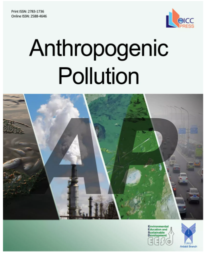

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Determining the dynamics of land use changes in a long-term time span in Erzurum, Turkey

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Abstract:

Land use change shapes landscapes and is crucial for effective natural resource management, requiring a deep understanding of its trends for informed land management. The study utilized Landsat TM and Sentinel-2 satellite images spanning 1994 to 2023 to generate a 30-year land use change map of Erzurum. After processing of satellite images in ENVI, the Maximum Likelihood Algorithm used for classification and the Kappa coefficient used for reliability of results. Single and dynamic land use change indices used to assss the changes in LULC classes. The results indicated appropriate accuracy in the classified maps with a Kappa coefficient exceeding 0.75. The results revealed that the most significant land use changes in the Erzurum region were related to the conversion of rangeland to agricultural land. Over the period from 1994 to 2023, there was a notable increase in agricultural land use in Erzurum, contrasting with negative trends in waterbodies and garden areas. Rangeland experienced the most significant decline, decreasing by 19.22%, while agricultural land increased by 18%. Indicating the highest growth among land use categories. According to the Single Dynamic Index, Bare Ground exhibited a change of +0.32%, while tree lands displayed a notably high dynamic degree of +0.31%. The significant expansion of agricultural land in Erzurum is primarily driven by agriculture being the main livelihood for local communities. This shift from rangelands highlights the strain on natural resources, necessitating careful management planning to balance agricultural expansion with environmental conservation concerns.

Keywords: Landscape dynamics; Change detection; Lulc change; Dynamic index; Land use management

1. Introduction

Over past decades, the expansion of human needs has notably intensified the utilization of land resources, leading to significant impairments in various land uses due to substantial land use changes (DeMontis et al., 2017). In recent years, concerns have arisen regarding the impact of land use pattern changes resulting from deforestation and agricultural development or elimination on the quality of water and soil resources, causing a serious crisis. Most concerns have centered on the hydrological hazards and local downstream biodiversity implications of land use changes (Oztas, 2019). Multiple factors contribute to the changing landscape, including human activities such as urban development, tourism, coastal expansion, sand and gravel extraction, land-use changes, and terracing in sloping lands. The dynamics of land use have been influenced by a complex interplay of climatic, human, and natural factors. Climate change, including shifts in precipitation patterns and temperature extremes, directly impacts agricultural productivity and water availability, exacerbating land degradation processes such as erosion and soil nutrient depletion (Plieninger et al., 2016; Borrelli et al., 2020; Khiavi et al., 2022). Human activities, such as urbanization and industrial expansion, drive rapid land conversion and habitat fragmentation, intensifying pressures on natural ecosystems (Wang et al., 2020). Additionally, natural factors like geological processes and ecological succession contribute to ongoing changes in land cover and land use patterns, shaping landscapes over time (Assede et al., 2023).

Additionally, factors like drought and climate change play a role (Plieninger et al., 2016; Hoang et al., 2020; Nguyen and Hens, 2021; Burgi et al., 2022). Undoubtedly, all human activities in nature ultimately result in spatial alterations in land uses. Therefore, evaluating changes in the land surface provides a dynamic reflection of past human land use, serving as a dynamic and vital framework for sustainable land use (Zhang et al., 2014; Liu et al., 2017; Khiavi and Mostafazadeh, 2021).

Understanding these diverse drivers is crucial for developing effective strategies to manage and better uses of land resources and mitigate the adverse impacts of land use change on environmental and socio-economic systems (Mosatfa et al., 2021). Land use changes resulting from human activities are currently occurring more rapidly in developing countries than in developed ones. The population growth in developing cities has prompted rapid alterations in land use/land cover and accelerated environmental degradation (Oguz and Zengin, 2011). Effective management addressing all aspects of land degradation is vital to minimize the adverse effects of climate change, preserve biodiversity, and ensure food security and livelihood sustainability (Cowie et al., 2018).

