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A comprehensive Landsat 8 NDVI and NDBI data preparation for the vegetation trend analysis in Iran

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Abstract

Ensuring the availability of accurate and consistent datasets is crucial for reliable vegetation monitoring and trend analysis. While many studies in the Islamic Republic of Iran concentrate on vegetation change detection using data from satellites with coarse spatial resolutions, such as MODIS (Moderate Resolution Imaging Spectroradiometer), there is a noticeable gap in the literature regarding suitable datasets for moderate satellite image resolution like Landsat 8 (OLI). These datasets offer unique capacity and challenges that warrant specific attention in the development of change detection methods. This study addresses this gap by presenting a Landsat 8 dataset of Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-up Index (NDBI) covering the years 2013-2023. To compile this dataset, we downloaded 880 Landsat 8 scenes for Iran, with the majority (84%) acquired in August. Of the 880 Landsat 8 scenes, 461 had zero cloud cover, accounting for 52.3% of all scenes analyzed in the study. Although this study did not directly undertake a vegetation trend analysis, it provides valuable insights into the challenges and considerations necessary for vegetation trend analyses in Iran. Future research could explore the impact of pixel size on vegetation trend analysis by comparing datasets from different sources, including Landsat 8, to further enhance our understanding of vegetation dynamics in Iran.

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Introduction

Identifying and describing land use/cove alterations over time represents the initial instinctive action in pinpointing the catalyst behind such transformations and understanding the process of change. Satellite remote sensing has historically served as an effective tool for detecting and categorizing alterations in the state of the Earth's surface across time periods (Verbesselt et al., 2010). Continuous Earth Observation time series provide valuable insights into the fluctuations of vegetation over time, spanning from regional to global scales. Understanding vegetation trends through change analysis is crucial for various reasons. Firstly, vegetation trends serve as vital indicators of environmental changes over time, facilitating the assessment of ecosystem health, degradation, or improvement, and identifying areas susceptible to issues like desertification or deforestation (Higginbottom and Symeonakis, 2014; Yengoh et al., 2015). Secondly, vegetation trends provide insights into how ecosystems respond to climate change, including shifts in vegetation types, phenology, and productivity, contributing to climate change studies (Adole et al., 2016; Eastman et al., 2013; Zeng et al., 2020). Thirdly, changes in vegetation cover and composition directly impact biodiversity, and monitoring vegetation trends aids in identifying habitat loss or fragmentation, invasive species encroachment, and guiding conservation efforts (da Silva et al., 2021; Turner et al., 2013).

Normalized Difference Vegetation Index (NDVI) plays an important role in vegetation trend analysis. As a widely used measure of vegetation greenness and health, NDVI serves as the foundation for assessing vegetation dynamics over time (Li et al., 2021). By quantifying the difference between near-infrared and visible light reflected by vegetation, NDVI provides valuable insights into changes in vegetation cover, density, and productivity (Forkel et al., 2013). Thus, NDVI plays a fundamental role in vegetation trend analysis, providing essential information for understanding and managing the dynamics of terrestrial ecosystems (Rahimi et al., 2022). The number of NDVI papers indexed in the Web of Science Core Collection saw a significant increase over the decades, with 795 papers in the 1990s, 3361 papers in the 2000s, and a substantial rise to 12,618 papers in the 2010s (Huang et al., 2021).

