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# Provincial-level analysis of land use changes following the 2023 Kahramanmaraş earthquakes using sentinel-2 land use/land cover time series data

## Sentinel-2 arazi kullanımı/arazi örtüsü zaman serisi verileri kullanılarak 2023 Kahramanmaraş depremleri sonrası arazi kullanımındaki değişimlerin il düzeyinde analizi

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**Abstract**

Natural disasters significantly impact human settlements and land use. The February 6, 2023, Kahramanmaraş earthquakes caused extensive changes in land use and land cover (LULC) across 11 provinces in Turkey. This study analyzes these changes using Sentinel-2 LULC time series data from 2022 to 2023. The study area includes Adana, Adıyaman, Diyarbakır, Gaziantep, Hatay, Kahramanmaraş, Kilis, Malatya, Osmaniye, Şanlıurfa, and Elazığ. LULC classifications—agriculture, settlement, bare ground, trees, and water—were analyzed using ArcGIS to assess annual change rates. Results indicate that settlements expanded, especially in Hatay, Gaziantep, and Osmaniye (3-4%), due to post-earthquake reconstruction. Agricultural land increased in Şanlıurfa and Kilis but declined in Elazığ and Adıyaman. Bare ground areas decreased, suggesting erosion control and afforestation efforts. Small increases in water bodies were observed, indicating potential environmental benefits. These findings highlight the importance of sustainable land management and post-disaster planning to mitigate future risks.

**Keywords**: Disaster management, GIS, LULC, Remote sensing, Sentinel-2

**Öz**

Doğal afetler, insan yerleşimleri ve arazi kullanımı üzerinde önemli değişimlere yol açmaktadır. 6 Şubat 2023 Kahramanmaraş depremleri, Türkiye'deki 11 ilde arazi kullanımı ve arazi örtüsünde (LULC) büyük değişimlere neden olmuştur. Bu çalışmada, Sentinel-2 LULC zaman serisi verileri kullanılarak 2022-2023 yılları arasındaki değişimler analiz edilmiştir. Çalışma alanı Adana, Adıyaman, Diyarbakır, Gaziantep, Hatay, Kahramanmaraş, Kilis, Malatya, Osmaniye, Şanlıurfa ve Elazığ illerini kapsamaktadır. Tarım, yerleşim, çıplak arazi, ağaçlık alanlar ve su kaynakları gibi LULC sınıfları ArcGIS yazılımı kullanılarak yıllık değişim oranları açısından değerlendirilmiştir. Sonuçlar, yerleşim alanlarının genişlediğini, özellikle Hatay, Gaziantep ve Osmaniye'de %3-4 oranında arttığını ve bunun yeniden yapılandırma sürecinden kaynaklandığını göstermektedir. Tarım arazileri, Şanlıurfa ve Kilis'te artarken, Elazığ ve Adıyaman'da azalmıştır. Çıplak arazi alanlarının azalması, erozyon kontrolü ve ağaçlandırma çalışmalarına işaret etmektedir. Su kaynaklarındaki küçük artışlar, çevresel sürdürülebilirlik açısından olumlu bir gelişme olarak değerlendirilmiştir. Bu bulgular, sürdürülebilir arazi yönetimi ve afet sonrası planlamanın önemini vurgulamaktadır.

**Anahtar kelimeler**: Afet yönetimi, CBS, AÖAK, Uzaktan algılama, Sentinel-2

## 1 Introduction

Natural disasters have long been a major challenge for human settlements, and earthquakes are among the most destructive [1]. One of the most severe earthquakes in recent years struck Turkey on February 6, 2023, with two major shocks originating in Kahramanmaraş. The first earthquake (Mw 7.8) occurred in Pazarcık District and the second (Mw 7.7) in Elbistan District, causing widespread destruction in 11 provinces, including Adana, Adıyaman, Diyarbakır, Gaziantep, Hatay, Kahramanmaraş, Kilis, Malatya, Osmaniye, Şanlıurfa, and Elazığ [2,3]. By 6 March 2023, 1 month after the devastating earthquakes occurred, 1 712 182 buildings in the 11 affected provinces were checked by the authorities. In total, 35 355 buildings collapsed, 17 491 had to be demolished immediately, 179 786 were seriously damaged, 40 228 were moderately damaged, and 431 421 were slightly damaged [4]. These earthquakes claimed the lives of more than 53 000 people and resulted in the destruction or damage of 1 929 313 residential or rural dwellings in the affected provinces [5].

Uncontrolled land use and unplanned urbanization have played an important role in increasing the risks associated with natural disasters. This situation exacerbates the effects of disasters such as earthquakes and floods, which are frequently experienced in Turkey [6]. The phenomenon of

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urbanization in Turkey has been extensively analyzed in the context of natural disaster risks, with studies highlighting how unplanned urbanization exacerbates these risks [7,8].

These studies show that uncontrolled land use and unplanned urbanization are critical factors in increasing the devastating impacts of natural disasters. The rapid expansion of urban areas often takes place at the expense of agricultural land, converting it into residential and industrial zones, while coastal areas are increasingly occupied by seasonal housing developments. Historical evidence from the 1966 Varto, 1967 Adapazarı, 1970 Gediz, and 1999 Marmara earthquakes shows that inappropriate land use is a primary factor in the extent of earthquake-induced damages [3,5]. Similarly, the catastrophic effects of the earthquakes centered in Kahramanmaraş on 6 February 2023 further highlight the consequences of inappropriate site selection for settlements, emphasizing the need for sustainable land use planning and disaster-resilient urban development strategies.

LULC change analysis has emerged as a critical component of post-disaster assessment, providing valuable insights into the spatial dynamics of affected regions. Pre- and post-earthquake analyses of LULC play a critical role not only in determining physical damage but also in ensuring social, economic, and ecological sustainability [9]. Researchers and land managers can evaluate the impacts of human activities on land use, monitor deforestation or urban expansion, and analyze the effectiveness of land management strategies for socio-economic and environmental development [10]. Such studies not only provide an understanding of a region's ecology and vegetation cover but also enable the assessment of changes, such as the increase in built-up areas, which affect hydrological processes like surface runoff, peak flow characteristics, water quality, and flow patterns [11-13]. For example, post-earthquake LULC assessments have been used to evaluate reconstruction efforts, monitor the expansion of built-up areas, and assess environmental degradation [14,15]. In particular, LULC changes are closely associated with land degradation, loss of agricultural productivity, deforestation, water cycle disruption, and urban sprawl [16,17]. Moreover, the dynamics of LULC influence key ecological functions and socio-economic parameters, such as food security, water availability, and vulnerability to hazards [18,19]. Studies also demonstrate that the characterization of LULC transformations can help evaluate resilience and adaptive capacity in disaster-prone areas. For instance, in the context of the 2005 Kashmir earthquake and the 2015 Nepal earthquake, post-disaster LULC analyses were instrumental in tracking settlement shifts, evaluating environmental impacts, and guiding policy for sustainable reconstruction [20,21]. These examples highlight that LULC change analysis is not only a tool for quantifying physical alterations but also a framework for long-term planning and disaster risk reduction.

The use of remote sensing technologies, especially pre- and post-earthquake satellite data, to analyze post-disaster land use changes is of great importance in monitoring environmental changes. These technologies provide important insights not only into the extent of physical damage but also into post-disaster regional sustainability and recovery processes [22-26].

In recent years, the high-resolution imagery and frequent transit capabilities of Sentinel-2 satellite data have enabled rapid detection and mapping of environmental changes in disaster areas. In the aftermath of the Lone Pine (California) earthquakes in 2020, the Thessaly (Greece) earthquakes in 2021, and the major earthquakes in Turkey on February 6, 2023, Sentinel-2 satellite data were effectively used, and their rapid analysis capabilities in disaster monitoring processes were emphasized [27]. At the same time, while addressing land use changes in Hatay, one of the provinces most affected by the February 6, 2023, earthquakes in Turkey, another study examined and analyzed post-disaster land use changes in Adana, Mersin, Gaziantep, Hatay, and Kahramanmaraş provinces more comprehensively with Sentinel-2 satellite data [28,29]. Although these studies clearly show how Sentinel-2 satellite data is an effective and important tool in disaster monitoring and assessment processes, post-disaster land use changes in a large geographical area covering 11 provinces have not been addressed in a holistic manner.

This study aims to make a comprehensive assessment of post-disaster settlement reconstruction and regional recovery processes using Sentinel-2 satellite data. In this context, the present study provides a significant and original contribution to the literature through comprehensive LULC change analyses conducted over a broad geographical area encompassing 11 provinces affected by the February 6, 2023 earthquakes. While existing studies are often confined to limited spatial extents, this research distinguishes itself both in terms of its extensive spatial coverage and the adoption of more advanced and innovative methodologies compared to traditional approaches. Specifically, the use of high-resolution (10 m) Sentinel-2 satellite imagery, combined with artificial intelligence–based classification algorithms, enables more precise, rapid, and reliable detection of post-disaster environmental changes. This approach facilitates the identification of physical destruction and supports the monitoring of reconstruction processes, the assessment of ecosystem responses, and the analysis of regional sustainability in the aftermath of the disaster. Consequently, the study offers decision-makers a high-accuracy, data-driven, and holistic evaluation framework, which is critical for disaster management, spatial planning, and sustainable development strategies. In this regard, the research aims to make tangible contributions both to the scientific literature and to practical disaster planning and policy-making processes.

## 2 Material and methods

This study employs an integrated approach combining Geographic Information Systems (GIS) and Remote Sensing technologies to detect and analyze LULC changes caused by the 6 February 2023 Türkiye earthquakes. The methodology comprises data acquisition, reclassified, and temporal analysis for change detection is performed. The LULC classification results for the pre- and post-earthquake years are compared. In addition to the percentage change formula, spatial distribution maps are created to examine the effects at different scales. Dynamic maps and thematic layers are generated to visualize the results. Comparisons of changes, both spatial and class-based, are supported by maps and graphs. The Methodology of the study is shown in Figure 1.

