Introducing a Learning Tool (QSVI): A QGIS Plugin for Computing Vegetation, Chlorophyll, and Thermal Indices with Remote Sensing Images

Nuray ~~Baş*~~Baş[1],

[1]Department of geomatic, Sivas Cumhuriyet University, ~~Department of Geomatics Engineering,~~ Sivas, 58170, Turkey~~,~~

~~-~~*Correspondence to*~~:~~: Nuray Baş ~~(nuraybas@email.com), Orcid number: 0000 0003 2036 6686~~ (nuraybas@gmail.com)

Abstract~~:~~

~~Recent advances in remote~~. Remote sensing technology ~~have increased the demand for software that supports educational and research activities. However, commercial software often comes with high costs and complex interfaces, presenting challenges for users. In contrast, open-source software offers a more accessible and cost-effective solution, making it increasingly popular for remote sensing and image processing applications. This study introduces a new computational approach for widely~~can be used ~~vegetation indices, including~~to monitor environmental changes using satellite imagery. However, to obtain a more precise model, it is necessary to process high-resolution and multilayered data, which requires high-capacity software. Commercial software is often difficult to access by students and researchers because of its high cost and complex interface. This paper introduces a plug-in called QSVI (QGIS Sentinel Vegetation Indices (QSVI) designed in open-source QGIS (Quantum GIS) software using Python. The QSVI can quickly process and automatically calculate many environmental indices on a single platform. These included the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), ~~and Atmospherically Resistant~~Atmospheric Resilient Vegetation Index (ARVI~~). It also presents new tools for assessing chlorophyll, specifically the~~), Leaf Area Index (LAI~~) and~~), Chlorophyll ~~Vegetative~~Vegetation Index (CVI), ~~as well as thermal indices like the~~ Urban Thermal Field Variation Index (UTFVI~~)~~), and Thermal ~~Discomfort~~Disturbance Index (TDI). ~~Developed using Python, a popular programming language, within QGIS, the QSVI plugin features rapid processing capabilities and a user-friendly interface, making it particularly accessible for both researchers and educators. The effectiveness of the application was evaluated~~. The performance of the QSVI was tested in the Sarıyer ~~district~~District of Istanbul ~~using remote sensing data from the European Space Agency's Sentinel-2 and Sentinel-3 satellites.~~, Turkey. The results indicate that ~~the~~for Sentinel-2 data, QSVI ~~plugin significantly~~ reduces ~~computation~~processing time ~~compared to popular geographic information system (GIS) software, including ArcGIS, GRASS GIS, and SAGA GIS. For Sentinel-2 datasets, QSVI is, on~~by an average~~,~~ of 2.1 minutes ~~faster than these applications. Additionally, for Sentinel-3 datasets, QSVI performs approximately~~compared to common commercial software such as ArcGIS, GRASS, and SAGA-GIS. Sentinel-3 data were processed 13.6 seconds ~~faster~~

Stil Tanımı: Normal: Yazı tipi: (Varsayılan) Times New Roman, 10 nk, İngilizce (Birleşik Krallık), İki Yana Yasla, Aralık Sonra: 0 nk, Satır aralığı: 1.5 satır

Stil Tanımı: Başlık 1: Yazı tipi: (Varsayılan) Times New Roman, 10 nk, Kalın, Yazı tipi rengi: Siyah, İngilizce (Birleşik Krallık), Aralık 16 nk, İki Yana Yasla, Aralık Önce: 24 nk, Sonra: 12 nk, Satır aralığı: tek, Satırları birlikte tutma

Stil Tanımı: Başlık 2: Yazı tipi: (Varsayılan) Times New Roman, 10 nk, Kalın, Yazı tipi rengi: Otomatik, İngilizce (Birleşik Krallık), İki Yana Yasla, Aralık Önce: 12 nk, Sonra: 12 nk, Satır aralığı: tek, Satırları birlikte tutma

Stil Tanımı: Başlık 3: Yazı tipi: (Varsayılan) Times New Roman, 10 nk, Kalın, Yazı tipi rengi: Otomatik, İngilizce (Birleşik Krallık), İki Yana Yasla, Aralık Önce: 12 nk, Sonra: 12 nk, Satır aralığı: tek, Satırları birlikte tutma

Stil Tanımı ...

