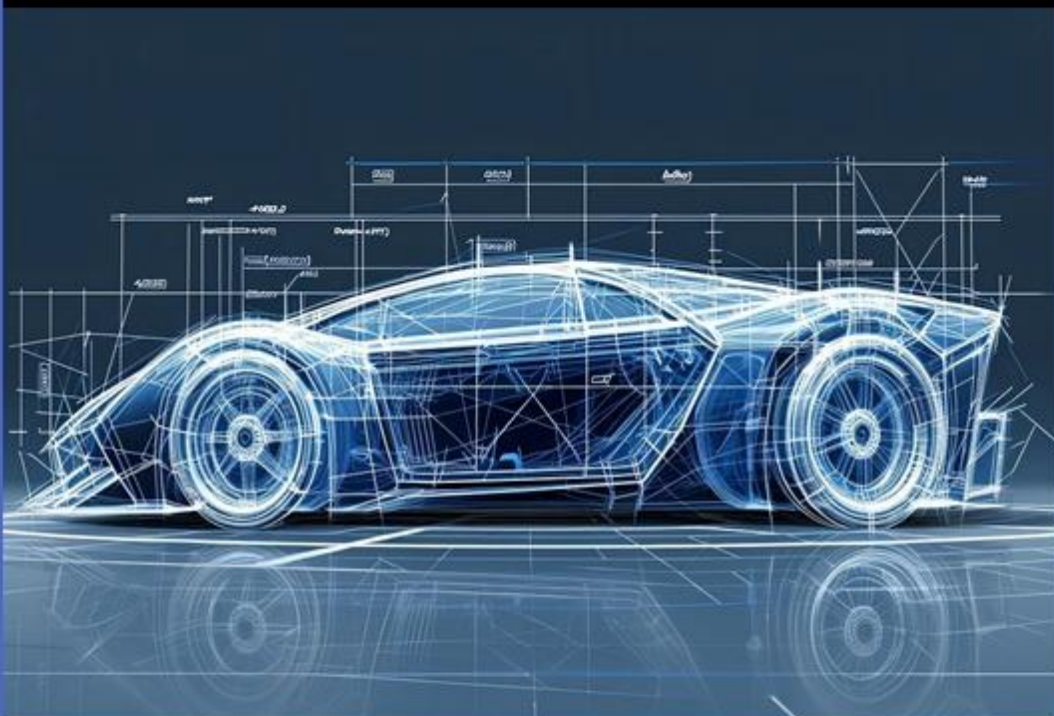
NEW TRENDS AND FRONTIERS IN ENGINEERING



All Sciences Academy

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CONTENT

Methodology for Calculating the Normalized Difference Vegetation Index (NDVI) Utilizing LANDSAT Data in Remote Sensing

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INTRODUCTION

Considering the limitations of population expansion, it seems improbable that agricultural producing areas can be substantially expanded on Earth. Consequently, fulfilling the requirements for agricultural products necessitates enhancing the yield per unit area in agriculture. Consistent with this purpose, the application of technology such as Remote Sensing and Geographic Information Systems is crucial for monitoring, analyzing, and planning agricultural activities.
Remote sensing can yield precise and reliable data regarding agricultural items. Furthermore, assessing plant diversity in agricultural regions facilitates the development of distinct or prospective agricultural zones allocated for each crop type, hence enhancing product regulation and yield forecasting. Utilizing remote sensing and Geographic Information Systems, these studies can be conducted with great precision across extensive areas in a brief timeframe.

The potential for employing GIS and RS techniques in index calculation through spatial analysis is substantial. Remote sensing data, including aerial pictures and satellite images, are often transformed into valuable information, such as land cover maps, by two standard methods: manual interpretation and computer-assisted digital processing. In manual interpretation, analogue photographs or satellite images are visually analyzed, and the findings are outlined directly on the photographs or images, or on tracing paper laid over them [1], [2].

Remote sensing data serve as fundamental resource for the analysis of environmental processes at both local and global scales. This data is utilized to identify change detection in recent decades. Remote sensing data, including Landsat, Sentinel, and Spot imagery, are highly beneficial for visualization, categorization, and analysis of geographical areas. The data can be classified according to resolution, electromagnetic spectrum, energy source, imaging medium, and the number of bands. A greater resolution of satellite data (spatial, spectral, radiometric, and temporal) results in a higher degree of accuracy in classification [3].

