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ASSESSMENT OF LANDSCAPE VEGETATION COVER IN THE CLIMATE CHANGE ERA USING GEOSPATIAL DATA AND REMOTE SENSING TECHNIQUES: A CASE STUDY OF KHINIS, KURDISTAN REGION, IRAQ

Abstract: The spatiotemporal changes of vegetation in the Khinis area, Kurdistan Region of Iraq, were investigated using satellite images (Landsat and Sentinel) between 1977 and 2021. Based on its historical and ecological significance, this study investigates land cover and natural resources condition changes. The Normalized Difference Vegetation Index (NDVI) was calculated using remote sensing and GIS, and the statistics were evaluated in the Statgraphics Centurion. The result showed a decrease in vegetation cover. Increased vegetation was seen during wet years, while decreased vegetation was observed for sparse vegetation (desert) during dry years. Moreover, seasonally, spring had a moderate vegetation increase while winter and summer exhibited minimum and lower values respectively based on Sentinel data. The analysis of vegetation indices suggests that the vegetation in the study area is declining as a result of climate and anthropogenic factors, which implies that effective conservation and sustainable development management are needed to prevent and reduce land degradation of the Khinis area, which is part of its rich natural and cultural heritage.

Keywords: NDVI, land cover change, Landsat, Sentinel, Khinis area, vegetation dynamics, sustainable management

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Introduction

The upper Mesopotamia is a region in the cradle of agricultural, cultural and natural landscapes evolution that has witnessed several land cover changes in the last few decades (Youssef, 2019). Since 1992, in order to preserve nature from destruction, reduce the loss of biodiversity and to maintain the environmental sustainability, countries have agreed upon the Rio declaration, as a basis for the formulation of policies and procedures for international cooperation and environmental issues (UN, 1992). In general, protected areas are meant for the maintenance of natural and cultural values for supporting sustainable development (IUCN, 2008). The current global climate change has become an emerging environmental issue for natural resources and landscape sites (IPCC, 2021). The average temperature of the earth's surface and sea levels is increasing, and the precipitation, drought and flooding conditions are varying in some parts of the world; meanwhile, the growth of vegetation is shifting in response to climate change and land degradation.

This region has many natural landscapes that have not been destroyed yet in the northern part of Iraq and Iraq in general. The study area is situated in the Kurdistan Region and has many natural elements such as vegetation, water bodies, natural landscape diversity and it has not suffered from any destruction yet (Buringh, 1960). Due to socio-political instability in the last three decades, Khinis natural landscape area is facing many challenges, but this part has not yet been fully understood. Few papers studied vegetation dynamic and the relationship of vegetation and land cover in the study area, however, a long-term vegetation study in this area in conjunction with the land cover change analysis in this study will be helpful for understanding the relationship between land degradation and changes in vegetation cover. Thus, the main objective of this study is to understand the vegetation dynamics using the vegetation index and land cover classification in order to help in planning for better management of the Khinis natural landscape area.

Changes in land cover are central to natural resources management and environmental monitoring (Ahmed, 2016). Land use change brought on by agricultural activities, overgrazing, and land degradation through soil erosion can diminish land productivity and the overall wellbeing of ecosystems; these negative impacts could become severe in the context of climate change (Melese, 2016; Hailemariam et al., 2016).

Moreover, vegetation cover plays an important role in ecosystem health and environmental monitoring. Climate change impacts significantly on vegetation cover because it changes the spatial and temporal patterns of climatic parameters like temperature and precipitation (Tong et al., 2017). Drought, desertification, and dust storm have affected the agricultural activities of Iraq (McKee et al., 1993; Ahmed, 2016).

Remote sensing (RS) integrated with geographic information systems (GIS) is the tool of choice for monitoring and analysis of the Earth's surface dynamics (Zhang et al., 2010). It has been widely used for the study of long-term change in vegetation cover (Batool et al., 2015) and provides an opportunity to study and assess land cover at the large scale with a low cost from satellite images.

Vegetation greenness as determined by satellite data, the Normalized Difference Vegetation Index (NDVI) (Akinsanola & Babalola, 2016; Lamchin et al., 2004) has been used to study the cover of the vegetation and its relationship in relation to local climate (Rasul & Ibrahim, 2017). Thus, using remote sensing coupled with Geographical Information Systems (GIS), an environment can be investigated both spatially and temporally (Giri et al., 2003; Hashemi et al., 2013; Hoare et al., 2013).

This research aims to analyze vegetation trends during the last few decades based on the analysis of Landsat and Sentinel satellite images. In this study, the software of remote sensing (GIS and SNAP) was used to calculate the NDVI, and statistics to evaluate ecosystem and landscape change. Furthermore, this research highlights the ecological and cultural characteristics of the Khinis region and its potential as a protected area.

The specific objectives are:

(i) to assess spatio temporal vegetation dynamics using NDVI based on Landsat and Sentinel satellite data,

(ii) to study the influence of environmental and climate variables on vegetation cover,

(iii) to investigate the value of the Khinis area as a possible landscape for protection.

The outcome of this research may be an important basis for the conservation of ecosystems and the protection of natural and cultural heritage sites.

Material and methods

Study area. Khinis is an archaeological site situated approximately 43 km from the city of Duhok, at the entrance of the narrow Gomel Gorge, one of several small gorges in the Kurdistan Region that channel water from the southern Zagros Mountains toward the plains of northern Iraq as shown in Figure (1). The geographic coordinates of Khinis area are 36°45’41” N and 43°25’12” E. The archeological area core zone of Khinis is 23.53 ha and the buffer zone area is 54.09 ha, while the total area is 77.62 ha.

The Khinis area is experiencing environmental pressures that threaten its preservation. For instance, the hillock around which the Gomel flows down before arriving at the Great Relief is marked with small spots that damage and distort the natural landscape. In addition, there is a lack of sufficient conservation for the carved properties (inscriptions and rock reliefs), (Morandi Bonacossi, 2018).

The purpose of making a sustainable development plan in a natural and historical site is to preserve not only excavation remains, but also the natural landscapes and resources of the area where it is considered into serious proper management.

The area of Khinis is defined as a heritage landscape dating back between the 9th and 7th centuries BC during the Neo-Assyrian Empire.

As much as the Khinis area is concerned, the main cause of site preservation is affected is environmental around. For instance, the hillock around which the Gomel flows down before arriving at the Great Relief is marked with small spots that damage and distort the natural landscape. In addition, there is a lack of sufficient conservation for the carved properties (inscriptions and rock reliefs) (Morandi Bonacossi, 2018).

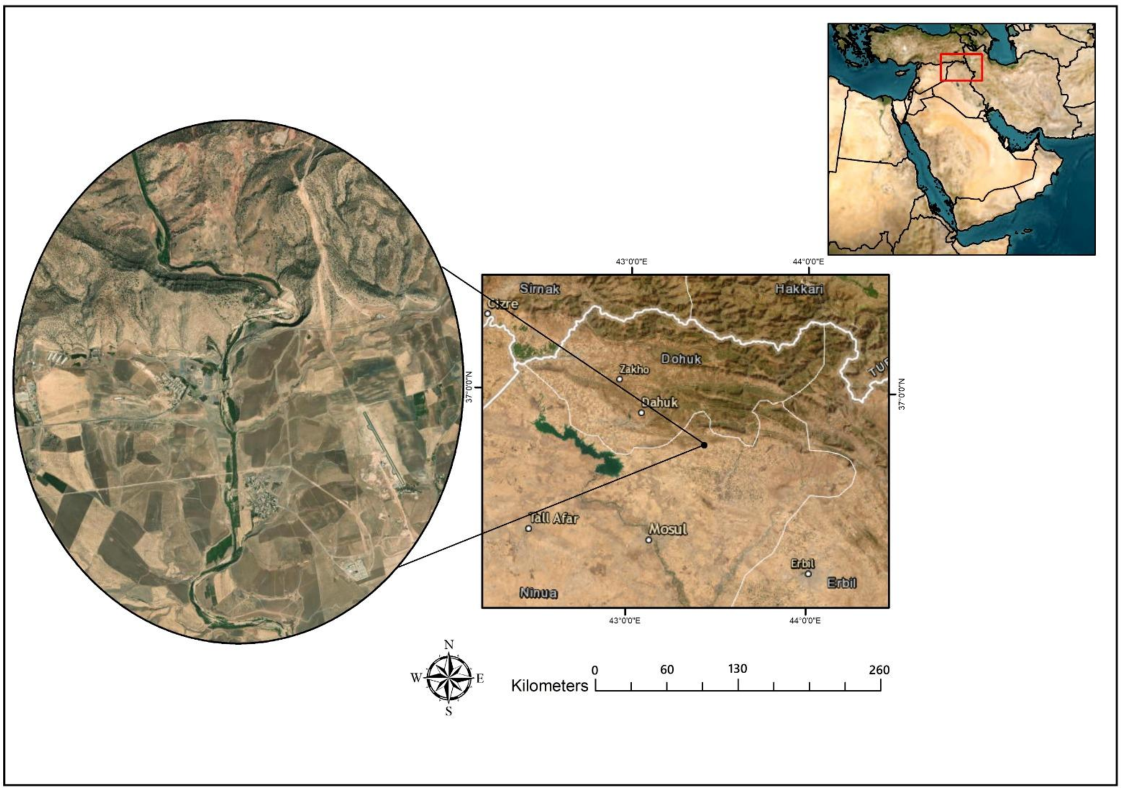

Figure 1. The map of the study area
Source: Authors' elaboration based on ESRI World Imagery

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Satellite images collection. Multi-spectral satellite images and hydrological data used in our study were collected form the Sentinel hub and USGS websites (Table 1).