Turkey is one of the highly vulnerable countries facing serious problems of land degradation and desertification due to climate change impacts and increased pressure on natural resources owing to land demands (Oztas, 2019). However, the improper use and inappropriate agricultural practices within land planning and management have perpetually fragmented the competent lands, which are vital for ensuring the future. Turkish lands suffer significantly from degradation processes, especially erosion, compaction, acidification, salinization, alkalization, organic matter loss, fertility reduction, and pollution. Moreover, recent surface sealing has become the most threatening factor due to escalating pressures from industrial development, population growth, and urbanization (Cowie et al., 2018; Oztas, 2019; Nguyen et al., 2019). Remote Sensing (RS) and Geographic Information Systems (GIS) are powerful and cost-effective tools for assessing the spatial and temporal dynamics of land use (Dewan and Yamaguchi, 2009; Serra et al., 2008). Various studies employing satellite imagery and remote sensing techniques in land cover/land use changes (Rawat et al., 2013; Oguz and Zengin, 2011) and the examination of land use dynamics (Khiavi and Mostafazadeh, 2021) have revealed a decrease in natural lands and an increase in agricultural lands during the studied time intervals. Regarding the impact of land use dynamics on rivers (Zhang et al., 2014; Xian et al., 2005; Qi et al., 2013), these studies have investigated the actual changes and the dynamic effects of land use alterations on hydrological regimes. Xiulan and Yuhai (1999) analyzed methods for studying land use dynamic changes, focusing on various models such as land resource quantity and spatial change models. Their study emphasized the need for diverse modeling approaches to understand land use changes effectively. Lambin et al. (2003) reviewed land-use/cover change dynamics in tropical regions, emphasizing cropland, deforestation, and urbanization. They proposed a framework considering resource scarcity, market opportunities, and policy interventions. Their findings highlight the need for integrated, place-based research to predict new land-use changes effectively. Liu and Andersson (2004) emphasized the critical role of temporal dynamics in urban morphology modeling, stressing the importance of appropriately managing time to ensure realistic landscape simulations. They cautioned against extreme temporal variations leading to unrealistic patterns, especially in fast-changing processes, underscoring the importance of temporal considerations in land-use modeling. Briner et al. (2012) explored the intricate interplay among economic factors, climate change, and land-use decisions in mountainous regions, specifically the Visp area in Switzerland. Their study employed a spatial dynamic modeling approach integrating ALUAM with forest and crop models to assess climate-induced impacts on land-cover dynamics and ecosystem services. Hassan et al. (2016) examined land use and cover changes in Islamabad, Pakistan, from 1992 to 2012 using geospatial techniques. Their study found increased agricultural, built-up, and water areas, while forest and barren lands declined, driven by economic development, climate change, and population growth. Feng et al. (2020) analyzed China's land use changes (2000–2050) using GlobeLand30 data and a LandCA model, highlighting a notable increase in land Exchange intensity compared to Quantity intensity. Deng and Quan (2022) used Intensity Analysis to study land use and land cover transitions in Hengyang from 1980 to 2015, noting a significant acceleration around 2005. They introduced a new transition pattern to visualize intensity and identified a stable shift from cultivated to built-up areas. Their research using the PLUS model forecasts reduced forest and cultivated land, with a slight increase in waterbodies, offering insights for sustainable land management in Hengyang. Manzoor et al. (2022) analyzed land-cover changes in Ghana's Northern regions from 1992 to 2015. They found a faster rate of change from 1992 to 2003 compared to 2003 to 2015, emphasizing expansions in arable land and tree/forest cover at the expense of semi-arid shrublands. Despite gains in local forest cover due to afforestation policies, overall trends indicated a decline in natural habitats, necessitating policy interventions to address environmental impacts in northern Ghana. Hussain et al. (2024) employed remote sensing to study historical land use changes and land surface temperature (LST) trends in Multan, Pakistan. Using the CA-Markov Chain model, they projected scenarios for 2035 and 2050, revealing a 10.96% increase in built-up areas from 1990 to 2020. This led to a significant decline in vegetation cover, 77.57% by 2035 and 71.4% by 2050. The study underscores remote sensing's importance in tracking past trends and forecasting future changes.