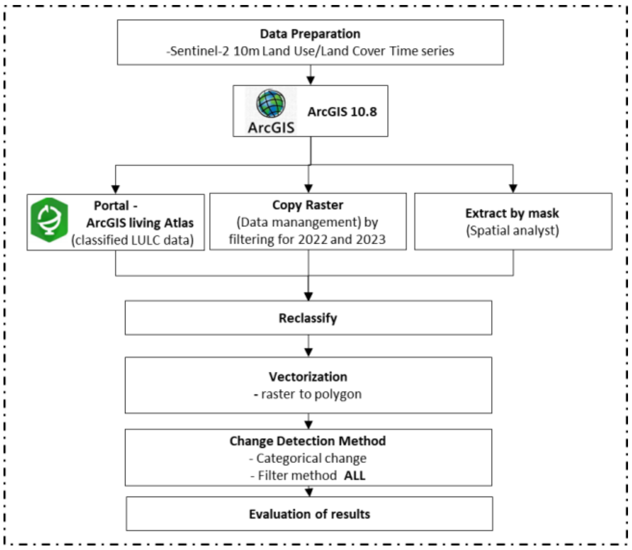



**Figure 1.** Workflow diagram

## 2.1 *Study area*

The study area covers 11 provinces in the southern and southeastern regions of Turkey that were affected by two major earthquakes centred in Kahramanmaraş on February 6, 2023. These provinces are Adana, Adıyaman, Diyarbakır, Gaziantep, Hatay, Kahramanmaraş, Kilis, Malatya, Osmaniye, Şanlıurfa, and Elazığ (Figure 2). These regions are of critical importance both in terms of their vulnerability to natural disasters and the changes in land use dynamics due to intensive human activities. The study area is diverse in terms of both physical geography and social structure, providing a unique opportunity to analyze land use changes.

The study area is in the Mediterranean, Eastern Anatolia, and Southeastern Anatolia regions and exhibits different geographical and climatic characteristics. For example, coastal areas such as Adana and Hatay have a Mediterranean climate, while inland areas such as Malatya, Elazığ, and Diyarbakır have continental climates. These climatic differences have a direct impact on land use diversity; there are various land types, such as agricultural areas, areas with trees., rangelands, and residential areas, in the region.

These regions are also areas with a high concentration of active fault lines, which increases the extent of physical and environmental changes that occur after earthquakes. It has been observed that settlements have rapidly expanded, agricultural areas have shrunk, and bare land has increased. Initial assessments after the earthquakes reveal that these land use changes may affect social and economic sustainability in the region and should be considered in disaster management strategies.

## 2.2 *Data collection and processing*

In this study, high-resolution Sentinel-2 satellite imagery was used to analyse the effects of the 2023 Kahramanmaraş earthquakes on LULC in 11 provinces. Sentinel-2 is an Earth observation mission developed by the European Space Agency (ESA) under the Copernicus Programme and is designed to monitor changes in the land surface [30].

Sentinel-2 has an instrument called the MultiSpectral Imager (MSI) and collects data in 13 spectral bands in the visible, near infrared, and shortwave infrared spectra. The following table details the band characteristics of Sentinel-2 (Table 1):

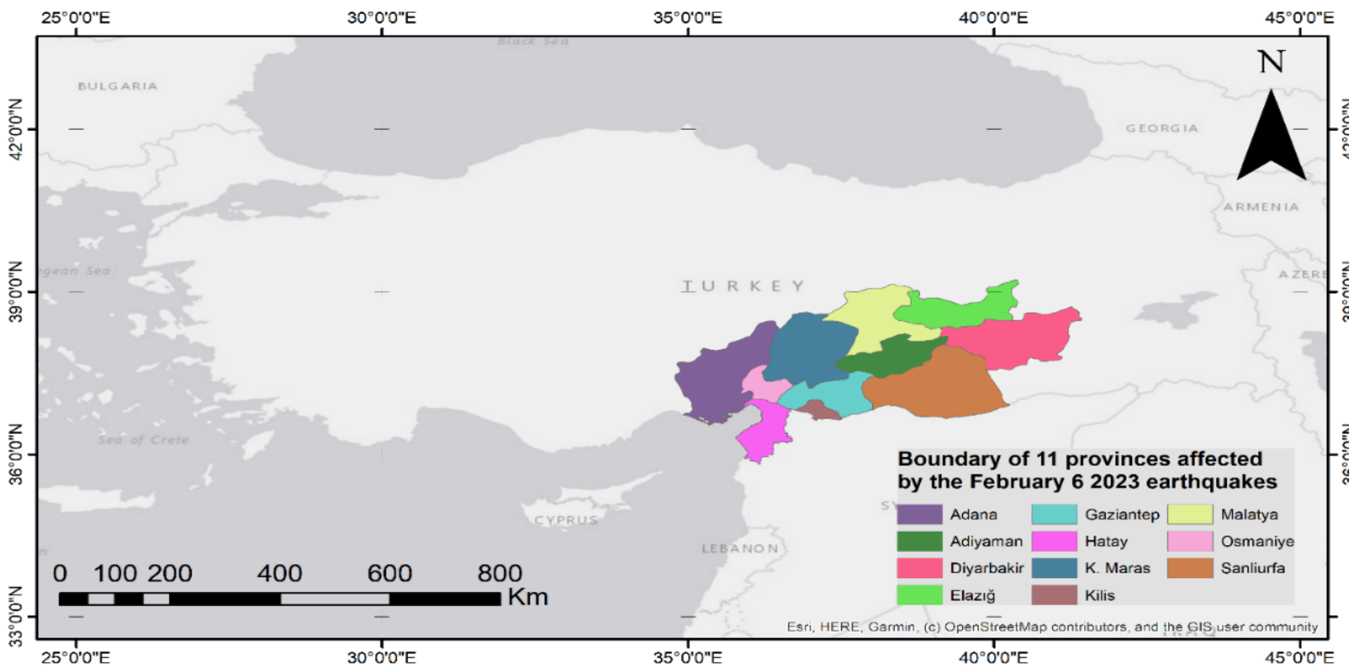



**Figure 2.** 11 Cities affected after the Kahramanmaraş earthquake: spatial distribution of the study area

**Table 1**. Sentinel-2 spectral band characteristics [30]

| Bands | Band Name | Central Wavelength (nm) | Bandwidth (nm) | Spatial Resolution (m) |
|---|---|---|---|---|
| **B1** | Coastal Aerosol | 442.7 | 21 | 60 |
| **B2** | Blue | 492.4 | 66 | 10 |
| **B3** | Green | 559.8 | 36 | 10 |
| **B4** | Red | 664.6 | 31 | 10 |
| **B5** | Red Edge 1 | 704.1 | 15 | 20 |
| **B6** | Red Edge 2 | 740.5 | 15 | 20 |
| **B7** | Red Edge 3 | 782.8 | 20 | 20 |
| **B8** | Near Infrared (NIR) | 832.8 | 106 | 10 |
| **B8A** | Narrow NIR | 864.7 | 21 | 20 |
| **B9** | Water Vapor | 945.1 | 20 | 60 |
| **B10** | Cirrus | 1373.5 | 31 | 60 |
| **B11** | Shortwave Infrared (SWIR) 1 | 1613.7 | 91 | 20 |
| **B12** | Shortwave Infrared (SWIR) 2 | 2202.4 | 175 | 20 |

The data were obtained through the ‘Sentinel-2 10m Land Use/Land Cover Time Series’ dataset available through ArcGIS Living Atlas of the World [31]. This dataset is derived from ESA Sentinel-2 imagery and provides global land use and land cover classifications at 10-meter resolution. The dataset is updated annually as of 2017 and produced by automatic classification methods using cloud computing platforms. The classified maps include Version 003 of the global Sentinel-2 land use/land cover data product. They are produced by a deep learning model trained using over five billion hand-labeled Sentinel-2 pixels sampled from more than 20,000 locations. In this way, it allows monitoring changes in land use. The class definitions of this dataset are given in Table 2.

In the study, the relevant dataset was analysed in detail through ArcGIS Living Atlas. The dataset contains land use/cover classifications provided by Sentinel-2 at 10 m spatial resolution. Considering the relevant provincial borders (Adana, Adıyaman, Diyarbakır, Gaziantep, Hatay, Kahramanmaraş, Kilis, Malatya, Osmaniye, Şanlıurfa, Elazığ), the data were downloaded in GeoTIFF format. The downloaded raster data were transferred to ArcGIS 10.8 environment. The data were georeferenced using a standard coordinate system (WGS 1984 UTM Zone 37N). The study area was cut to be within the administrative boundaries of 11 provinces using the Extract by Mask tool and only the data belonging to the study area were obtained.

The main reason for using classified data from the Atlas Living platform in the study is that the changes in land use before and after the disaster can be detected in detail thanks to the high spatial and spectral resolution specified in the technical specifications. The 10 m resolution classified images used made it possible to make detailed classifications, especially in urban and agricultural areas. The land use/cover classifications in the dataset were converted into nine main categories (water, trees, flood vegetation, crops, built area, bare ground, snow/ice, and clouds) in accordance with the scope of the research. In 2022 and 2023, reclassification was performed to correct minor classification inconsistencies in the data. The 12-bit radiometric depth of Sentinel-2 data ensured high data quality and level of detail. In addition, ground control using ArcGIS 10.8 software was supplemented with recent high-resolution imagery from Google Earth Pro to confirm the accuracy of the classifications in the dataset.