Table 1. Summary of the datasets used

Sources	Time period	Resolution Spatial	Data access
Sentinel 2	JAN. MAY. SEPT. 2021	10	https://apps.sentinel-hub.com/eo-browser/
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Landsat1	MAY 1977	80	https://earthexplorer.usgs.gov/
Landsat5	MAY 1987	30	https://earthexplorer.usgs.gov/
Landsat5	MAY 1997	30	https://earthexplorer.usgs.gov/
Landsat5	MAY 2007	30	https://earthexplorer.usgs.gov/
Landsat8	May 2017	30	https://earthexplorer.usgs.gov/

Source: Sentinel Hub (Sentinel-2 data) and USGS EarthExplorer (Landsat data)

Climate change indicators data collection. The Soil & Water Assessment Tool (SWAT) climate dataset was used to assess annual precipitation patterns, as well as daily and annual mean temperatures throughout the study period. The data were obtained from the Global Weather Data for SWAT database (USDA, 2023). To further evaluate climatic variations in the study area, the NCEP/NCAR reanalysis dataset was also utilized to characterize and assess local climate conditions over the period 1977–2013 (NOAA, 2023).

The datasets used in this study include multi-temporal Landsat imagery (1977–2017), Sentinel-2 imagery (2020–2021), and climate-related datasets (SWAT, NCEP, and GRACE). These data were selected due to their suitability for long-term environmental monitoring, availability, and appropriate spatial and temporal resolution for NDVI and climate variability analysis. Prior to analysis, satellite images were pre-processed through band composition, NDVI calculation, and integration into ArcMap and SNAP environments. However, some limitations exist, including differences in spatial resolution between Landsat and Sentinel data, temporal gaps between datasets, and limited availability of detailed vegetation ground data for the study area.

Image preprocessing. The preprocessing of all the satellite images utilized for the study was performed before any further processing was done, ensuring their reliability. To facilitate physical consistency with the images captured at different times, digital numbers were converted to top-of-atmosphere reflectances (radiometric calibration), and atmospheric correction was also performed to reduce atmospheric scattering and absorption effects and improve the accuracy of the vegetation indices.

In addition, all satellite images were subsetted over the Khinis study area to remove the irrelevant surroundings and obtain the area of interest. In this way, the spatial analysis was ensured to be the same for the whole area and reduced the computational complexity of the processing. These preprocessing techniques were applied on the Landsat and Sentinel images before computing the NDVI.

Normalized Difference Vegetation index (NDVI) calculation. NDVI is selected for this study based on its robust status as a well-established metric for evaluating vegetation health, biomass density, and spatial patterns. NDVI proves especially adept at capturing vegetation fluctuations across temporal scales in arid and semi-arid environments like Khinis.

Given that vegetation has a major influence on microclimate by governing surface temperatures, rates of evapotranspiration, soil moisture dynamics, and carbon fluxes, shifting NDVI values offer valuable insight into land cover alterations as well as climatic variability in the study area. Hence, NDVI represents an apt proxy for examining the effects of climate change and anthropogenic pressures on the ecological status of the study area.

NDVI was calculated using the standard normalized difference equation:

$$NDVI = \frac{NIR - R}{NIR + R}$$

where NIR represents the near-infrared band reflectance and Red represents the red band reflectance of the satellite imagery.

Landsat data analysis. The Landsat dataset imagery of 1977, 1987, 1997, 2007, and 2017 was imported to ArcMap software (Environmental Systems Research Institute (ESRI), 2012. ArcGIS Release 10.5. Redlands, CA). To composite bands of one image for the year, the features of Data Management and Raster icon were used. The same process was applied to all Landsat images.

Landsat missions used in this study include Landsat 1, Landsat 5, and Landsat 8, covering the period from 1977 to 2017. For NDVI calculation, the red and near-infrared (NIR) bands were selected according to each sensor specification (e.g., Landsat MSS, TM, and OLI sensors). Prior to analysis, all images were radiometrically calibrated and atmospherically corrected, and then clipped to the boundary of the Khinis study area. NDVI was calculated using the standard formula (NIR − Red) / (NIR + Red) at pixel level. The resulting NDVI rasters were then processed in ArcMap, where pixel values were extracted and summarized to generate statistical outputs, including mean, median, and distribution patterns. This analysis was intended to assess long-term vegetation dynamics and detect spatial-temporal changes in land cover over the study period.

To calculate NDVI using ArcMap of Landsat satellites from 1 to 8, the value of pixel from specific intervals for every ten years of Landsat images was calculated. The resulting data were later uploaded to the STATGRAPHSICS Centurion application for statistical analysis.

Sentinel data analysis. We chose to supplement the Landsat data with Sentinel-2 images because of its higher spatial (10 m) and revisit resolution, which allows a more fine grained and up to date assessment of vegetation variability and seasonal changes. This is useful in areas with small scale variation in vegetation, such as Khinis.

Sentinel-2 Level-1C images were acquired from Sentinel Hub, and preprocessed using SNAP to generate surface reflectance products, with cloud masking. Level-2A products were generated using the Sen2Cor algorithm. Images were masked to the region of interest. NDVI was derived using NIR (Band 8, 842 nm) and red (Band 4, 665 nm) at 10 m pixel resolution, using Equation (1). The NDVI images were then exported and visualized in ArcMap, and values extracted for statistical analysis using Statgraphics Centurion.

Sentinel 2 images were selected for three seasons, January (winter, vegetation minimum); May (spring, maximum growth), and September (late summer, minimum growth), to assess seasonal variations in vegetation condition and climatic effects.

Cross-Sensor NDVI Consistency and Resolution Considerations. In order to facilitate a sound comparison of vegetation parameters, the images from Landsat and Sentinel-2 were analyzed independently then combined using complementary approaches. This strategy was adopted because differences in the two sensors (spatial resolution, spectral band characteristics, radiometric resolution and revisit time) could cause discrepancies in vegetation index calculation between different sensors.

Landsat images (30–80 m) were acquired from 1977 to 2017, to study the historical vegetation changes. Sentinel images (10 m) were acquired for the recent 2020 to 2021 period, for studying seasonal vegetation changes and dynamics. The results of Landsat and Sentinel images were compared with each other in terms of the overall trends in vegetation cover, statistical parameters and seasonal trends.

In order to ensure a reliable comparison of images acquired from different satellites, the images were atmospherically corrected (to derive surface reflectance) and the same vegetation indices were computed for all images, using Equation 1. For the sake of spatial comparability, all images were clipped at the same border. No direct pixel-wise comparisons of NDVI values in Landsat and Sentinel datasets were performed, as this might be affected by differences in spatial resolution and radiometric resolution between sensors, which could cause scale effects in the reflectance data.

Despite these standardization efforts, uncertainty is caused by differences in sensor spatial resolution (30–80 m for Landsat and 10 m for Sentinel-2), which might affect vegetation parameter estimation. The uncertainty might also be affected by temporal inconsistencies between acquisition dates (as there are differences between Landsat and Sentinel imagery acquisition dates and within the Sentinel-2 acquisition period) and pixel mixing problems, for Landsat images. However, in order to ensure reliable estimates of NDVI values, we combined Landsat and Sentinel-2 images for the comparison of overall vegetation cover patterns.

Climate change indicators analysis. Climatic and hydrological factors are significant in vegetation change and ecosystem states especially in dry areas such as Khinis area. These were included in our study to supplement the observed vegetation variability in terms of NDVI values but not to show any cause-effect relationship.

To interpret terrestrial water storage anomalies in regional scales, and which is considered as a proxy to hydrological changes (Tapley et al., 2004) in the study area, we also included precipitation, temperature, evapotranspiration (ETc), and Terrestrial Water Storage Anomaly from GRACE. Precipitation is the source of water for vegetation growth, and temperature controls evapotranspiration and plant stress. ETc is a measure of atmospheric need for water and indicates the water loss from plants. GRACE is a satellite-based data which shows variations of terrestrial water storage in large scales. GRACE was included to show a picture of long period drought and water deficit from hydrological point of view. However, due to its coarse resolution and showing the variability in the whole basin rather than a small location, results from GRACE are viewed as a trend at regional scale, rather than Khinis.

