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Original Research Paper

Analysis of Vegetation Cover Dynamics Under Drought Stress Using Satellite Images: Case Study: Panjab City-Afghanistan

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ABSTRACT

This study analysis of vegetation cover changes using Landsat imagery and the Normalized Difference Vegetation Index (NDVI) across different value thresholds. The analysis spans an eight year period between 2015 and 2023 and is based on two Landsat scenes acquired in June and July. First, cloud free and noise free images from the Landsat-8 Operational Land Imager (OLI) were selected. Second, image correction procedures and the performance of a pan-sharpening approach were evaluated to generate a high quality vegetation map. A statistical pan-sharpening algorithm was applied to enhance the spatial resolution of Landsat-8 multispectral bands from 30 m to 15 m. Third, methods for extracting vegetation characteristics from remote sensing data using NDVI were described. Finally, the results were analyzed and interpreted. The findings indicate that drought has strongly influenced vegetation cover in the study area. In June 2015, vegetation corresponding to NDVI thresholds of 0.48–0.65, 0.65–1, and 0.48–1 covered 4.378%, 1.44%, and 5.81% of Panjab City, respectively. By June 2023, these values declined to 3.36%, 1.12%, and 4.48%, representing reductions of 1.01%, 0.32%, and 1.33%. Similarly, in July 2015, vegetation cover within the same threshold ranges accounted for 3.47%, 1.87%, and 5.34%. In July 2023, coverage decreased to 2.80%, 0.86%, and 3.66%, with corresponding changes of 0.67%, 1.01%, and 1.68%. Overall, the NDVI-based analysis demonstrates a clear and direct relationship between drought conditions, reduced rainfall, and vegetation decline. The applied methodology is efficient and can be readily extended to other regions for vegetation mapping, monitoring, and assessment at regional planning scales.

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1 INTRODUCTION

Vegetation has become an important topic of interest to scientists and researchers based on the important role it plays in vital interconnected systems on Earth, one of the important functions of vegetation is soil stabilization and enrichment [1]. Degradation of vegetation and reduction of biodiversity causes wider environmental and ecological problems, such as destruction of topsoil, increase in temperature, air pollution and reduction of food resources for humans and wildlife [2]. In addition, it has an irreplaceable function in regulating the global carbon balance and maintaining global climate stability [3]. As an important issue in global change, the response of vegetation growth to climate change has attracted much attention. Because estimating carbon absorption on continental scales has become an urgent necessity for countries. The pattern of vegetation change in response to global change is still a controversial issue and a matter of differing opinions. Vegetation is the dominant component of terrestrial ecosystems, which plays an important and vital role in the cycle of global resources and energy [4].

Using the reaction and phenological response of vegetation as an indicator of climate change is due to the response and fluctuations of vegetation to climate variables [5]. For example, there is growing evidence linking phenological changes and fluctuations in vegetation cover, particularly early flowering in Europe and North America, to warmer temperatures over the past 30 years [6]. Another fundamental and important reason is that changes in vegetation phenology have a significant effect on the survival and persistence of species whose behavioral patterns are intricately coordinated with it [7]. Like pollinators [8] and bird species whose reproductive position depends on the timing of their reproductive cycle. This timing can be attributed to factors such as: temperature, environmental conditions, geographical location, etc. [9]. Observation and field measurements of vegetation phenology is a simple and intensive task. Therefore, it is reasonable to turn to earth observation satellite platforms for phenological measurements using remote sensing devices and tools. The most well-known example is the use of the normalized difference vegetation index NDVI, which is obtained by measuring the optical reflectance of sunlight in red and near-infrared wavelengths [10], [11].

NDVI is one of the most widely used and practical VIs, which is based on the difference in the reflectance of the near-infrared and red bands [12]. It has two major advantages: (1) It has a strong relationship with vegetation and the fraction of photo synthetically active radiation absorbed by vegetation [13], and (2) It is more sensitive to low vegetation than dense vegetation [12].

There are more than a hundred vegetation indices obtained from multispectral images and each of them can be used according to research objectives [14]. The index algorithm, which is based on remote sensing, includes several bands and can describe them [15]. Vegetation indices are widely used to estimate vegetation density from satellite and aerial images [16], [17]. It is commonly used to perform vegetation dynamics, which is an important research topic [18], [19]. NDVI is widely used to investigate the relationship between spectral variability and vegetation cover. Changes in the reflectance of surface materials across different spectral bands provide a fundamental mechanism for understanding features in remote sensing [20]. NDVI is a best indicator for identifying long-term changes in vegetation cover and its condition. Changes in vegetation cover are the main cause of changes in land surface temperature, which is related to vegetation density [21] and it is only the first remote sensing investigative production used to analyze the complexities of multispectral imagery [14]. The Vegetation Index incorporates the benefit of satellite-based remote sensing to detect rapid changes in vegetation cover in terms of phases [21], This index estimates photosynthetic activity with a combination of the red (R) and Near-Infrared (NIR) bands, which are generally conditioned by the presence of chlorophyll [22].The NDVI Index is essential in the study of vegetation phenology, dynamic monitoring and global changes [23], [24]. It is now the most popular index used to evaluate

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vegetation cover. This widespread use and popularity are due to the way NDVI is calculated with any multispectral sensor in the visible and near-IR bands [14]. Vegetation mapping through remote sensing images involves various considerations, processes and techniques [25]. However, the resolution of satellite remote sensing images is such as the image details (pixels) usually represent several land covers .In addition, remote sensing instruments sense electromagnetic energy moving through the atmosphere. Therefore, the seasonality of vegetation index measurements over time may reflect trends in changes in land cover and visibility limitations (such as changes in water vapor and airborne particulate matter) as well as actual phenological responses. As a Consequence, more precisely, such studies of NDVI seasonality trends have shown that NDVI is very impressionable to ecological community conditions [26],especially when combined with maximum values to reduce the effects of atmospheric pollutants, such as vapors, clouds and aerosols are coupled [27]. Therefore, it has a significant value as an indicator of environmental changes [28]. Recent studies have demonstrated the usefulness of terrestrial water storage data for drought monitoring and environmental assessment in water-limited regions [29], The integration of satellite observations with climatic variables has also improved the understanding of environmental dynamics and ecosystem responses to changing environmental conditions [30].