The reviewed literature indicates a consensus on the pivotal role of temporal dynamics and the interplay between various factors shaping land-use changes. However, there remains a significant need for quantitative measures, particularly in assessing the dynamic intensity of land-use changes across specific categories, to provide more comprehensive insights into the intricacies of these transformations. Therefore, the absence of quantitative assessments measuring the land use dynamic degree for distinct land categories is observed, which could significantly enrich our understanding of land-use transitions in diverse landscapes and aid in more precise policy interventions for sustainable land management.

LULC change employs diverse methodologies such as the Land Use Dynamic Index (LUDI) and Land Use Intensity Analysis (LUIA), which quantify changes in intensity and speed across specific land use categories over time. Changes in extent, rate, and intensity provide critical understandings into the spatial distribution and magnitude of transformations, highlighting shifts in land cover types and their consequences. Spatial and temporal models, including spatial dynamic modeling and temporal change analysis, integrate remote sensing data and GIS to predict future scenarios and evaluate historical trends.

Studies on land use changes in different regions of Turkey have shown that land use change characteristics are among the most influential factors determining landscape alterations (Yilmaz et al., 2007; Oguz and Zengin, 2011; Oztas, 2019). Turkey has experienced significant urban population growth in recent decades due to industrial developments and migrations. The excessive growth of cities towards suburban areas has led to the emergence of new residential zones, putting pressure on rural areas near cities and the natural areas surrounding them. Consequently, new residential areas around cities have been integrated with them due to the changes in their functionality (Oguz and Zengin, 2011). Consequently, this transformation has led rural areas to merge with large urban centers, and rural settlements have transformed into districts or sometimes into municipalities of major cities (Yengul, 2007). Given the diverse range of land use types and the varying factors influencing land management practices in Erzurum, Turkey, this study aimed to comprehensively analyze the dynamics of land use changes using single and integrated dynamic index. It sought to identify the key drivers impacting the scale and intensity of these changes over time in the Erzurum region.

2. Materials and methods

2.1 Study area

Erzurum constitutes approximately 1.30% of Turkey's land. It is the largest city in Eastern Anatolia and the fourth-largest city in Turkey after Konya, Sivas, and Ankara. The population of the Erzurum province, according to records in 2020, is estimated at 758,279 individuals. The economy of the Erzurum province primarily relies on agriculture, animal husbandry, and the service sector (Yilmaz et al., 2007; Ozgul and Comakli, 2021). With high elevation, rugged topography, and smooth plains, the Erzurum province stands out as the most significant region in Eastern Anatolia. Erzurum Province, with its fertile rangelands and agricultural lands, has significant production capacities in livestock farming and agriculture. Its average elevation from sea level is approximately 1950 meters. The annual average precipitation is approximately 435 millimeters, and the annual mean temperature is 6 degrees Celsius (Ozgul and Comakli, 2021; Oguz and Zengin, 2011). The Erzurum basin is surrounded to the south by volcanic rocks of the Palandoken Mountain range and to the north by the Dumlubaba Mountain range. The elevated volcanic plateau of Kargapazarı lies to the east within the basin. The Neogene volcanoes in northeastern Anatolia (Erzurum, Ardahan, Kars, Agrı) belong to nepheline-normative basalts (alkaline) (hawaiites, mugearites, quartzous trachytes, etc.) (Bayraktutan et al., 1996; Bayraktutan, 2023). Figure 1 illustrates the map depicting the location of the study area.