Throughout the year, researchers and scientists have encountered many spectral indices to address intricate environmental issues. Numerous indices currently exist, each possessing distinct significance in the analysis. The following are the most prevalent indices derived from free satellite data [4].

What is Normalized Difference Vegetation Index (NDVI)?

The Normalized Difference Vegetation Index (NDVI) is a well-established concept, utilized since 1973 to facilitate the assessment and monitoring of plant health efficiently. Currently, NDVI is the predominant vegetation index utilized in remote sensing, particularly due to recent improvements in earth observation and drone technologies.

The NDVI is a prevalent index derived from multispectral and/or hyperspectral data, calculated as a normalized ratio of the red and near-infrared bands. The NDVI is commonly employed to assess canopy growth or health, leading to numerous studies that compare it with the Leaf Area Index (LAI), defined as the ratio of actual leaf area to its projected area on the ground [5], [6].

NDVI is a remote sensing technique that utilizes light reflection in the visible and near-infrared (NIR) spectra to assess the quantity and vitality of vegetation in a given area. NDVI is extensively utilized in agriculture, forestry, and ecology to assess vegetation growth and health, as well as to detect regions of stress or damage. NDVI measurements can be utilized to delineate and categorize vegetation types, as well as to identify temporal variations in vegetation cover.

The NDVI serves as an index of plant health, determined only by the reflection of various light wavelengths in the visible and near-infrared spectrum by cellular structures. It facilitates the detection and quantification of live green vegetation by analyzing the interaction of objects with light. To assess the plant's health, it is essential to evaluate the absorption and reflection values of red and near-infrared (NIR) light, as indicated by the Normalized Difference Vegetation Index [7].

The NDVI layer offers significant insights regarding vegetation in a certain region. Below are few examples:

1. Vegetation cover: NDVI serves as a metric for estimating the extent of vegetation cover in a specified region. Elevated NDVI values often signify increased vegetation, whereas diminished values denote reduced vegetation.
2. Vegetation health: NDVI serves as a tool for monitoring temporal variations in vegetation health. Abrupt declines in NDVI values may signify stress or harm to vegetation, including drought, disease, or insect infestation.
3. Crop monitoring: NDVI is frequently employed to assess crop vitality and yield. Through the analysis of NDVI values over time, farmers and researchers can pinpoint failing areas within their fields and modify their management strategies accordingly.
4. Land cover classification: NDVI serves as a technique for categorizing land cover types. Regions exhibiting elevated NDVI values are typically linked to woods or grasslands, whilst regions with diminished NDVI values may correspond to water bodies or barren soil.

The NDVI layer serves as an effective instrument for analyzing vegetation patterns and environmental changes over time. It is applicable across various domains, including agriculture, forestry, and land management [8].

What is the method for calculating NDVI?

Plants have a distinctive reflectance property, reflecting a greater amount of near-infrared (NIR) light while absorbing a larger proportion of visible light. Healthy plants possess elevated chlorophyll levels, enabling them to absorb greater light in the red spectrum while reflecting more light in the near-infrared area. NDVI utilizes this trait of plants to distinguish between healthy vegetation and non-vegetation or unhealthy vegetation [9],[10].

NDVI is determined by subtracting the reflectance of the NIR band from that of the red band and thereafter dividing the result by the sum of the reflectance values of both the NIR and red bands. NDVI values span from -1 to 1, where -1 signifies the absence of vegetation, 0 represents bare soil or water, and values approaching 1 denote increased quantities and healthier flora.

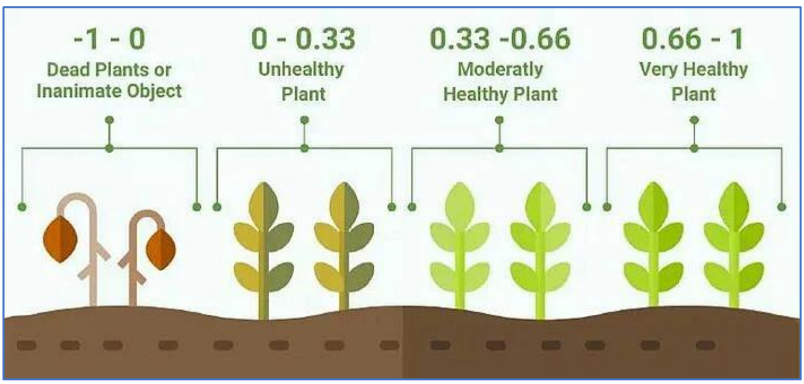

Fig. 1. NDVI values range [9]

NDVI has been utilized indirectly to assess the cumulative impact of rainfall on vegetation over a specified duration, rangeland carrying capacity, crop yields across various crop kinds, and environmental quality as a habitat for diverse animals, pests, and illnesses.