Punjab is one of the southwestern cities of Bamyan province, where no study has been conducted on vegetation or vegetation changes in this region. Therefore, understanding vegetation changes in this region, where rainfall has decreased significantly in recent years, is a fundamental need. In this paper, we focus on investigating vegetation changes, estimating vegetation increase and decrease by statistical analysis of NDVI from the Landsat-8 satellite sensor. This research, using the Landsat-8 sensor with a spatial resolution of 30 meters and a time return period of 16 days, investigates the vegetation of the study area. In this regard, Landsat-8 satellite data were prepared for analysis after performing the necessary preprocessing and correction steps. Then, using the NDVI index and statistical methods, the vegetation of the region was extracted and its change trend and the impact of drought on vegetation were investigated.

2 MATERIALS AND METHOD

2.1 Study Area

Panjab is one of the 8 cities of Bamyan province of Afghanistan and according to the population census of 2011, the population of this city is 66300 people and it has an area of 1891 square kilometers (km^2). Panjab is at 2,700 meters above sea level, it has the highest altitude in the Bamyan province, the city of Panjab is located 298 km from the capital of Afghanistan Kabul city. The name of Panjab is derived from the confluence of the Ghorghori, Tagab Bargh, Narges, Mehr and Terps rivers, which unite in this area to form the five-water sea. Panjab is located between 34˚ 20' 00" and 34˚ 37' 00" N, and 66˚ 31' 30" and 66˚ 40' 00"E. Kabul-Daikundi, Bamyan-Daikundi, Bamyan-Ghor roads pass through this city. This city is bordered from the east by part of Behsud city of Maidan Wardak province, and a part of Yakavlang city of Bamyan province, from the west with Ashtarlay city of Daikundi province, and Waras city of Bamyan province, from the north with Yakavlang city of Bamyan province, and Lal Sarjangal city of Ghor province and from the south side is on the same border with Waras city of Bamyan province and the secondpart of Behsud city of Maidan Wardak province. According to the classification of the World Meteorological Organization (WMO), Panjab includes a humid continental climate with cool Summers and cold and snowy Winters due to its high altitude. Its annual rainfall is 305 mm on average. The summer of this region passes without any precipitation, while April is the wettest month of the year with 77 mm of precipitation. Panjab city is a good place for livestock with its grasslands and high mountains covered with plants.