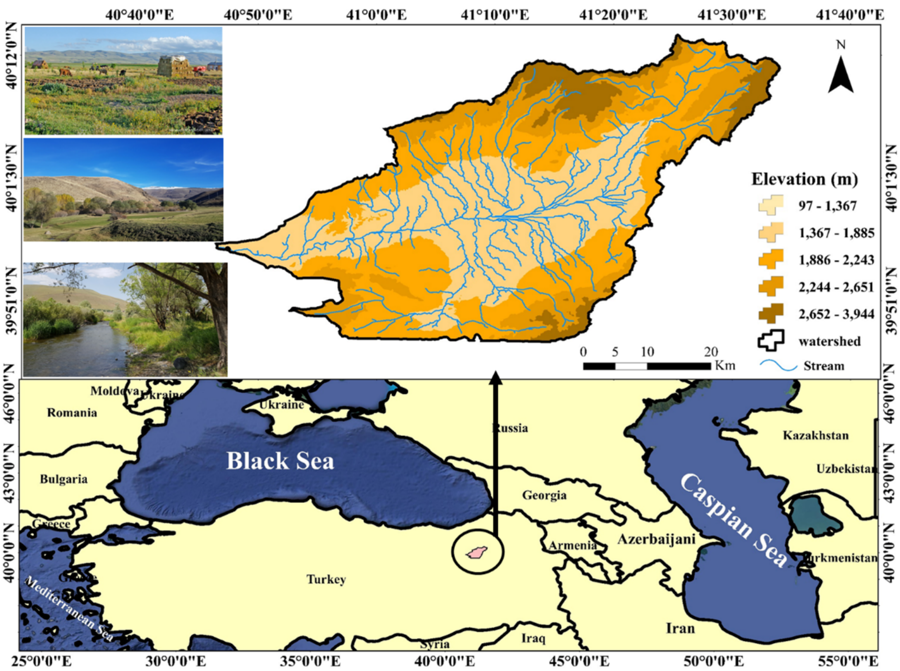

Figure 1. Location of the study area Erzurum, Turkey.

2.2 Methodology

2.2.1 Land use extraction

In the present study, based on the satellite image quality, maximum vegetation coverage, and absence of cloud cover over the study area, three images from Landsat satellite for the years 1994, 2002, and 2011, along with two images from Sentinel-2 for the years 2017 and 2023, were selected and downloaded. Table 1 delineates the specifications of the satellite images utilized in the current research. The years 1994, 2002, 2009, 2016, and 2023 were chosen as target years because significant land use changes were distinctly observable during these years, and the selection of cloud-free satellite images was feasible.

The satellite image dataset processing involved atmospheric radiometric corrections using the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercube (FLAASH) algorithm within ENVI 5.3 software (Aghaei et al., 2020). Corrections are essential for satellite images to be used effectively. The initial step was to apply radiometric corrections and sensor-specific corrections (DN1) to the imagery. For satellite image classification, the most suitable method employed was supervised classification, with the most frequently used algorithm being the Maximum Likelihood Algorithm (Mostafazadeh and Khiavi, 2022). This algorithm describes the distribution of reflectance numbers of a sample using a probability density function, in which the reflectance value of each pixel is classified into a specific spectral response class based on its variance. The assumption in this algorithm is that the data distribution of each class is centered around the mean pixel reflectance value following a normal distribution. To assess the accuracy of the classified images, the Kappa coefficient was extracted using TerrSet 18.00 software.

2.2.2 Single and integrated land use dynamic

The land use dynamic index indicates the extent of changes in one land use in comparison to other land uses. Equation (1) was employed to determine the land use dynamic index.

$$K_{single} = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \tag{1}$$

in which K_{single} represents the intensity index of changes for each land use/land cover over each time period, U_a and U_b denote the area of each land use from the beginning to the end of the examined period, and T stands for the time interval used in each period. A higher value of K_{single} indicates a more intense change in that land use compared to others, with positive and negative values indicating an increasing or decreasing trend of that land use among the rest.

2.2.3 LUCC dynamic degree index

The land use dynamism index indicates the quantitative speed of changes for each land use, playing a positive role in the future land use change process. Its value was calculated using Equation (2) (Sun et al., 2012).

$$K_{total} = \left[\frac{\sum_{i=1}^{n} |\Delta LU_{i-j}|}{2\sum LU_i}\right] \times \frac{1}{T} \times 100\% \quad (j = 1,2,3,\ldots,n) \tag{2}$$

where K_{total} represents the index of dynamism for each land use during the examined period. Lu_i is an area of specific land use at the beginning of the research, $\Delta\ LU_{i\text{-}j}$ is the changing area of certain land use over a given time period, and T also represents the time to the year.