**Table 2.** Sentinel-2 10m Land Use/Land Cover Time Series class definitions [31]

| Value | Name | Description |
|---|---|---|
| 1 | Water | Predominantly water-covered areas, including rivers, lakes, oceans, and flooded salt plains. |
| 2 | Trees | Dense, tall vegetation (~15+ feet), including wooded areas, plantations, and mangroves. |
| 4 | Flooded Vegetation | Seasonally flooded areas with mixed vegetation; includes rice paddies and emergent wetlands. |
| 5 | Crops | Human-planted cereals and crops (not trees); includes corn, wheat, soy, and fallow fields. |
| 7 | Built Area | Human-made structures and infrastructure, including roads, cities, and paved surfaces. |
| 8 | Bare Ground | Areas with little to no vegetation, such as deserts, exposed rock, and dry salt flats. |
| 9 | Snow/Ice | Permanent snow or ice, typically in mountains or polar regions (e.g., glaciers, snowfields). |
| 10 | Clouds | Areas without land cover data due to persistent cloud cover. |
| 11 | Rangeland | Open grasslands with sparse vegetation, including natural meadows, pastures, and savannas. |

### *2.3 Change detection analysis*

To detect and quantify LULC changes for each class at the district level, the following formula can be used. This example focuses on various LULC classes such as water, trees, submerged vegetation, agricultural areas, built-up areas, bare ground, snow/ice, clouds, etc. LULC Percentage Change Formula is presented Equation (1) [32]:

$$Percentage\ Change = \frac{Area\ final - Area\ initial}{Area\ initial} * 100 \quad (1)$$

Where "Area_initial" refers to the total area of a specific LULC class at the beginning of the observation period, and "Area_final" denotes the same at the end. This formula provides a robust framework for detecting and quantifying shifts in land use and cover over time.By employing Sentinel-2 data, spatial changes induced by the earthquakes were identified and quantified at macro and micro scales. While macro-scale analysis provided an overarching view of regional dynamics, micro-scale assessments revealed localized impacts that were less discernible at larger scales. Dynamic maps and statistical outputs highlighted changes in key areas, including urban zones, agricultural lands, and natural habitats.

This methodological approach offers significant insights into the spatial and temporal dynamics of LULC changes in disaster-affected areas. The findings contribute to sustainable urban planning, disaster recovery, and land management strategies by revealing critical patterns and trends in land use changes triggered by the earthquakes.

In the study, the differences between the 2022 and 2023 LULC maps were calculated using the Raster Calculator tool, thus determining the changes in land cover. Zonal statistics analysis was performed to calculate the size (in km²) of the changing areas for each province. Finally, for visualisation purposes, choropleth maps and graphs were created, highlighting in particular urban expansion, agricultural changes, and deforestation trends. For each category, the changing areas are shown.

## 3 Results and discussions

In this study, the LULC changes in 11 provinces in the south and southeast of Turkey due to the February 6, 2023, Kahramanmaras earthquakes were examined in detail. It has revealed important findings for understanding post-earthquake land use dynamics and developing sustainable disaster management strategies. Using Sentinel-2 satellite imagery and GIS, this analysis aims to provide critical data for post-disaster land use planning by revealing the magnitude and distribution of both spatial and temporal changes. In particular, the research focused on identifying the regional characteristics of changes such as decreasing agricultural land, expanding settlements, and increasing proportions of bare land. Figure 5 showing land use and land cover changes and Figure 3 and Figure 4, which present the percentage distribution for the years 2022 and 2023, clearly show that settlements have expanded after the earthquake, while agricultural and natural areas have decreased.

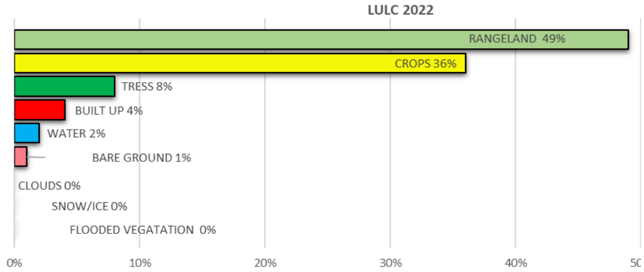



**Figure 3.** Percentage distribution of LUCL classes in 11 provinces for 2022

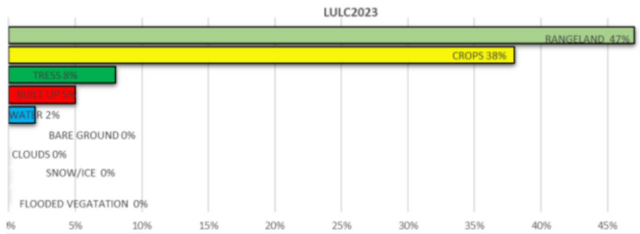



**Figure 4.** Percentage distribution of LULC classes in 11 provinces for 2023

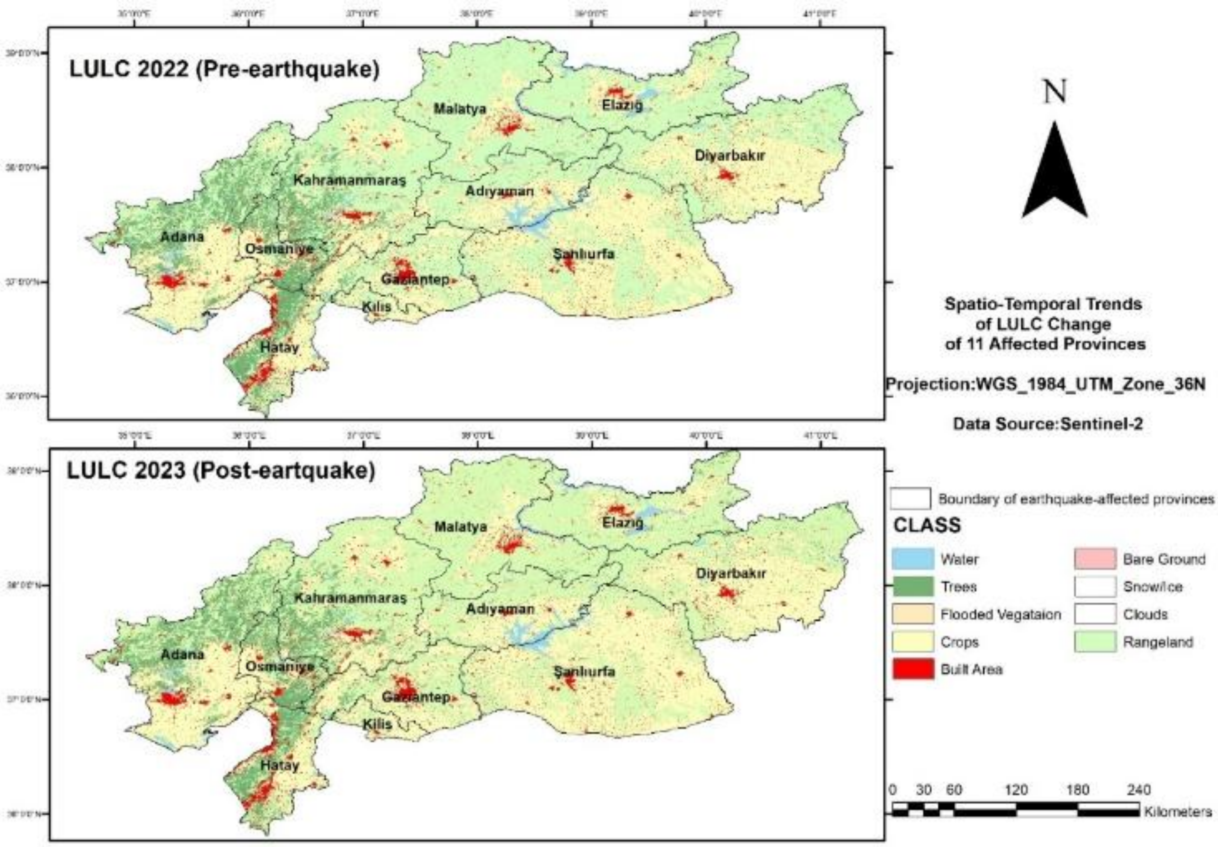



**Figure 5.** LULC change map for 11 provinces between 2022-2023

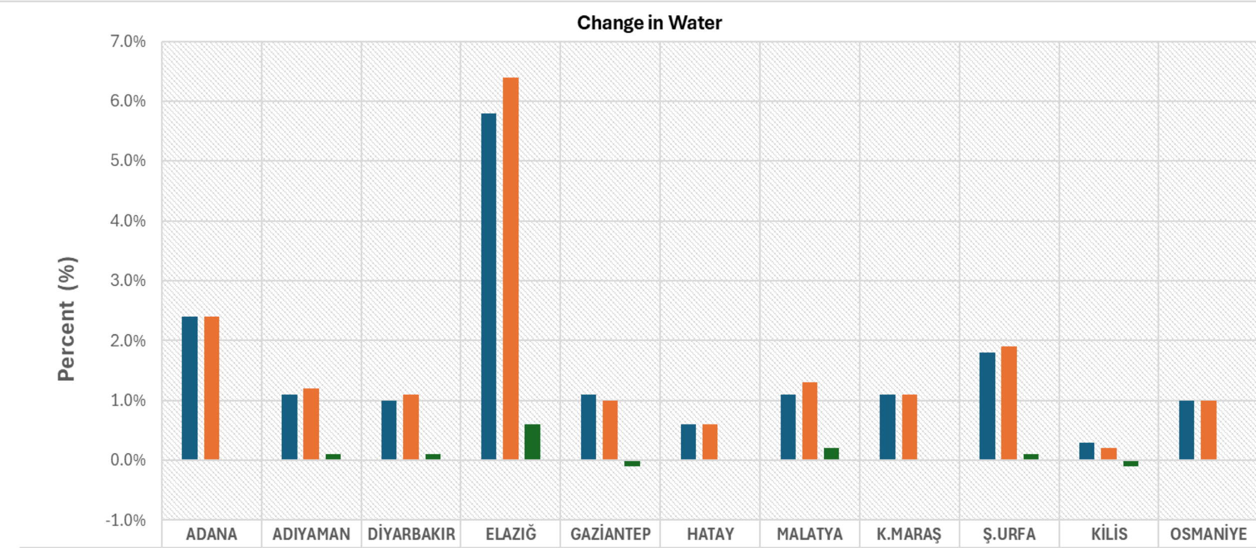
### *3.1 Water class changes and maps in post-earthquake land use*

Post-earthquake land use changes in water class have varied due to various factors such as regional environmental conditions, infrastructure status, and management policies. When these changes are analysed on a provincial basis, it is observed that there are both increasing and decreasing trends.