NDVI is derived from satellite imaging, in which the satellite's spectrometer or radiometric sensor quantifies and records reflectance values for both red and NIR bands across two distinct channels or pictures. Kriegler et al. (1969) were the pioneers in proposing the Normalized Difference Vegetation Index (NDVI), which is computed by subtracting the red channel from the near-infrared (NIR) channel and dividing the resultant difference by the sum of both channels, expressed as follows [11], [12], [13], [14]:

$$NDVI = (NIR - RED) / (NIR + RED) \quad (1)$$

where,

RED = the red portion of the electromagnetic spectrum (0.6-0.7 μm) and

NIR = the near infrared portion of the electromagnetic spectrum (0.75-1.5 μm).

In addition, for agricultural and vegetation condition monitoring, clouds are partially screened from NDVI images by producing Maximum Value Composites (MVC) over 10-day, 16-day, or 1-month periods, where the highest NDVI pixel value within the time period is retained under the assumption it represents the maximum vegetation "greenness" during the period [15].

Spectral reflectance

Radiance (watts $steradian^{-1}$ m^{-2} μm^{-1}) quantifies the energy flux detected by a sensor. Radiance values are frequently converted to digital numbers (DN) as 6-bit or 7-bit (MSS), 8-bit (TM, ETM+), or 12-bit (Landsat 8) unsigned integers. Reflectance is a dimensionless metric representing the ratio of radiation reflected by an item to the radiation incident on that object. NDVI values span from −1 to 1, irrespective of whether radiance, reflectance, or digital number (DN) is utilized as input. Generally, the values are negative for aquatic environments, about zero for rocks, sands, or concrete surfaces, and positive for vegetation, encompassing crops, shrubs, grasses, and forests. Higher NDVI values indicate more pronounced consequences for robust vegetation greenness. Employing reflectance mitigates the impact of dispersed radiation in the atmosphere [16]. On clear days, the scattering of solar radiation is inversely related to the fourth power of the wavelength ($\sim \lambda - 4$, where λ denotes wavelength) (Fig. 2).

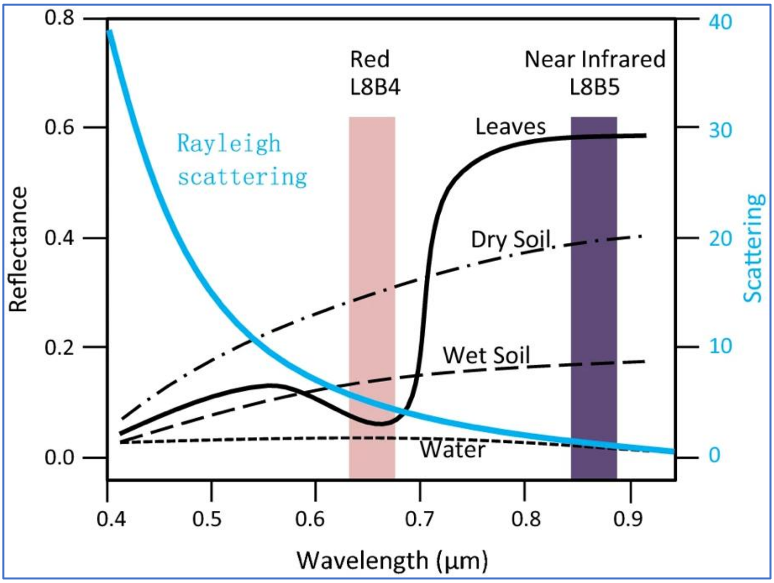

Fig. 2. An illustration of spectral response curves and their intersections with red (Landsat 8 Band 4) and near infrared bands (Landsat 8 Band 5) as well as the wavelength-dependent scattering [17].

This idea of pronounced wavelength dependency on atmospheric scattering is referred to as Rayleigh scattering, indicating that shorter (red) wavelengths scatter more intensely than longer (near infrared) wavelengths, hence influencing the computation of NDVI [17].