While the indicators operate at different spatial and temporal scale compared to NDVI, these provide some contextual information that may support interpreting trends. For example, it may indicate that NDVI declined during years with low precipitation and high evapotranspiration or vice versa. This relationship is not meant to indicate cause-effect rather a comparison and contextual analysis. The combination of NDVI with the climatic and hydrological indicators provides additional information regarding changes to the environment that may contribute to observed vegetation change. These indicators are limited by their different spatial resolution from that of NDVI (high resolution of NDVI and lower for other indicators) as they are retrieved from different satellites that have differences in their resolution. This should be borne in mind as the limitation in the interpretations.

Evaluation of crop evapotranspiration. Crop evapotranspiration (ETc) data were extracted from the SWAT (Soil and Water Assessment Tool) database along with climate-related hydrological modeling outputs and assessed via a Microsoft Excel Worksheet 2016. The reason for the selection of this dataset was that the modeled data is estimated to provide a comprehensive representation of the loss of water through a combination of evaporation and plant transpiration during the period for which data is obtained.

These data of ETc were obtained in MS Excel 2016 for the study period. Missing values were corrected; monthly as well as annual mean, minimum, maximum, and standard deviations were derived. In addition, mean seasonal ET values were also derived based on the seasonal vegetation patterns considered during the NDVI derivation to compare vegetation dynamics to the hydrological characteristics of the study area, where no relationship was inferred between vegetation indices and ETc data.

Water equivalent thickness and Annual fluctuation in Khinis Area. data were obtained from the GRACE Tellus satellite database (NASA, 2023; Swenson & Wahr, 2006) and analyzed using Microsoft Excel 2016.

Annual precipitation and mean temperature. To evaluate the annual precipitation and mean temperature for the Khinis area, data were collected from the National Centers for Environmental Prediction (NCEP) reanalysis dataset (Kalnay et al., 1996) and analyzed using Microsoft Excel 2016.

Data verification. To ensure that the accuracy and validity of the remote sensing products were confirmed, a multi-stage data checking was carried out in order to check the similarity and spatial correspondence of NDVI values of the Landsat and Sentinel datasets.

In cases where it is not possible to access data for field validation over long periods of time (i.e., 1977 to 2021) Google Earth images were used for data cross-checking and verification purposes for visual validation of land use/land cover and vegetation spatial distribution patterns in recent years, which is common practice in remote sensing analysis, especially for long term retrospective analysis of vegetation changes. Landsat and Sentinel derived NDVI products were compared with Google Earth images and spatial distribution patterns of dense vegetation, sparse vegetation, bare surface and water bodies were visually checked to verify a rough agreement between the datasets. The purpose of this step was to verify the spatial correct of the vegetation distribution and trends of NDVI.

Finally, results were also compared with regional and global climate and vegetation databases to ensure consistency with previous study (e.g. decrease of vegetation during drought years and increase of vegetation during high rainfall years). Although this comparison does not provide statistically accuracy of the dataset, it adds credibility to the observed temporal NDVI patterns. Since, Google Earth images are only used for recent periods verification of the datasets, which cannot completely verify datasets in the historical periods. This kind of qualitative and supportive verification method is often used for long-term remote sensing data analysis where ground truth data are not available for historical periods.

Results

The study yielded quantitative proof of spatiotemporal and seasonal shifts in vegetation cover throughout the Khinis region, which confirms the study aims of examining extended changes in vegetation and the environment.

NDVI spatiotemporal assessment. Figure 2 illustrates the findings of the temporal and spatial data gathering and computing, together with land cover changes at the Khinis area archeological site, based on the NDVI pictures of each sampling year. This additionally demonstrates the spatial distribution of vegetation visually, illustrating the concentration of vegetation that is very dense near water and the sparse vegetation which makes up most of the buffer zone. This image represents the raster data for NDVI for the study region of Khinis, calculated using data from the red and near-infrared band bands of the Sentinel-2 data.

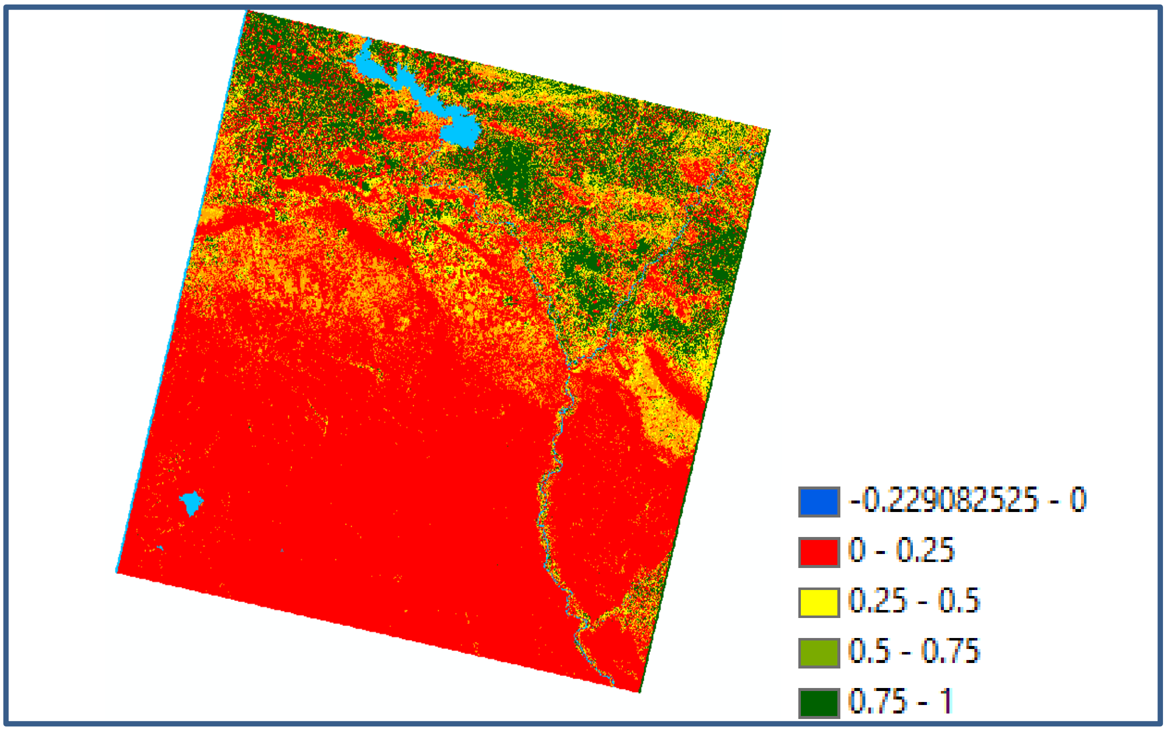


Figure 2. NDVI raster output for the Khinis study area showing spatial vegetation distribution (2021)
Source: Authors' elaboration based on Sentinel-2 imagery (Copernicus/ESA) and GIS processing

The NDVI raster output is presented using a color-coded classification representing vegetation density across the study area. Dense vegetation corresponds to higher NDVI values (displayed in green), while intermediate values represent sparse vegetation (yellow). Lower NDVI values correspond to bare soil and rock (red), and water bodies (blue), as indicated in the map legend. NDVI values range from −1 to +1, where higher values indicate healthier and denser vegetation cover. The classification thresholds used for interpretation are provided in Table 2. Mean and standard deviation values of NDVI were calculated for both Landsat and Sentinel datasets, as shown in Table 2.