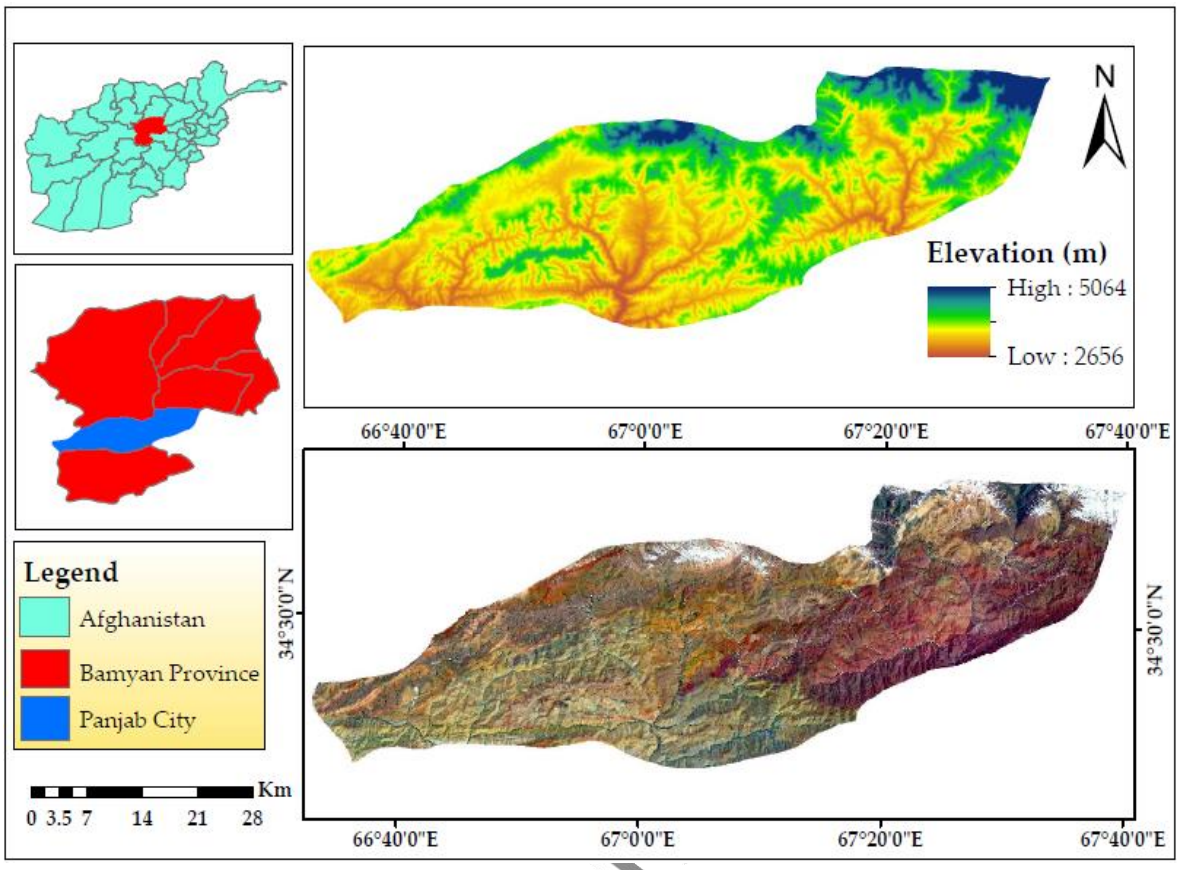

Figure 1. The location of Panjab city in Bamyan province of Afghanistan showing the study area.

2.2 Landsat images

A remote sensing sensor is a key device that records data about an object or scene remotely [25]. Data from multispectral satellite sensors Landsat are useful sources of remote sensing data [31], which has provided images for more than 40 years and continues. This is in favor of long-term research [32]. Landsat data have been used to investigate how the Earth's surface has changed for decades because of its long history and relatively high spatial resolution [33]. Currently, remote sensing change detection methods use remote sensing images at two different times [34]. In this study, the Landsat remote sensing data set was obtained from the United States Geological Survey (USGS), Panjab city. The detailed description of different types of Landsat images along with their acquisition time and resolution are shown in Table 1. In general, four types of images were acquired from the Operational Land Imager (OLI) multispectral scanner system sensor, from USGS, where Path 154 and Row 36 pass through Panjab. Images from different periods, for example, 2015 and 2023, were retrieved. Which act as an objective representation of spatial usage patterns in the respective times [35]. The time of acquisition was in June and July, when spring crops are usually the most intense.

Article

Table 1. Image data summary of Landsat satellite imagery used in the study.

2015				2023			
Path/Row	Date	Satellite/Sensor	Resolution(m)	Path/Row	Date	Satellite/Sensor	Resolution(m)
154/36	12/6/2015	Landsat-8/OLI	30	154/36	2/6/2023	Landsat-8/OLI	30
154/36	14/7/2015	Landsat-8/OLI	30	154/36	20/7/2023	Landsat-8/OLI	30

2.3 Method

2.3.1 Preprocessing

Pre-processing of satellite images is required to avoid data distortion or manipulation and to establish direct correlation between data and biophysical phenomena [36]. Correction methods are applied to remove noise in satellite images. With the advancement of spectroscopic imaging systems, the correction of atmospheric effects has been continuously improved [37]. Atmospheric correction, and radiometric [38], [39], were used to remove noise to reduce the effects of cloud cover and cloud shadow.

2.3.2 Pan-sharpening

High-resolution remote sensing images contain sufficient target detail and dynamically provide global observation data for many military and civilian applications (e.g., aeronautics, astronautics [40], threat monitoring [41], and military reconnaissance) [40]. Pan-sharpening is an impressive method to combine a low spatial resolution multispectral image with a higher resolution panchromatic image to obtain an image with high spectral and spatial resolution and rich spectral information [42]. To perform a spatial transformation in which the spatial element and the spectral element are separated into separate components in multispectral images with low spatial resolution. After that, the resulting spatial part of the panchromatic images is injected into the original multispectral images to produce enhanced multispectral images. Based on this idea, several related research studies have been presented. For example, [43]. Based on the image fusion Strategy, A general and comprehensive solution that is capable of modeling any established Component Substitution(CS) image fusion method is presented. According to this Strategy, an expanded intensity component is defined as the weighted average of Multispectral (MS) bands. The weights are obtained as regression coefficients between the MS bands and the spatially degraded panchromatic image aiming to capture the spectral responses of the sensors. After integrating it with the Gram-Schmidt spectral sharpening method, the generalized intensity-color-saturation fusion method, the proposed preprocessing module enables the generation of fused images. With the alike resolution but increased spectral quality with respect to the standard implementation. Furthermore, quantitative scores performed on spatially degraded data clearly confirm the superiority of the augmented methods over their baselines. Gram-Schmidt transform method is used to obtain and produce a multispectral digital image with advanced spatial resolution [44].