In Elazığ, an increase of 0.6% was observed in water areas (Figure 6). This increase is associated with the post-earthquake environmental recovery process and more effective management of water resources. The measures taken by local governments to protect natural resources after the earthquake can be considered one of the main reasons for this increase. This shows that water resources in Elazığ were successfully protected and managed during the post-earthquake recovery process. Small increases in water surfaces were also recorded in Diyarbakır, Adıyaman, Malatya, and Hatay. These increases are considered a result of ongoing efforts to protect natural water resources and environmental sustainability policies. The rebalancing of ecosystems after the earthquake and the impact of local climatic conditions are among the factors supporting the expansion of water surfaces in these regions. In Adana, Osmaniye, Kahramanmaraş, and Hatay, there has been no significant change in water areas. The fact that existing water resources remain stable indicates that ecosystem balance is maintained, and environmental degradation is limited in these regions. The preservation of agricultural water resources, especially in regions such as Adana and Hatay, indicates stability in water management. This indicates that the existing infrastructure in the region is functioning effectively, and water management policies are properly implemented. In Gaziantep and Kilis, a 0.1% decrease in water area was observed. This decrease indicates that pressure on water resources is increasing and local environmental conditions need to be carefully monitored. Resettlement processes in the region, partial damage to infrastructure, and increasing agricultural needs are among the possible reasons for these decreases. Protection of water resources and implementation of sustainable policies are crucial to mitigate the impacts of these reductions and ensure long-term water security. The percentage changes in water surfaces across the 11 provinces between 2022 and 2023 are presented in detail in Figure 3 and 4.

Overall, the analysis of post-earthquake water class changes shows that the environmental and infrastructural dynamics of each province are influential. Increases in water areas in and around Elazig are considered a positive indicator of environmental recovery, while decreases in Gaziantep reveal the measures that need to be taken in terms of water management and environmental sustainability (Figure 7). In provinces such as Adana, Osmaniye, and Hatay, no change in water areas was observed, indicating that the existing ecosystem balance was maintained. These findings provide important data for shaping post-disaster water resources management and environmental sustainability policies. Specific plans should be developed for the water resources management of each province, and these plans should be adapted according to post-disaster needs. Such analyses provide a scientific basis for protecting water resources and ensuring sustainable development.

The increase in the amount of water in the Palu district of Elazığ after the earthquake and the decrease in the amount of water in Gaziantep after the earthquake are clearly demonstrated visually on the maps (Figure 7).




| | ADANA | ADIYAMAN | DİYARBAKIR | ELAZIĞ | GAZİANTEP | HATAY | MALATYA | K.MARAŞ | Ş.URFA | KİLİS | OSMANİYE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2022 | 2.4% | 1.1% | 1.0% | 5.8% | 1.1% | 0.6% | 1.1% | 1.1% | 1.8% | 0.3% | 1.0% |
| 2023 | 2.4% | 1.2% | 1.1% | 6.4% | 1.0% | 0.6% | 1.3% | 1.1% | 1.9% | 0.2% | 1.0% |
| Change in Water | 0.0% | 0.1% | 0.1% | 0.6% | -0.1% | 0.0% | 0.2% | 0.0% | 0.1% | -0.1% | 0.0% |

**Figure 6.** Percentage change in water coverage (2022-2023) across 11 provinces

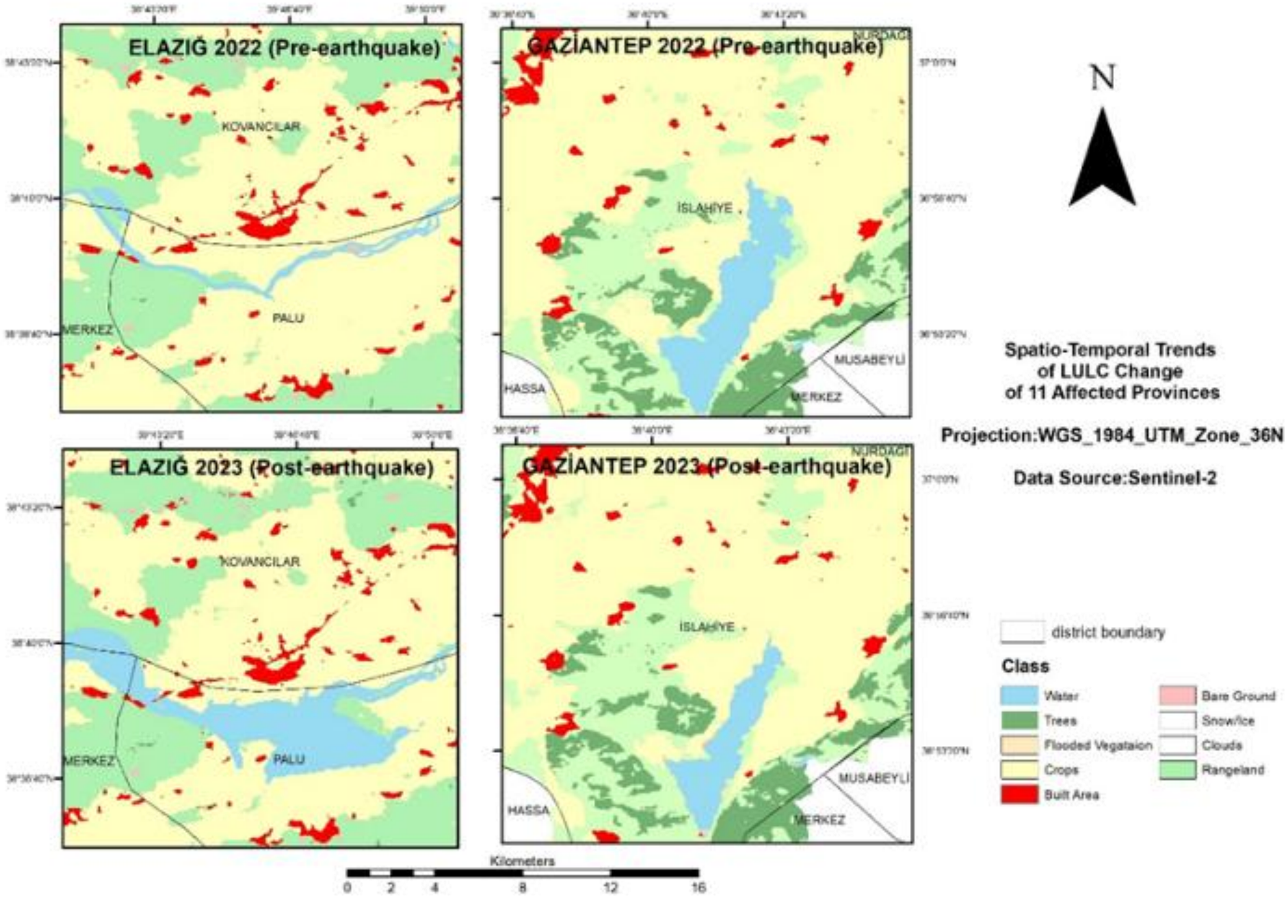



**Figure 7.** Post-earthquake water class changes and spatial reflections in Elazığ / Gaziantep

### *3.2 Change of trees class in post-earthquake land use*

Post-earthquake changes in the tree class varied between 2022 and 2023 in line with local environmental conditions and land use dynamics. Changes in wooded areas were shaped by various factors such as ecosystem balance, environmental sustainability practices, and reconstruction processes in each province. The analysis of these changes was evaluated on a spatial and percentage basis, and the findings are visualized in Figure 8. Small increases in wooded areas were observed in Adıyaman, Diyarbakır, Elazığ, Gaziantep, and Kilis. Especially in Gaziantep and Kilis provinces, an increase of 0.3% was recorded, which is considered a positive development in terms of environmental sustainability. This can be attributed to the local governments' implementation of policies focused on environmental protection and the realization of restructuring processes in line with the principle of protecting natural resources. Moreover, these increases indicate that the natural ecosystems in the regions have experienced positive impacts during the post-earthquake recovery process. In Malatya and Şanlıurfa provinces, there was no significant change in wooded areas. This indicates that the ecosystem balance in the region is maintained, and environmental conditions are stable. The fact that wooded areas have remained stable indicates that strategies for the conservation of natural resources are effectively implemented in these provinces. In Adana, Hatay, Kahramanmaraş, and Osmaniye, on the other hand, declines in wooded areas were observed.1.5% decrease was recorded in Hatay and a 1.4% decrease in Adana. These reductions indicate that post-earthquake reconstruction processes were carried out in a way that could lead to the conversion of in areas with trees into residential or agricultural areas. Moreover, these reductions are directly linked to local environmental impacts and land use dynamics. Increasing settlement and infrastructure needs after the earthquake is one of the main factors contributing to the decline in areas with trees. Overall, the assessment of changes in tree class shows how regional differences have an impact on the management of natural resources. While small increases in wooded areas in provinces such as Gaziantep and Kilis reveal the positive effects of sustainable practices, decreases in provinces such as Hatay and Adana emphasize the need to protect natural resources and increase afforestation efforts. These findings suggest that post-disaster land use policies should be reshaped in line with the principles of maintaining ecosystem balance and sustainable management of natural resources. Woodland conservation is critical for regional ecological sustainability and natural resource management.

After the earthquake, the decrease in tree class in Adana and the increase in Kilis (Figure 9) were spatially revealed through maps.

