Monitoring Vegetation Hotspots in Raparin Administration, Kurdistan Region, Using Remote Sensing and NDVI Time Series Analysis

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ABSTRACT

Vegetation hotspots within the Raparin Independent Administration (RIA) or (Raparin Area) in Kurdistan Region of Iraq are increasingly impacted by human activities, land use changes, and climate variability. Effective conservation and sustainable management of these ecologically sensitive areas require continuous monitoring of vegetation dynamics. This study analyzes vegetation cover changes in the Raparin region, northeastern Sulaimani Province, over a 35-year period (1990–2025) using multitemporal Normalized Difference Vegetation Index (NDVI) data derived from Landsat satellite imagery. The region's complex topography, ranging from 500 to over 3,000 meters in elevation, and its semi-arid to cold continental climate provide a diverse ecological context for analysis. Results reveal a general decline in vegetation during the 1990s, followed by a gradual recovery in subsequent decades, with forested mountainous areas maintaining relative stability and functioning as biodiversity refuges. In contrast, lowland plains exhibit greater vegetation variability, influenced by agricultural practices, urbanization, and climatic fluctuations. Spatial hotspot analysis using the Getis-Ord Gi* statistic identifies a dense, stable belt of high vegetation productivity along the southern border with Iran, alongside fragmented low-productivity cold spots in plains and mountainous rocky zones. These findings emphasize the importance of targeted conservation efforts in forested hotspots and restoration initiatives in vulnerable areas. This study demonstrates the critical role of remote sensing and spatial analysis in monitoring vegetation dynamics and guiding biodiversity conservation under changing environmental and socio-economic conditions.

Key Words: Vegetation Hotspots, Remote Sensing, NDVI Time Series, Vegetation Dynamics, Raparin Independent Administration

پوختە:

گۆڕانی جۆرایەتی زیندەگی بە شێوەیەکی گشتی و داینامیکی ڕووپۆشی ڕووەکی وەك یەکێك لە گرنگترین بنەماکانی جۆراوجۆریەتی زیندەگی بە تایبەتی، لە سنوری ئیدارەی سەربەخۆی ڕاپەرین (RIA) یان (دەڤەری ڕاپەڕین) لە هەرێمی کوردستان، زیاتر کاریگەرە بە چالاکییەکانی مرۆڤ، گۆڕانکارییەکانی بەکارهێنانی زەوی و گۆڕانی کەش و هەوا. پاراستنی کاریگەر و بەڕێوەبردنی بەردەوامی ئەم ناوچە هەستیارانەی سیستمی ژینگەی پێویستی بە چاودێریکردنی بەردەوامی داینامیکی ڕووپۆشی ڕووەکی هەیە. ئەم تویژینەوەیە گۆڕانکارییەکانی ڕووپۆشی ڕووەکی وەك یەکێك لە گرنگترین بنەماکانی جۆرایەتی زیندەگی لە دەڤەری ڕاپەڕین، باکووری ڕۆژهەڵاتی پارێزگای سلێمانی، لە ماوەی ٣٥ ساڵدا (١٩٩٠-٢٠٢٥) بە بەکارهێنانی داتای فرە کاتیی و نیشاندەری ڕووەکی جیاوازی ئاساییکراوە (NDVI) کە لە وێنەکانی مانگی دەستکردی لاندسات وەرگیراوە، شی دەکاتەوە. تۆپۆگرافیای ئاڵۆزی ناوچەکە کە بەرزییەکەی لە نێوان ٥٠٠ بۆ زیاتر لە ٣٠٠٠ مەتردایە، و کەش وهەوای کیشوەری نیمچە وشک تا سارد و بەفراوی، زەمینەیەکی ژینگەی هەمەچەشن بۆ شیکاری دابین دەکات. ئەنجامەکانی توێژینەوەکە دابەزینی گشتی ڕووپۆشی ڕووەک لە ماوەی ساڵانی نەوەدەکاندا ئاشکرا دەکەن، دواتر لە دەیەکانی دواتردا وردە وردە ڕووپۆشی ڕووەکی گەشەسەندنی بە خۆیەوە بینیوە، بە شێویەکی گشتی ڕووپۆشی ڕووەکی لە ناوچە شاخاوییە دارستانییەکانی ناوچەکەدا سەقامگیریەکی ڕێژەی بەخۆیەوە بینیوە و کەمترین گۆڕاکاری تیایدا ڕویداوە بە درێژای ماوەی توێژینەوەکە، کە ئەمەش وەك پەناگەی جۆراوجۆریەتی زیندەگی بە خاڵێکی ئەرێنی گرنگ دادەنرێت. لە بەرامبەردا، ناوچە نزم و دەشتەکان گۆڕانی زیاتری ڕووەکی پیشان دەدەن، کە لە ژێر کاریگەری چالاکییە کشتوکاڵییەکان، کشانی شارنشینی و گۆڕانی کەشوهەوادان. لەلایەکی ترەوە شیکاری خاڵە گەرمەکانی شوێنی بە بەکارهێنانی تەکنیکی ئاماری گێتیس-ئۆرد گی* پشتێنەیەکی چڕ و جێگیر بە بەرهەمهێنانی ڕووەکی بەرز بە درێژایی سنووری نێودەوڵەتی ئێران لە باشووری خۆرهەڵات بۆ باکوری خۆرهەڵات پیشاندەدات، شانبەشانی ئەوە خاڵە ساردەکانی پارچەپارچەکراو و کەم ڕووەك لە دەشتەکان و ناوچە بەردینەکانی شاخاویدا دەستنیشان دەکات. ئەم دۆزینەوانە جەخت لەسەر گرنگی هەوڵەکانی پاراستنی ئامانجدار لە شوێنە گەرمەکانی دارستانەکان و دەستپێشخەرییەکانی نۆژەنکردنەوە لە ناوچە لاوازەکان دەکەنەوە. ئەم توێژینەوەیە ڕۆڵی گرنگی هەستکردن لە دوورەوە و شیکاری شوێنی لە چاودێریکردنی داینامیکی ڕووپۆشی ڕووەک و ڕێنماییکردنی پاراستنی جۆراوجۆری زیندەگی لە ژێر گۆڕانی بارودۆخی ژینگەیی و ئابووری-کۆمەڵایەتیدا نیشان دەدات.

ملخص

تتأثر البؤر النباتية الساخنة في إدارة رابارين المستقلة (RIA) أو (منطقة رابارين) في إقليم كردستان العراق بشكل متزايد بالأنشطة البشرية، وتغيرات استخدام الأراضي، وتقلبات المناخ. يتطلب الحفاظ الفعال والإدارة المستدامة لهذه المناطق الحساسة بيئيًا رصدًا مستمرًا لديناميكيات الغطاء النباتي. تُحلل هذه الدراسة تغيرات الغطاء النباتي في منطقة رابارين، شمال شرق محافظة السليمانية، على مدى ٣٥عامًا (١٩٩٠-٢٠٢٥) باستخدام بيانات مؤشر الغطاء النباتي الموحد متعدد الأزمنة (NDVI)المستمدة من صور أقمار لاندسات الصناعية. تُوفر تضاريس المنطقة المعقدة، التي يتراوح ارتفاعها بين ٥٠٠ و٣٠٠٠م، ومناخها القاري شبه الجاف إلى البارد، سياقًا بيئيًا متنوعًا للتحليل. تكشف النتائج عن تراجع عام في الغطاء النباتي خلال تسعينيات القرن الماضي، أعقبه انتعاش تدريجي في العقود اللاحقة، مع محافظة المناطق الجبلية الحرجية على استقرار نسبي وكونها محميات للتنوع البيولوجي. في المقابل، تُظهر السهول المنخفضة تنوعًا نباتيًا أكبر، متأثرة بالممارساتالزراعية والتوسع العمراني والتقلبات المناخية. يُحدد تحليل النقاط الساخنة المكانية باستخدام إحصائية Getis-Ord Gi* حزامًا كثيفًا ومستقرًا من الإنتاجية النباتية العالية على طول الحدود الجنوبية مع إيران، إلى جانب بقع باردة مجزأة منخفضة الإنتاجية في السهول والمناطق الجبلية الصخرية. تُؤكد هذه النتائج على أهمية جهودالحفظ المُستهدفة في النقاط الساخنة الحرجية ومبادرات الاستعادة في المناطق المعرضة للخطر. تُوضح هذه الدراسة الدور الحاسم للاستشعار عن بُعد والتحليل المكاني في رصد ديناميكيات الغطاء النباتي وتوجيه الحفاظ على التنوع البيولوجي في ظل الظروف البيئية والاجتماعية والاقتصادية المتغيرة.

الكلمات المفتاحية: النقاط الساخنة للغطاء النباتي، الاستشعار عن بُعد، سلسلة زمنية لمؤشر الغطاء النباتي الوطني، ديناميكيات الغطاء النباتي، إدارة رابارين المستقلة

Introduction

Vegetation is one of the most important natural resources for any region, providing life-supporting systems for both humans and wildlife. It plays a vital role in maintaining the balance of ecosystems, supporting agriculture, regulating the climate, and offering many other environmental services (Harte, 2001). However, in many regions of the world, biodiversity and Vegetation are facing serious threats due to human activities, land-use changes, and climate change (Sharma et al., 2022). The Kurdistan Region of Iraq, especially the Raparin Administration, is an area with unique ecological and biological richness. Unfortunately, like many other parts of the world, it is now facing increasing pressure on its natural resources (Mohammed et al., 2024). This makes it extremely important to monitor and protect the vegetation hotspots in this area (Sharma et al., 2022).