3. Results and discussion

3.1 LULC transfer matrix analyses

In order to classify satellite images, supervised classification along with the maximum likelihood method was employed. The accuracy of these images was also assessed using the Kappa coefficient, which yielded values of 0.73, 0.82, 0.79, 0.89, and 0.82 for the years 1994, 2002, 2009, 2016, and 2023, respectively. According to the results shown in Table 2, the percentage of waterbodies area decreased from 0.24% in 1994 to 0.09% in 2023. The trees lands, however, experienced an increase from 0.32% in 1994 to 0.34% in 2023. Additionally, Rangeland decreased from 66.69% in 1994 to 47.47% in 2023. Despite the decrease in Pasture and Orchard land uses, Cropland exhibited a remarkable growth, increasing from 29.02% in 1994 to 47.02% in 2023. During this period, Flooded Vegetation and Bare Ground did not experience significant changes.

Throughout the studied years (1994 to 2023), Pasture land use witnessed the most substantial change with a 19.22% decrease. Correspondingly, Agricultural land use had the highest increase of 18% among land uses. Residential land use showed a consistent increase throughout all periods, except for 2009 and 2016 when no changes were observed. Furthermore, trees lands experienced a marginal decrease of 0.02% of the total area, and finally, waterbodies displayed a decreasing trend to 0.15% during the studied years. The results concerning the area and percentage of each land use are presented in Table 2. Figure 2 displays the land use maps corresponding to the studied years. According to the findings of Oguz and Zengin (2011), Erzurum has under-

Table 1. Satellite imagery used characteristics in the research to evaluate LULC change.

Sensor	Date	Path	Row
Landsat-7-ETM	26 July 1994	172	32
Landsat-8- OLI	3 Jun 2002	172	32
Landsat-8- OLI	23 July 2011	172	32
Sentinel-2	2017	-	-
Sentinel-2	2023	-	-

Table 2. Area and percentage of each land use in different years of the study period.

Land use class	Year Statistics	water bodies	Trees	Flooded vegetation	Rangeland	Crops	Built area	Bare ground
1994	Area (km^2)	4.06	5.31	0.19	488.03	60.31	2.39	1121.57
	Percentage (%)	0.24	0.32	0.01	29.02	3.59	0.14	66.69
2002	Area (km^2)	1.53	3.96	0.20	488.07	68.01	7.67	1112.49
	Percentage (%)	0.09	0.24	0.01	29.02	4.04	0.46	66.14
2009	Area (km^2)	1.35	12.50	0.10	606.75	75.48	12.69	973.23
	Percentage (%)	0.08	0.74	0.01	36.07	4.49	0.75	57.86
2016	Area (km^2)	1.84	3.98	0.12	671.24	75.48	8.06	920.97
	Percentage (%)	0.11	0.24	0.01	39.91	4.49	0.48	54.76
2023	Area (km^2)	1.56	5.71	0.46	790.89	83.67	1.26	798.37
	Percentage (%)	0.09	0.34	0.03	47.02	4.97	0.07	47.47