Remote sensing data serve as major sources for analyzing environmental processes on both local and global scales. This data is utilized to identify change detection in recent decades. Remote sensing data, including Landsat, Sentinel, and Spot imagery, are invaluable for visualization, classification, and analysis of regions. The data can be classified according to resolution, electromagnetic spectrum, energy source, imaging medium, and number of bands. Increased resolution of satellite data (spatial, spectral, radiometric, and temporal) correlates with enhanced accuracy in classification [18].

Landsat satellite image

Landsat data are predominantly utilized for classification purposes. Landsat data comprise multiple bands categorized by their wavelengths, including blue, green, red, infrared, thermal, and panchromatic bands. The panchromatic band enhances data resolution. Landsat 7 data has a total of 8 bands, whereas Landsat 8 data consists of 11 bands.

Analysis of the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), and Normalized Difference Water Index (NDWI) use only four spectral bands: Green, Red, Near Infrared (NIR), and Shortwave Infrared (SWIR).The Landsat Missions consist of operating Earth-observing satellites equipped with remote sensors to gather data and imagery of our globe, functioning under the U.S. Geological Survey (USGS) National Land Imaging (NLI) Program. Products derived from imagery obtained by sensors on the Landsat satellites are stored in the USGS Earth Resources Observation and Science (EROS) Center in Sioux Falls, South Dakota [19].

The interagency initiative accomplished its objective on July 23, 1972, with the launch of the Earth Resources Technology Satellite (ERTS-1), subsequently dubbed Landsat 1. Project EROS resulted in other worldwide collaborations centered on research and technology, including a foundational initiative on the operation of Landsat. Each commissioned satellite embodied the esteemed legacy of the program. Landsat 2, 3, and 4 were launched in 1975, 1978, and 1982, respectively [19].

Recently released Landsat satellites equipped with sensors have augmented the volume of Earth observation data: Landsat 7 in April 1999, Landsat 8 in February 2013, and Landsat 9 in September 2021. All Landsat satellites have been launched from Vandenberg Air Force Base, officially referred to as Vandenberg Space Force Base, as of May 2021.

The Landsat Next mission is scheduled for launch in late 2030 or early 2031. Landsat Next will consist of a constellation of three observatories launched simultaneously, offering enhanced temporal revisit capabilities within a new World Reference System, returning data across 26 spectral bands, and collecting approximately 20 times more data than Landsat 9 [19].

The Landsat satellite is equipped with two scientific instruments: the Operational Land Imager 2 (OLI-2) and the Thermal Infrared Sensor 2 (TIRS-2) (Table. 1). The OLI–2 records observations of the Earth's surface in visible, near-infrared, and shortwave-infrared wavelengths, while TIRS-2 quantifies thermal infrared radiation emitted from the Earth's surface (Fig. 3).

Table 1. Landsat 8-9 Operational Land Imager (OLI) and Thrmal Infrared Sensor (TIRS) [20]

Bands	Wavelength micrometers)	esolution meters)
nd 1 – Coastal aerosol	0.43 – 0.45	30
nd 2 – Blue	0.45 – 0.51	30
nd 3 – Green	0.53 – 0.59	30
nd 4 – Red	0.64 – 0.67	30
nd 5 – Near Infrared (NIR)	0.85 – 0.88	30
nd 6 – SWIR 1	1.57 – 1.65	30
nd 7 – SWIR 2	2.11 – 2.29	30
nd 8 – Panchromatic	0.50 – 0.68	15
nd 9 – Cirrus	1.36 – 1.38	30
nd 10 – Thermal Infrared (TIRS) 1	10.60 – 11.19	100
nd 12 – Thermal Infrared (TIRS) 2	11.50 – 12.51	100

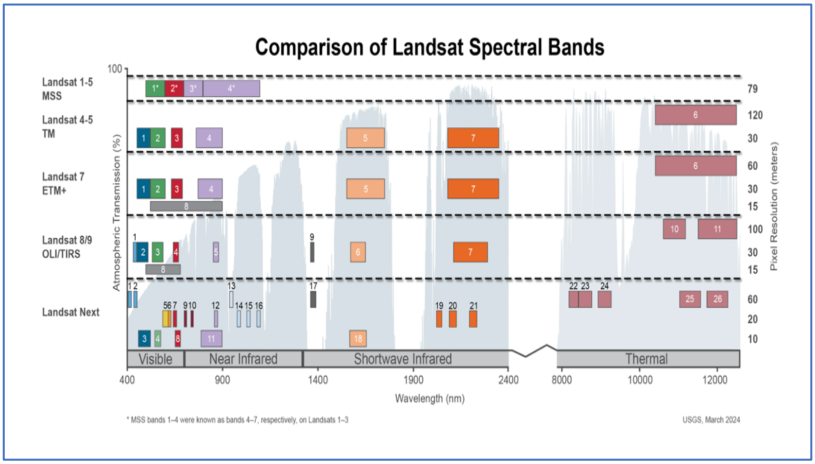

Fig. 3. Comparison of Lndsat spectiral bands [19]