Vegetation trend analysis, and various global coverage products derived from Advanced Very High Resolution Radiometer (AVHRR) data have been instrumental in numerous studies focusing on vegetation at different spatial scales (Beck et al., 2011). However, the AVHRR sensor design is widely recognized to have limitations for vegetation monitoring due to its original design not being intended for this specific purpose (Fensholt et al., 2009). In Iran, Khormizi et al. (2023) utilized the daily NDVI product from the AVHRR sensor, known as AVH13C1 with a spatial resolution of 0.05 x 0.05 degrees, for a vegetation trend analysis between 1982 and 2019. Indeed, the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor has also been extensively utilized for vegetation analysis. Its moderate spatial resolution, frequent revisit times, and multispectral capabilities make MODIS an invaluable tool for monitoring vegetation dynamics on a global scale. For example, an 11-year time series analysis of MODIS 16-day composite NDVI data demonstrated its adequacy in deriving statistically significant trend values for approximately 50% of Mongolia's surface (Eckert et al., 2015). Eisfelder et al. (2023) also introduced the novel TIMELINE NDVI product, which offers a consistent collection of daily, 10-day, and monthly NDVI composites at a spatial resolution of 1 km. The dataset is derived from AVHRR data and covers Europe and North Africa, spanning from 1981 to 2018.

Recent studies in Iran have also focused on utilizing MODIS products for vegetation trend analysis. For example, the trend of vegetation dynamics in Kermanshah City was assessed using the NDVI MOD13Q1 product over the period from 2000 to 2017 (Najafi et al., 2019). Gholamnia et al. (2019) utilized a time series of NDVI data spanning from 2000 to 2016, derived from MODIS, for the Semi-Arid Region of Kurdistan. In another study, vegetation trend analysis throughout Iran was conducted using two decades' worth of MODIS NDVI datasets (MOD13Q1) with 250m resolution spanning from 2000 to 2020 (Ghorbanian et al., 2022). Firoozi et al. (2020) also utilized NDVI products from the Terra Satellite MODIS sensor (MOD13A3) with a spatial resolution of 1x1 km and covered a 15-year statistical period from 2000 to 2014. The study aimed to analyze changes in vegetation trends at a pixel-based scale during April, May, and June in the Sistan Plain, located in eastern Iran.

However, the estimation of trends relies on several factors, including the length of the time series, its temporal and spatial resolution, the quality of the measured data, and the statistical method employed (Forkel et al., 2013). Ensuring the availability of accurate and consistent datasets is a fundamental principle to guaranty reliable results for vegetation monitoring and trend analysis (Huang et al., 2021; Verbesselt et al., 2010). While many studies in Iran focus on vegetation change detection based on coarse spatial resolutions from satellites like MODIS, there is a notable gap in the literature regarding suitable datasets for moderate satellite image resolution like Landsat (MSS, TM, OLI) that can offer unique capabilities and challenges that warrant specific attention in the development of change detection methods (Banskota et al., 2014; ED Chaves et al., 2020; Hemati et al., 2021). For example, Fensholt et al. (2009) evaluated the accuracy of GIMMS (Global Inventory Modelling and Mapping Studies) NDVI time series trend analysis by comparing it with the 1 km resolution Terra MODIS (MOD13A2) 16-day composite NDVI data, the SPOT Vegetation (VGT) 10-day composite (S10) NDVI data, and in-situ measurements from a test site in Dahra, Senegal. The comparison reveals that the three datasets exhibit different patterns of NDVI trends.

Recent studies have tried to provide datasets with better spatial resolution, such as Landsat data, for vegetation trend analysis. For example, Zhao et al. (2023) presented a Landsat 30-meter/15-day Fraction of Vegetation Cover (FVC) dataset across China. Fassnacht et al. (2019) offered vegetation trend datasets covering the entire Tibetan Plateau with a spatial resolution of 30 meters for the timeframe spanning from 1990 to 2018. This trend served as the driving force behind the development of a Landsat-based vegetation trend dataset covering the entire Iran with a pixel size of 30 meters and spanning a decade (2013-2023). In addition to NDVI, we also present a dataset for the Normalized Difference Built-up Index (NDBI), which is useful in assessing urbanization and land development trends (Rahimi et al., 2021). NDBI is calculated using near-infrared and shortwave infrared bands and is particularly sensitive to built-up areas and impervious surfaces (Kshetri, 2018). By incorporating NDBI into our dataset, we aimed to provide researchers and policymakers with a more holistic view of land cover dynamics, facilitating informed decision-making and sustainable development practices. Our dataset holds significant value for analyzing vegetation trends at both regional and local levels. Moreover, it can find applications in diverse fields of research such as wildlife ecology, and climatology.