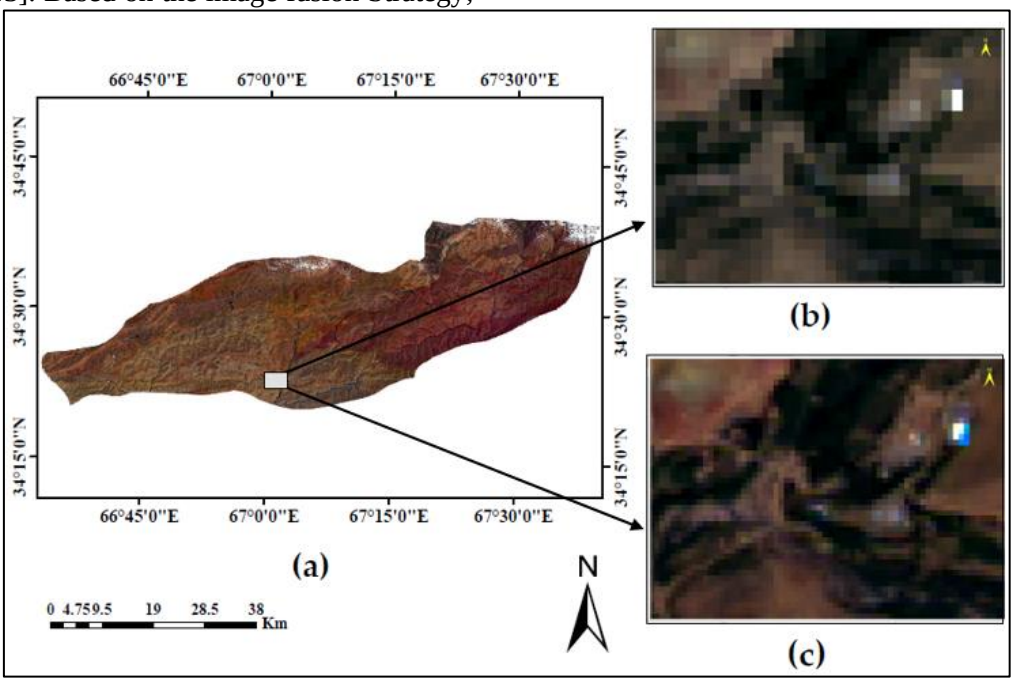

Figure 2. The pan sharpening Effect on the 2023 image: (a) whole region; (b) selected area before sharpening; (c) Selected area after sharpening (White rectangle shows sample area for comparison).

2.3.3 NDVI

Since objects including vegetation have their own unique spectral features reflective or emissive regions, it is possible to identify them from remote sensing images by their unique spectral features. A good option in vegetation mapping is, among other things, the use of remote sensing technology, spectral radiation in the red and near-infrared regions. The radiation in these areas can be included in the spectral Vegetation Indices (VI), which are directly related to the intercepted part of the photosynthetically active radiation. Spectral signs of photosynthetically active and non-photosynthetically active vegetation showed an obvious difference and can be used to estimate the quantity and quality of grass and plain fodder [24].

NDVI is the preferred index for vegetation change analysis and is widely used in the study of vegetation change and vegetation response to climate change [45]. NDVI is commonly used as an evaluation index in vegetation growth monitoring using remote sensing satellite data [46], because NDVI is closely related to photosynthetically active radiation absorbed by photosynthetic tissues. NDVI values range from -1 to 1 regardless of radiance, reflectance, or Digital Number (DN) as input [22]. In general, the effect is positive for waters, for rock, sand or concrete surfaces close to zero, and in vegetation its values can be from 0.2 to above, which including grasses, shrubs, plants and forests. In other words, higher NDVI means more powerful messages for greenness, vegetation is intense. The use of reflection is useful to reduce the effect of scattered radiation in the atmosphere [46]. Which is received using the following relationship.

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (1)$$

Here, NIR is the reflectance in the near-infrared waveband [47], RED represents the red band [48], and NDVI is the original values. Here, different threshold was used to obtain vegetation changes.

3 RESULTS

This research covers a large range of subject matter the investigation of vegetation changes using remote sensing images. First, cloud-free and noise-free images from remote sensing sensors and their applications in vegetation mapping were selected to accelerate suitable remote sensing products for suitable applications. Second, image preprocessing techniques and methods of how to extract plant features from remote sensing images were discussed. In particular, vegetation extraction through the use of satellite images was discussed. Third, a section was devoted to the analysis of the results.

In order to investigate changes in vegetation cover and investigate changes in vegetation density from Landsat satellite images, radiometric and atmospheric corrections were made after selecting without cloud images. In the processing of satellite images, the Index NDVI index was used, and in different threshold values in the time frame of 2015 and 2023, respectively, in the months of June and July, when the vegetation in this region grows and reaches its final growth, and after July, the vegetation has lost its color and is slowly disappearing

The results in Fig. 3, show that in 2015, the NDVI index is 82.71 km^2 of vegetation with lower density in threshold values of 0.48-0.65 in June. At threshold values of 0.65-1, the vegetation cover with strong texture and high density reaches 27.23 km^2, and in the threshold values of 0.48-1, the total vegetation cover reaches 109.93 km^2.