Table 2. The NDVI value

Value	Characteristics	Colors
0>	water, snow and cloud	🟦
0.25	rock and bare soil	🟥
0.50	desert vegetation	🟨
0.75	moderate vegetation	🟩
1	dense vegetation	🟩

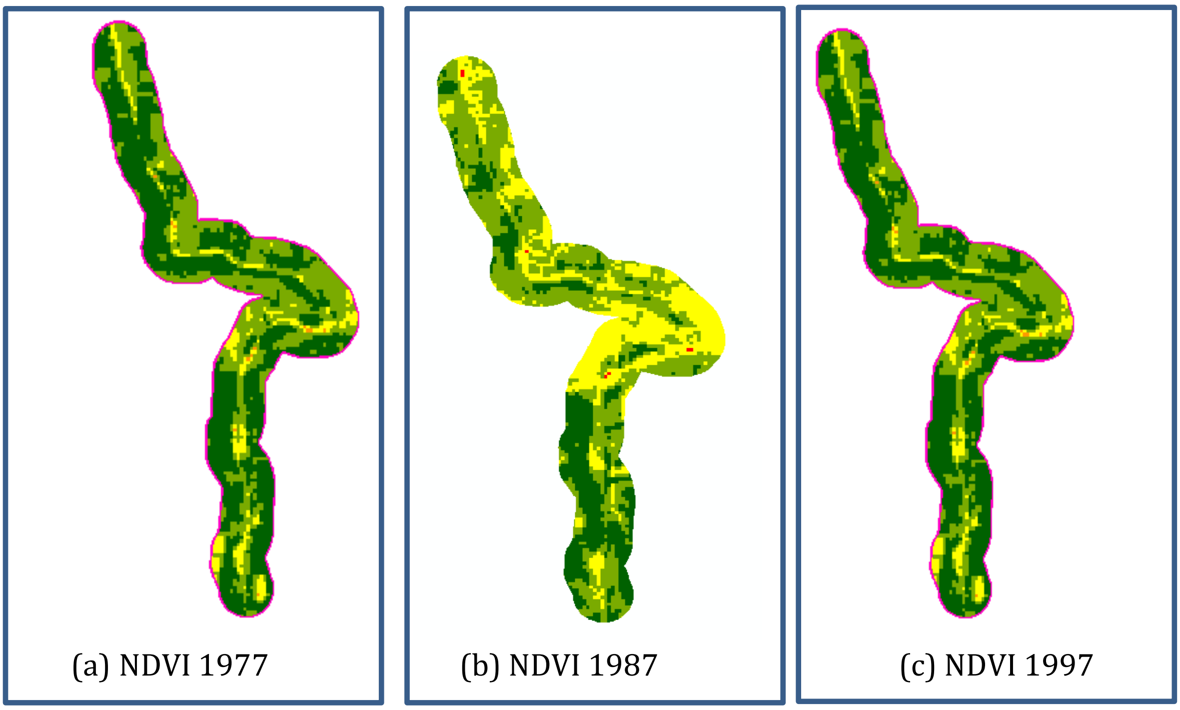
Source: Authors' elaboration based on NDVI standard interpretation from Landsat and Sentinel-2 imagery

Landsat images captured over the Khinis area from 1977 to 2017 were used in this study (Figure 3). Landsat satellites provide medium spatial resolution imagery (30–80 m) and multiple spectral bands suitable for monitoring land use and land cover changes driven by climate variability, urbanization, drought, fire, and vegetation dynamics (Wulder et al., 2019). Landsat is widely recognized as an effective dataset for long-term environmental change analysis due to its continuous historical archive (Roy et al., 2014).

The NDVI images from 1977 to 2017 indicate vegetation dynamics over 40 years, selecting May as the growing season as shown in Figure 3. In 1977, large areas under the buffer zone show healthier vegetation (dark green), moderate vegetation (light green), and sparse vegetation (yellow), with some bare soil (red). By 1987, vegetation becomes more indicating drier conditions. In 1997, vegetation recovered, indicating improved growth conditions. In 2007 and 2017, vegetation declined, although moderate vegetation remained. Some small red points near the river indicate areas of bare soil or exposed surfaces.

Sentinel images of the recent period. The Sentinel 2 earth observation program consists of Sentinel 2A and 2B satellites. NDVI was calculated for three seasons: January (winter), May (growing season), and September (dry summer), as shown in Figure 4.

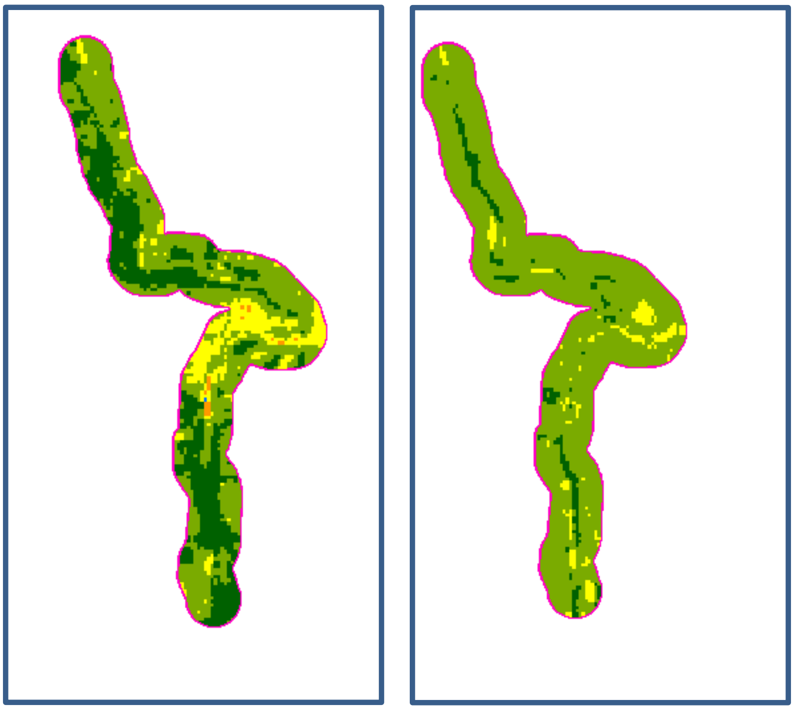
Integrated NDVI images from 2020–2021 show that the area mostly contains rock and sparse vegetation. In January 2021, sparse vegetation increased compared to 2020, likely due to higher winter precipitation and improved soil moisture availability. In May, total vegetation increased, possibly as a result of favorable spring conditions, including moderate temperatures and sufficient water availability. During the summer, dense and moderate vegetation expanded in the buffer zone, indicating the influence of the river in sustaining vegetation growth despite dry climatic conditions.



(a) NDVI 1977

(b) NDVI 1987

(c) NDVI 1997

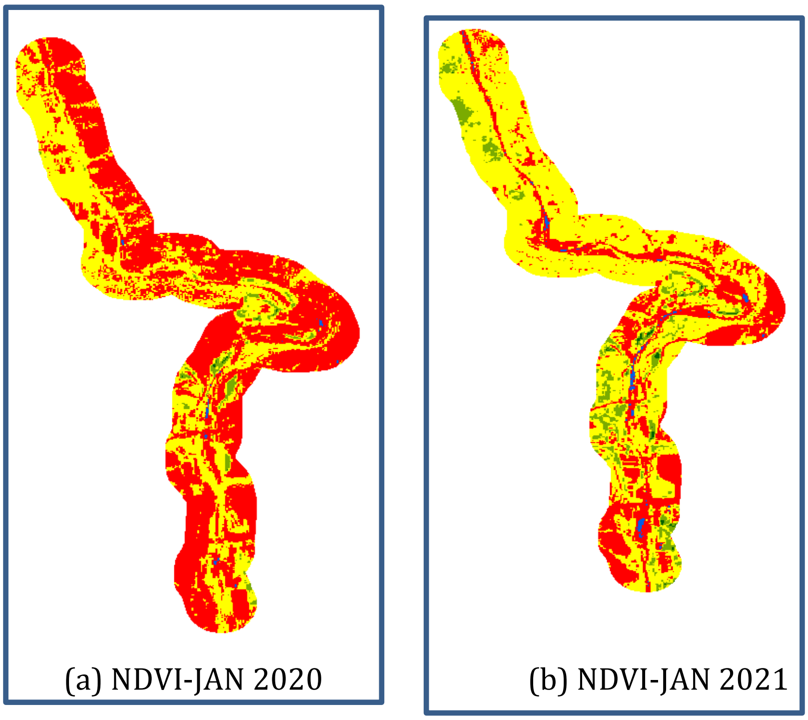


(d) NDVI 2007

(e) NDVI 2017

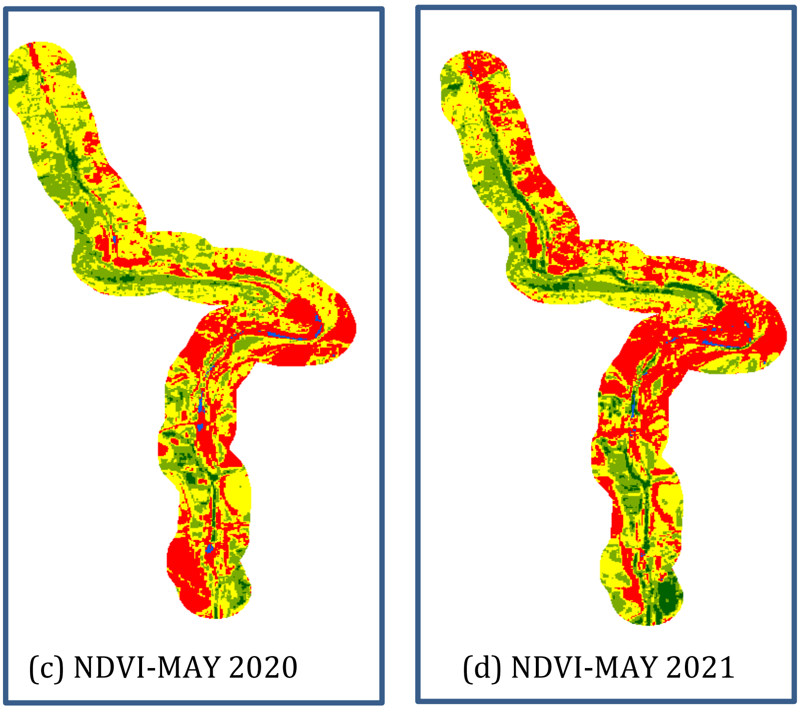
Figure 3. NDVI spatial distribution of the Khinis area derived from Landsat imagery: (a) 1977, (b) 1987, (c) 1997, (d) 2007, and (e) 2017