Methods

Study area

Approximately 81% of Iran's land area is occupied by diverse natural features, comprising forests, deserts, rangelands, and bushes. Notably, rangelands cover nearly half of the country's land area, with a significant portion categorized as poor quality. Deserts encompass about 20% of Iran's territory, mainly located in the central, eastern, and southeastern regions, primarily within the Irano-Turanian ecological region (Talebi et al., 2014).

Landsat 8 dataset

Figure 1 shows the location of Iran and the paths and rows of the Landsat satellite. In this study, we considered 80 Landsat scenes for the whole of Iran, for the years 2013 to

2023, comprising 880 Landsat scenes for the whole period. To download this collection, we used https://earthexplorer.usgs.gov/ and in the search criteria section, we selected the cloud percentage of zero percent and considered August as the desired month. August was considered desirable as it marks the peak growing season in Iran. Also, August typically experiences minimal cloud cover compared to other months, particularly during the summer season, reducing the likelihood of data obstruction or interference from clouds and ensuring clearer satellite imagery for analysis.

Next, we chose Landsat Collection 2 level 2 and among the available satellites, we selected Landsat 8 satellite (OLI/TIRS). The Level-2 Surface Product (L2SP) comprises Surface Reflectance (SR), Surface Temperature (ST), ST intermediate bands, an angle coefficients file, and Quality Assessment (QA) Bands. It is generated by applying corrections for atmospheric effects to a Level-1 Systematic Terrain (Corrected) (L1GT) or Level-1 Precision Terrain (Corrected) (L1TP) product (Landsat, 2020). The image data in Level-2 Surface Product (L2SP) are atmospherically corrected (Landsat, 2020).Then, for each path and row per each year, we visually checked the list of available images. Although we tried to download all the images in August, in some years or routes, there were no images available for this month, or they were covered by clouds, so we decided to download the images in July instead. The priority was to download images with 0% cloud cover; however, we were forced to download images with cloud cover for some northern regions of Iran.