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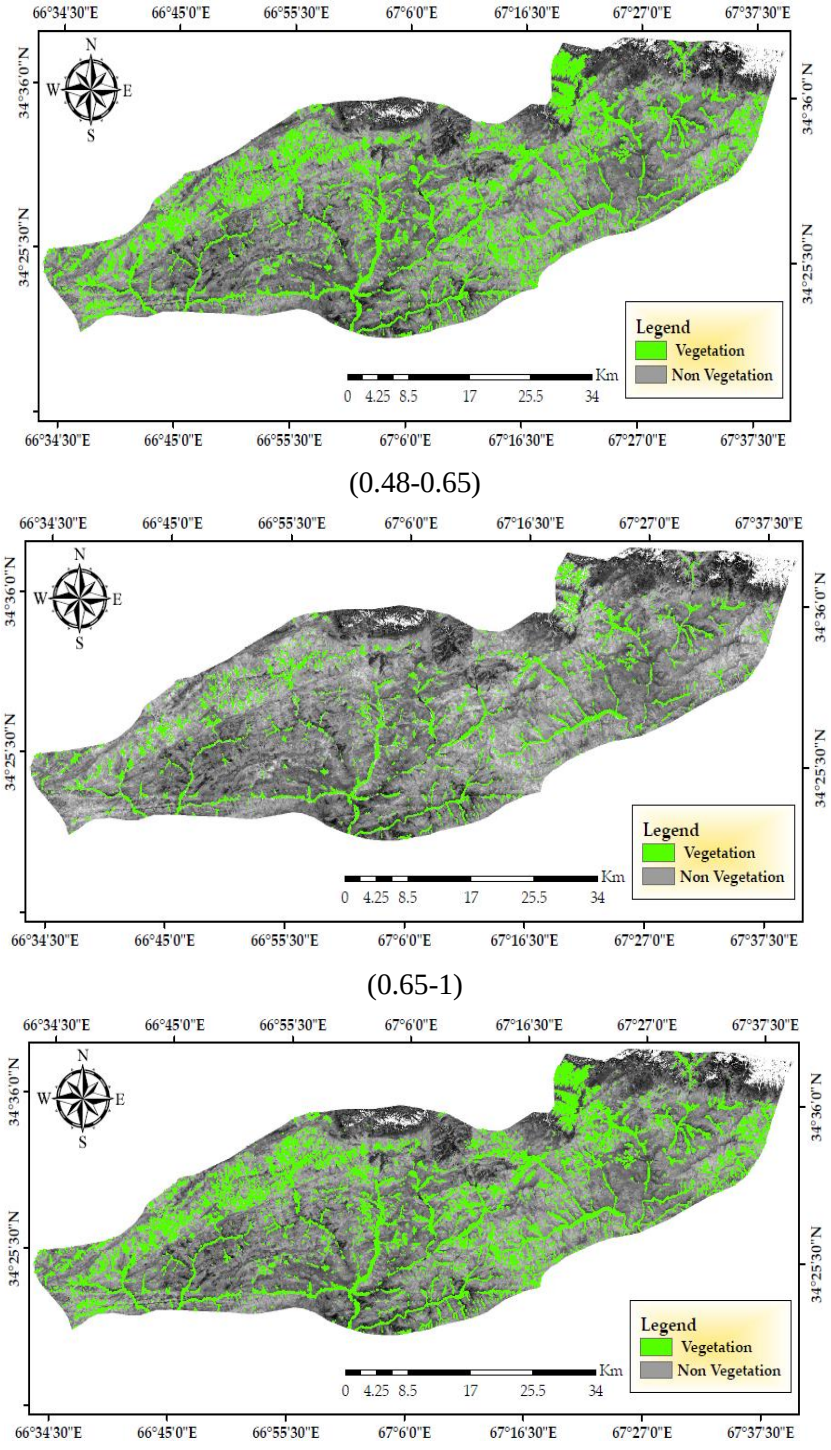


(0.48-0.65)

(0.65-1)

(0.48-1)

Figure 3. Vegetation map of Panjab city for June 2015 in threshold values.

Table 2. Vegetation cover of Panjab city for June 2015 (km^2).

Year	**June ۲۰۱۵**		
Threshold Values	0.48-65	0.65-1	0.48-1
Vegetation	82.71	27.23	109.93

In June 2023, this number will decrease. Fig. 4, shows the map of vegetation cover with higher, lower and total density, which in the threshold values of 0.48-0.65, the vegetation cover reaches ۶۳.50 km^2, in the threshold values of 0.65-1, which has the highest density, the vegetation cover is 21.24 km^2, and in threshold values of 0.45-1, which indicate the total vegetation cover, which is 84.73 km^2. Compared to 2015, vegetation with lower density has decreased by 19.21 km^2. The vegetation cover with high density and texture decreased by 5.99 km^2, and the total vegetation cover in June is 25.20 km^2 has decreased.

