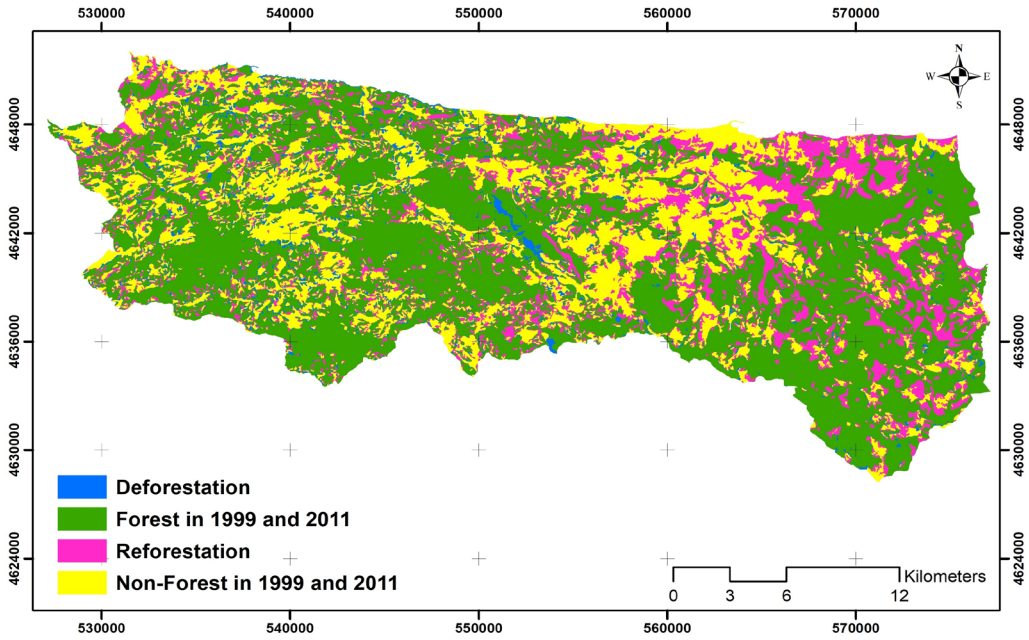

Figure 3. The map of reforestation and deforestation in Inebolu FE.

In their study on the land change in the central district of Kastamonu province from 1999 to 2016, Doğan and Buğday (2018) observed that forest areas had a decline of 7.8%, agricultural areas declined by 13.9%, and there was a notable growth of 10.9% in residential areas [35]. This finding contrasts with the present study's results. The primary factor contributing to this phenomenon can be attributed to the selection of the study location within the city center, along with the observed growth in the urban population. The study analyzed the land transformation in Kastamonu province from 1999 to 2014. The results revealed a notable rise of 15.1% in the extent of forested areas [34]. The study by Turan et al. (2009) investigated the patterns of land development in the Kastamonu province over 23 years, from 1984 to 2007 [36]. The study's results revealed a significant rise of 28.96% in the extent of residential areas over this period. In this study, they found that forest areas increased to 111466 ha, while forest opening areas decreased to 112888 ha. According to Aydın and Aydın (2011), there was a notable rise of 35.6% in the productive forest area of Küre FE, which is under the jurisdiction of the Kastamonu RDF, over the period from 1997 to 2010 [37]. Additionally, this study revealed a decrease in the degraded forest area by 19.01% and a reduction in forest opening areas by 1.32%. The survey also observed a comparable decline of 14.07% in agricultural areas. The results presented here resemble the outcomes seen in the investigation above.

The study additionally revealed variations in LULC change across several regions of Türkiye. The survey conducted by Sautı and Karahalil (2022) presented an analysis of the alterations in LULC within the Yuvacık Planning Unit (PU) from 1972 to 2015 [31]. Over a 43-year timeframe, it was ascertained that almost 99% of the total forest area was converted to residential areas. In this study, implementing rehabilitation activities resulted in a notable reduction in degraded forest areas. Furthermore, there has been a substantial rise of 117.2% in the presence of mixed forests. Aksoy and Kaptan (2022) analyzed land change patterns within the Bartın FE from 1999 to 2019 [3]. Their results revealed a notable rise in forest areas by 17.4%, residential areas by 84.6%, and water areas by 20.1%. The data showed a significant reduction of 33.2% in agricultural areas concurrent with these increases. According to the study conducted by Sivrikaya et al. (2011), there was a notable decline in the forested area of Cumaova PU during a span of 21 years, from 1987 to 2008 [24]. The research showed a reduction of 5%, with the forest area decreasing from 5089 hectares to 4426 hectares. A 5.5% and 10.4% decline was seen in residential and agricultural areas, respectively.

4. Conclusions

This study examines the changes in eight different LULC classes over twelve years, specifically focusing on the 1999 and 2011 forest cover-type maps of the Inebolu FE. The analysis showed that the study area exhibited a forest cover of 17.9% and a deforestation rate of 3.8% during 12 years. As of 2011, the forest area accounted for 71% (47180.7 ha) of the total area, while the non-forest areas accounted for 29% (19309.5 ha). When analyzing changes in LULC, it is evident that the highest degree of change, in comparison to the period between 1999 and 2011, was observed in agricultural areas (37.0%), followed by broadleaf forest areas (27.7%) and degraded forest areas (19.4%). The observed decline in population throughout the specified period is believed to have exerted a significant influence on the observed transformations. The research area has experienced a substantial conversion of degraded forest areas, totaling 9031.8 hectares, into productive forest areas. Undoubtedly, rehabilitation studies can be identified as contributing factors to this phenomenon. There is a pressing need to expedite and expand rehabilitation endeavors in regions of forest degradation. Assessing land use/land cover changes is crucial for comprehending the temporal dynamics within forest ecosystems and ensuring their sustained continuity. The results of this study can serve as a vital foundation for decision-making and administrative operations undertaken by authorized units associated with the General Directorate of Forestry.

Author Contributions: The authors designed the study, analyzed the forest cover-type maps, produced the maps, analyzed the data, and wrote the manuscript.

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Conflicts of Interest: The authors declare that they have no competing interests or conflicts of interest.

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