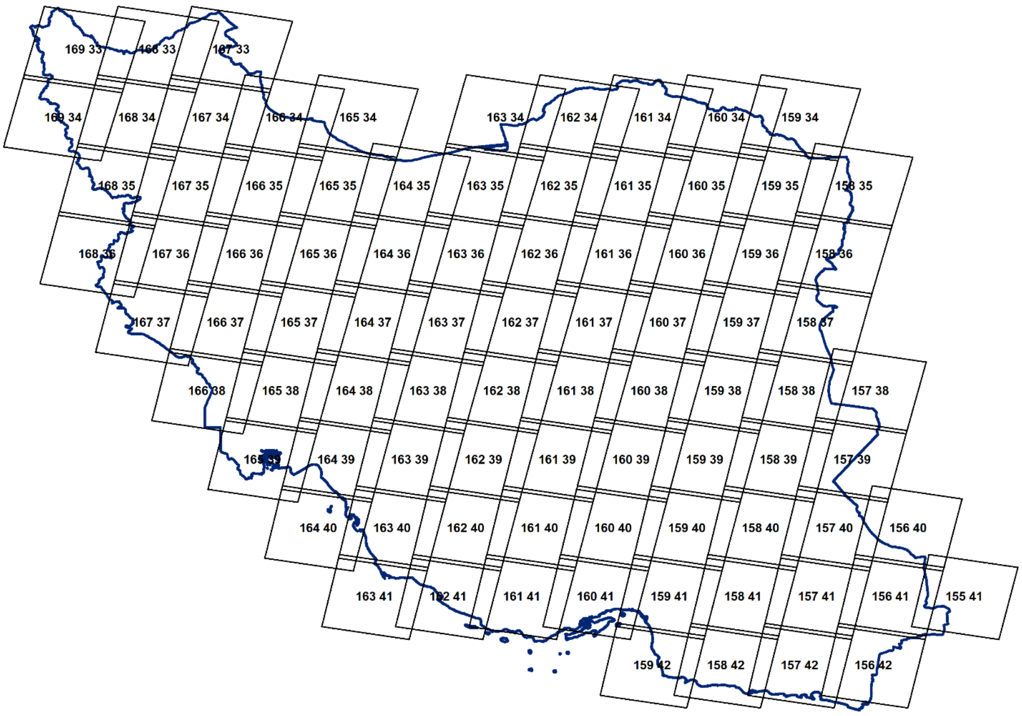

Figure 1. Location of Iran and Landsat path/row

NDVI calculation

In Landsat 8 imagery, the Near-Infrared (NIR) band is typically represented by Band 5, and the Red band is represented by Band 4. Therefore, in Landsat 8 data, the bands used for calculating NDVI are Band 5 for NIR and Band 4 for Red based on equation 1. The Normalized Difference Vegetation Index (NDVI) values range between -1 and 1. Negative NDVI values, close to -1, typically correspond to water bodies. Values close to zero (-0.1 to 0.1) generally indicate areas covered with barren rock, sand, or snow. Low positive NDVI values

(0.2-0.4) are associated with areas covered with shrubs and grassland, while higher values indicate denser vegetation (Guha et al., 2021).

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

NDBI calculation

Built-up areas and bare soil tend to reflect more Shortwave Infrared (SWIR) radiation than Near-Infrared (NIR) radiation (Kshetri, 2018). The Normalized Difference Built-up Index (NDBI) is another graphical indicator commonly utilized for measuring urban areas, particularly built-up areas or artificial structures. It is calculated using two bands, typically the Shortwave Infrared (SWIR) and Infrared (IR) bands. Similar to NDVI and other indices, the NDBI ranges from -1 to +1. A positive value on the NDBI scale indicates the presence of artificial structures or built-up areas, while a lower value suggests the availability of natural or physical features (Guha et al., 2021). A positive NDBI value indicates an increase in the built-up area. Specifically, NDBI values ranging between 0.1 and 0.3 are indicative of built-up areas, while values exceeding 0.25 represent bare lands (Chatterjee and Majumdar, 2022). We calculated NDBI using equation 2.

$$NDBI = \frac{SWIR - RED}{SWIR + RED}$$

Results

Landsat 8 monthly data distribution

Figure 1 illustrates the monthly distribution of Landsat data across different months. According to the data presented in 1a, out of a total of 880 scenes, the majority, 740 scenes (84%), were acquired in the month of August. This indicates a pronounced concentration of Landsat data acquisition during August compared to the other months. The distribution further reveals that July and June follow with 79 and 45 scenes, respectively, representing a notable decrease compared to August. September is represented by 15 scenes, indicating a further decline in data acquisition compared to the preceding months. Lastly, May shows the least amount of data acquisition with only 1 scene recorded. Figure 1b illustrates the distribution of Landsat data per day of the year, providing a more granular view of data acquisition trends. The data reveals that the majority of data downloads occurred between the 213th and 244th days of the year, which corresponds to the period from late July to late August. This timeframe notably represents the month of August, aligning with the findings from Figure 1a, which indicated a significant concentration of Landsat data acquisition during this month. Figure 1c presents a bar chart depicting the distribution of Landsat data per day of the year, offering an alternative visual representation of the data distribution across different time periods.

Figure 3 presents various graphs illustrating the cloud cover percentage of Landsat 8 datasets analyzed in this study. According to Figure 3a, the majority of Landsat scenes exhibit less than 5 percent cloud cover, although a few scenes have a higher percentage. In Figure 3b, the average cloud cover percentage per year is depicted, revealing that in the years 2017, 2019, and 2022, Landsat data exhibited the minimum cloud cover, whereas 2021 had the maximum. Notably, each year's average cloud cover per scene remains below 0.5 percent, indicating generally low cloud cover across all years. Figure 3c focuses on the number of scenes with zero cloud cover per year, showing that 461 out of 880 Landsat scenes had zero cloud cover, accounting for 52.3% of all scenes analyzed in the study. These findings provide valuable insights into the cloud cover characteristics of Landsat 8 datasets used in the study, highlighting both the overall low cloud cover percentages and the variability across different years.