Monitoring Vegetation dynamics is not an easy task, especially in large or hard-to-reach areas like Raparin. Traditional field surveys are useful but they are time-consuming, expensive, and sometimes not possible due to rough terrain or security reasons. This is where modern technology can play a big role. Remote sensing, which means collecting information about the Earth's surface through satellites, offers a practical and powerful tool for monitoring vegetation and environmental changes over large areas and long periods (Nasir et al., 2022). One of the simplest but most widely used tools in remote sensing is the Normalized Difference Vegetation Index (NDVI). NDVI is a simple calculation that shows how "green" an area is by measuring the difference between visible and near-infrared light reflected by vegetation. Healthy and dense vegetation usually has a high NDVI value, while dry or damaged vegetation has a lower NDVI (Huang et al., 2021).

NDVI time series analysis refers to studying NDVI values over a long period, like ten or twenty years, to see how vegetation cover has changed over time. This method helps researchers identify trends and patterns in vegetation health and density. In recent years, this method has been widely used to monitor forests, grasslands, wetlands, and other important ecosystems. Many international studies have shown the usefulness of NDVI in detecting deforestation, land degradation, and the impacts of droughts and climate variability (Dhillon et al., 2023). In our study, we apply this method specifically to the Raparin Administration, which has not been sufficiently studied in terms of long-term vegetation trends and biodiversity conditions.

Many studies have shown that remote sensing, especially NDVI, is a useful tool for monitoring vegetation and biodiversity. NDVI helps track plant health and changes in green cover over time using satellite images. Studies like (Pettorelli et al., 2005) and (Evans & Geerken, 2004) have used NDVI to understand changes in ecosystems and to identify areas at risk of land degradation. In nearby regions like Iran and Turkey, researchers have successfully used NDVI to detect biodiversity hotspots and monitor environmental changes. For example, (Jabbari et al., 2015) used remote sensing technology for mapping and monitoring vegetation cover in Iran, while (Güler & Turgut, 2024) studied Monitoring Türkiye's Vegetation Cover with NDV in Turkey. These studies show that NDVI is a reliable method for large areas. In the Kurdistan Region, a few studies have used satellite images to map land cover changes, especially around cities like Sulaymaniyah(Nasir et al., 2022; Rasul et al., 2017). However, very little research has focused on vegetation and biodiversity hotspots, especially in Raparin Administration. This study will use NDVI time series to fill this gap and give a clearer picture of vegetation and biodiversity changes in Raparin.

The main aim of this study is to use NDVI time series analysis from satellite data to monitor and evaluate the changes in vegetation cover in the Raparin Administration. By identifying areas where NDVI has significantly decreased or increased, we can better understand which parts of the zone are facing ecological degradation and which parts remain healthy. This will help to identify current vegetation hotspots and regions where conservation efforts should be focused. The study will cover the period from 1990 to 2025 using freely available satellite images such as Landsat sensors which offer a good balance of spatial resolution and time coverage.

The Raparin Administration is located in the northeastern part of the Kurdistan Region and includes diverse landscapes such as mountains, valleys, rivers, and agricultural lands. It also contains important habitats for many plant and animal species. The area is experiencing rapid changes due to population growth, expansion of towns and villages, road construction, agricultural development, and sometimes overgrazing and deforestation. These changes can have serious effects on biodiversity hotspots, which are areas that contain high numbers of species or rare ecological systems. However, there is currently a lack of scientific information on how these changes have affected vegetation cover and biodiversity in Raparin over the past two decades.

This research is important for several reasons. First, it provides a scientific method to regularly monitor the condition of the natural environment without the need for constant field visits. Second, it offers decision-makers, local governments, and environmental agencies valuable information that can be used in conservation planning, land management, and sustainable development. Third, it raises awareness about the importance of protecting biodiversity in the Raparin Administration, especially at a time when natural resources are under growing pressure from human needs and climate challenges. Finally, the methodology applied in this study can also serve as a model for other regions in Kurdistan that face similar environmental problems.

In summary, the study combines modern satellite technology with simple vegetation analysis techniques to answer an important question: how has the vegetation cover changed in Raparin Administration over the past twenty-five years, and what does this tell us about the condition of Vegetation hotspots? We hope that the findings of this research will contribute to a better understanding of ecological changes in Raparin and support future conservation actions in the area.

Study Area Description

The Raparin Administration of Sulaimani province is a part the Kurdistan Region of Iraq, which is situated between longitude (44° 33' 40.6" - 45° 23' 9.98") east and latitude (36° 0' 21.58" - 36° 30' 6.28") north. It consists of the two districts (Rania, and Pshdar), and has an area of (2205.2) square kilometers (Figure 1). The region is known for its diverse landscapes, which include high mountains, rolling hills, wide valleys, natural forests, and important river systems. These natural features make the Raparin Administration one of the most environmentally rich areas in Iraq.

The Raparin Administration experiences a climate that ranges from semi-arid to Mediterranean. Summers are usually hot and dry, with average temperatures around 35.6°C, while winters are cold, averaging 7.7°C, and bring rainfall and occasional snowfall, especially in the mountainous regions. Annual rainfall varies between 622.2 and 800-mm. Precipitation is not evenly spread across the region—areas in the north and east, particularly close to the Zagros Mountains, receive more rain than the southern and western parts. These differences in rainfall patterns create diverse habitats that support a wide range of plant and animal life.

The Raparin Administration is home to many important ecosystems, such as natural oak forests, mountain grasslands, river valleys, and wetlands. These areas are valuable for biodiversity because they support a wide range of plant and animal species, some of which are rare or endangered. In recent years, the region has been facing growing environmental pressures from rapid urban growth, agricultural expansion, road construction, and overgrazing. These activities have caused changes in vegetation cover and have put many natural habitats at risk (Mohammed et al., 2024). The importance of studying the Raparin Administration comes from both its natural richness and the challenges it faces. By focusing on the whole region, this research aims to get a clear and complete picture of how vegetation and biodiversity are changing over time. The results can help protect the most important natural areas and guide future conservation plans in Raparin Administration.

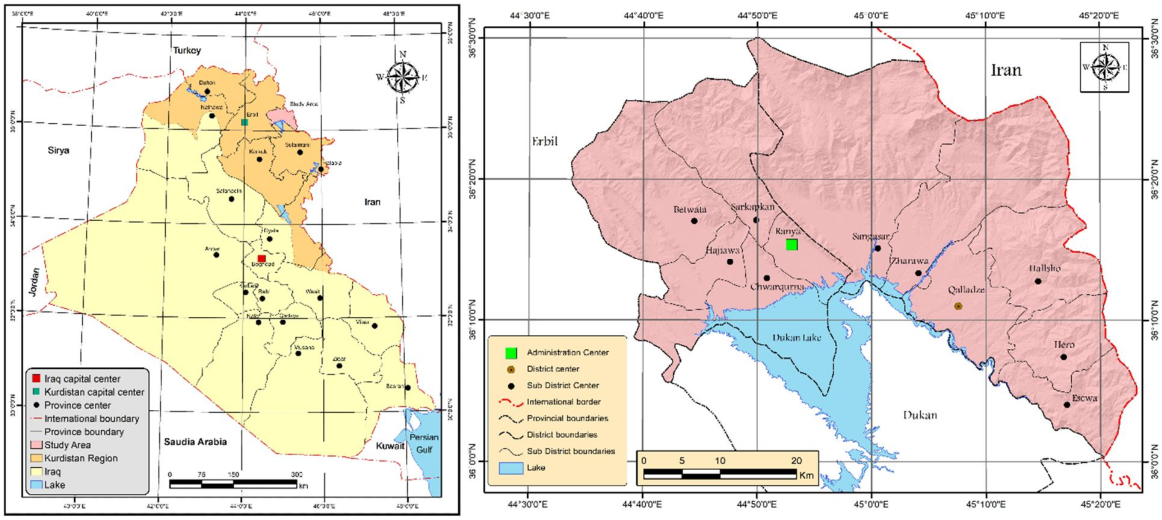


Figure 1. Geographical location of the study area within Iraq and the Kurdistan Region.

Data and Methodology

3.1. Data and Preprocessing

This study is based on satellite images collected from the Landsat program, which is provided by the United States Geological Survey (USGS) https://www.usgs.gov/. Landsat is well-known for offering long-term, consistent, and free satellite data, making it ideal for studying changes in vegetation over large areas (Wulder et al., 2008). For this research, we used data covering the period from 1990 to 2025, which allows to track how vegetation cover has changed across the Raparin Administration over more than three decades. The Landsat images have a 30-meter resolution, which is suitable for studying regional landscapes. The study used data from multiple Landsat sensors, including Landsat 5 (TM), Landsat 7 (ETM+), Landsat 8 (OLI), and Landsat 9 (OLI-2). Using different generations of Landsat helps to create a continuous and reliable time series while reducing gaps caused by poor-quality images.