Stil Tanımı ...

Stil Tanımı: Köprü: Yazı tipi rengi: Mavi

Stil Tanımı ...

Stil Tanımı ...

Stil Tanımı: Normal (Web)

Stil Tanımı: HTML Önceden Biçimlendirilmiş

Stil Tanımı: Style14

Stil Tanımı: Style9

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirilmiş: MS title, Desen:Yok

Biçimlendirdi ...

Biçimlendirdi ...

Biçimlendirdi ...

Biçimlendirilmiş ...

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi ...

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

than the others. These time savings highlight QSVI's efficiency in handling large datasets and demonstrate its advantages in environmental monitoring and analysisquicker than with the same software. The findings indicate that QSVI can be an alternative tool for researchers and students because of its easy accessibility and low cost. Because of its speed and simple interface, it can provide practical solutions for both researchers and students.

Keywords: python ; Qgis-plugin; sentinel data; environmental indices

1 Introduction

Digital software applications have become important resources in both education and research, particularly in the field of remote sensing. These tools facilitate the integration of traditional methods, enhance student motivation, and provide researchers with new ways to conduct personalised data analysis. By simplifying complex analytical processes, digital software also makes it easier and faster to complete research tasks, allowing more effective use of time and resources. A number of studies have demonstrated that technology-based approaches can enhance student performance by between 15% and 25% in comparison to traditional methods (Bernard et al., 2019; Sung et al., 2021; Zheng et al., 2022). This is particularly evident in the field of remote sensing, where specialised software facilitates the interpretation of data (Surampalli et al., 2020).

To support these educational and research needs, this paper presents an open source plugin specifically designed for remote sensing applications. This plugin includes several functionalities aimed at both supporting computer-based learning for students and facilitating advanced data analysis for researchers. In particular, open-source platforms have become important in this context as they encourage active interaction, self-directed experimentation and shared learning (Gomez et al., 2010; Dinçer, 2017). These tools provide users, including students and researchers, with the ability to explore complex datasets, test applications, and contribute to scientific knowledge in ways that may not be possible using traditional methods.

In the field of remote sensing, this capability is of particular significance, as open-source software facilitates the efficient and repeated analysis of environmental changes, making use of spatial, spectral, and temporal data from extensive and remote regions. For example, the application of open-access Normalized Vegetation Index (NDVI) analysis has been effective in detecting changes in vegetation and land cover in a range of ecosystems, as observed in Wadi Yalamlam (Aldhebiani et al., 2018). This approach demonstrates how open-access software in remote sensing not only supports educational objectives but also advances environmental research and monitoring, thereby providing a comprehensive understanding of ecological changes (Bastiaanssen et al., 2000; Wachendorf et al., 2018).

In addition to software advancements, the accessibility of open-source data sets has further facilitated educational and research activities in the field of remote sensing. To consider an example, the Landsat imagery, which is widely recognised for its multispectral data, makes it possible to analyse the spectral relationships across pixels, which is valuable for precise environmental classification and monitoring (Ran et al., 2017; Narine et al., 2019). Furthermore, the Copernicus programme's Sentinel satellites provide open-access data that is crucial for environmental analysis. Sentinel-2 Level 2A (L2A) data, which

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), 11 nk, Türkçe (Türkiye)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), 11 nk, Türkçe (Türkiye)

has been corrected for atmospheric effects by the European Space Agency (ESA), offers users data that is ready for direct analysis. Sentinel-3 extends this utility by including a thermal band, which allows for studies that are focused on temperature dynamics an essential aspect of environmental and climate research.