Source: Authors' elaboration based on Landsat imagery (USGS EarthExplorer) and GIS processing



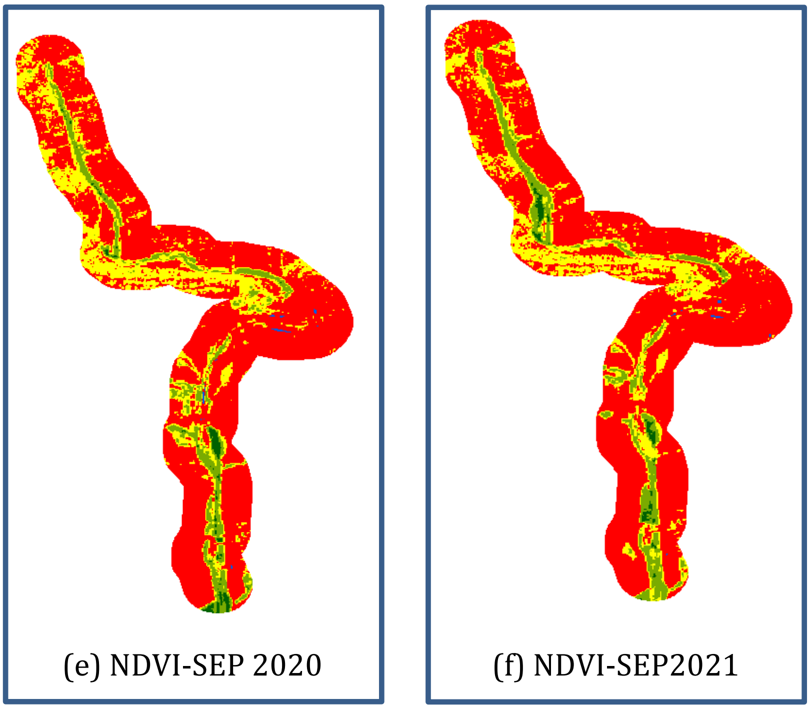
(a) NDVI-JAN 2020

(b) NDVI-JAN 2021



(c) NDVI-MAY 2020

(d) NDVI-MAY 2021



(e) NDVI-SEP 2020

(f) NDVI-SEP2021

Figure 4. NDVI spatial distribution of the Khinis area derived from Sentinel-2 imagery: (a) January 2020, (b) May 2020, (c) September 2020, (d) January 2021, (e) May 2021, and (f) September 2021

Source: Authors' elaboration based on Sentinel-2 imagery (Copernicus/ESA) and GIS processing

The analyses of the value NDVI as the pixel index. Statgraphics Centurion software was used to compute statistical NDVI metrics for comparison across years. NDVI data from ArcMap were imported to the software to compare Landsat and Sentinel images Figure 5.

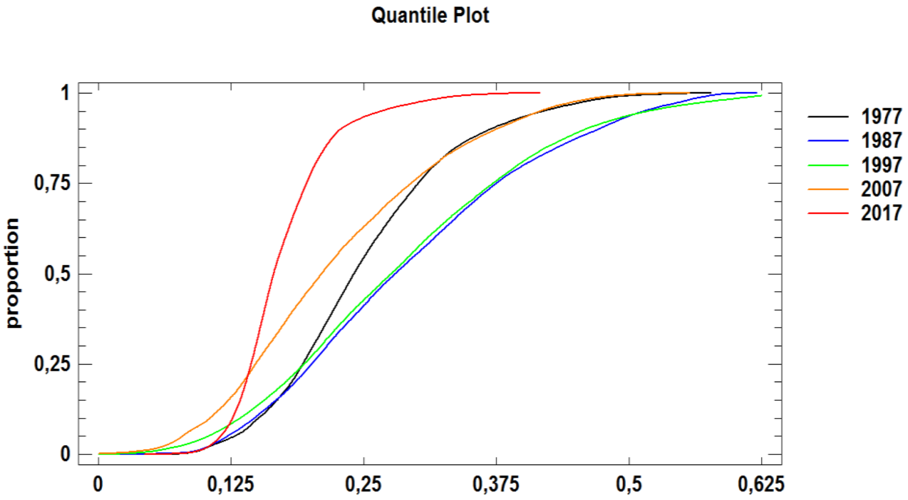


Figure 5. The quantity value of NDVI from Landsat images

Source: Authors' elaboration based on Landsat imagery (USGS EarthExplorer) and GIS processing

The graph above describes the NDVI values of each year. For instance, in 1987 and 1997 is appearing as the highest value of dense vegetation which is above 0.5 and basically it is because they are in wet period. While the 50 percentage of NDVI value is under 0.25 which defined as dry condition where it is including for all different years. Eventually, the values above 0.25 to 0.5 identify as sparse vegetation, that might involve for the year of 1977 and 2007 mostly and 2017 hardly. Therefore, the line of 2017 determine as the 90 percentage of the area is under the desert vegetation in the buffer zone of the area.

In the Figure 6 describe the value of vegetation according to the number of NDVI pixels.

Figure 6. The portion value of NDVI from Landsat images from box-plot chart
Source: Authors' elaboration based on Landsat imagery (USGS EarthExplorer), GIS processing, and statistical analysis

In the box plot of figure 6 above the value of NDVI can describe the number of the pixel degree as value of vegetation cover in the study area though interquartile. The distribution of NDVI values is illustrated using box plots in Figure 6. The interquartile range (box) represents the spread of moderate vegetation values, which is more extensive in 1987 and 1997. The whiskers indicate values outside the central 50% of the data, where lower values correspond to sparse vegetation, bare soil, or rock surfaces. In 2007, the lower whisker extends below zero, indicating the presence of water bodies, such as the river. Unfortunately, the value of water body is not clearly visible due to low resolution of the Landsat images, but thanks to the box plot that can make it possible to be visible. However, the box of 1977 can explain that around 20 percentage is the vegetation area between sparse and moderate vegetation. While in the very small area of rock and soil vegetation can be saw with sparse while most of the rest of vegetation can be visible around 0.30 to 0.40 which mostly define the rock and desert vegetation area. The indicators of outliner might describe to survive even during the dry time.

In the Table 3 there is a good description relating to average, median and as so on. It can be notice that from whole five years of sentinel images data the lowest value of average and median can be seen in 2017. Which are these indicators has a significant decreased over the previous years, as shown in Table 4.

Table 3. Summary statistics values of Landsat images

Year	Count	Average	Median	Variance	Minimum	Maximum	Range
1977	34094	0.25227	0.240856	0.007336	0.0625529	0.577066	0.504503
1987	34094	0.294322	0.27973	0.0142367	0	0.620253	0.620253
1997	34094	0.287988	0.276017	0.01589994	0.0315789	0.678571	0.71015
2007	34094	0.225702	0.210454	0.0104666	0.0769231	0.557143	0.634066
2017	34094	0.174253	0.16523	0.00214602	0.0430308	0.416143	0.373112

Source: Authors’ elaboration based on Landsat imagery (USGS EarthExplorer) and statistical analysis

Table 4. Correlation between the values of NDVI from Landsat images

Correlation				
	NDVI 1987	NDVI 1997	NDVI 2007	NDVI 2017
NDVI 1977	0.5938	0.6333	0.5392	0.2532
NDVI 1987		0.7051	0.7253	0.2691
NDVI 1997			0.5523	0.2208
NDVI 2007				0.452

Source: Authors’ elaboration based on Landsat-derived NDVI data and statistical analysis

It’s always essential to see the strong and weak relationship of NDVI among each year in order to get realized about the exact condition and be able to manage it or assess it in right way. In the table atop the values are classified using color coding. For example, the values of 2017 can describe that there are no relationships out of other year’s values as been colored by red. While there is a strong connection between 1997 to 1987 and 2007 as depended by green colors. With yellow colors explain the sick correspondence of 2007 to twenty years earlier. Consequently, the correlation among Landsat NDVI values indicates substantial changes over the forty-year period, particularly in 2017, where NDVI values show a clear deviation from previous years. These statistical results were processed using Statgraphics Centurion software (Figure 7).