To make the work easier and more efficient, we used Google Earth Engine (GEE) to access and process the data. GEE gives access to the full Landsat archive and provides surface reflectance data, which means the images have already been adjusted for atmospheric effects like dust and moisture. This helps to make the data more accurate and consistent from year to year. Before analyzing the images, some preprocessing steps were necessary. First, we applied atmospheric correction to remove unwanted effects caused by the atmosphere, ensuring the images better reflect the true condition of vegetation on the ground. Second, we used cloud masking to filter out cloudy areas, since clouds can hide the land surface and affect the accuracy of the results. GEE makes it easier to automatically mask clouds using built-in tools.

Since the focus of the study is on vegetation, the study only used images from the growing season, which generally falls between March and July, depending on rainfall and elevation. To represent each year, we created median NDVI images, which show the typical greenness of the land during the growing season while minimizing the influence of clouds or short-term disturbances. This approach, using long-term Landsat data with Google Earth Engine, provides a solid and practical method for monitoring vegetation trends and identifying vegetation hotspots across the Raparin Administration in a clear and reliable way.

3. 2. NDVI Time Series Analysis

After collecting and preparing the NDVI data, the next step was to analyze how vegetation has changed over time. The study used GEE to create a yearly time series of NDVI values from 1990 to 2025 for the Raparin Administration. This means we calculated one NDVI image for each year, which shows the average vegetation condition during the growing season. To understand the long-term changes, the study used temporal trend analysis. This helps to see if vegetation is increasing, decreasing, or staying stable in different parts of the region. For this, we used simple statistical tools available in GEE to measure changes over time for every pixel in the study area.

The study also applied hotspot detection methods to identify areas with significant changes. Two common methods were used are the Mann-Kendall trend test and Sen's slope estimator. The Mann-Kendall test helps detect if there is a consistent upward or downward trend in NDVI values over the years. Sen's slope shows how strong the trend is, meaning how fast vegetation is increasing or decreasing. These methods give a clearer picture of where vegetation health is improving and where it is getting worse. By using these tools in GEE, we could quickly process large amounts of data and get accurate results on how vegetation has changed over more than 30 years in the Kurdistan Region.

3. 3. NDVI Change Detection Analysis

To assess the temporal dynamics of vegetation cover across the three decades of the study period, as well as to quantify significant increases and decreases between the initial phase (1990) and the final phase (2025), a change detection analysis was conducted using ENVI software. Specifically, the Change Detection – Difference Map tool, integrated within the Image Change Workflow, was employed. This approach calculates the pixel-by-pixel difference in Normalized Difference Vegetation Index (NDVI) values between two temporal datasets. Positive difference values indicate an increase in vegetation cover, whereas negative values represent a decrease. For multi-decadal analysis, NDVI composites corresponding to each decade were generated, enabling the detection of gradual trends over time. For the two-phase comparison (1990 vs. 2025), difference maps were produced to identify areas of substantial vegetation gain (Big increase) and substantial vegetation loss (Big decrease).

The workflow involved image co-registration to ensure precise spatial alignment, radiometric normalization to minimize atmospheric and sensor-related differences, and thresholding to classify the magnitude of change. The resulting maps were used to quantify the spatial extent (in km^2) and proportion (%) of each change category, providing a clear representation of vegetation dynamics within the study area. Change detection techniques in ENVI have been widely applied for vegetation monitoring and land cover change analysis in various ecological and geographical contexts (Hussain et al., 2013; Lu et al., 2004).

3. 4. Vegetation Hotspots Identification

After identifying the NDVI trends, the next step was to find out which areas can be considered vegetation hotspots. In this study, we focused on areas where the vegetation stayed healthy or improved over time, based on the NDVI values from 1990 to 2025. These areas are important because healthy vegetation usually supports more plants, animals, and overall biodiversity.

A hotspot refers to a geographic area where the occurrence of a particular phenomenon is significantly higher than would be expected under a random spatial distribution. Hotspot analysis is a statistical method that identifies spatial clusters of high (hot spots) or low (cold spots) values and evaluates their statistical significance (Anselin, 1995; Getis & Ord, 1992). This approach is widely used in environmental monitoring, biodiversity assessment, and land-use change studies to detect patterns of spatial concentration. The Getis-Ord Gi∗G_i^*Gi∗ statistic is a commonly applied method for hotspot detection. It determines whether high or low values cluster spatially beyond what would be expected from random chance, producing a *z*-score that reflects the intensity of clustering (Getis, 1996). Hotspots are typically classified according to confidence intervals (e.g., 90%, 95%, and 99%), indicating the statistical significance of the observed pattern.

Mathematically, the Getis-Ord Gi∗G_i^*Gi∗ statistic is expressed as:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2}{n-1}}}$$

Where:

- xjx_jxj = attribute value for feature *j*
- wi,jw_(Abedi Gheshlaghi & Valizadeh Kamran, 2018)wi,j = spatial weight between features *i* and *j*
- nnn = total number of features
- X¯\bar(Abedi et al.)X¯ = mean of the attribute values
- SSS = standard deviation of the attribute values

High positive *z*-scores indicate statistically significant hotspots (areas with high values surrounded by other high values), while high negative *z*-scores indicate cold spots (areas with low values surrounded by other low values). Values close to zero indicate no apparent spatial clustering.

Hotspot analysis has been effectively applied in ecological and environmental research, such as identifying vegetation-rich zones under threat, detecting vegetation degradation patterns, and mapping land-use change (Ding et al., 2015; Ord & Getis, 2001). In this study, the Getis-Ord Gi∗G_i^*Gi∗ tool in ArcGIS was used to identify statistically significant clusters of NDVI values, allowing the detection of persistent zones of vegetation abundance or degradation.

Results

4. 1. NDVI Time Series Analysis

To analyze the changes in vegetation cover and assess vegetation hotspots in the Raparin Administration, a time series of NDVI data was used, spanning a 35-year period from 1990 to 2025. Due to the lack of suitable satellite imagery, the years 2003 and 2012 were excluded from the analysis. For ease of interpretation, the remaining years were divided into three equal time periods: First Period: 1990–2000, Second Period: 2001–2013, and third Period: 2014–2025. Across these three periods, NDVI values show both temporal and spatial variation. In general, mountainous areas in the north, northeast, and western parts of the region, typically covered by forests, showed greater stability in vegetation cover over time. In contrast, lowland plains experienced more significant fluctuations, often linked to changes in land use and agricultural practices.

During the first decade, vegetation covers experienced considerable variation. The highest NDVI value was recorded in 1996 (0.921394), while the lowest peak NDVI value within this period was seen in 2000 (0.684788). Across these years, the average highest NDVI was 0.720342, while the average lowest value dropped to -0.210483 (Figure 2). Spatially, while changes occurred across the entire region, vegetation in the mountainous forested areas remained relatively stable. In contrast, the plains showed major fluctuations, largely driven by shifts in seasonal agriculture. For instance, in 1990, much of the Pishdar Plain appeared barren, as it was a military-restricted zone during that time and no farming activity was present (Figure3).

In the second period, NDVI values indicate a general improvement in vegetation cover. The highest NDVI was observed in 2013 (0.832185), while the lowest peak NDVI occurred in 2009 (0.599938). This drop may be linked to drought conditions following a particularly dry year in 2008. The average maximum NDVI across this period was 0.681230, and the average minimum value was -0.262875 (Figure 4). Similar to the first period, forest-covered mountainous zones remained stable, while plains showed more noticeable changes, again influenced by shifts in the types and extent of summer and winter agriculture (Figure 5).

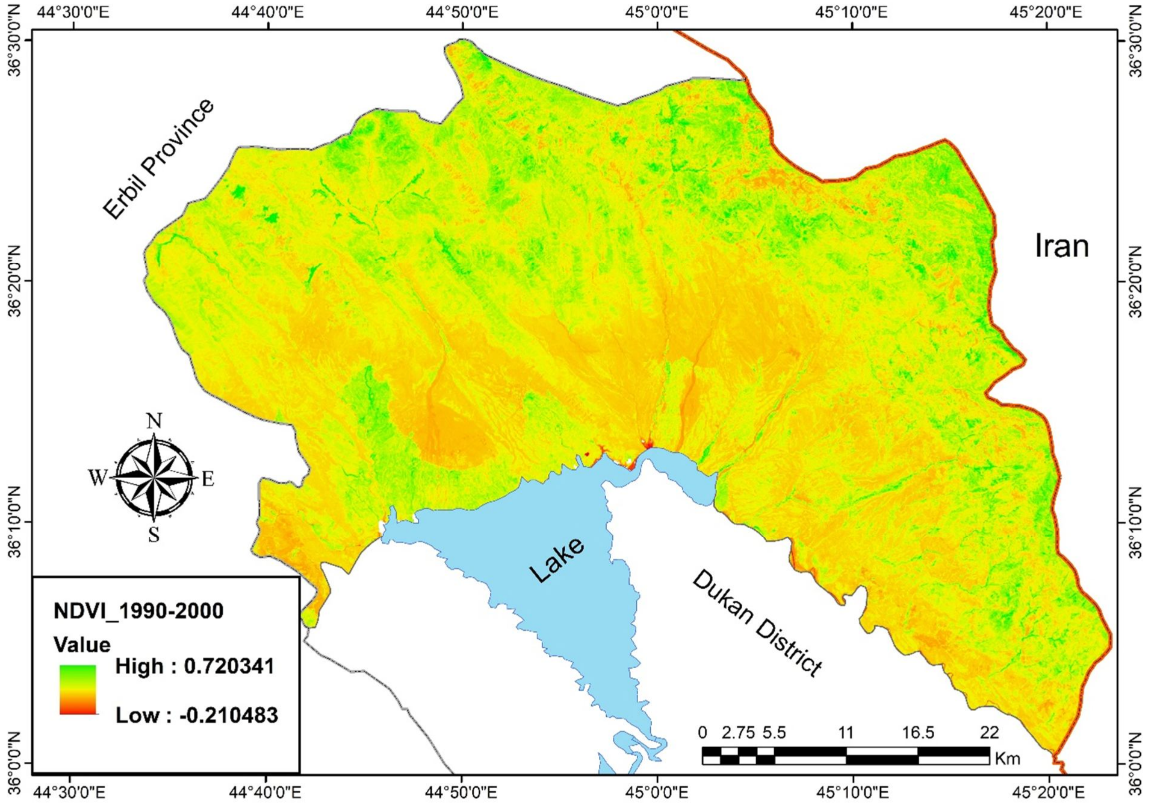


Figure 2. Decadal Mean NDVI Map for the Raparin Administration (1990–2000).