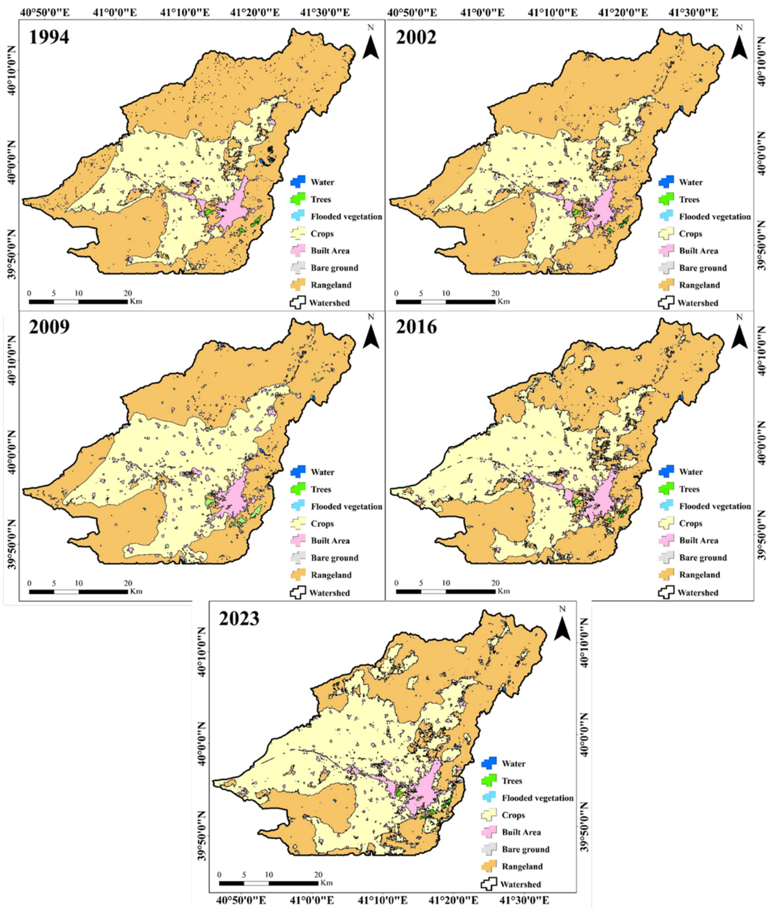

Figure 2. Land use maps of the Erzurum area in 1994, 2002, 2009, 2016, and 2023 years.

gone rapid changes in land use, especially in residential and agricultural areas. Their analysis showed that the residential and agricultural areas increased by 3079 and 3542 hectares, respectively, from 1987 to 2007, leading to a significant reduction in grassland area.

3.2 Analysis of the dynamics of land-use change in the study area

The degree of land use dynamics changes in various periods in the studied region is shown in Table 3. According to the results, the highest rate of land use changes occurred in Residential land use during the 1994-2002 period and continued in the subsequent period. The rate of changes in trees lands increased initially compared to other periods, indicating a trend towards degradation. The presence of waterbodies also experienced significant changes, showing a much faster rate in the first period compared to other periods. Rangeland, however, maintained a relatively stable trend in the rate of changes across all periods.

According to the results presented in Table 3, the value of unit dynamic degree for Bare Ground is 0.32%+. However, the trees lands exhibits a high dynamic degree of +0.31%.

Table 3. Percentage of the single dynamic of land use change degree in the Erzurum area of Turkey.

	Water bodies	Trees	Flooded vegetation	Rangeland	Crops	Built area	Bare ground
1994-2002	-0.09	-0.04	0.01	0.00	0.02	0.32	0.00
2002-2009	-0.02	0.31	-0.07	0.03	0.02	0.09	-0.02
2009-2016	0.05	-0.10	0.02	0.02	0.00	-0.05	-0.01
2016-2023	-0.02	0.06	0.41	0.03	0.02	-0.12	-0.02
1994-2023	-0.02	0.00	0.05	0.02	0.01	-0.02	-0.01

In the second period (1994 – 2002), the highest dynamic degree was attributed to Bare Ground with a value of +0.32%, whereas the dynamic degree for Built Area was 0.00%. This finding aligns with Khiavi and Mostafazadeh (2021), who reported the highest dynamic degree for Forest land use. For the study area during the (2002 – 2009) period, the highest dynamic degree was +0.31% for Trees and +0.02% for Built Area. Additionally, for the period (2009 – 2016), the dynamic degree for Trees was −0.10%, while it was 0.00% for Built Area. Moreover, during the period (2016 – 2023), the highest value was +0.41% for Flooded Vegetation, and for the period (1994 – 2023), the lowest dynamic degree was 0.00% for Trees and +0.02% for Crops. Oguz and Zengin (2011) admitted that the conversion of land use from Pasture to Agriculture has been the major transformation in the Erzurum region. As observed in Figure 3, the higher degree of dynamics is related to land uses predominantly influenced by human activities. The results from Liu et al. (2017) showed a reduction in ecological areas due to human activities in the Northeast China region from 1996 to