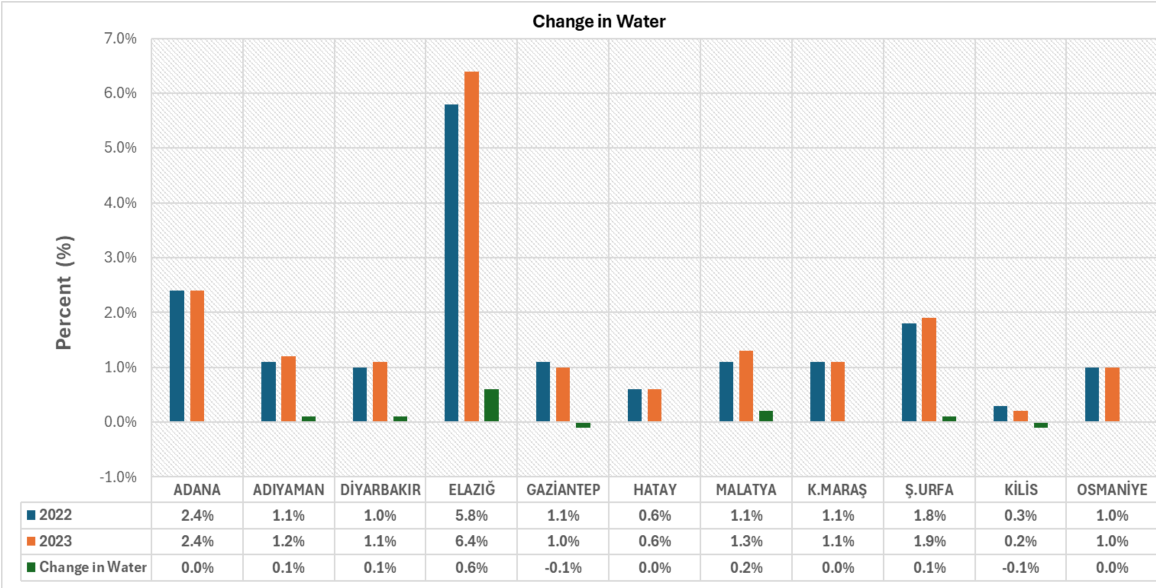



**Figure 8.** Percentage change in tree coverage (2022-2023) across 11 provinces

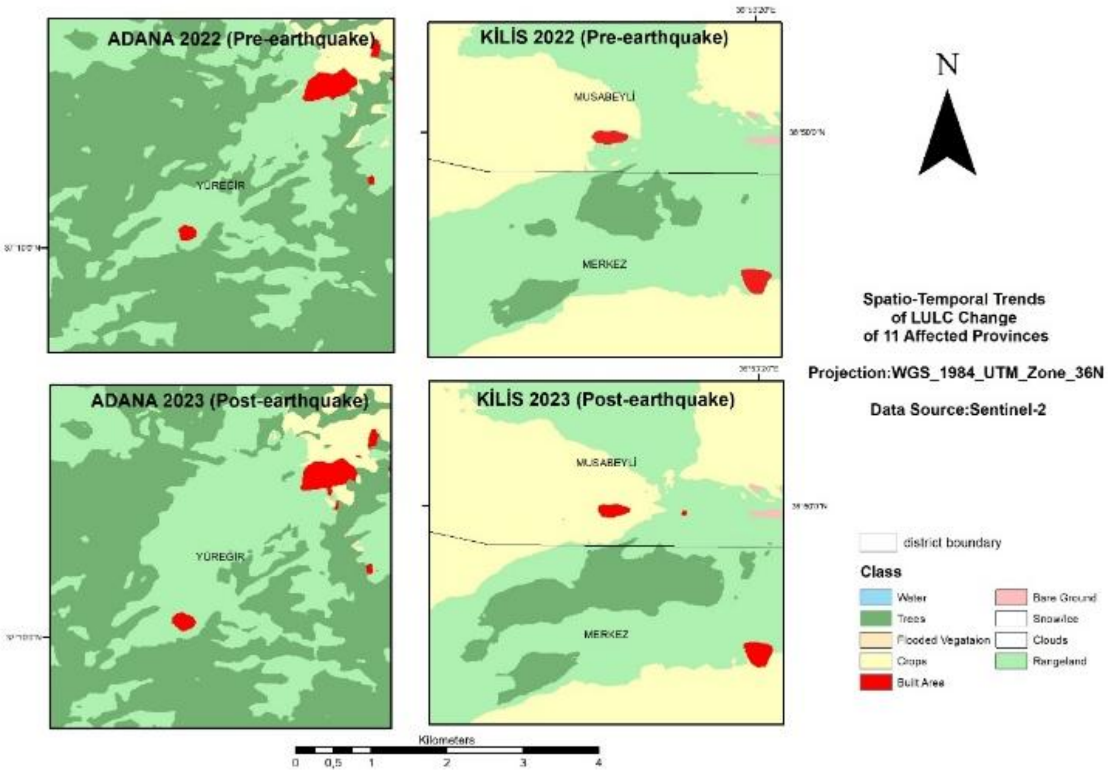



**Figure 9.** Post-Earthquake tree class changes and spatial reflections in Adana/Kilis

### *3.3 Change of crops class in land use after earthquake*

In the one year following the earthquake, it was observed that agricultural activities in the 11 affected provinces accelerated in some regions, while agricultural areas shrank in others due to local dynamics and reconstruction processes. The agricultural sector is critical for economic and social recovery, especially in rural areas. Therefore, it is important to assess the changes in agricultural land not only in terms of percentages but also in terms of long-term impacts and regional economic dynamics.

Agricultural areas increased in Şanlıurfa, Kilis, Diyarbakır, Gaziantep, and Malatya. This increase was particularly remarkable in Şanlıurfa (8.5%) and Kilis (5.2%) (Figure 10). This shows that regional agricultural policies are being implemented effectively and economic mobility in rural areas continues. In provinces with large agricultural production potential, such as Şanlıurfa, the increase in agricultural area contributes positively to both economic recovery and regional food security. Similarly, the increase in Kilis can be considered an important development in terms of rural development and economic sustainability. Smaller increases were also observed in Diyarbakır, Gaziantep, and Malatya, emphasizing the importance of agricultural activities in rural areas in the recovery process. Adana and Hatay provinces did not experience a significant change in agricultural areas. This indicates that agricultural production in these provinces is maintained in a balanced manner and ecosystem balance is preserved. The fact that agricultural areas have remained stable indicates that the existing agricultural infrastructure in the region is robust, and agricultural activities have continued without interruption in the post-earthquake period. On the other hand, a decrease in agricultural areas was observed in Kahramanmaraş, Elazığ, Adıyaman, and Osmaniye provinces. A decrease of 1.4% was recorded in Elâzığ and 1.5% in Adıyaman. These decreases are attributed to factors such as restructuring processes, urban transformation activities, and the conversion of agricultural areas into residential areas. This once again shows how critical it is for rural development to protect and support agricultural areas. During the restructuring process, ensuring the sustainability of agricultural production and increasing investments in agricultural infrastructure should be a strategic priority for economic recovery in these regions.

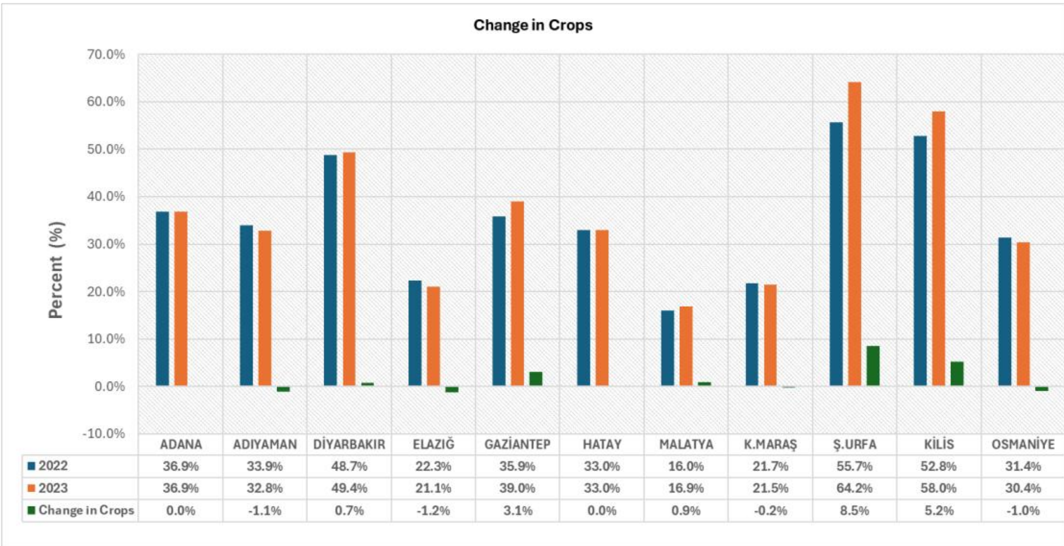



**Figure 10.** Percentage of 2022-2023 Crops in 11 Provinces

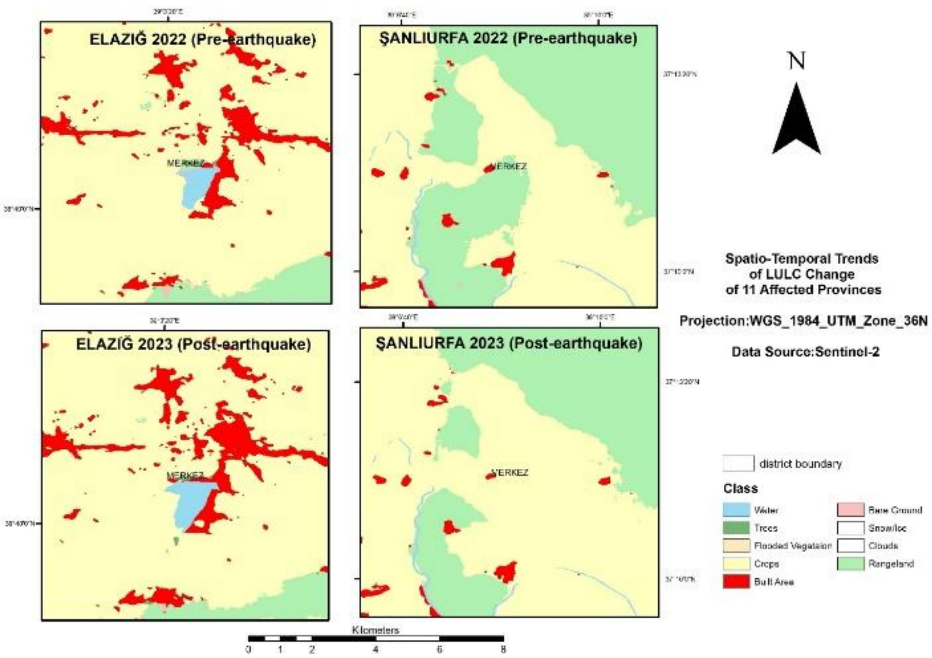



**Figure 11.** Changes in agriculture class and spatial reflections after the earthquake in Elazig/Şanlıurfa

Overall, changes in agricultural areas provide important data for assessing the effectiveness of agricultural sustainability and post-disaster recovery policies. In regions where agricultural areas are expanding, it is important to maintain existing policies and make these increases permanent. On the other hand, in regions with decreasing agricultural areas, it is necessary to reorganize land use policies, take strategic steps to encourage agricultural production, and adopt sustainable development policies. These analyses shed light on future planning to protect and strengthen agricultural areas.