In the most recent period, vegetation patterns continued to show variation, though the trend generally points to healthier vegetation. The highest NDVI value in the entire study was recorded in this period—in 2019 (0.983240)—coinciding with the rainiest season (2018–2019). On the other hand, 2025 saw a sharp decline, with a maximum NDVI of only 0.772771, likely due to another dry year affecting vegetation growth. The average highest NDVI for this period reached 0.783945, while the average lowest value was -0.404798 (Figure 6 and 7). Once again, vegetation cover in mountainous, forested regions remained relatively unchanged, highlighting their ecological stability. Plains continued to experience more dynamic changes, influenced by human land-use patterns and climatic variations. However, Throughout the study period, vegetation cover and NDVI values exhibited variations across years, decades, and locations, as discussed in the preceding sections. According to the study's findings on areas experiencing the most significant changes between the initial period (1990) and the final period (2025), Figure 9 shows that only 144.7 km² (6.6%) of the study area experienced a significant increase (Big Increase) in vegetation cover, while 92.5 km² underwent a significant decrease (Big Decrease).

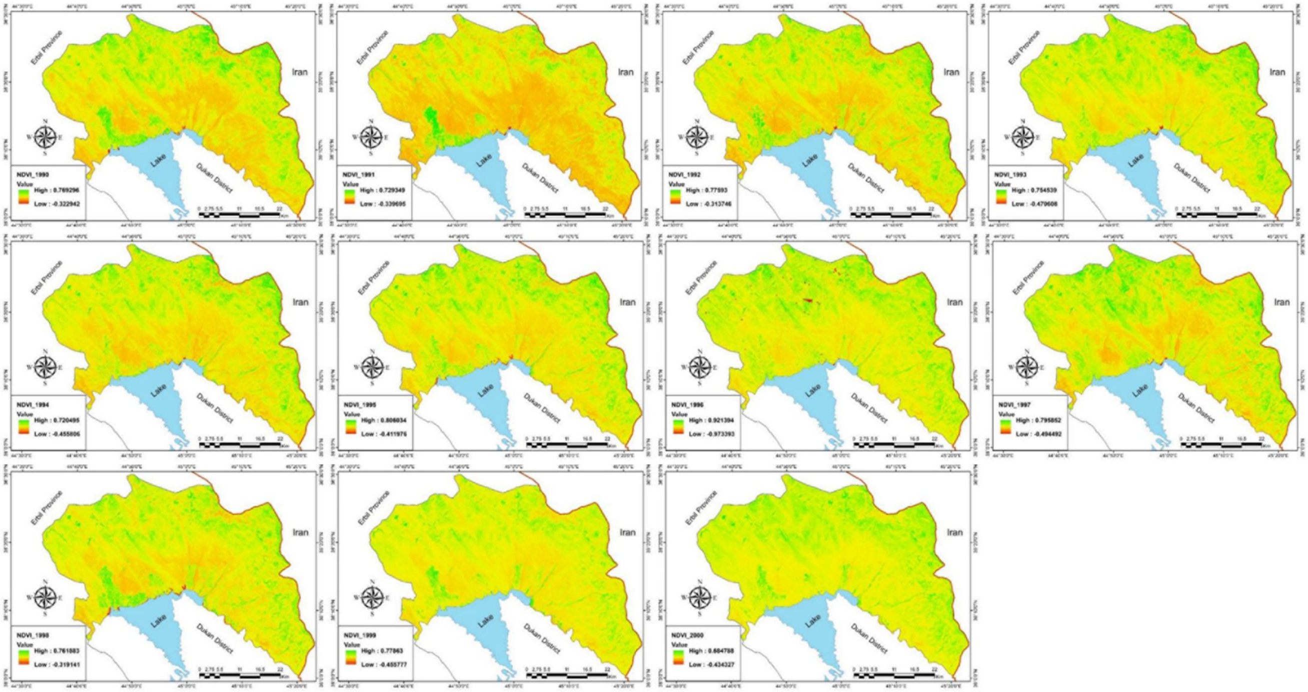


Figure 3. NDVI Time Series Maps (1990–2000) for Monitoring Vegetation Patterns and Vegetation Hotspots in the Raparin Administration.

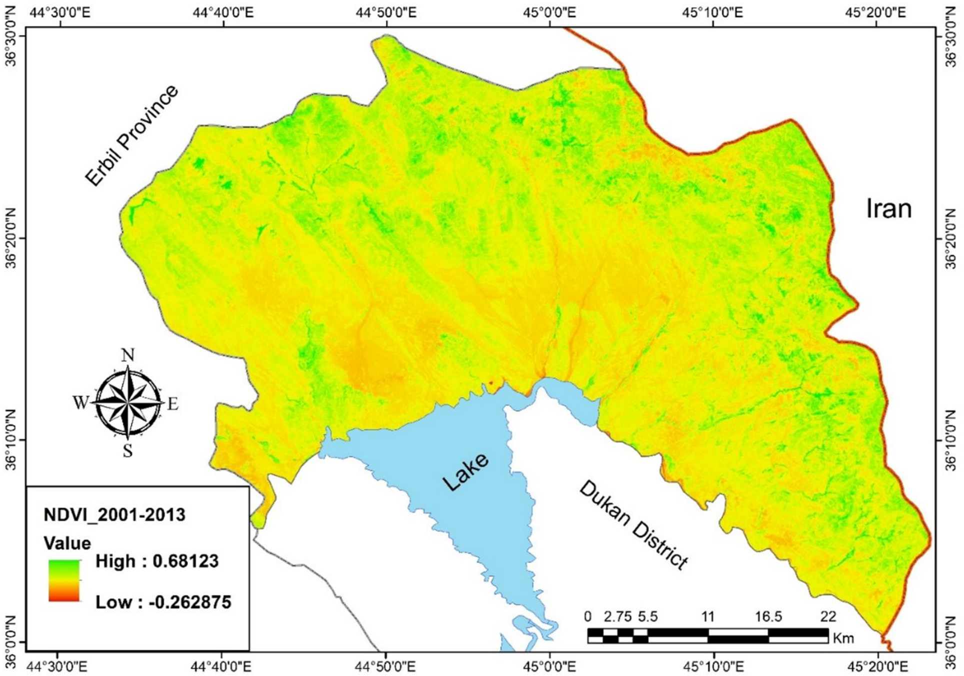


Figure 4. Decadal Mean NDVI Map for the Raparin Administration (2001–2013).

Overall, the NDVI time series analysis reveals a pattern of fluctuating vegetation cover across the Raparin region over the past three and a half decades. The data suggest that mountainous forest zones function as biodiversity refuges, maintaining consistent vegetation cover, while plains reflect higher sensitivity to both climate variability and anthropogenic land-use changes. These findings provide a strong basis for identifying and monitoring vegetation hotspots, particularly in areas that have remained stable and ecologically intact throughout the study period.