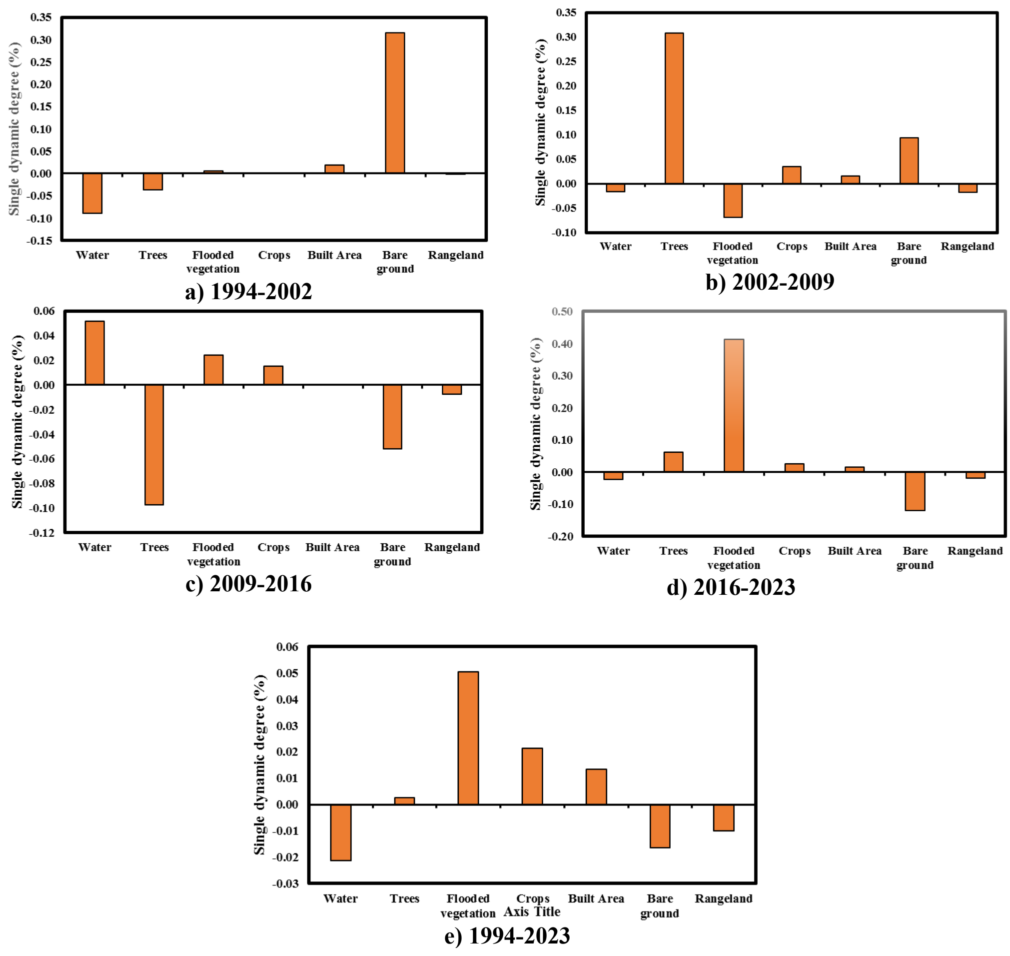

Figure 3. Single dynamic use/cover change in the Erzurum area of Turkey.

2014. According to their findings, the transformation from natural lands to agricultural and residential lands occurs due to human activities.

In this regard, Wang et al. (2018) argue that socio-economic development drives the evolution of land-use policies in relation to urbanization phases in China. They demonstrate that these drivers significantly influence land-use changes and advocate for policy reforms to sustainably manage and protect land amid rapid urban and industrial growth. In their global synthesis, Guneralp et al. (2020) examined urban land expansion trends from 1970 to 2010, focusing on urban population densities and land transitions. They found that smaller to medium-sized urban areas experienced higher expansion rates and declines in population density, particularly notable in India, China, North America, and Europe. Their findings indicate that more than 60% of urban expansion occurred on former agricultural lands, posing significant implications for land use and sustainability in regions like China, Southeast Asia, and Europe.

Moreover, Ganaie et al. (2021) observed the impact of increasing human population on land use and cover changes in Kashmir Valley's Wular Lake catchment. They reported substantial decreases in water bodies (−51.60%), swamps/marshy areas (−30.92%), and dense forests (−10.56%) due to population growth. Their study highlighted negative correlations between population increase and categories such as snow cover, water bodies, and dense forests, underscoring significant degradation of fragile ecosystems in the western Himalayas.

Ghute et al. (2023) used remote sensing and GIS in Maharashtra, India's Upper Purna River basin to assess natural and human impacts, mapping changes over three decades. They found rising agricultural land, built-up areas, and water bodies, with decreases in vegetation and barren land.