Landsat 9 enhancements feature elevated radiometric resolution for OLI-2, with quantization increased from 12 bits in Landsat 8 to 14 bits, enabling sensors to discern more nuanced variations, particularly in darker regions like lake bodies or dense woods [20].

An example of NDVI computation utilizing Landsat imagery within QGIS.

Normalized difference values are not provided when downloading multispectral imagery; however, they can be easily computed independently. We will now generate an NDVI raster utilizing our Landsat data as a case study.

Demonstration area

The province of Tekirdağ, designated as the demonstration area, is situated in north-western Turkey, north of the Marmara Sea, within the Thrace Region, between 40°36´ and 41°31´ north latitude and 26°43´ and 28°08´ east longitude. Tekirdağ province is located 141 km from Edirne, 194 miles from Çanakkale, 131 km from Istanbul, and 122 km from Kırklareli, including an area of 6,313 km² (Fig. 4).

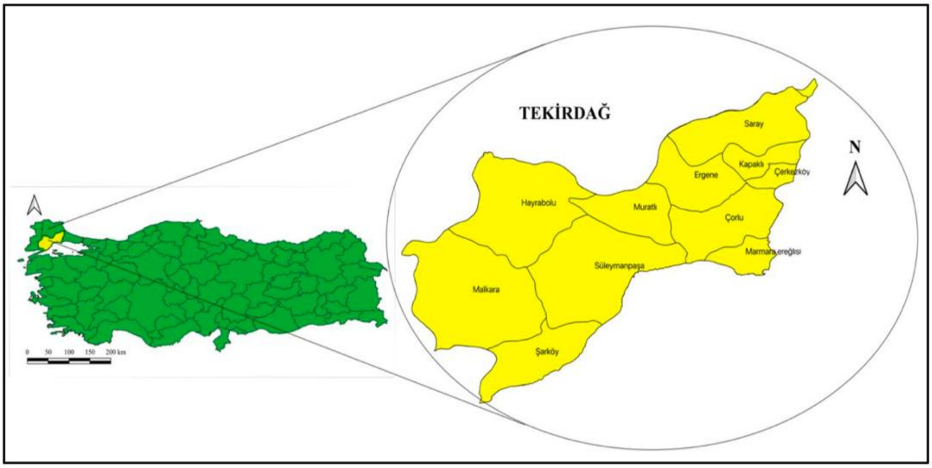

Fig. 4. Demonstration area

Acquisition of Landsat imagery

For the demonstration, data is required for the analysis to be conducted. Satellite imagery. Various satellites offer multispectral imagery, enabling the collection of environmental data, which will be utilized to discover the environmental components influencing Tekirdag.

Two bands from the Landsat satellite are required for the NDVI demonstration. These correspond to Band-4 (Red) and Band-5 (Near Infrared). Landsat 8-9 satellite pictures can be downloaded at no cost via https://glovis.usgs.gov/app. Landsat-8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) Band 4 (Red) and Band 5 (NIR) data, with a spectral resolution of 30x30, were downloaded on June 17, 2024 [19].

Image preprocessing

The satellite data obtained were analyzed utilizing QGIS 3.34.9 LTR software. QGIS is a professional Geographic Information System program developed on Free and Open Source Software (FOSS) and takes pride in its identity. QGIS is an accessible Open Source Geographic Information System governed by the GNU General Public License. QGIS is an official initiative of the Open Source Geospatial Foundation (OSGeo). It operates on Linux, Unix, Mac OSX, Windows, and Android, and accommodates many vector, raster, and database formats and functionalities [21].

All images were geometrically adjusted to conform to the UTM zone 35N projection and the WGS84 datum.