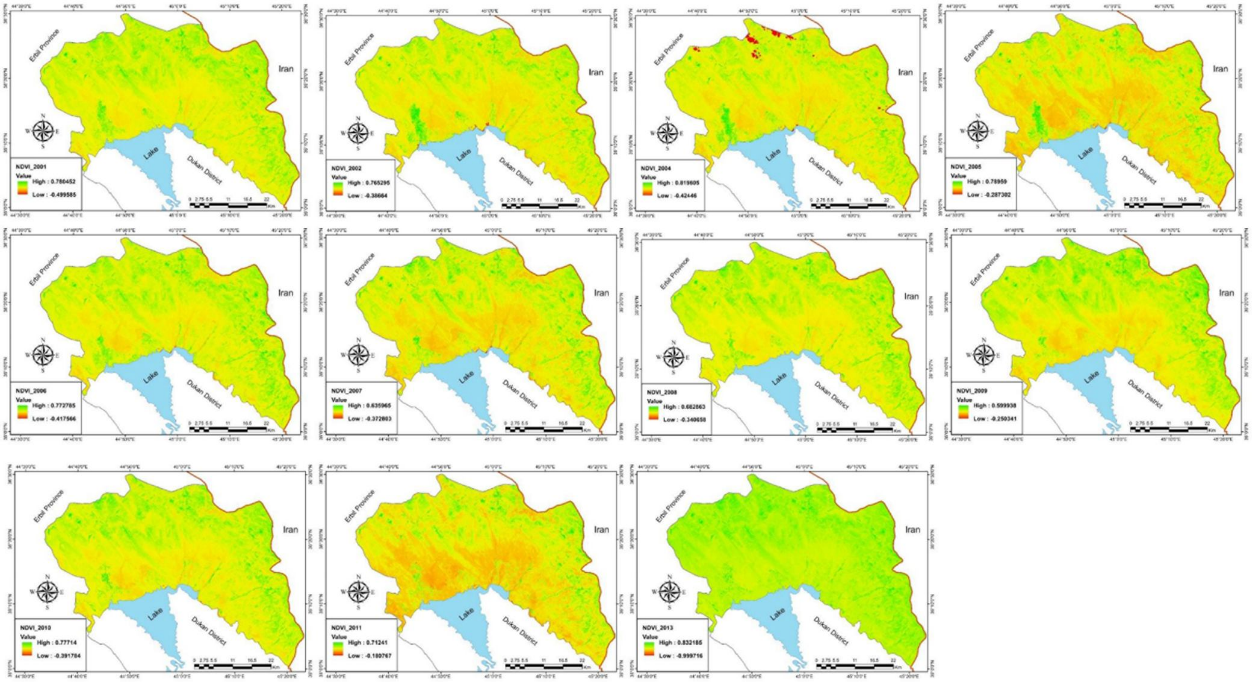


Figure 5. NDVI Time Series Maps (2001–2013) for Monitoring Vegetation Patterns and Vegetation Hotspots in the Raparin Administration.

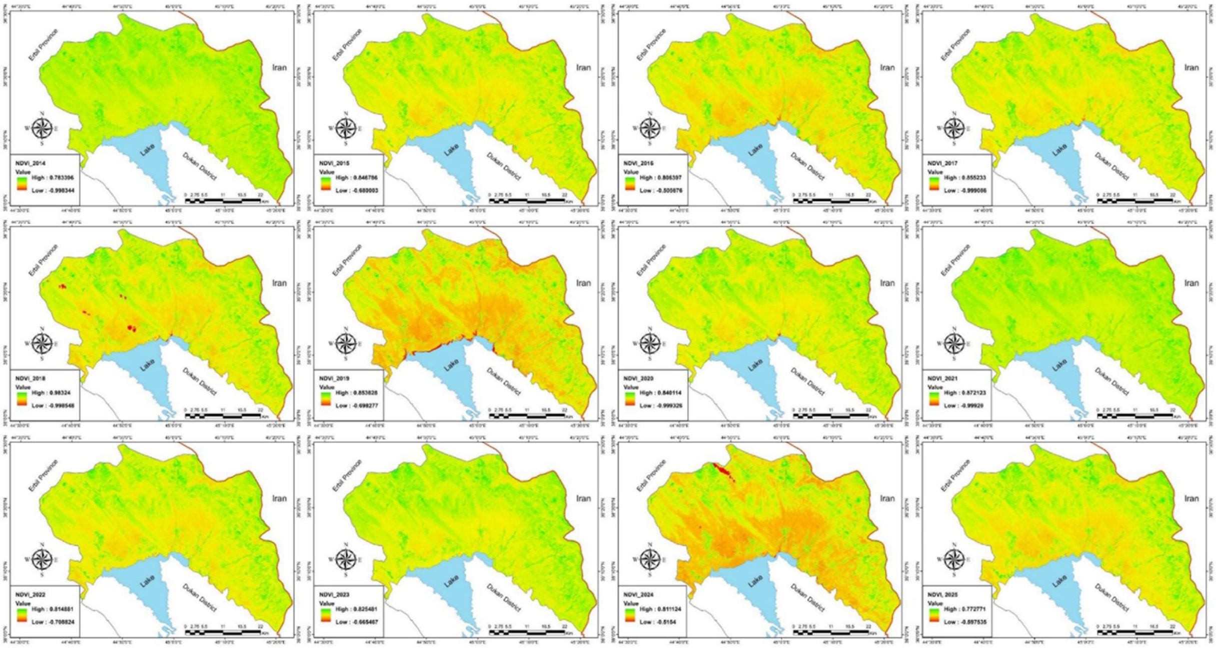


Figure 6. NDVI Time Series Maps (2014–2025) for Monitoring Vegetation Patterns and Vegetation Hotspots in the Raparin Administration.

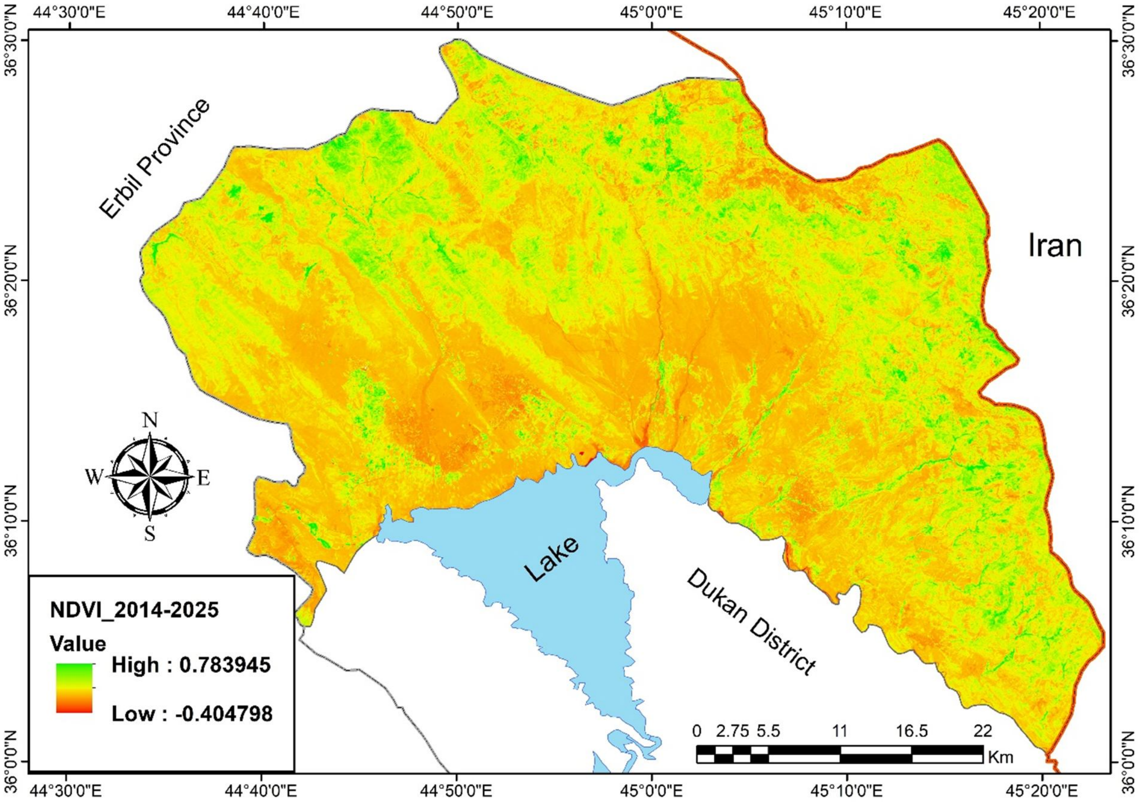
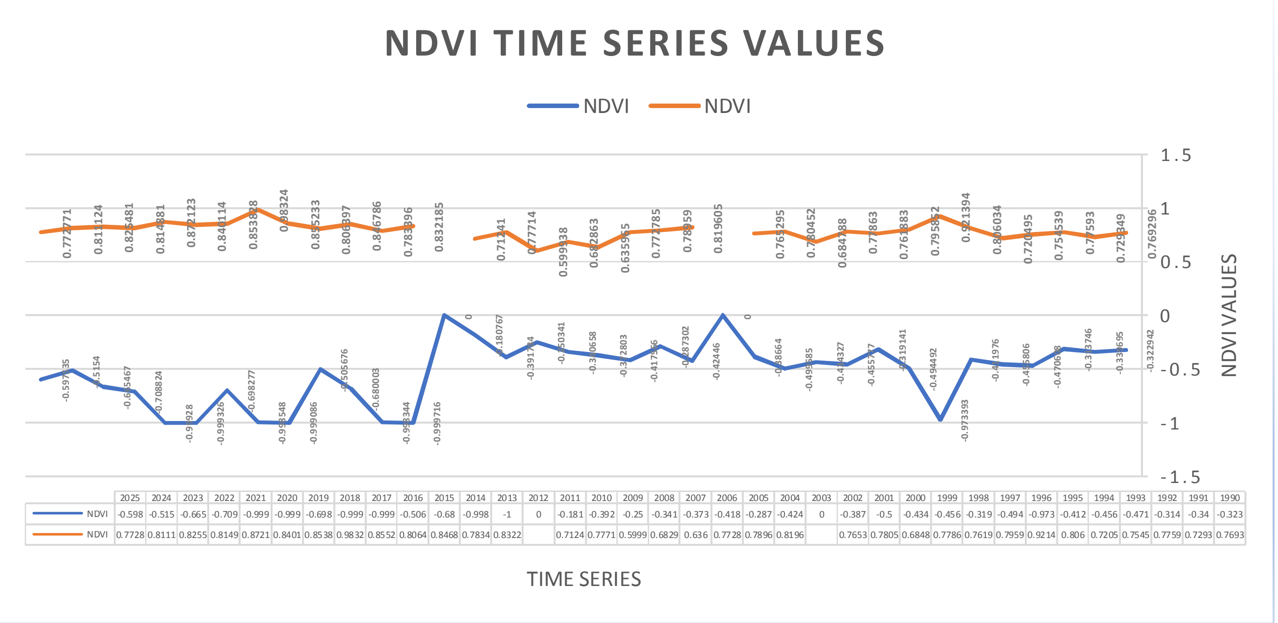


Figure 7. Decadal Mean NDVI Map for the Raparin Administration (2014–2025).