The increase in agricultural areas and decrease in rangelands in Şanlıurfa after the earthquake, and the decrease in agricultural areas and increase in residential areas in Elazığ after the earthquake are shown spatially on the maps (Figure 11).

### *3.4 Change of built area class in land use after earthquake*

Post-earthquake changes in the "built area" class in 11 provinces reflect the expansion of settlement areas and reconstruction processes. These changes varied depending on the demographic and economic dynamics of the provinces, infrastructure requirements, and post-disaster recovery processes. While increases in settlement areas were evident in regions where reconstruction efforts were intensified and urbanization pressure increased, some provinces experienced contraction or conversion of existing settlement areas to different land use types.

Hatay province recorded an increase of 4%. This reflects the rapid reconstruction activities in the region and the expansion of residential areas to respond to the growing housing need. The reconstruction of heavily damaged buildings after the earthquake and the creation of new residential areas are among the main reasons for this increase. Increases of 3% in Gaziantep and Osmaniye indicate that urbanization pressures continue, and new residential areas are being created to meet the housing, and infrastructure demands in these provinces. These increases are important in terms of showing how urbanization dynamics are combined with restructuring processes. In Adıyaman, Adana, Elazığ, and Diyarbakır, an increase of 1% was recorded. These rates reveal that settlements in these provinces have expanded at a more limited scale, and urban growth has continued at local scales. Lower rates of increase in these provinces may indicate that restructuring processes are still in their early stages or that urbanization pressure remains at a lower level. On the other hand, Şanlıurfa and Kilis provinces experienced a 1% decrease in settlements. This reduction may be associated with the conversion of existing settlements to other land use types or population shifts to different regions in resettlement processes. Moreover, these decreases may indicate that reconstruction and urbanization processes in some regions have progressed more slowly than expected.

In general, these changes observed in the post-earthquake "built areas" class clearly reveal that post-disaster reconstruction processes and urbanization dynamics differ across provinces. While the expansion in settlement areas can be considered an indicator of reconstruction processes, planning this expansion in a sustainable manner is critical in terms of infrastructure management and control of environmental impacts. On the other hand, in regions with shrinking settlement areas, analyzing the causes of this situation and making the necessary policy adjustments are important for the success of post-disaster development and reconstruction processes. A detailed analysis of these changes provides a valuable source of information for future disaster management and urban planning processes. Post-earthquake changes in settlement areas have revealed the rates of expansion and contraction in 11 provinces between 2022-2023, and these data are presented in detail in Figure 12.

The 4% increase in the settlement class in Hatay and the 3% increase in Gaziantep indicate the expansion and reconstruction processes in the settlement areas in both provinces, and these changes are clearly monitored spatially through the maps (Figure 13).

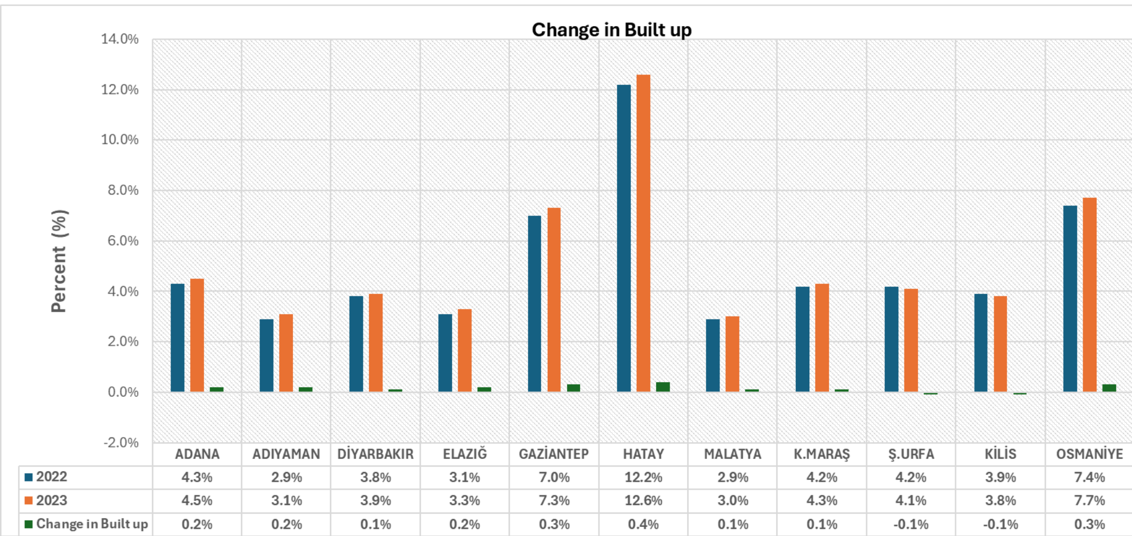



**Figure 12.** Percentage 2022-2023 built areas in 11 provinces

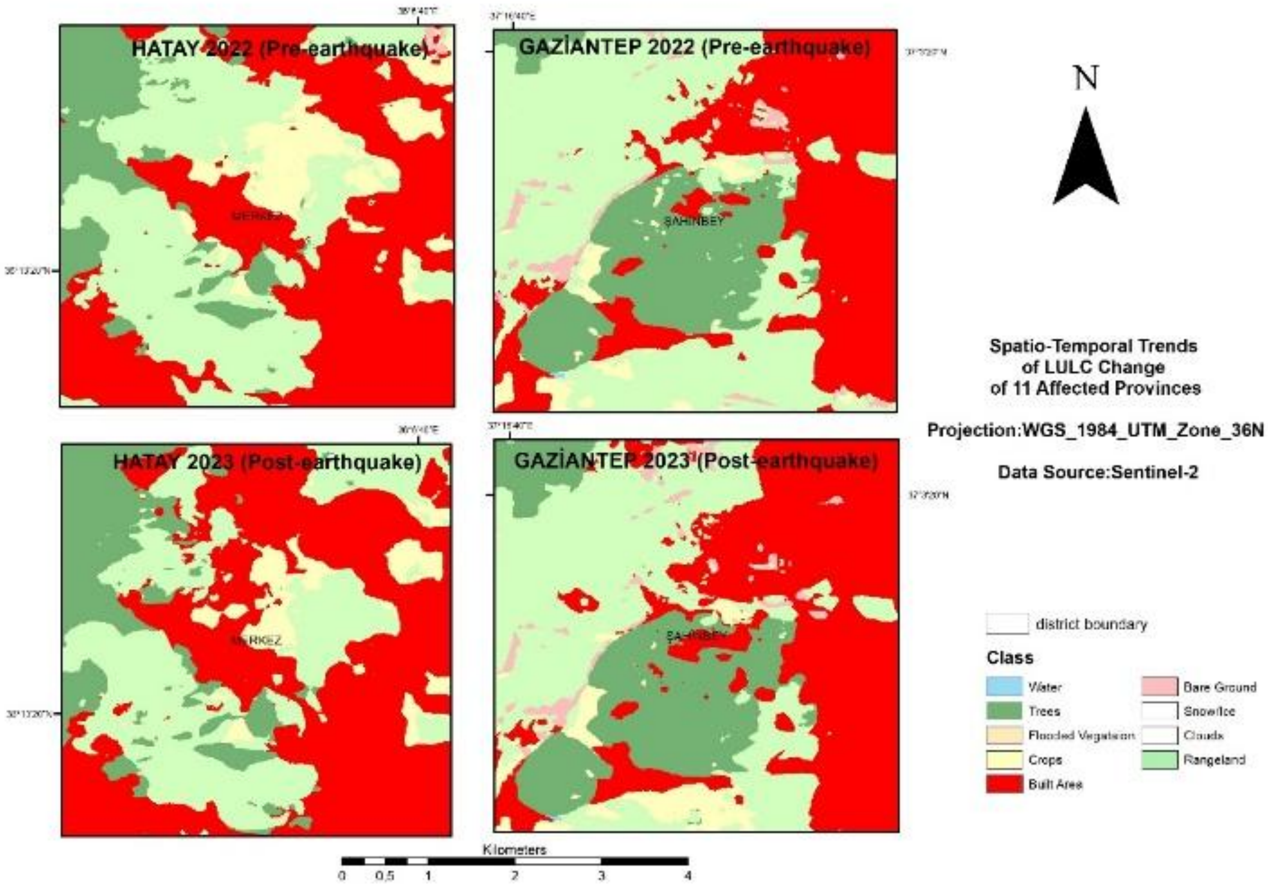



**Figure 13.** Post-Earthquake settlement class changes and spatial reflections in Hatay/Gaziantep

### *3.5 Changes in bare ground class in post-earthquake land use*

In the post-earthquake period, the changes observed in bare ground areas in 11 provinces were shaped by natural processes and anthropogenic interventions. The decrease in bare ground areas in some regions can be considered an indicator of environmental improvement efforts and increased agricultural activities. These changes are presented in detail in Figure 14 in terms of percentages between 2022 and 2023.