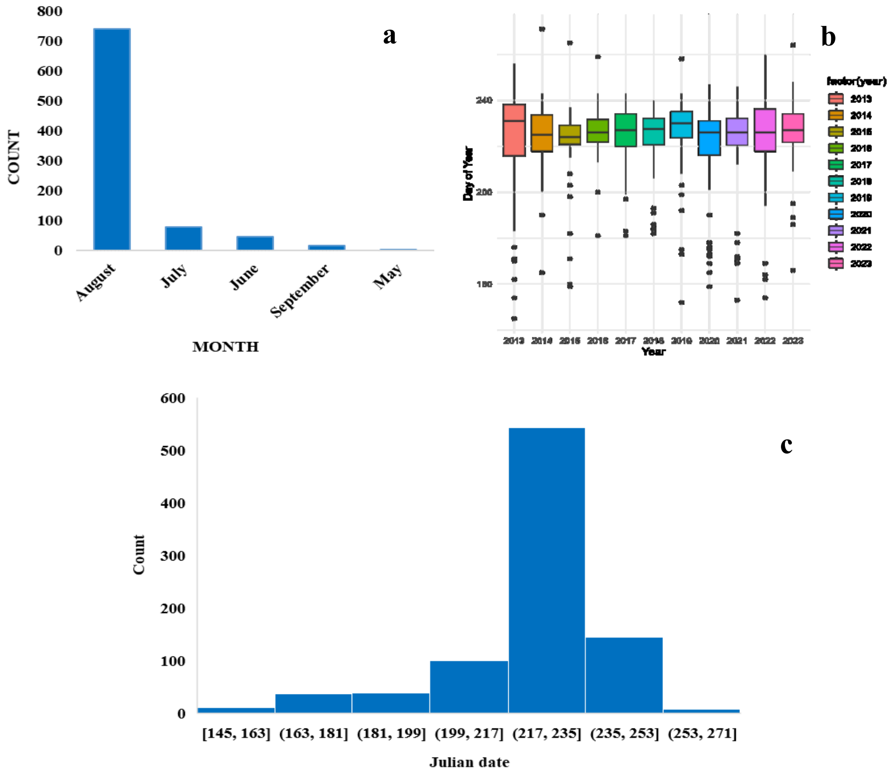

Figure 2. Monthly distribution of downloaded Landsat 8 scenes. (a), number of Landsat scene per month (b), box plot of monthly distribution of Landsat scene in day of year, and (c) number of Landsat scene in day of year