Figure 4 illustrates the integrated dynamic land use changes. According to the results, the highest total degree of land use dynamic changes occurred for the period 1994 – 2023, with 0.017%, and the lowest degree was for the period 1994 – 2002, with 0.001%. The results indicate an increasing trend from the period 1994 – 2002 to the period 2002 – 2009, followed by a decreasing trend in the period 2009 – 2016, and then an increase again in periods 3 and 4.

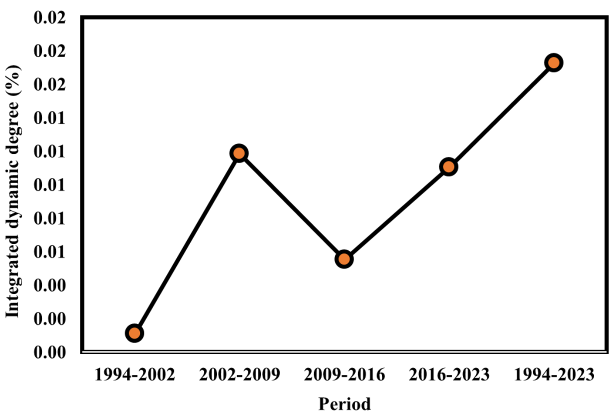

Figure 4. Integrated dynamic of land-use change in Erzurum area of Turkey.

4. Conclusion

In this study, the trend of land use changes in Erzurum from 1994 to 2023 over a 30-year period was investigated. The results obtained from assessing land use maps using the maximum likelihood method in different years, with the aid of kappa and overall accuracy coefficients, indicate a high accuracy of the prepared land use maps, serving as a monitoring tool for land use changes in the region. In the city of Erzurum, the results showed a recent trend of residential area development towards the south, where agricultural lands are being utilized. Conversely, the area of rangelands has drastically decreased, replaced in some parts of the region by impermeable and irreversible residential lands. However, between 2009 and 2016, due to favorable agricultural conditions or minimal changes in land use in this sector, there were significantly fewer alterations in the rangelands, remaining relatively constant in both periods. From 1994 to 2023, owing to agricultural expansion and attention to the agricultural sector, the number of waterbodies increased, catering to farmers for agricultural irrigation. However, in subsequent periods, due to a severe decline in agricultural lands and neglect of this sector, some of these blue zones have gradually dried up due to the surrounding residents' neglect. The results obtained from the intensity of changes and degrees of dynamism in land use demonstrate that if no action is taken, the trend of land use changes will continue similarly in the future. Consequently, more rangeland areas will transform into agricultural lands, along with areas featuring irreversible structures. The findings of this study can be utilized in land development plans and proper management strategies to understand the current trend of land use changes in the Erzurum region. The study's utilization of satellite imagery spanning three decades highlights the comprehensiveness of monitoring land use changes in Erzurum, shedding light on the dynamic transformation of landscapes.

-Implications

The employed indices like Change Intensity and Integrated Dynamic Index allowed for a robust evaluation of these changes, offering valuable insights into the shifts and trends across different land use categories over time. The conversion of rangeland to agricultural land emerged as a prominent trend, suggesting potential implications for regional ecosystems and sustainable resource management, particularly concerning the livelihoods of local communities reliant on agriculture. The observed decline in waterbodies and garden land use alongside the significant increase in agricultural land underscores the pressing need for strategic planning in balancing land utilization for sustaining ecosystems and preserving water resources. The notable shift in land use patterns, particularly the substantial decrease in rangeland and simultaneous increase in agricultural land, calls for cautious decision-making in resource management to ensure ecological resilience and support local livelihoods.

-Future studies

Future research endeavors should delve into the deeper socio-economic and ecological implications of the ongoing conversion of rangeland to agricultural land in the Erzurum region. Exploring the nuanced drivers and consequences of such land use shifts on local ecosystems, water resources, and community livelihoods could provide valuable insights for sustainable land management strategies. Furthermore, prospective studies could focus on predictive modeling using advanced remote sensing techniques and statistical analyses to forecast potential future land use scenarios, enabling proactive decision-making in resource allocation and conservation efforts within the region.

Authors Contributions
All authors have contributed equally to prepare the paper.

Availability of Data and Materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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

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