	2025	2024	2023	2022	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990
NDVI	-0.598	-0.515	-0.665	-0.709	-0.999	-0.999	-0.698	-0.999	-0.999	-0.506	-0.68	-0.998	-1	0	-0.181	-0.392	-0.25	-0.341	-0.373	-0.418	-0.287	-0.424	0	-0.387	-0.5	-0.434	-0.456	-0.319	-0.494	-0.973	-0.412	-0.456	-0.471	-0.314	-0.34	-0.323
NDVI	0.7728	0.8111	0.8255	0.8149	0.8721	0.8401	0.8538	0.9832	0.8552	0.8064	0.8468	0.7834	0.8322		0.7124	0.7771	0.5999	0.6829	0.636	0.7728	0.7896	0.8196		0.7653	0.7805	0.6848	0.7786	0.7619	0.7959	0.9214	0.806	0.7205	0.7545	0.7759	0.7293	0.7693

Figure 8. Annual Maximum and Minimum NDVI Trends in the Raparin Administration (1990–2025).

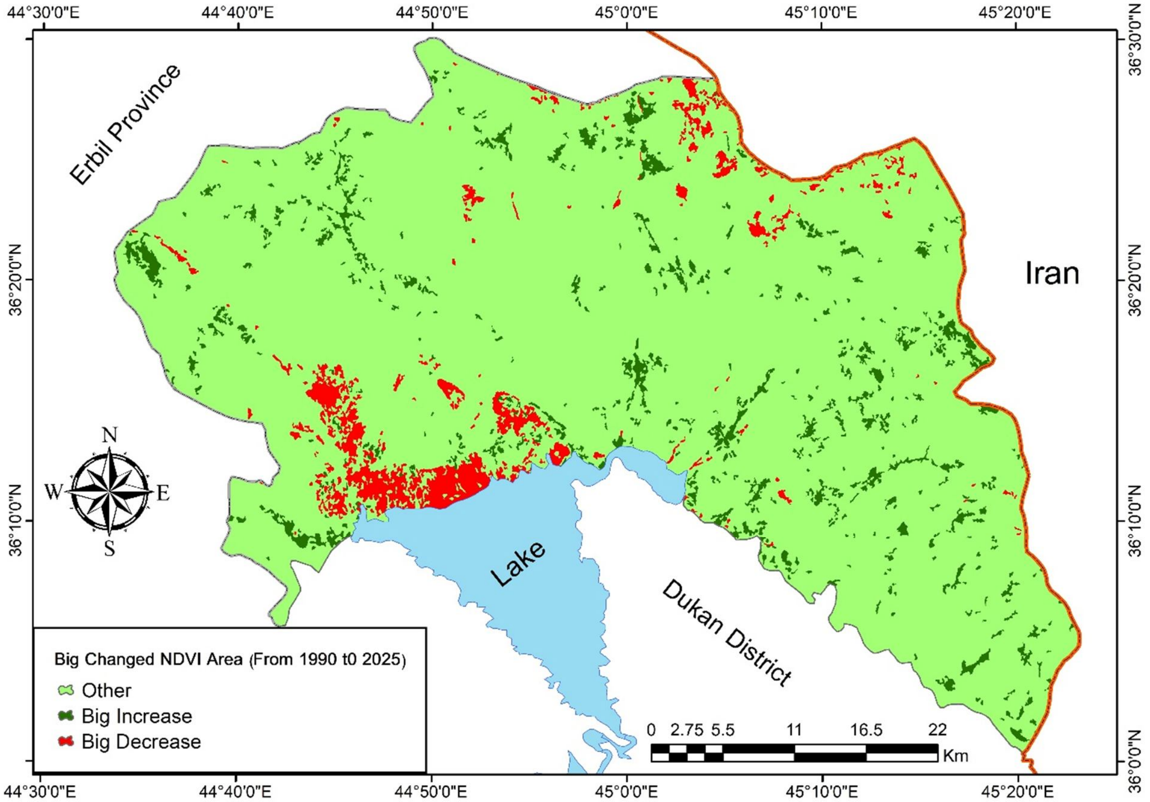


Figure 9. Big Changed NDVI area (Big Increase, and Big Decrease) during the study period from 1990 to 2025.

4. 2. Analysis of NDVI change over the past three decades

To assess the extent and direction of vegetation change in the Raparin region over time, a change detection approach was applied to NDVI data using the Difference Map technique within the (ENVI) environment. This method helped detect areas where NDVI values have increased or decreased over three key time periods. The results were analyzed both spatially and temporally, and are presented in both map (Figure 10) and table format (Table 1).

Each time span covers roughly a decade and allows for comparisons of NDVI-based vegetation trends across the region. During the first decade, most of the study area experienced a decline in NDVI values, indicating a loss or degradation of vegetation cover. About 1989 km² (or 90.2% of the total area) saw a moderate decrease in NDVI values (between 0 and -0.5). Only 188.1 km² (8.53%) of the region showed a slight improvement in NDVI (between 0 and +0.5). A very small portion (2.29 km², or 0.1%) showed a strong increase in NDVI (> +0.5). Sharp declines in NDVI (less than -0.5) were negligible (0.01%). This period reflects a general negative trend in vegetation cover, likely driven by a combination of factors including land abandonment, reduced agricultural activity, and land degradation following the civil conflict between Kurdish parties. Additional contributing factors may include economic hardship due to the financial crisis, deforestation, and increased reliance on natural vegetation by local residents for heating and cooking in the absence of fuel. Moreover, this decline was exacerbated by severe drought conditions affecting the region in the final two years of the period.NDVI Change from 2001 to 2013 shows a shift toward vegetation recovery, especially in certain parts of the region. A significant increase in NDVI values > 0.5 was observed over 421.4 km² (19.11%), suggesting strong vegetation regeneration, possibly due to expanded agriculture or better rainfall in some years. However, a large portion of the area (1743.8 km², or 79.08%) still experienced a moderate NDVI decrease, though slightly lower than in the first period. Only 3.44 km² (0.15%) showed minor NDVI increases. High NDVI decline (< -0.5) increased slightly to 14.42 km² (0.65%). These results suggest that while vegetation loss was still widespread, certain zones, particularly in foothill areas and along valley systems, began to recover, likely tied to re-agriculturalization and possibly post-conflict rehabilitation.

The third period presents a very different pattern, with the highest proportion of NDVI increase in the entire 35-year study. A remarkable 51.11% of the total area (1127 km²) showed a moderate increase in NDVI (0 to 0.5), indicating widespread recovery of vegetation cover. Areas with significant NDVI decline (> -0.5) dropped to 48.66% (1073 km²). Strong NDVI increases (> 0.5) were still limited (4.2 km², or 0.19%) but present in localized pockets, possibly forested or protected zones. Sharp declines in NDVI (< -0.5) remained rare (0.705 km² or 0.03%). These findings confirm a general positive trend in vegetation, especially in plains and agricultural lands. This may be due to favorable rainfall (e.g., in 2019), improved farming practices, or ecological restoration efforts. The mountainous and forested areas again remained largely stable. The NDVI change analysis highlights clear temporal shifts in vegetation patterns across the Raparin region. A strong decline in vegetation during the 1990s was followed by a gradual recovery, with the most positive changes observed in the last decade. This trend provides a solid foundation for identifying critical zones of vegetation, assessing land management success, and guiding future conservation efforts.