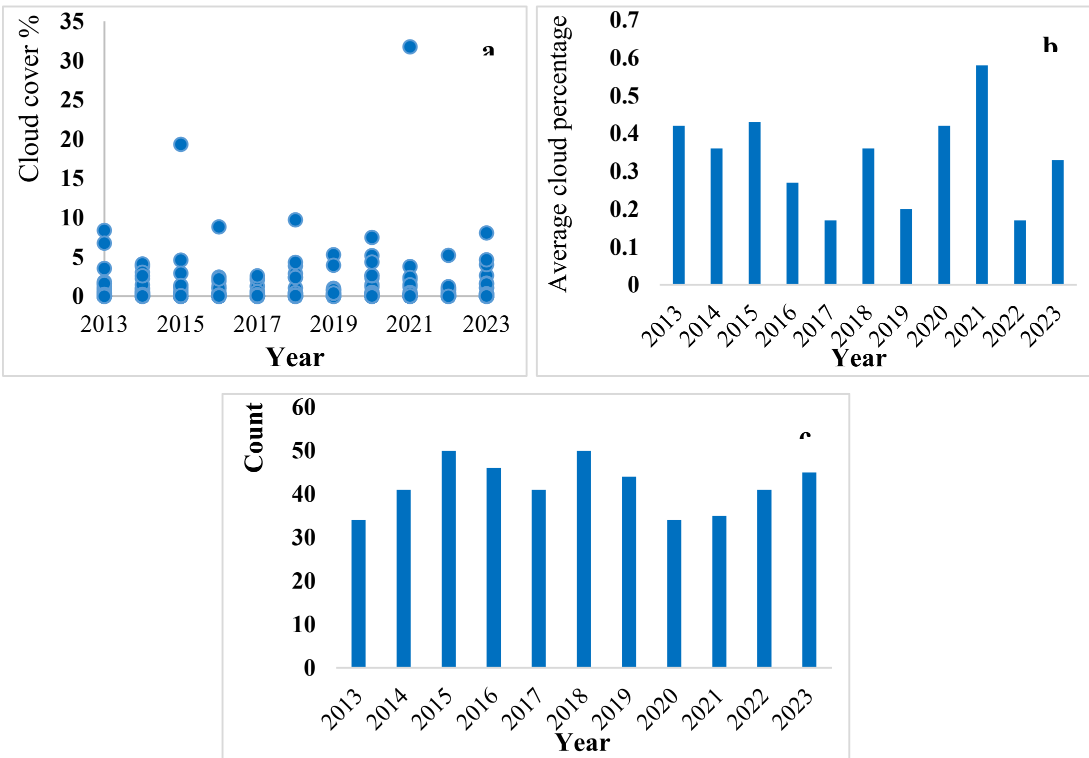

Figure 3. Cloud cover percentage of downloaded Landsat 8 scenes. (a), scatter plot of Landsat scene per year (b), bar graph of average cloud percentage per year, and (c) bar graph of number of scenes with cloud coverage of zero per year.

Figure 4 illustrates examples of NDVI and NDBI indices generated for Iran. Subfigure (a) represents NDVI in 2013, while (b) depicts NDVI in 2023. Subfigure (c) displays NDBI in 2013, and (d) presents NDBI in 2023. In NDVI images, lighter colors indicate vegetation cover, while darker colors indicate non-vegetated areas. Notably, the northern forests of Iran exhibit the highest NDVI values. Conversely, in NDBI images, lighter colors denote non-vegetated areas, whereas darker colors signify vegetated regions.