In Hatay, Osmaniye, Adana, and Şanlıurfa, there has been no significant change in bare ground areas. This indicates that a balanced structure of land use is maintained in these provinces and natural processes remain stable. The steady state in these regions indicates that environmental factors have not changed and current use continues in a sustainable manner. In the provinces of Kahramanmaraş, Gaziantep, Malatya, and Diyarbakır, there has been a decrease in bare ground areas. These decreases are associated with the expansion of settlements, restructuring processes, and increased agricultural activities. Restructuring processes seem to be effective in reducing bare ground areas in these regions. This change reflects the impact of both natural and social processes on land use. Elazığ and Adıyaman stand out as the provinces with the most significant decrease in bare ground areas. A 3% decrease was recorded in Elazığ and a 2% decrease in Adıyaman. These decreases can be explained by the impact of environmental improvement activities such as erosion control and afforestation work and increased agricultural activities. Such activities in the region contribute to both the conservation of natural ecosystems and the sustainable development of local economic activities.

In general, the changes in bare ground areas show that post-disaster recovery processes are different in different regions. In provinces that experienced a decrease, environmental remediation efforts and reconstruction were effective, while in regions that experienced an increase, agricultural activities and expansion of settlement areas were prominent. This clearly demonstrates how post-disaster reconstruction processes and urban growth interact with environmental factors. These findings emphasize the importance of planning local land management policies in line with environmental sustainability principles.

The post-earthquake reduction of wastelands in Elazığ and Adıyaman has manifested itself in the conversion to rangeland areas, especially around water sources. This change is associated with environmental regulations supporting erosion control and animal husbandry and is considered a positive development for sustainable land use (Figure 15).

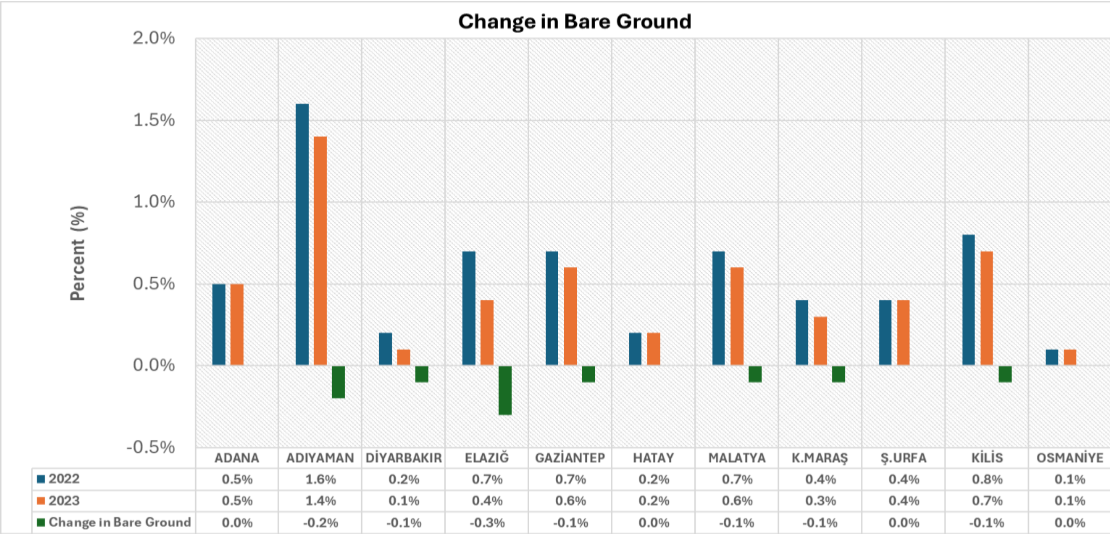



**Figure 14.** Percentage of bare ground in 11 provinces (2022-2023)

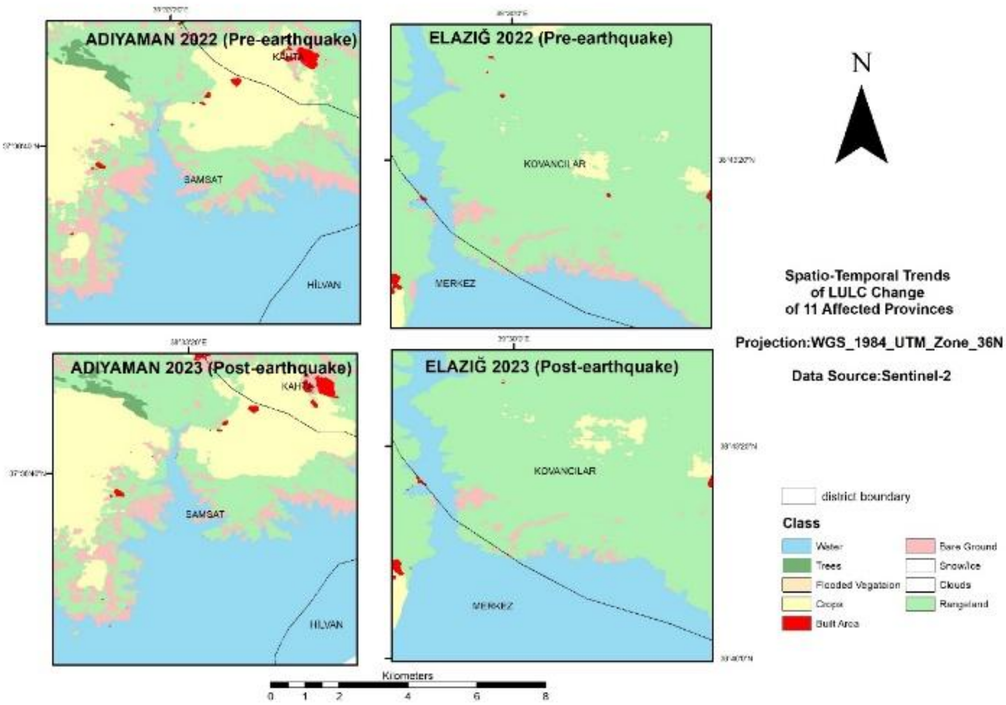
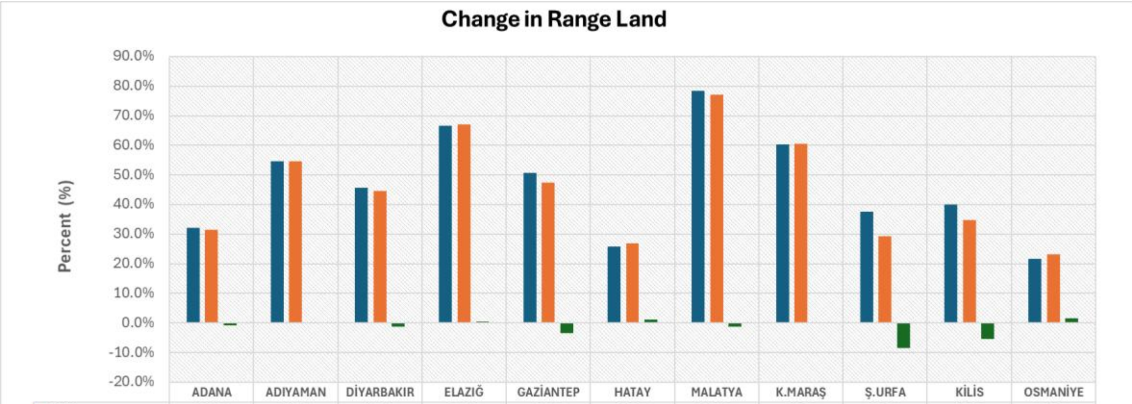



**Figure 15.** Changes in Bare Ground class and spatial reflections after the earthquake in Adıyaman/Elâzığ

### *3.6 Change of Rangeland Class in Land Use After Earthquake*

In the post-earthquake period, rangeland areas in 11 provinces experienced various changes because of different dynamics. These changes were shaped by urbanization, agricultural activities, and sustainable land management policies. The percentage distribution of changes in rangeland areas is presented in detail in Figure 16. There was a 4% increase in rangeland areas in Elazığ and a 3% increase in Kahramanmaraş. These increases are considered positive developments that support sustainable land management and livestock breeding activities. Similarly, increases of 1.7% were observed in Osmaniye and 1.1% in Hatay. These increases reflect efforts to maintain environmental balance and strengthen agricultural activities. There has been no significant change in rangeland areas in Adıyaman, indicating the stability of existing rangeland areas and the preservation of natural ecosystems. On the other hand, a small decrease of 0.8% in rangeland areas was recorded in Adana. Significant decreases of 8.4% were observed in Şanlıurfa and 5.4% in Kilis. These decreases are mainly attributed to the conversion of rangelands to agricultural land. The 3.4% decrease in Gaziantep is an indication of the transformation of settlements and urban growth pressures. Malatya and Diyarbakır experienced more limited decreases of 1.2%, indicating a slight pressure on natural ecosystems. Overall, changes in rangeland areas reveal regional differences in post-disaster reconstruction processes. In regions where rangeland areas have expanded, sustainable land management and livestock breeding activities seem to have yielded positive results. On the other hand, agricultural activities and urbanization pressures have negative impacts on natural areas in regions with decreasing rangelands. These findings emphasize that post-disaster land management and planning should be balanced with the protection of natural areas and sustainable economic activities. Figure 16 provides a critical dataset for spatial and quantitative analysis of these changes.