Table 1. NDVI Change Classes by Area (km²) and Percentage (%) in the Raparin Administration (1990 to 2025)

Change Indicators	Change NDVI from 1990 to 2000		Change NDVI from 2001 to 2013		Change NDVI from 1990 to 2000	
	Area km^2	%	Area Km^2	%	Area Km^2	%
Unclassified	25.6	1.161	22.14	1.004	0.297	0.013
Increase NDVI Value (> 0.5)	2.29	0.104	421.4	19.11	4.198	0.19
Increase NDVI Value (> 0.000 <= 0.5)	188.1	8.531	3.44	0.156	1127	51.11
decrease NDVI Value (< -0.000 >= -0.5)	1989	90.2	1743.8	79.08	1073	48.66
decrease NDVI Value (< -0.5)	0.221	0.01	14.42	0.654	0.705	0.032
Total	2205.2	100	2205.2	100	2205.2	100

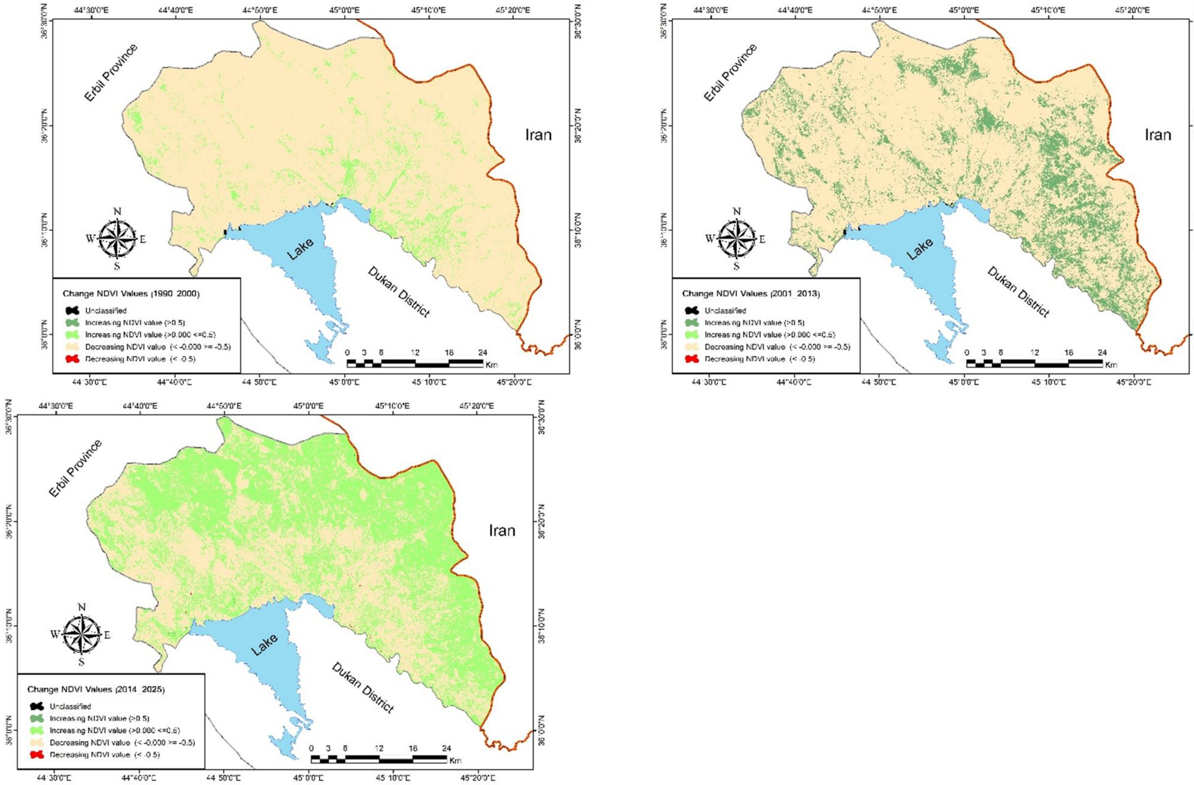


Figure 10. NDVI Change detection (Increase, and Decrease) in the Raparin Administration A) From 1990 to 2000, B) From 2001 to 2013, and C) From 2014 to 2025.

4. 3. Vegetation Hotspots Analysis

The Getis-Ord Gi* analysis of the 35-year average NDVI in the Raparin Administration revealed a near balance between large, contiguous hot spot and cold spot zones, each indicating areas of persistently different vegetation productivity that are highly relevant for biodiversity monitoring. Hot spots, representing significantly higher NDVI values, covered 1,045.858 km² (47.43%) at the 99% confidence level, with smaller areas at the 95% (10.482 km²; 0.475%) and 90% (5.104 km²; 0.231%) confidence levels. Cold spots, indicating significantly lower NDVI values, occupied 1,073.609 km² (48.69%) at the 99% confidence level, with minor coverage at the 95% (10.268 km²; 0.466%) and 90% (5.269 km²; 0.239%) confidence levels. Areas without statistically significant clustering were limited to 54.610 km² (2.476%), table 2 summarizes the spatial analysis results from a Getis-Ord Gi* hotspot analysis, showing how much area (in km²) and percentage of the total study area fall into statistically significant hot spots, cold spots, or no significant clustering, categorized by confidence levels (99%, 95%, 90%). The spatial analysis of vegetation cover hotspots shown in Figure 11 indicates that these hotspots form a dense belt along the southern border with Iran, extending northward and northwestward. This region is mainly forested and has remained relatively stable throughout the study period, despite its remote population and increasing urbanization and agricultural activities. The area receives substantial rainfall, which contributes positively to biodiversity. Conversely, cold spots are predominantly located in hilly, plain, and agricultural areas that experience lower rainfall and are more affected by urban sprawl, resulting in reduced vegetation. Additionally, isolated cold spots appear in mountainous regions with rocky terrain and high elevation, such as the Qandil Mountains.

Table 2. Area and Percentage Coverage of Significant Hot and Cold Spots Identified by Getis-Ord Gi* Analysis at Multiple Confidence Levels

Getis-Ord-Gi*	**Value**	**Area Km^2**	**%**
Cold Spot - 99% confidence	-3	1073.609	48.69
Cold Spot - 95% confidence	-2	10.26798	0.466
Cold Spot - 90% confidence	-1	5.269376	0.239
No Significant	0	54.60965	2.476
Hot Spot - 90% confidence	1	5.103749	0.231
Hot Spot - 95% confidence	2	10.48199	0.475
Hot Spot - 99% confidence	3	1045.858	47.43
Total		2205.2	100

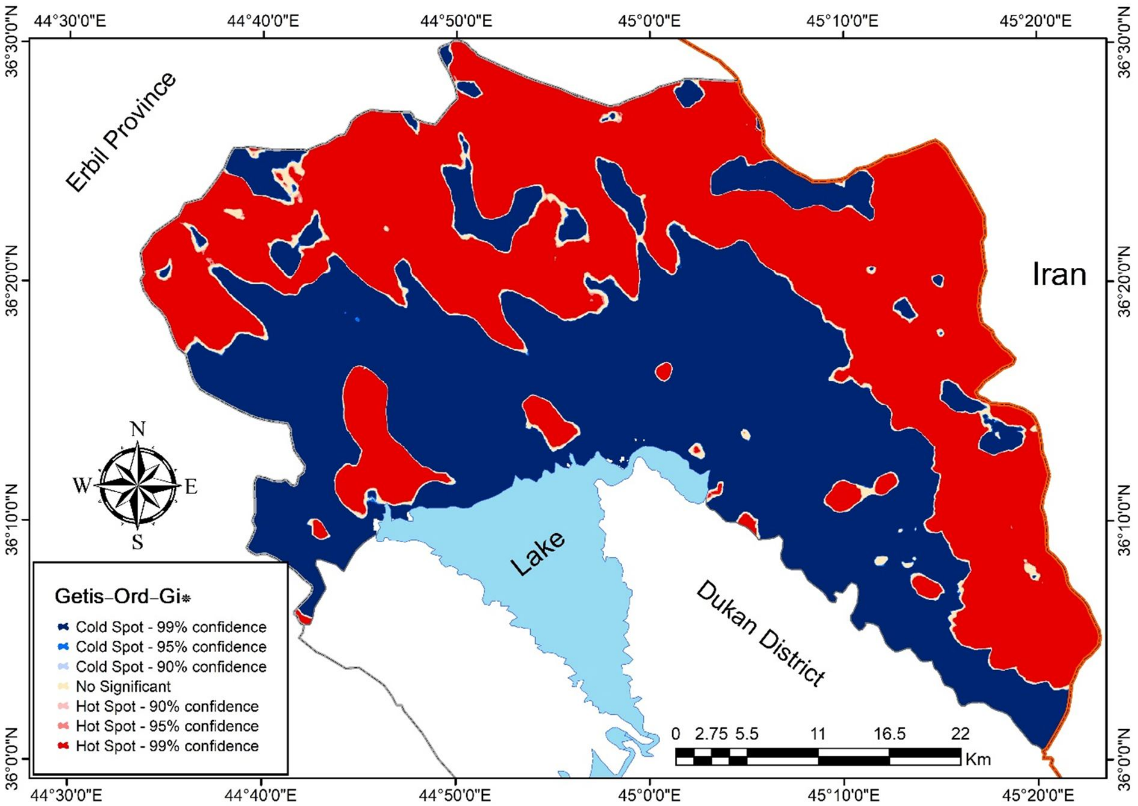


Figure 11. Average NDVI Getis-Ord Gi* analysis results for the study period.

Discussion

This study presents a comprehensive temporal and spatial assessment of vegetation dynamics and vegetation hotspots in the Raparin Administration over a 35-year period using NDVI time series and spatial statistics. The observed temporal fluctuations in NDVI values highlight the complex interactions between climatic variability, land use changes, and anthropogenic pressures influencing vegetation patterns.

The stability of vegetation cover in mountainous and forested areas throughout the study period aligns with findings from similar regions worldwide, where elevation and forest cover often buffer against rapid ecological change (Turner et al., 2001; Zhou et al., 2017). These zones serve as biodiversity refuges, maintaining ecological integrity despite external pressures. In contrast, the greater variability observed in the plains reflects the sensitivity of these areas to human activities such as agriculture expansion, urbanization, and land degradation (Nasir et al., 2022). Such dynamics are consistent with global patterns showing that lowland and agricultural landscapes often experience more pronounced vegetation fluctuations due to land use intensity and climatic impacts (Running, 2008).