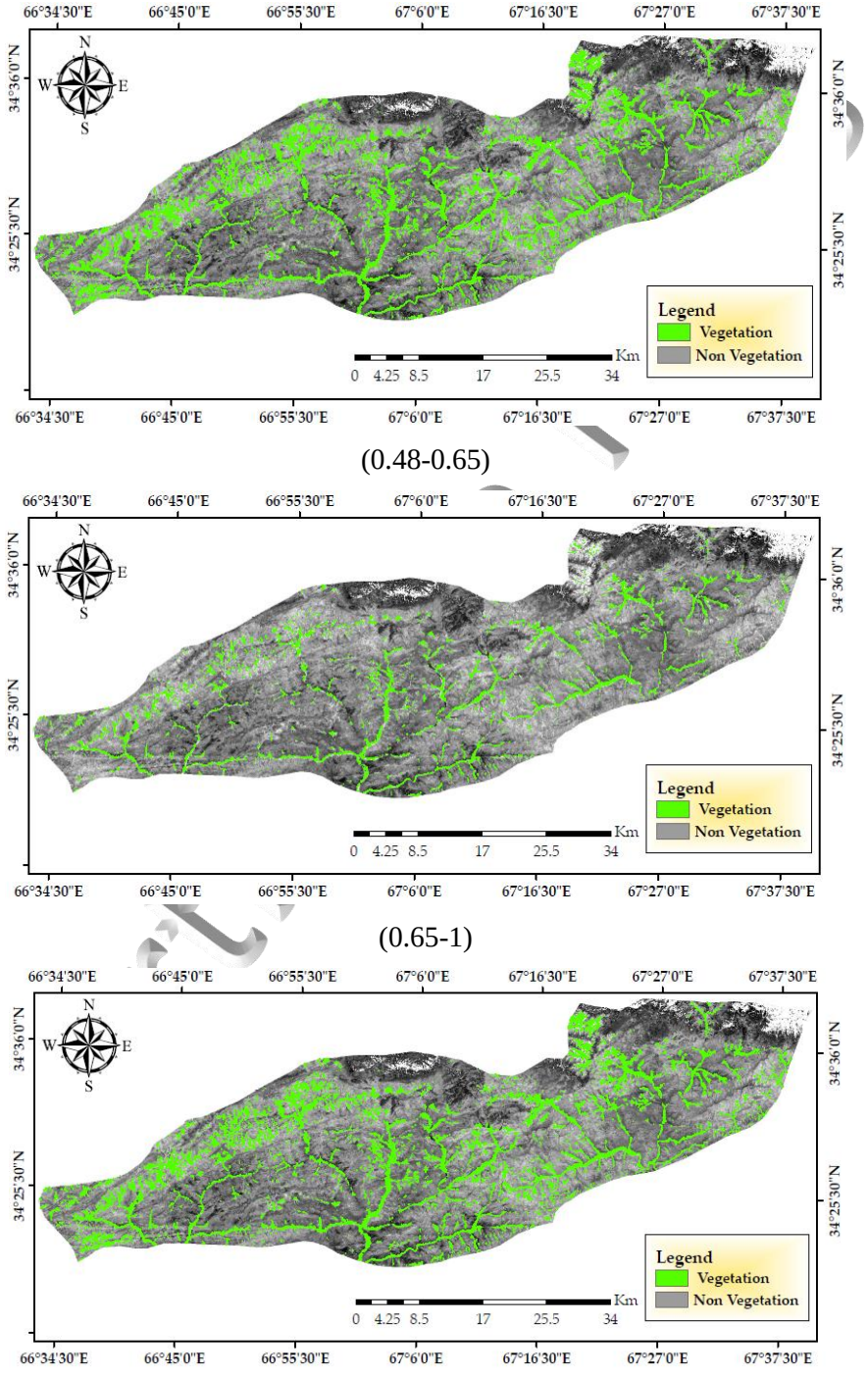


Figure 4. Vegetation map of Panjab city for June 2023 in threshold values.

Table 3. Vegetation cover of Panjab city for June 2023 (km^2).

Year	June ۲۰۲۳		
Threshold values	0.48-65	0.65-1	0.48-1
Vegetation	63.50	21.24	84.73

Table 4. Vegetation changes of Panjab city in June 2015 and 2023 (km^2).

NDVI threshold values	0.45-0.65	0.65-1	0.45-1
Vegetation 2015	82.71	27.23	109.93
Vegetation 2023	63.50	21.24	84.73
Changes	-19.21	-5.99	-25.20

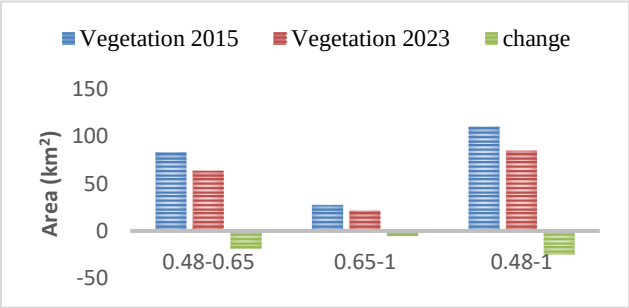
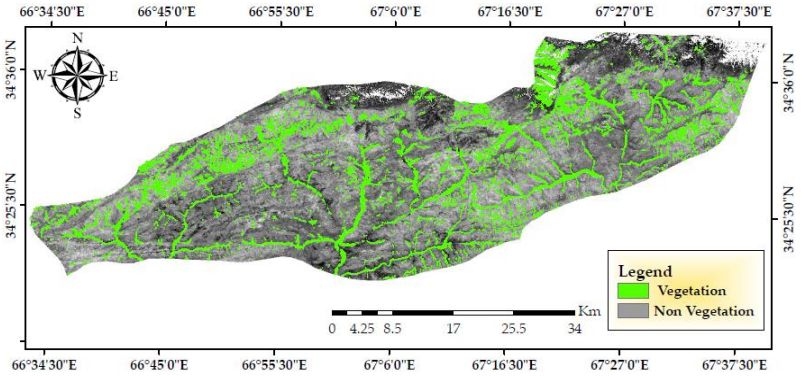


Figure 5. Vegetation changes of Panjab city in June 2015 and 2023 based (km^2).

In Figure 6, the vegetation cover of July 2015 is 65.57 km^2 in threshold values of 0.45-0.65. These figures show the lower density of vegetation in the NDVI index in this region. Vegetation with the highest density in threshold values of 0.65-1 reaches 35.45 km^2. In total, at threshold values of 0.48-1, vegetation reaches 101.02 km^2 in the NDVI index and covers this area.



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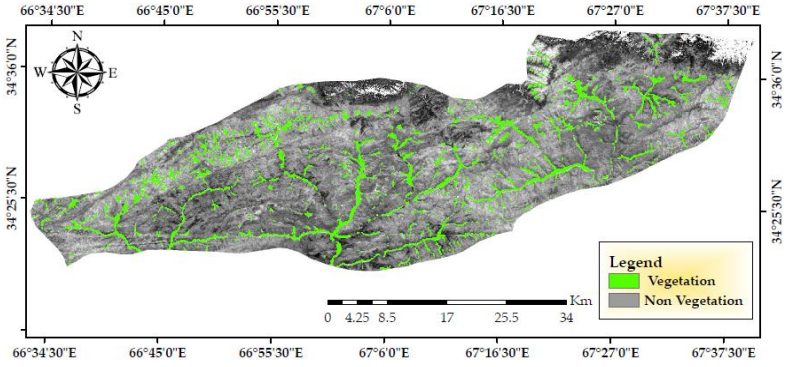