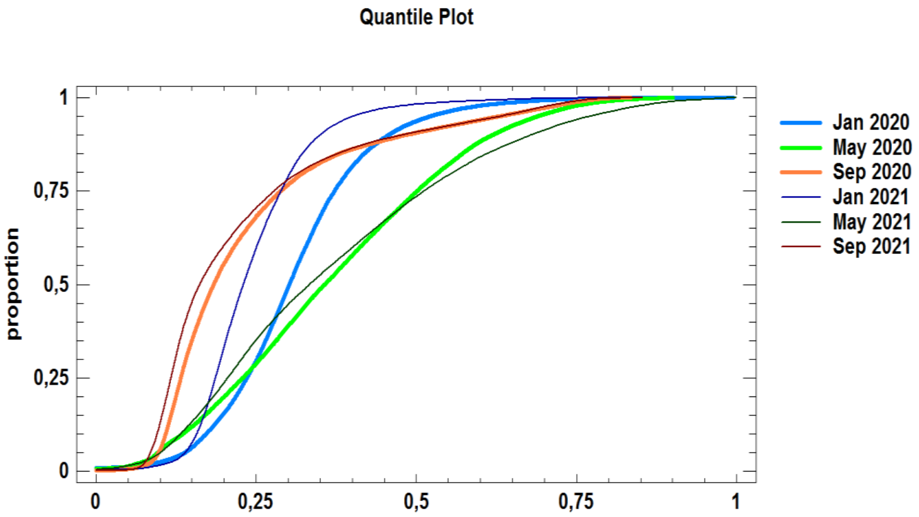


Figure 7. the quantity value of NDVI from Sentinel images
Source: Authors' elaboration based on Sentinel-2 imagery (Copernicus/ESA) and statistical analysis using Statgraphics Centurion

Sentinel data were processed using the same methodology as Landsat images. As shown in Figure 7, the values have been distinguished between each three samples of two different years.

Generally, the appearance in the figure of two different years are similar between every three samples with the same time period. Basically, the highest value of vegetation, which is around 0.60 represent in May with the two different years as seen in green colors. For the case of January 2020 and 2021 in blue colors, around 70 percentage the plants can be found around 0.30 which define the sparse vegetation. Finally, the summer season shows different seasonal behavior as seen in September of 2020 and 2021. The portion of vegetation decreases to 0.1 which determines bare soil and desert conditions (Figure 8).

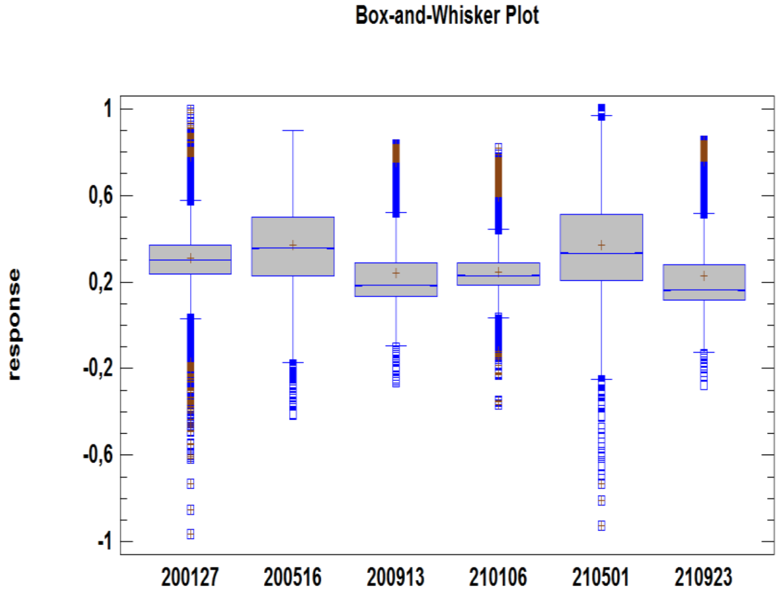


Figure 8. the portion value of NDVI from Sentinel images from box-plot chart
Source: Authors' elaboration based on Sentinel-2 imagery (Copernicus/ESA) and statistical analysis

In Figure 8 of Sentinel images is clearly visible the greatness of Sentinel satellites of their high resolution. The water body is understandably be seen.

The high percentage of median box can hold it by May in both interval, which represent the amount of moderate vegetation within some rate of dense. In case of large size of bare surface or soils can be found mostly in January with two different years according to minimum whisker of outline. One interesting point is found it in January 2020 that the amount of water been increased in the river stream this is due to flooding happened in the region and that might impact the vegetation around it.

With case of September two various years has seen the minimum value is rise it up that is considering with rock and soil. While the maximum value is around 0.4, which makes the vegetation survive during the driest time (Table 5).

Table 5. Summary statistics values of Sentinel images

Year	Average	Median	Variance	Minimum	Maximum	Range
JAN 2020	0.309039	0.301889	0.3333	-0.96349	0.995098	1.95859
MAY 2020	0.036947	0.356903	0.3333	-0.41508	0.901019	1.3161
SEP 2020	.0240212	0.183912		-0.26141	0.834586	1.096
JAN 2021	0.245477	0.230345	0.2	-0.36646	0.819536	1.186
MAY 2021	0.371696	0.333452	0	-0.92593	0.998375	1.9243
SEP 2021	0.227378	0.162326		-0.27465	0.852997	1.2765

Source: Authors' elaboration based on Sentinel-2 imagery (Copernicus/ESA) and statistical analysis

The table describe the statistical values of different sample with two various intervals. Looking from abroad, the average and standard deviations the numbers look very similar as the same period but different years. For example, in both May and September of 2020 and 2021, the numbers are very close, while only January 2020 and 2021 show a difference that might indicate environmental change (Table 6).

Table 6. Correlation between the values of NDVI from the Sentinel images

	MAY 2020	SEP 2020	JAN 2021	MAY 2021	SEP 2021
JAN 2020	0.5052	0.1763	0.6242	0.2252	0.0854
MAY 2020		0.4645	0.5211	0.6625	0.3918
SEP 2020			0.5704	0.6355	0.8588
JAN 2021				0.4624	0.4894
MAY 2021					0.5386

Source: Authors' elaboration based on Sentinel-2-derived NDVI data and statistical analysis

The weak relationship can be seen among 2020 January to the same year but September and 2021 May and September. While the strong correspondence has found with 2020 and 2021 September. The rest have generally the good link between them.

Crop Evapotranspiration. Between 1999 and 2014, an obvious increase in the evapotranspiration index was observed between the spring and fall seasons, showing a positive correlation with different climatic indicators, as shown in Figure 9. In this study, evapotranspiration refers to reference evapotranspiration (ET_0), calculated using standard climatic parameters (e.g., temperature, precipitation, solar radiation, and relative humidity).

Figure 9 shows the changes in evapotranspiration in Duhok city. The line colors represent solar radiation, relative humidity, precipitation, and minimum and maximum temperatures. These measurements illustrate the increasing trend of these indicators during the spring and fall seasons over the 15-year period up to 2014. Due to the lack of recorded data after 2014, the study was not able to assess the current situation.

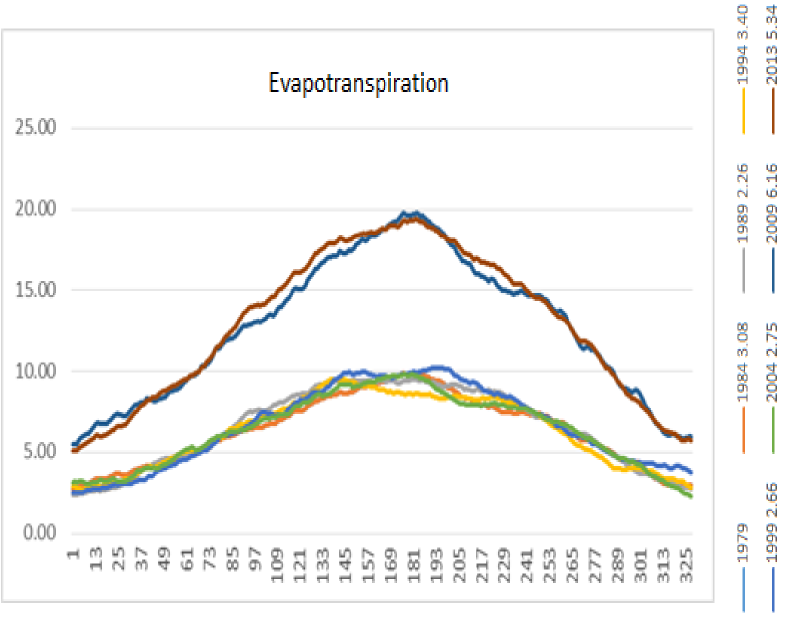


Figure 9. Evapotranspiration
Source: Authors' elaboration based on meteorological data (NOAA/NCEP) and statistical analysis

Annual precipitation. The annual Precipitation of national region of Kurdistan has been analyzed, and it explains the portion of the precipitation shows a significant decreasing change in the past eight years starting from nineteen seventy-seven as seen in the Figure 10.