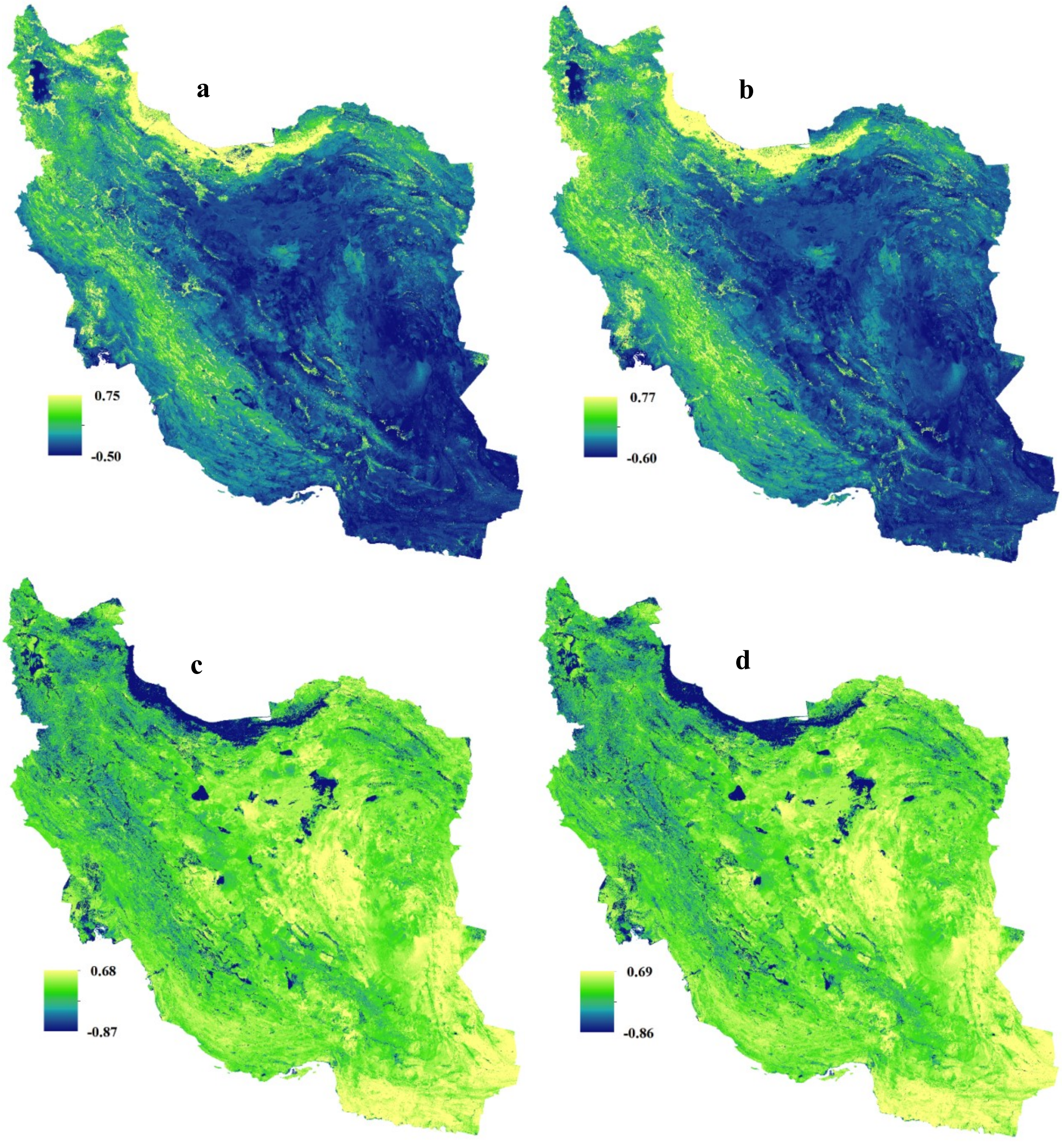

Figure. 4. Examples of NDVI and NDBI indices created for Iran. (a), NDVI in 2013 (b), NDVI in 2023, and (c) NDBI in 2013, and (d) NDBI in 2023.

Discussion

Regarding the limited availability of comprehensive Landsat satellite data with a 30-meter resolution for conducting vegetation studies in Iran, this research aimed to compile such a dataset spanning a decade. Compiling satellite data for vast countries like Iran presents challenges; for instance, it was impractical to gather all data on a single specified day and month, necessitating data collection from various months. Another issue pertained to cloud cover in satellite imagery, which significantly affected this study. The northern regions, characterized by forest cover and high humidity, were particularly impacted by cloud cover, whereas the central, eastern, southern, and western parts, known for their dry and semi-arid climates, allowed for the extraction of cloud-free images. Data analysis also revealed that the majority of the dataset had minimal cloud cover, with over half of it exhibiting 0% cloud cover.

Nevertheless, satellite images are often affected by contamination resulting from atmospheric conditions, cloud cover, and limitations in sensor capabilities. Hence, it is essential to preprocess NDVI time series data by applying smoothing techniques before utilizing them in applications (Li et al., 2021). Therefore, it is commonly understood that satellite images typically require atmospheric corrections. Despite using Landsat Collection 2, level 2 data, which inherently incorporates atmospheric corrections (Landsat, 2020), it is advisable to verify the process post-graph preparation. Users are recommended to apply filters such as Savitzky-Golay (SG) (Chen et al., 2021) to yield more reliable outcomes on NDVI trend graphs or other methods as reviewed by Li et al. (2021). Additionally, it is suggested that users take into account the provided information regarding cloud cover for each scene as supplementary material. This allows for targeted studies in regions of Iran with minimal cloud cover, enabling a more localized and regional focus based on the conducted analyses.