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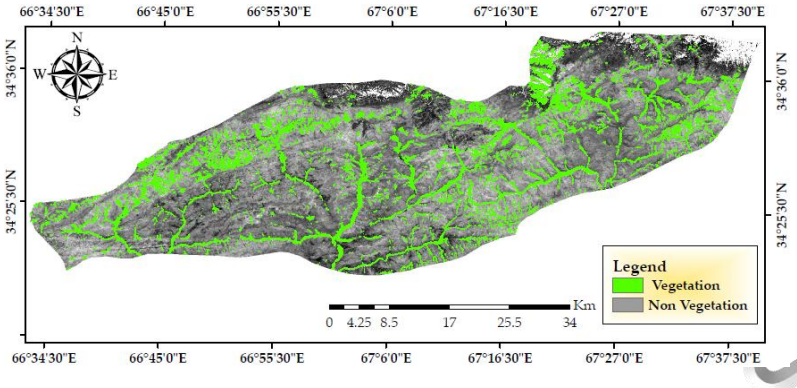


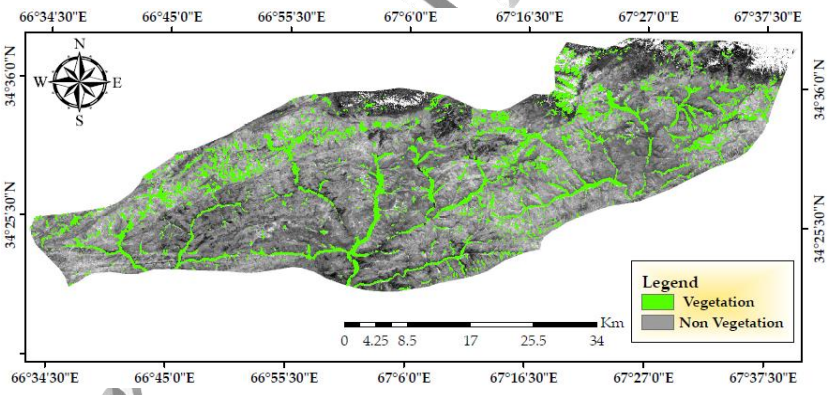
(0.48-1)

Figure 6. Vegetation map of Panjab city in July 2015 in threshold values.

Table 5. Vegetation coverage of Panjab city in July 2015 based on (km^2).

Year	July ۲۰۱۵		
Threshold values	0.48-65	0.65-1	0.48-1
Vegetation	65.57	35.45	101.02

In July 2023, in Figure 7, based on the (NDVI) index, the vegetation cover is 52.99 km^2 in the threshold values of 0.48-0.65, and 16.23 km^2 in the threshold values of 0.65-1. In the collection at the threshold value of 0.48-1, the vegetation cover is 69.22 km^2. Compared to July 2015, these values show that the vegetation cover with lower density decreased by 12.58 km^2, and the vegetation cover with higher density decreased by 19.23 km^2, and the total decreased by 31.8 km^2.



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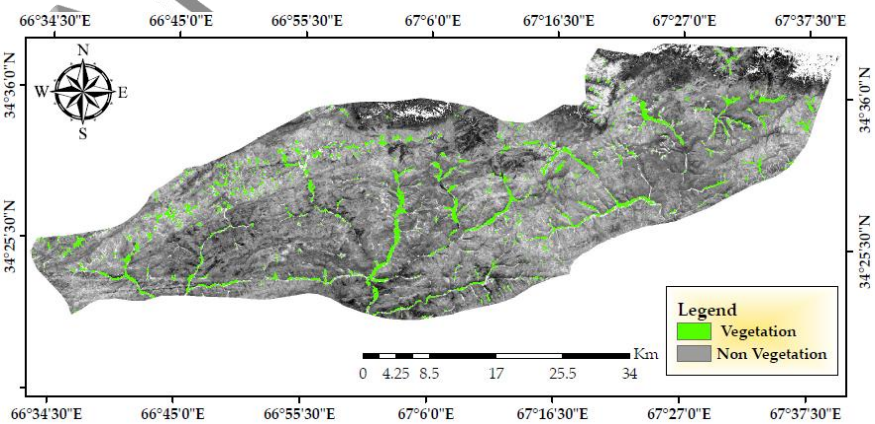

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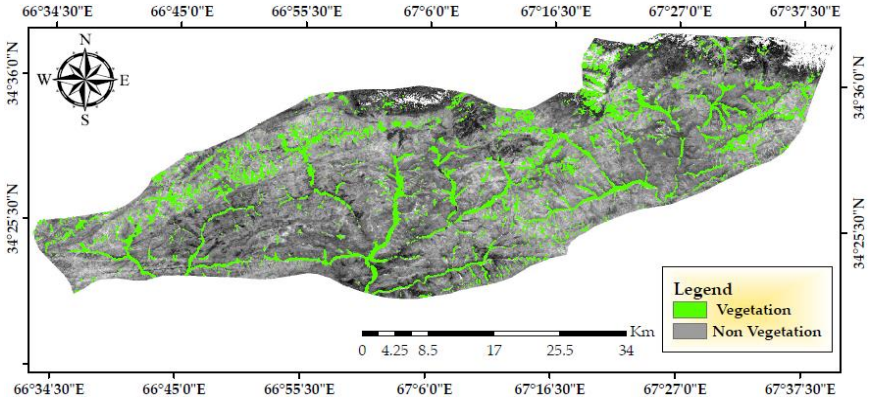

(0.48-1)

Figure 7. Vegetation map of Panjab city in July 2023 in threshold values.

Table 6. Vegetation coverage of Panjab city in July 2023 based on (km^2).