The post-earthquake decreases in rangeland areas and increase in crops in Şanlıurfa, and the post-earthquake decrease in rangeland areas and increase in crops in Kilis can be explained by the conversion of rangelands to agriculture and the increasing need for agriculture (Figure 17).




| | ADANA | ADIYAMAN | DİYARBAKIR | ELAZIĞ | GAZİANTEP | HATAY | MALATYA | K.MARAŞ | Ş.URFA | KİLİS | OSMANİYE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2022 | 32.2% | 54.7% | 45.7% | 66.7% | 50.8% | 25.8% | 78.4% | 60.3% | 37.7% | 40.1% | 21.6% |
| 2023 | 31.4% | 54.7% | 44.5% | 67.1% | 47.4% | 26.9% | 77.2% | 60.6% | 29.3% | 34.7% | 23.3% |
| Change in Rangeland | -0.8% | 0.0% | -1.2% | 0.4% | -3.4% | 1.1% | -1.2% | 0.3% | -8.4% | -5.4% | 1.7% |

**Figure 16.** Percentage 2022-2023 range land in 11 provinces

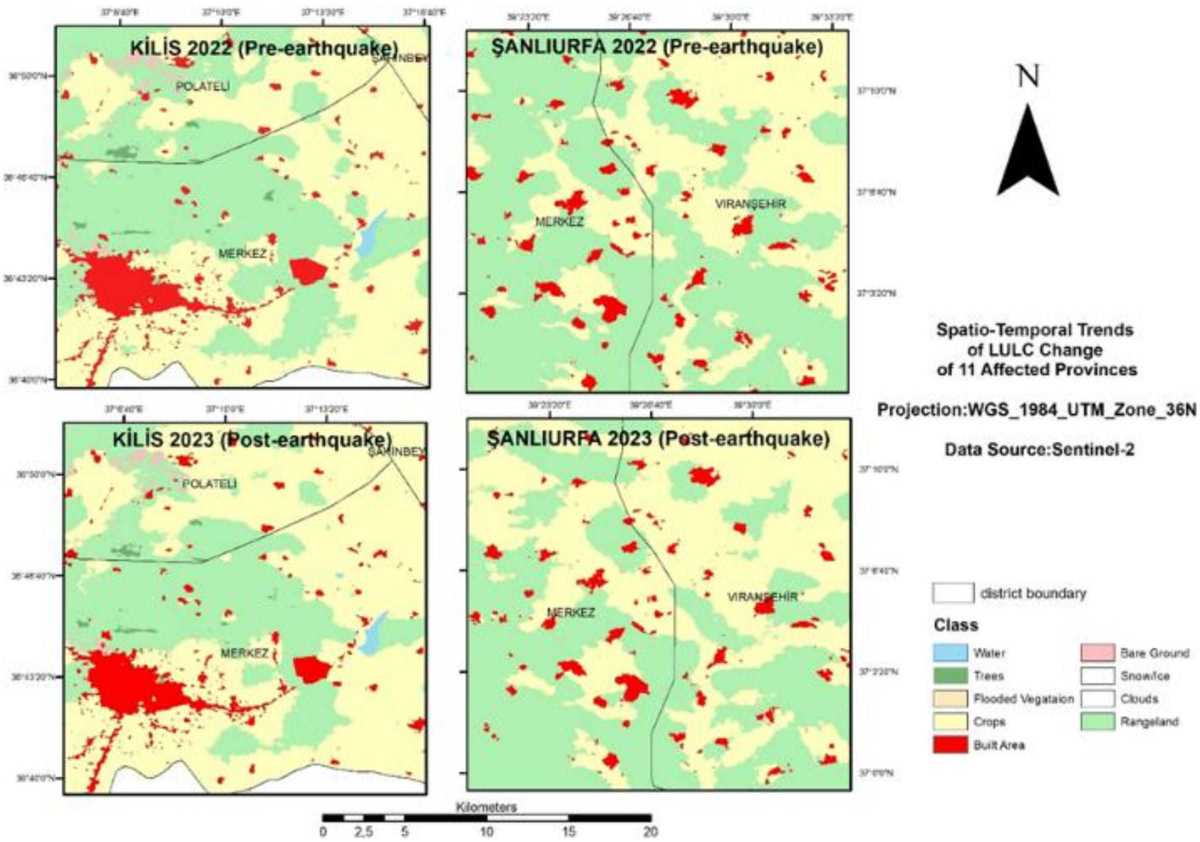



**Figure 17.** Rangeland Class Changes and Spatial Reflections after Kilis / Şanlıurfa Earthquake

### 3.7 *Change of other classes in land use after the earthquake*

The changes observed in other land use classes in the post-earthquake period provide a limited but meaningful assessment. No significant change was recorded in the flooded vegetation class in both years. This suggests that areas falling into this category are either absent or have not changed in all the provinces surveyed. Similarly, no change was observed in the snow/ice and clouds classes (0.0%). This implies that these categories do not have a significant presence in the studied regions and therefore do not have a significant impact on land use.

## 4 Discussion

The earthquakes that occurred on February 6, 2023, centered in Kahramanmaraş, caused extensive destruction, particularly in the provinces of Hatay, Gaziantep, and Kahramanmaraş, and significantly accelerated urbanization and reconstruction processes across the affected regions. In Gaziantep and Hatay, rapid urban expansion was observed, likely driven by their strong economic infrastructures. In contrast, Şanlıurfa and Kilis exhibited notable increases in agricultural land use, indicating the persistence of economic activity in rural settings. In Elazığ, a substantial rise in water bodies was detected, while in both Elazığ and Adıyaman, reductions in barren land were accompanied by conversions to rangeland, particularly in areas surrounding water bodies. This transition can be interpreted as a positive development in terms of natural resource recovery and environmental sustainability. Other provinces exhibited more limited land use changes; however, a general trend of increasing urbanization was apparent, often counterbalanced by decreases in rangeland areas.

Notably, some regions showed agricultural expansion and environmental improvements, which had beneficial impacts in the post-disaster context. The preservation and enhancement of agricultural and rangeland areas, particularly in provinces with less urbanization pressure, present a promising trend with respect to long-term environmental sustainability. The integration of spatial and quantitative tools—specifically, change detection maps and bar charts—enabled a comprehensive analysis of LULC transformations. While maps effectively visualized the spatial extent and intensity of these changes, graphs provided deeper insight into the proportional distribution of land use transitions. This combined approach offers a robust dataset that is critical for informed spatial planning and sustainable land management in the aftermath of large-scale natural disasters.

Beyond the findings of this study, the broader literature underscores that natural disasters—particularly earthquakes, floods, and wildfires—induce both short- and long-term changes in land use patterns, thereby influencing ecosystem transitions and post-disaster recovery trajectories. The magnitude of change is largely shaped by the severity of the disaster and the geographical context, whereas post-disaster planning plays a pivotal role in promoting environmental sustainability and long-term resilience. For instance, the 1999 Marmara Earthquake in Turkey led to accelerated urbanization and the expansion of industrial zones, consequently exacerbating environmental risks [33]. Similarly, the 2001 Bhuj Earthquake in India resulted in significant loss of agricultural lands, although rural development initiatives and infrastructure improvements contributed to economic recovery [14]. The 2011 Tōhoku Earthquake and Tsunami in Japan caused massive urban reconstruction, yet the destruction of agricultural areas posed serious threats to environmental sustainability [34]. The 2008 Wenchuan Earthquake in China severely damaged agricultural and forested areas, but large-scale ecological restoration and disaster management policies subsequently accelerated environmental rehabilitation [35].

The 2023 Kahramanmaraş earthquakes exhibited similar dynamics. Post-disaster processes led to a rapid expansion of residential zones, particularly in urban areas, resulting in the loss of agricultural lands and posing significant challenges to the conservation of natural resources. These shifts entail not only economic losses but also serious risks for long-term environmental sustainability. Changes in land use following disasters often have interconnected social, economic, and ecological consequences that are critical to achieving sustainable development goals. The agricultural sector, along with key industries such as textiles and steel, suffered significant production disruptions, supply chain failures, and raw material shortages, all of which negatively affected the national economy. As noted by Sabırsız and Şöhret [36], the transformation of agricultural lands resulted in a decline in production and employment, with potentially adverse implications for long-term economic growth. Given that the earthquake-affected provinces represent a significant share of Turkey's gross domestic product—especially in the agricultural and industrial sectors—the Kahramanmaraş earthquakes triggered both regional and national economic disruptions. Although financial support provided by the Ministry of Agriculture and Forestry played a vital role in short-term economic recovery, more comprehensive and long-term strategies are required to mitigate the multifaceted impacts of such disasters.

In conclusion, the findings of this study not only provide empirical evidence of post-earthquake LULC changes in southeastern Türkiye but also highlight the importance of integrating geospatial technologies with socio-economic and environmental considerations. Future research should continue to explore the complex interrelationships between disaster dynamics, land use change, and sustainable recovery, particularly in regions prone to high seismic risk.

## 5 Conclusions

This study provides a comprehensive analysis of land use changes following the February 6, 2023 Kahramanmaraş earthquakes, highlighting their social, economic, and environmental impacts. The findings offer valuable insights for planning post-disaster reconstruction processes in a more sustainable and resilient manner. Uncontrolled expansion of settlement areas and the reduction of agricultural lands pose significant long-term risks, such as environmental degradation and economic losses. Therefore, protecting agricultural areas and planning settlements based on scientific risk assessments and active fault line analysis are critical steps for sustainable land use in disaster-affected regions.

The observed increase in bare soil areas raises concerns about heightened risks of erosion and environmental degradation. Ecosystem-based approaches should be prioritized for rehabilitating natural areas, including afforestation and re-vegetation efforts to enhance environmental recovery. Strengthening agricultural infrastructure and promoting sustainable agricultural practices are also crucial to preventing production losses and maintaining the ecological and economic value of agricultural lands.

The use of Sentinel-2 satellite imagery in this study demonstrated the effectiveness of remote sensing technologies in analysing large-scale changes rapidly and in detail. High-resolution satellite data enhances spatial accuracy and enables the detection of fine-scale changes, providing critical data for informed decision-making in disaster management. Such technologies are indispensable for both immediate response efforts and long-term urban planning.

In conclusion, this study offers a spatial and quantitative foundation for improving disaster management and sustainable development strategies. The effective integration of remote sensing and GIS can lead to more efficient disaster management processes while contributing to the conservation of natural resources and the development of resilient cities. These findings underscore the importance of data-driven approaches in planning and implementing post-disaster recovery efforts.

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**Conflict of interest**

The authors declare that there is no conflict of interest.

**Similarity rate (iThenticate):** 11%

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