The marked decline in vegetation cover during the 1990s corresponds temporally with socio-political instability and economic hardship, including the Kurdish civil conflict and financial crises, which likely contributed to land abandonment, deforestation, and degradation, as documented in conflict-affected regions (Dubinin et al., 2018). Additionally, severe droughts during this period exacerbated vegetation loss, highlighting the vulnerability of the region's ecosystems to climatic extremes (Vicente-Serrano et al., 2010).

Conversely, the gradual recovery and increased vegetation cover observed in the subsequent decades suggest a positive trajectory, potentially driven by post-conflict rehabilitation, improved land management, and more favorable climatic conditions, such as increased rainfall in 2019. These trends echo similar recovery patterns documented in post-disturbance landscapes elsewhere (Danet et al., 2018). However, despite overall improvements, spatial heterogeneity remains, with pockets of decline persisting, underscoring the need for targeted conservation and sustainable land use planning.

The Getis-Ord Gi* hotspot analysis revealed a near balance between areas of persistent high and low vegetation productivity. The dense belt of hotspots along the southern border with Iran, characterized by stable, forested ecosystems receiving substantial rainfall, represents a critical hotspot. This finding underscores the importance of transboundary forested landscapes in maintaining regional biodiversity and ecological resilience (Lausch et al., 2015). Meanwhile, cold spots predominantly located in low rainfall plains and areas affected by urban sprawl highlight regions vulnerable to degradation, where conservation and restoration efforts should be prioritized. Isolated cold spots in rocky, high-elevation mountainous areas, such as the Qandil Mountains, further illustrate the influence of topography and soil conditions on vegetation patterns, consistent with studies showing that harsh terrain and poor soil limit vegetation productivity (Körner, 2007). This spatial complexity emphasizes the necessity of incorporating diverse ecological factors into management strategies.

Overall, this study contributes valuable insights into the spatiotemporal dynamics of vegetation cover and biodiversity in a geopolitically sensitive region. The integration of NDVI time series with spatial hotspot analysis provides a robust framework for monitoring ecosystem health and guiding conservation efforts. Future research could benefit from incorporating additional environmental variables, such as soil moisture, land cover types, and socio-economic factors, to better understand the drivers of vegetation change. Additionally, long-term monitoring remains essential to track ongoing trends under changing climate and land use pressures.

Conclusion

This study demonstrates significant changes in vegetation cover across the Raparin Administration over the past 35 years, shaped by both environmental and human influences. The relative stability of forested mountainous areas highlights their critical role as biodiversity refuges, while the more variable plains underscore vulnerability to land use changes and climate fluctuations. The initial vegetation decline in the 1990s, followed by a gradual recovery, emphasizes the importance of effective land management and favorable climatic conditions in ecosystem restoration.

Based on these findings, we recommend focused conservation efforts in the stable forested hotspots to preserve their ecological integrity. At the same time, targeted restoration and sustainable agricultural practices should be promoted in the vulnerable plains and cold spot areas to reduce degradation. Furthermore, cross-border cooperation, especially along the Iranian border where dense vegetation hotspots exist, could enhance regional biodiversity protection. Lastly, continued long-term monitoring using remote sensing tools like NDVI is essential to detect emerging trends and guide adaptive management in response to future environmental and socio-economic changes.

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Conflict of interest

The authors affirms that no conflicts of interest are associated with the publication of this study.

References

Abedi Gheshlaghi, H., & Valizadeh Kamran, K. (2018). Evaluation and zoning of forest fire risk using multi-criteria decision-making techniques and GIS. *Journal of Natural Environmental Hazards*, *7*(15), 49-66.

Abedi, M., Norouzi, G.-H., & Bahroudi, A. (2012). Support vector machine for multi-classification of mineral prospectivity areas. *Computers & Geosciences*, *46*, 272-283. https://doi.org/https://doi.org/10.1016/j.cageo.2011.12.014

Anselin, L. (1995). Local indicators of spatial association—LISA. *Geographical analysis*, *27*(2), 93-115.

Danet, A., Anthelme, F., Gross, N., & Kéfi, S. (2018). Effects of indirect facilitation on functional diversity, dominance and niche differentiation in tropical alpine communities. *Journal of Vegetation Science*, *29*(5), 835-846.

Dhillon, M. S., Kübert-Flock, C., Dahms, T., Rummler, T., Arnault, J., Steffan-Dewenter, I., & Ullmann, T. (2023). Evaluation of MODIS, Landsat 8 and Sentinel-2 data for accurate crop yield predictions: A case study using STARFM NDVI in Bavaria, Germany. *Remote Sensing*, *15*(7), 1830.

Ding, L., Chen, K.-L., Liu, T., Cheng, S.-G., & Wang, X. (2015). Spatial-temporal hotspot pattern analysis of provincial environmental pollution incidents and related regional sustainable management in China in the period 1995–2012. *Sustainability*, *7*(10), 14385-14407.

Dubinin, V., Svoray, T., Dorman, M., & Perevolotsky, A. (2018). Detecting biodiversity refugia using remotely sensed data. *Landscape ecology*, *33*(10), 1815-1830.

Evans, J., & Geerken, R. (2004). Discrimination between climate and human-induced dryland degradation. *Journal of arid environments*, *57*(4), 535-554.

Getis, A. (1996). Local spatial statistics: an overview. *Spatial analysis: modelling in a GIS environment.*, 261-277.

Getis, A., & Ord, J. K. (1992). The analysis of spatial association by use of distance statistics. *Geographical analysis*, *24*(3), 189-206.

Güler, S., & Turgut, B. (2024). Monitoring Türkiye's Vegetation Cover with NDVI: Terrestrial and Temporal Perspectives. *SilvaWorld*, *3*(2), 87-98.

Harte, J. (2001). Land use, biodiversity, and ecosystem integrity: the challenge of preserving earth's life support system. *Ecology Law Quarterly*, 929-965.

Huang, S., Tang, L., Hupy, J. P., Wang, Y., & Shao, G. (2021). A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. *Journal of Forestry Research*, *32*(1), 1-6.

Hussain, M., Chen, D., Cheng, A., Wei, H., & Stanley, D. (2013). Change detection from remotely sensed images: From pixel-based to object-based approaches. *ISPRS Journal of Photogrammetry and Remote Sensing*, *80*, 91-106.

Jabbari, S., Khajedin, S. J., Jafari, R., & Soltani, S. (2015). Remote sensing technology for mapping and monitoring vegetation cover (Case study: Semirom-Isfahan, Iran). *Pollution*, *1*(2), 165-174.

Körner, C. (2007). The use of 'altitude'in ecological research. *Trends in ecology & evolution*, *22*(11), 569-574.

Lausch, A., Blaschke, T., Haase, D., Herzog, F., Syrbe, R.-U., Tischendorf, L., & Walz, U. (2015). Understanding and quantifying landscape structure–A review on relevant process characteristics, data models and landscape metrics. *Ecological Modelling*, *295*, 31-41.

Lu, D., Mausel, P., Brondizio, E., & Moran, E. (2004). Change detection techniques. *International Journal of Remote Sensing*, *25*(12), 2365-2401.

Mohammed, M. W., Nasir, S. M., & Khdir, S. H. (2024). Using Object-Based Image Analysis approach for analyzing the impact of annual average change of climate elements on LULC change in northern of Sulaimani province. 1st International Conference on Climate Changes and their Environmental Risks from a Geographical Perspective,

Nasir, S. M., Kamran, K. V., Blaschke, T., & Karimzadeh, S. (2022). Change of land use / land cover in kurdistan region of Iraq: A semi-automated object-based approach. *Remote Sensing Applications: Society and Environment*, *26*, 100713. https://doi.org/https://doi.org/10.1016/j.rsase.2022.100713

Ord, J. K., & Getis, A. (2001). Testing for local spatial autocorrelation in the presence of global autocorrelation. *Journal of regional science*, *41*(3), 411-432.

Pettorelli, N., Vik, J. O., Mysterud, A., Gaillard, J.-M., Tucker, C. J., & Stenseth, N. C. (2005). Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends in ecology & evolution*, *20*(9), 503-510.

Rasul, A., Balzter, H., Smith, C., Remedios, J., Adamu, B., Sobrino, J. A., Srivanit, M., & Weng, Q. (2017). A review on remote sensing of urban heat and cool islands. *Land*, *6*(2), 38.

Running, S. W. (2008). Ecosystem disturbance, carbon, and climate. *science*, *321*(5889), 652-653.

Sharma, A. K., Sharma, A. K., Sharma, M., & Sharma, M. (2022). Assessment of land use change and climate change impact on biodiversity and environment. In *Environmental pollution and natural resource management* (pp. 73-89). Springer.

Turner, M. G., Gardner, R. H., & O'neill, R. V. (2001). *Landscape ecology in theory and practice: pattern and process*. Springer.

Vicente-Serrano, S. M., Beguería, S., & López-Moreno, J. I. (2010). A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. *Journal of climate*, *23*(7), 1696-1718.

Wulder, M. A., White, J. C., Goward, S. N., Masek, J. G., Irons, J. R., Herold, M., Cohen, W. B., Loveland, T. R., & Woodcock, C. E. (2008). Landsat continuity: Issues and opportunities for land cover monitoring. *Remote sensing of environment*, *112*(3), 955-969.

Zhou, W., Pickett, S. T., & Cadenasso, M. L. (2017). Shifting concepts of urban spatial heterogeneity and their implications for sustainability. *Landscape ecology*, *32*(1), 15-30.