Steps for NDVI Processing Using QGIS

Two Landsat satellites, Band-4 (Red) and Band-5 (NIR), have been used for the territory boundaries of Tekirdağ, where NDVI is to be studied. First, the Band 4 and Band 5 images were merged with the "Raster/Miscellaneous/Merge" command, and then "Raser/Extraction/Clip Raster by Mask Layer...With the command Tekirdağ shapefile vector data, cutting by province boundary was implemented. (Fig. 5).

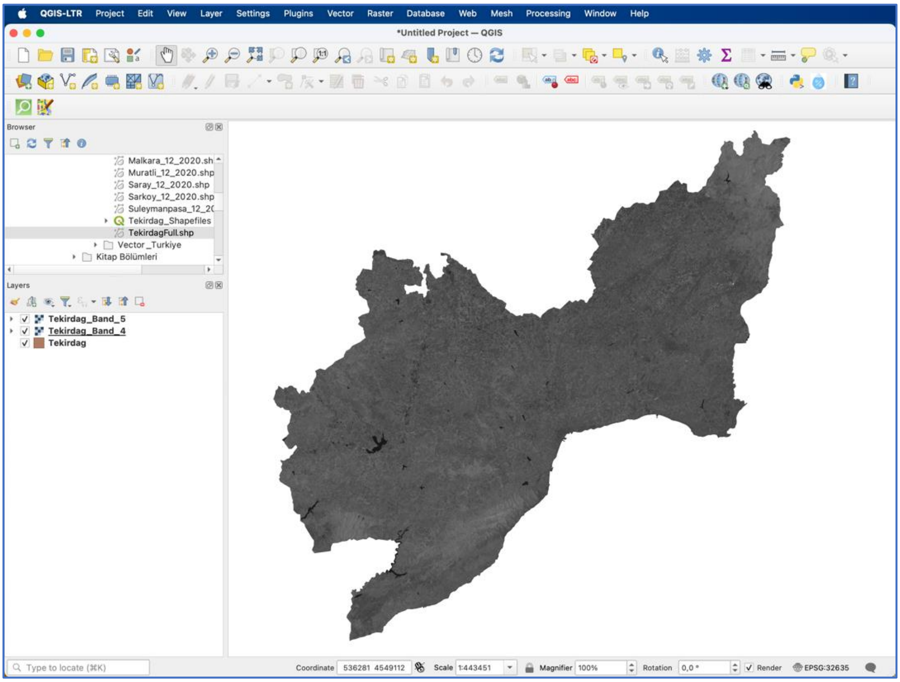

Fig. 5. Digital Elevation Model images of Tekirdağ Band 4 and Band 5.

The "Raster/Raster Calculator..." command in QGIS activates the raster calculation tool interface. This instrument enables the execution of mathematical operations on raster datasets.

The NDVI calculation is displayed on the Raster calculator screen utilizing the Red and NIR bands (Fig. 6) [22]. Simply choose an output option and file name, then click 'Run'. Upon completion of the raster calculation, the resultant NDVI layer will be incorporated into the QGIS interface. NDVI will be presented as a grayscale image (Fig. 7).