To date, at the national level, Ghorbanian et al. (2022) have conducted a comprehensive study utilizing a two-decade dataset (2000 to 2020) of MODIS NDVI datasets (MOD13Q1) for vegetation trend analysis in Iran. The per-pixel annual NDVI dataset was generated through the Google Earth Engine (GEE) platform, aggregating all available NDVI values within the growing season. This dataset was then subjected to the PolyTrend algorithm to discern linear and non-linear trends. The analysis encompassed nearly 14 million pixels, representing 44% of Iran's land area. Findings revealed a predominant increase in greenery compared to decline across the country. Linear trends were the most prevalent (14%), followed by concealed (11%), cubic (8%), and quadratic (2%) trends. Approximately 9% of the vegetation area exhibited no discernible trend and remained stable. Consequently, our dataset presents an opportunity to compare previous studies with the new study based on Landsat 8 data to elucidate the impact of pixel size on vegetation trend analysis. Undertaking a vegetation trend analysis, as described, was beyond the scope of our research. Moreover, utilizing Landsat dataset reveals that Iran comprises approximately 3,500,000,000 pixels, presenting a significant challenge for conducting a comprehensive trend analysis covering the entire country.

Our analysis of Landsat data distribution and cloud cover characteristics provides valuable insights into the availability and quality of datasets used in our study. The pronounced concentration of Landsat data acquisition in August, as indicated by the majority of scenes acquired during this month, underscores the importance of considering temporal biases in satellite imagery-based studies. Additionally, the consistently low cloud cover percentages across all years, with over half of the scenes exhibiting zero cloud cover, affirm the suitability of Landsat 8 datasets for our research purposes. These findings highlight the need for researchers to carefully assess and account for temporal and spatial variations in satellite data when conducting analyses, particularly in regions with distinct seasonal patterns like Iran. Understanding these nuances is crucial for ensuring the accuracy and reliability of results derived from remote sensing data. Moving forward, continued efforts to monitor and mitigate potential biases in satellite datasets will enhance the robustness of vegetation trend analyses and other applications reliant on remote sensing data.

Conclusion

In conclusion, this study aimed to address the challenge of limited Landsat satellite data availability with a 30-meter resolution for vegetation studies in Iran by compiling a decade-long dataset. The process of compiling satellite data for a vast country like Iran posed challenges due to the impracticality of gathering data on a single specified day and month, necessitating data collection from various months. Cloud cover in satellite imagery also posed a significant obstacle, particularly in northern regions with forest cover and high humidity, while other regions with dry and semi-arid climates allowed for the extraction of cloud-free images. To address issues of atmospheric contamination and cloud cover, preprocessing NDVI time series data with smoothing techniques before utilization in applications is recommended. Additionally, users are encouraged to consider supplementary information regarding cloud cover for each scene, facilitating targeted studies in regions of Iran with minimal cloud cover and enabling a more localized and regional focus based on conducted analyses. While this study did not directly undertake a vegetation trend analysis, it provides valuable insights into the challenges and considerations necessary for such analyses in Iran, particularly with the vast number of pixels present in Landsat datasets. Future research could explore the impact of pixel size on vegetation trend analysis by comparing datasets from different sources, such as Landsat 8, to further advance our understanding of vegetation dynamics in Iran.

Data Availability Statement: Data are available at https://doi.org/ 10.5061/ dryad.xpnvx0kqt. If you encounter any difficulties accessing the data, feel free to reach out for assistance at ehsanrahimi666@gmail.com.

MTL text files for each Landsat scene per year are available at https://github.com/ ehsanrahimi666/Landsat8-MTL.git

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Conflicts of Interest: “The authors declare no conflicts of interest.”

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