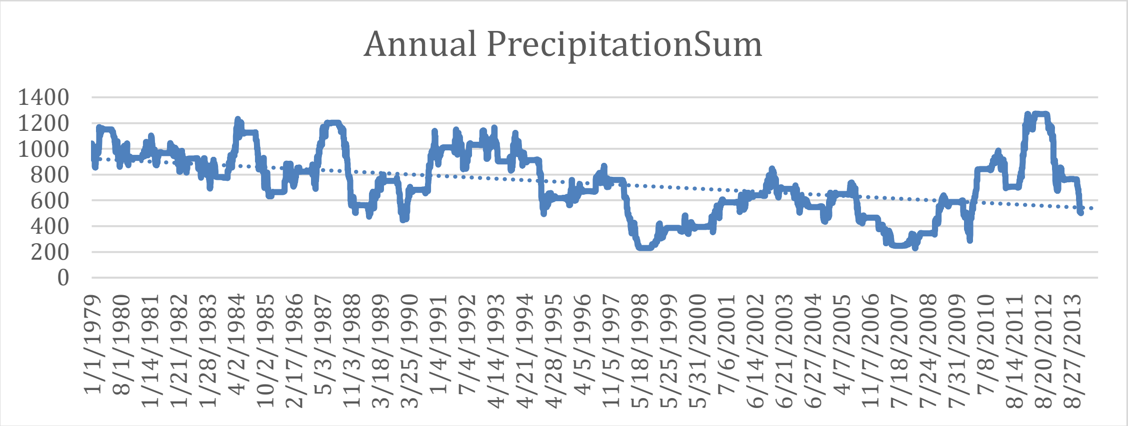


Figure 10. the precipitation changes over the past fifty years in the local region of Kurdistan
Source: Authors' elaborationbased on NCEP/NOAA precipitation data
and statistical analysis

Mean temperature. The changes in the annual mean temperature were assessed Figure 11 over a period of 34 years. The temperature seems to have been very constant and can be seen around 20 degrees. yet, at some points in time, lower values were observed, especially in 2012, which seemed to be the coldest degree measured, this variation is likely due to climatic variability rather than changes in satellite sensor resolution (Figure 11).

Figure 11. Mean temperature
Source: Authors' elaboration based on NCEP/NOAA reanalysis temperature data
and statistical analysis

The green line defines annual mean temperature while the red line describes the observation of mean daily temperature.

Water equivalent thickness. Following the GRACE twin satellites, launched to investigate Earth's water reservoirs by taking detailed measurements of Earth's gravity field changes. We found lower levels of water especially after 2010 describing thus a serious drought situation in the area.

In Figure 12 the value describes water equivalent of gravity, the value above zero from 2002 to 2009 can define as more strong water equivalent of gravity. While the opposite for the value under 0 is describe with low water equivalent as it can be seen from 2010 to next ten years. The exception in 2018 shows a different value, which is likely due to natural variability in the dataset rather than replacement of the satellite sensor (Figure 13).

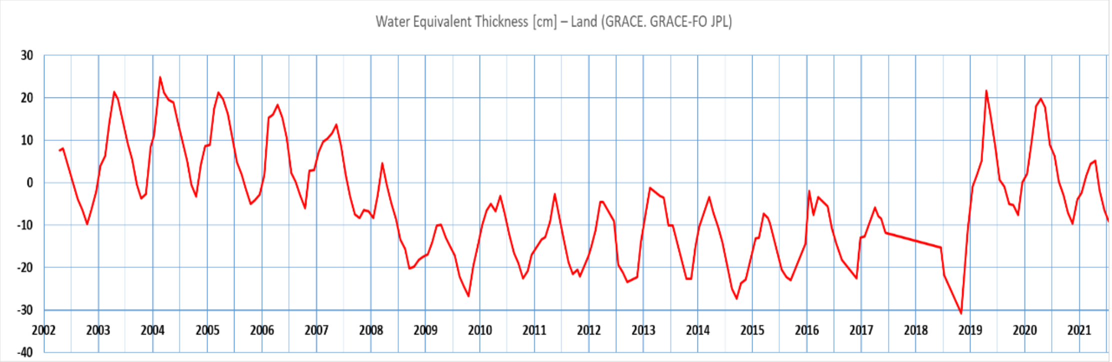


Figure 12. The water equivalent Thickness of Iraq over the past 20 years
Source: Authors' elaboration based on GRACE Tellus satellite data (NASA JPL)
and statistical analysis

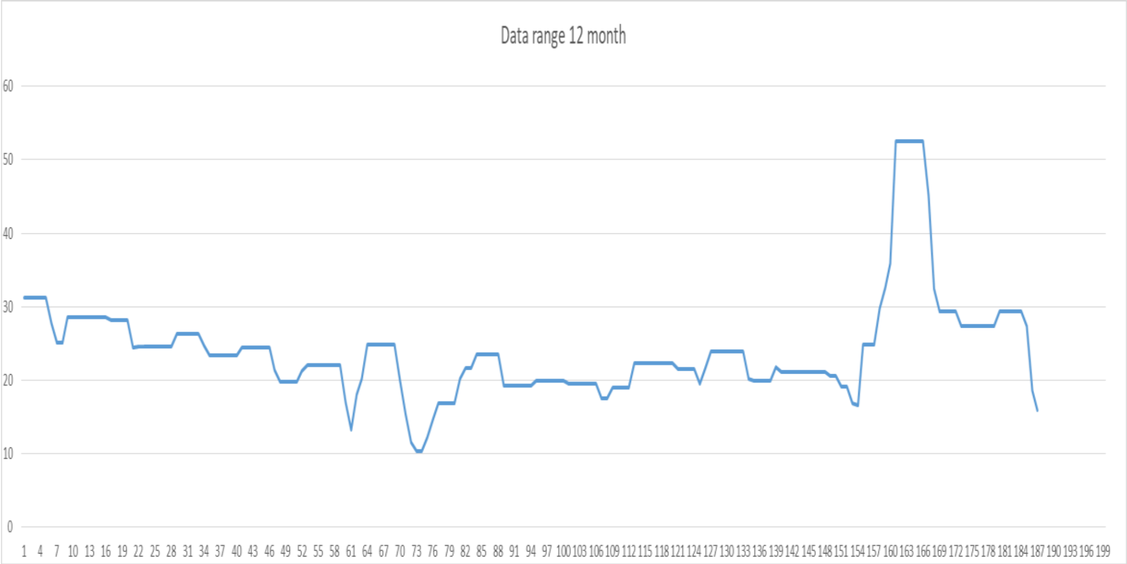


Figure 13. annual fluctuation of water equivalent thickness by GRACE Tellus satellite
Source: Authors' elaboration based on GRACE Tellus satellite data (NASA JPL)
and statistical analysis

The observed monthly changes in gravity are caused by monthly fluctuations in mass. Variations in the thickness of a very thin layer of water at the Earth's surface can be compared to the mass changes (i.e., in a layer up to several kilometers thick). The majority of monthly gravity fluctuations are caused by variations in water storage in hydrologic reservoirs, moving ocean, atmosphere, and land ice masses, and mass exchanges across various Earth system compartments.

The line graph describes the measurement of the annual minimum and maximum value of the fluctuation of water equivalent in Iraq over the 365 days over the past years. As it can be displaying the values show a significant decline.

Validation. To ensure the credibility of the NDVI results, a multi-source validation approach was applied. The spatial distribution of vegetation patterns derived from NDVI maps was visually compared with high-resolution Google Earth imagery for recent years. This comparison confirmed a strong spatial agreement between dense vegetation areas identified in NDVI outputs and actual vegetation observed near water bodies and river zones, while areas classified as sparse vegetation and bare soil corresponded well with exposed land surfaces.

In addition, consistency between Landsat and Sentinel-derived NDVI results was observed, despite differences in spatial resolution. Both datasets show similar spatial patterns and temporal trends, particularly the concentration of vegetation along water sources and the dominance of sparse vegetation in surrounding areas.

Furthermore, the observed decline in NDVI values over time is coherent with climate-related indicators presented in climate change indicators assessment, including decreasing precipitation and reduced water availability. This agreement supports the reliability of the detected vegetation changes and confirms that the results reflect actual environmental conditions rather than processing artifacts.

Discussion

As it is critical to determine whether the ecosystem settings of each researched site have experienced temporal and spatial changes, one of the most crucial issues for developing applicable strategies is immediately establishing the coverage of environmental ecosystem changes.