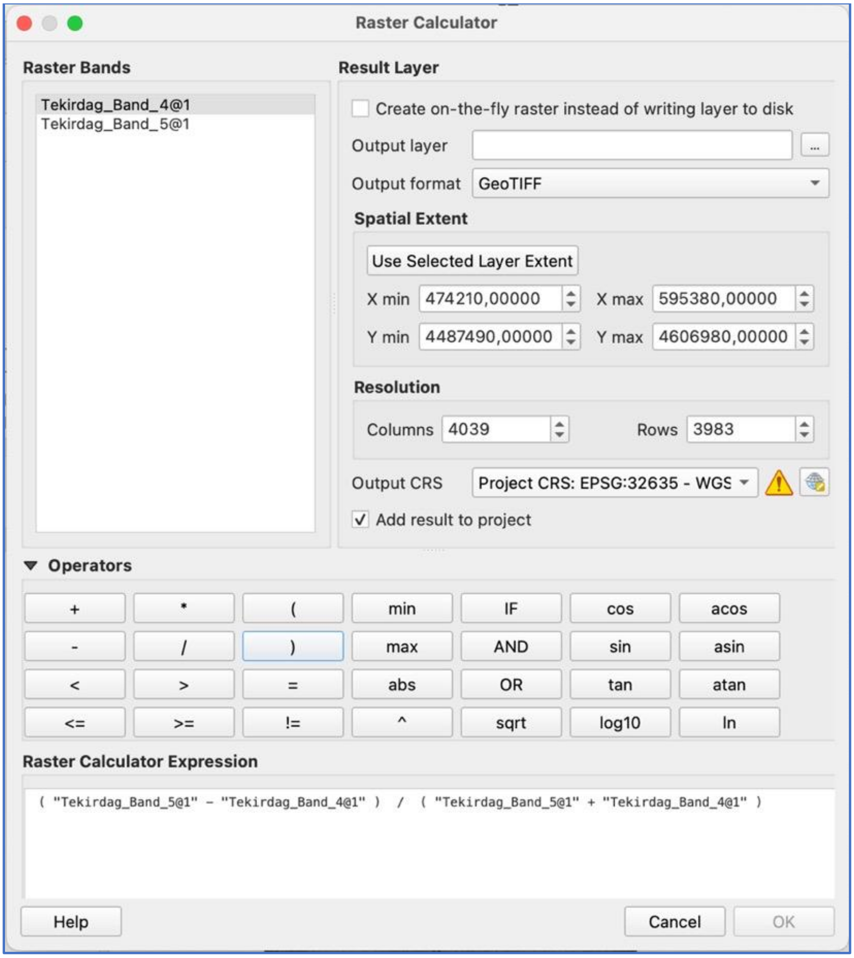

Fig. 6. Raster Calculater for NDVI formula.

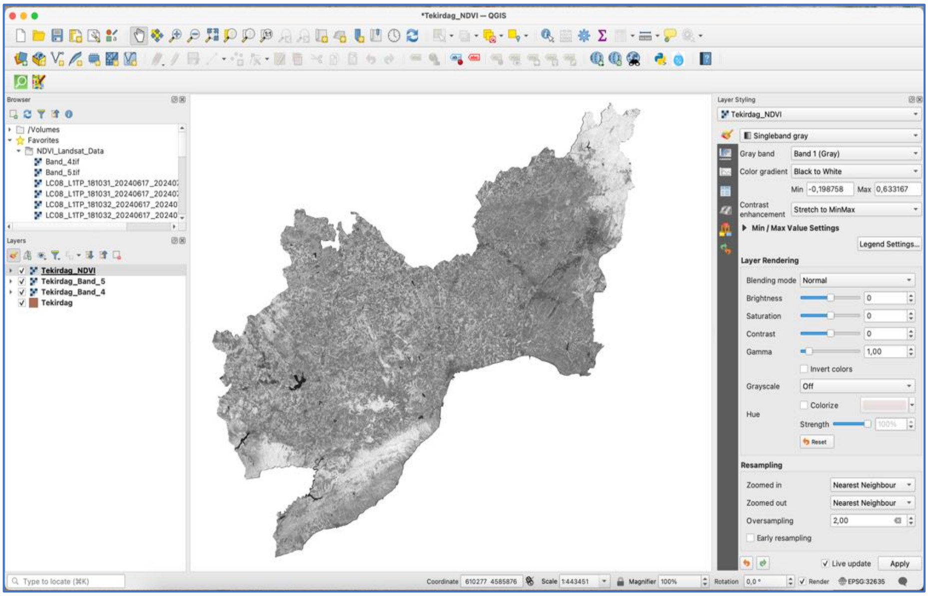

Fig. 7. NDVI displayed in grayscale.

At this stage, the color assignments for the NDVI map, prepared in greyscale, will be established using the 'Symbology' option inside the 'Layers' attributes. When the NDVI map is selected in the layers list, the symbol must be clicked to display the symbology properties options on the right side of the screen. (Fig. 8)