Year	July ۲۰23		
Threshold Values	0.48-65	0.65-1	0.48-1
Vegetation	52.99	16.23	69.22

Table 7. Vegetation changes of Panjab city in July 2015 and 2023 in (km^2).

NDVI threshold values	0.45-0.65	0.65-1	0.45-1
Vegetation 2015	65.57	35.45	101.02
Vegetation 2023	52.99	16.23	69.22
Changes	-12.58	-19.22	-31.80

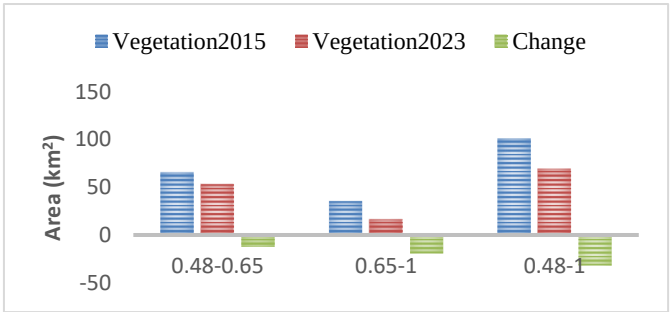

Figure 8. Vegetation changes of Panjab city in July 2015 and 2023 based (km^2).

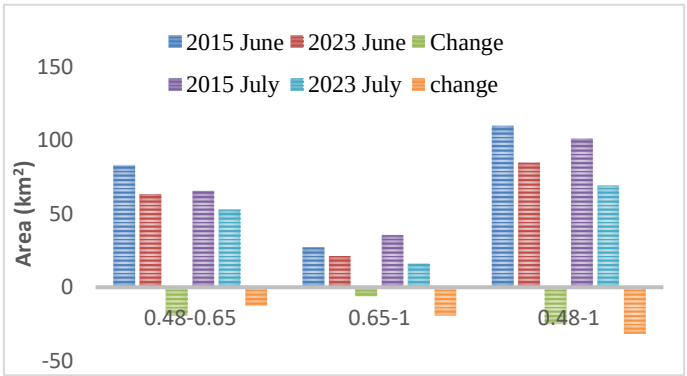

Figure 9. Vegetation changes of Panjab city in 2015 and 2023 in June and July at threshold values of 0.65-0.48, 1-0.65, 1-0.48 (km^2).

4 DISCUSSIONS

The aim of this study was to investigate the impact of drought on vegetation changes in Punjab during the period 2015-2023 using (NDVI) index. The results show a decrease in vegetation cover across the entire range, this decrease was observed in both June and July, indicating a gradual degradation of vegetation cover in the region. The decrease in dense vegetation cover and the relative increase in less dense vegetation cover indicate that the health and density of vegetation has weakened during the study period. The findings of this study are consistent with the results of studies conducted in arid and semi-arid regions. Previous studies have shown that reduced rainfall and the occurrence of frequent droughts lead to a decrease in (NDVI) values and a decrease in vegetation density [4]. Similar findings have been reported in drought-monitoring studies based on terrestrial water storage data, highlighting the strong influence of hydrological drought on environmental conditions [28].

Studies conducted in mountainous and arid regions also indicate that the vegetation cover of these areas is highly sensitive to changes in rainfall and humidity and experiences a significant decrease during periods of drought [4].

The reduction in vegetation cover observed in Punjab can be mainly attributed to drought conditions and reduced rainfall in recent years. Reduced soil moisture and limited access of plants to water resources have affected the growth and development of vegetation and have led to a decrease in (NDVI) values. Comparable relationships between water storage depletion, evapotranspiration, and ecosystem degradation have also been observed in recent remote sensing studies[50], And since the global warming trend has shown obvious heterogeneity at continental and global scales [50], it can have climatic effects. In addition to climatic factors, some human factors can also play a role in intensifying this trend. Land use changes, expansion of residential and agricultural areas, overexploitation of natural resources and destruction of vegetation are among the factors that are likely to have been effective in reducing the vegetation cover of the region.

Therefore, this project shows that the vegetation cover of Punjab city has been decreasing during this period of study and these changes can be explained by the drought conditions of the region as well as some human interventions. Drought is known as the main factor in the changes in the vegetation cover of the region and has played an important role.

It should also be noted that no two remotely sensed images are the same. Also, in the case of (NDVI) products, unlike land use classification methods that can be evaluated using reference data, a specific (NDVI) value does not have an exclusive interpretation. In this regard, there is no black/white reference data to validate (NDVI) data using conventional accuracy assessment methods [14].

5 CONCLUSION

This study examined the changes in vegetation cover of Punjab city between 2015 and 2023 using the (NDVI) index and Landsat-8 data. The results showed that vegetation cover in all the studied thresholds has shown a decreasing trend during this period. In June 2015, the area of vegetation cover in the thresholds of 0.48-0.65, 0.65-1 and 0.48-1, respectively, covered 4.37%, 1.44% and 5.81% of Punjab city, which decreased to 3.36%, 1.12% and 4.48% in June 2023. Furthermore, in July 2015, the threshold values expressed decreased from 3.47%, 1.87% and 5.34% in 2015 to 3.36%, 4.48% and 3.66% in 2023, respectively.

The greatest decrease in vegetation cover was observed in the threshold range of 0.48-1, which indicates an overall decline in the vegetation cover of the region during the study period. The results of the analyses indicate that recent droughts have been the most important factor in the decline in vegetation cover in Punjab. In addition, changes in land use and cover can play a role in intensifying this trend. Overall, the findings of the project indicate that the vegetation cover of Punjab has weakened significantly during 2015-2023, and its declining trend is consistent with the drought conditions of the region.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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