A certain amount of carrying capacity exists at every natural habitat. Researchers can use the change detection map to identify high priority area and evaluate land cover change, for example (Chaplin & Brabyn, 2013) used Landsat photos as input materials and used RS and GIS to successfully depict changes in forest cover into anthropogenic impacts in Nepal's Annapurna Conservation Area. Also, various studies focused on entirely investigating environmental implications (Rutherford et al., 2015) based on the aforementioned situations (Geneletti & Dawa, 2009; Yang et al., 2012).

Therefore, the use of Landsat and Sentinel satellite images as raw materials in this study is a valuable approach to examine the status of ecosystem environments within the important historical-natural sites of the given area. This study provides new integrated evidence of long-term vegetation dynamics by combining Landsat NDVI (1977–2017), Sentinel-2 seasonal NDVI (2020–2021), and climate and hydrological indicators, which has not been jointly applied in previous studies of the Khinis archaeological landscape.

First, this study utilized Landsat satellite for vegetation cover over the Khinis area, which has a good resolution and spectral bands for tracking land use and documenting land change as a result of climate change, urbanization, drought, wildfire, biomass changes (carbon assessments) and variety other natural and human-caused changes. In order to assess the interesting area, Landsat is an optimal option to analyze the data over past years. The result is shown with a significant difference. Landsat satellite imagery captured between every ten years starting from 1977 to 2017 in the short rainy month of May are used to observe spatiotemporal changes in the vegetation area parameters.

Although Landsat is widely used in long-term vegetation studies, its spatial resolution (30 m) is considered medium and may not capture fine-scale vegetation or water body variations compared to higher-resolution sensors such as Sentinel-2 (10 m).

This dataset provides useful remotely sensed imagery that highlight changes in land cover and terrestrial ecosystems around the river caused by increase in climate change that occurred over the past four decades (Wulder et al., 2012).

Moreover, the highest value of vegetation cover was observed during 1987 and 1997, coinciding with a wet period at that time. While dry conditions were observed during the rest of the study period, NDVI values between 0.25 and 0.5 representing sparse (rare) vegetation—were mostly observed in 1977 and 2007, in contrast to 2017, where this class was hardly detected. In this study, NDVI values below 0.25 correspond to bare soil or desert conditions, while higher values indicate increasing vegetation density. Therefore, based on the statistical analysis, the whisker of the year 2017 determines that 90 % of the area is under desert vegetation in the buffer zone.

These vegetation changes are strongly consistent with regional climatic variability, particularly decreasing precipitation and increasing temperature trends, which directly influence soil moisture availability and plant growth conditions.

One of today's greatest difficulties is ensuring that land is used sustainably while satisfying the food and wood demands of a growing global population. Sentinel-2 delivers reliable data on plant health, allowing for more informed decisions. The study made use of additional product from Sentinel satellites in the winter, summer and plant growth season during 2020 and 2021. In discussions on land cover transformations, the normalized performance of the (NDVI) was demonstrated through Sentinel-2 program (Boccardo & Perez, 2009).

However, as we found that Iraq is facing this huge challenge due to climate change in land cover changing, this declining of green areas is due to changes in different weather indicators. For instance, the study calculated the amount of annual precipitation from the 1970s to 2014 in Kurdistan region. The result show that precipitation was around 900 millimeters in the beginning of 1970s yet in the end of the decade it has seen a serious fall to around 500 millimeters.

This declare that the amount of precipitation has incredibly dropped. No doubt, the quantity of rainfall over the period of 44 years has also seen a notable conversion. For example, between 1983 and 1985 there was a jumping ratio of precipitation. Whilst the driest year can be found in 1998 and 2008. In this case, the data proof the development over the past 40 years can be through human activity and climate changes.

However, this method shows that the impact of precipitation over the ecosystem is a crucial topic to be considered. Which brings us to understand that the dry soil, shallow streams, and municipal water problems can all come from a lack of precipitation. Furthermore, annual mean temperature is another example of weather feature. And it seems that in some point in 1982, 1988, 1994 and 1996 negative values of the temperature were found, especially in 2012 where the coldest degree of mean temperature was measured. At same time, the evapotranspiration took advantage of this situation as the measurement can obviously describe the amount of increasing of indicators over the spring and fall season for the past 15 years till 2014. Due to the un-recording the data after 2014 the study could not assess the current situation due to data limitations.

Moreover, after we calculated annual water equivalent, we found that the measurement of the annual minimum and maximum values of the fluctuation of water equivalent in Iraq during the 365 days over the past years saw a significant change caused mainly by the amount of deep water rather than by the external impact of environment. While in the end of the year the fluctuation of water equivalent increased again, but this might highly be due to the satellite sensor changing.

These coupled relationships between vegetation, precipitation, and hydrological storage indicate that ecosystem change in the Khinis area is not driven by a single factor, but rather by interconnected climate–hydrology interactions. Similar coupled responses between NDVI decline and hydrological stress have been reported in semi-arid regions worldwide (Scanlon et al., 2005).

This is one of the key reasons why elements of the water cycle are expected to speed up when global temperatures rise, raising worldwide evaporation rates. More evaporation, on average, leads in more precipitation. Higher evaporation and precipitation rates are already having an effect, and as the temperature warms this century, the effects are expected to worsen. Direct climatic influences, climate-induced changes in vegetation, plant development rates, rates of soil water extraction by plants, and the effect of rising CO2 levels on plant transpiration are all factors that affect soil moisture levels.

Despite these insights, several limitations should be acknowledged. The use of multi-sensor data introduces uncertainty due to differences in spatial resolution (Landsat vs Sentinel-2), and NDVI values are sensitive to seasonal timing and atmospheric conditions, which may affect inter-annual comparisons. In addition, the lack of long-term field validation data limits direct ground-truth confirmation of satellite-derived vegetation trends.

All these facts show us how it is essential to assess the effect of an eco-environment over the land cover change as well as the landscape. And it is very clear how the landscape changed in the Khinis area, serious actions should be taken to protect this area in order to provide us the fresh air and water, healthy soil and food as well as medicine from the wild. Therefore, it is advised to develop a basic database about the area's natural resources (such as soils, water, and vegetative cover), to classify the area on hydro morphologic bases, and to create maps to classify the soils in the area to estimate the capability for plantation and growth.

From a development standpoint, the main goal of assessing and managing the Khinis area is to maintain a balanced relationship between human needs and environmental conservation (Lyon et al., 2011; McCarthy et al., 2004) as well as between the ecological environment’s carrying capacity and the long-term demands of landscape development.

Many studies have found that anthropogenic activities and the construction of artificial facilities have negatively impacted the environment (Arrowsmith & Inbakaran, 2002), reduced the value of natural resources (Buultjens et al., 2005), and caused broader ecosystem degradation (Smith & Newsome, 2002). In Iraq, the role in mitigating such impacts is still limited.

Especially, for the case of a heritage site, it is suggest creating a management structure for educating and increasing awareness of local citizens to design programs to protect these valuable reliefs and land from natural and human events through collaborative efforts between the people and the government to address the damaging problem.

Conclusions and recommendation

Local livelihoods can be strengthened through the sustainable management of natural areas in collaboration with local communities and conservation initiatives. Promoting awareness and appropriate livelihood decisions can help local populations protect vegetation and landscape resources while maintaining their traditional values.

This study demonstrates that the Khinis area has experienced significant spatiotemporal changes in vegetation cover over time, as shown through NDVI analysis using Landsat and Sentinel datasets. The results indicate a clear decline in vegetation density in recent years, reflecting ongoing environmental stress and land degradation processes.

Satellite NDVI results and accompanying statistics show that the region's vegetation is heavily affected by climatic variations, specifically precipitation and the availability of water. These findings reveal a close correlation between vegetation cover, seasonal change, and climate change in this area of the world. They further demonstrate the importance of environmental management and preservation for human development.

Thus, it is suggested that the responsible authorities create environmental management systems with the participation of the government, environmental organizations, the tourism sector, and local communities. It is also recommended that a remote sensing-based monitoring system be established to provide early warning of environmental change.

Environmental management should be implemented to improve vegetation restoration in buffer zones, afforestation, sustainable use and maintenance of water resources, control of activities around the archaeological site, and ecological management planning. In the meantime, the responsible management authority must plan environmental education, green management, plant protection, vegetation conservation and restoration for the buffer zone in order to increase environmental sustainability and tourism and to ensure cultural heritage management is also achieved.

For the future, it is suggested that further study can be conducted using other ecological indicators and by collecting more accurate remote sensing data, or by conducting field studies to obtain more detailed data for analysis on the vegetation-climate relationship and climate change in the archaeological site.

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Declaration of competing interests

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

Data availability

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Use of generative AI and AI-assisted technologies

Generative AI tools were used only for language editing and grammar improvement. The authors reviewed and approved all final content.

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