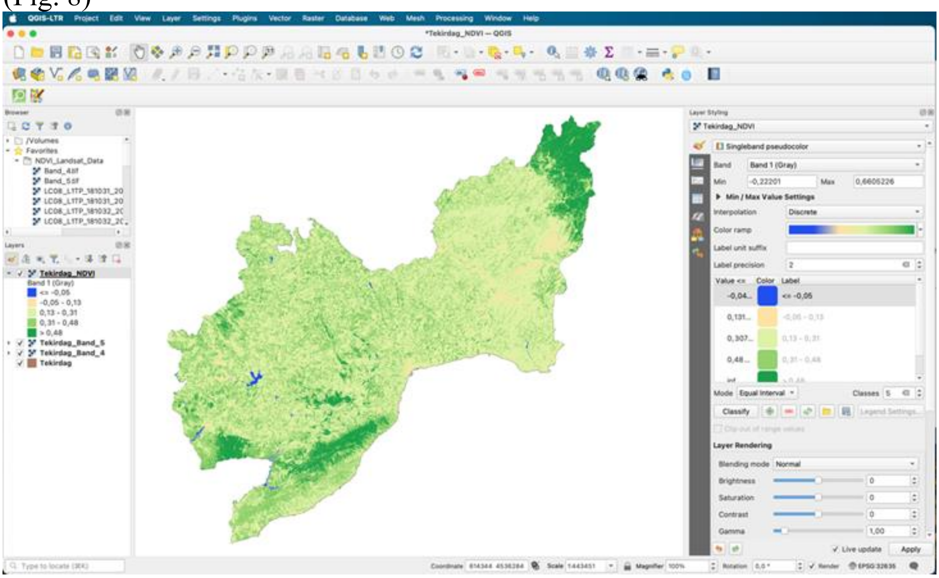

Fig. 8. NDVI colour adjustment.

In the final stage of our application, we generate the map components of the NDVI map (scale, North Arrow, lejant etc.) with the "Print Layout" functionality of the QGIS program. Consequently, we are generating the NDVI map for Tekirdağ province from the Landsat 9 satellite image on 17 June 2024. (Fig. 9).

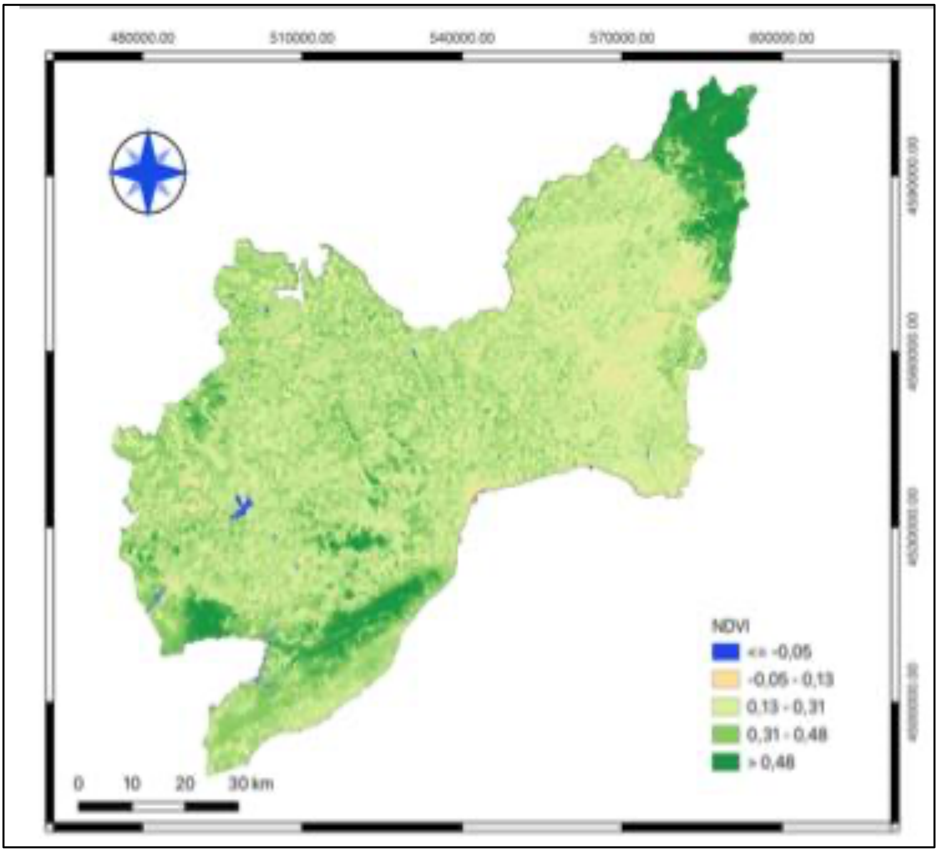

Fig. 8. NDVI map of Tekirdağ province in June 2024.

NDVI is a straightforward vegetation index that detects vegetation 'greenness' and is utilized in various applications. The computation of NDVI is straightforward; the most challenging aspect is acquiring the data. The QGIS raster calculator is an effective tool for computing NDVI and other vegetation indices. Mastering the QGIS raster calculator is a crucial component of acquiring proficiency in remote sensing analysis.

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