These images offer a wide range of potential applications across various academic disciplines, including agriculture (Segarra et al., 2020), grassland studies (Potočnik Buhvald et al., 2022), risk assessment (García-Fernández et al., 2020), and land cover classification (De Fioravante et al., 2021). Furthermore, they have been instrumental in studies related to land surface temperature (Nie et al., 2021), soil moisture (Liu et al., 2021), and oil spill detection (Kolokoussis et al., 2018). Such studies commonly make use of a variety of remote sensing indices, including the NDVI, (Peddinti et al., 2021; Roßberg, 2023), the Enhanced Vegetation Index (EVI),(Ram et al., 2009; Nepita-Villanueva et al., 2019), and the Water Index (Choudhary and Ghosh), which have been developed for the assessment and characterisation of environmental phenomena.

Nevertheless, the precise and rapid extraction of environmental information from images for monitoring purposes remains a time-consuming and challenging task (Carless et al., 2019; Kalacska et al., 2021). In addressing this challenge, QGIS provides a variety of plugins, offering a range of professional GIS applications that are easily accessible to users and can be downloaded directly. In addition to plugins developed by the QGIS team, independent organisations and developers contribute by creating and integrating their own plugins into the QGIS software, thereby demonstrating the collaborative approach that characterises the project. To provide an example, the Semi-Automatic Classification Plugin (SCP) is an especially valuable tool for the downloading, preprocessing and analysis of remote sensing data (Congedo, 2016; Congedo, 2021). Moreover, the SCP allows for the calculation of environmental indices, including the NDVI and the Atmospherically Resistant Vegetation Index (ARVI). Furthermore, the System for Automated Geoscientific Analyses (SAGA-GIS) (Conrad et al., 2015) and the Geographic Resources Analysis Support System (GRASS-GIS) are widely adopted tools for filtering, classifying, and analysing spatial data (GRASS-GIS, 2023). However, despite the usefulness of these popular plug-ins, non-experts may find it difficult to understand the manual input requirements of each tool. In addition, many users only need a partial set of the available functions, making the full software package unnecessarily complex. A simplified design with automated, single step calculations could effectively address these usability challenges. In this research, a novel plugin called QSVI (QGIS Sentinel Indices plugin) was designed with the primary purpose of improving the calculation of several indices that are crucial for remote sensing applications.

The plugin provides an easy-to-use interface that simplifies the calculation of several indices, including NDVI, EVI, ARVI, LAI, CVI, UTFVI and TDI. While indices such as NDVI and EVI are well known, the QSVI plugin improves the calculation process, allowing users to perform efficient analysis of large datasets and calculate multiple indices simultaneously. Its design supports fast computations on large datasets, providing scalability that benefits both beginners and experts.

In addition to simplifying analysis for students and researchers, the QSVI plugin is designed to improve the efficiency of environmental monitoring within an open source GIS environment. Unlike other tools such as SAGA-GIS and GRASS-GIS, which offer extensive but complex functionality, QSVI focuses on providing a simplified experience with automated, single-step calculations of basic indices such as NDVI, EVI, ARVI, and LAI. While these indices are widely recognised, QSVI differs by simplifying their calculation processes, making it easier to analyse large datasets quickly and reliably. This simplification is particularly valuable for users with less experience in remote sensing, promoting accessibility and operability.

The QSVI plugin therefore provides a double benefit: it supports basic education in environmental data analysis while facilitating advanced researchers. By providing an accessible interface with rapid processing capabilities, QSVI allows users to monitor critical environmental metrics with more ease and speed, helping to support informed decisions about environmental monitoring. In summary, QSVI is an adaptable and time-efficient tool that serves as both an educational resource and a practical application for environmental management, marking a significant advancement within the open source GIS community.

In recent years, the use of digital software for monitoring environmental dynamics in remote sensing areas has increased widely. These technologies are faster and more effective than the traditional methods. This is why researchers are increasingly preferring this approach. Research has indicated that when people use digital software, their performance increases by 15% to 25% (Bernard et al., 2014; Sung et al., 2016; Wulandari et al., 2021). Moreover, when interacting with software during the process, they may perform their own analysis and share information with other people (Dinçer, 2017; Gomez et al., 2010); therefore, this process can be executed rapidly, iteratively, and quickly with complex multi-layer datasets at different scales rather than traditional methods.

Some research shows that using environmental indices such as the Normalized Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI), which are used for land use monitoring, show better performance (Aldhebiani et al., 2018). Moreover, these indices have often been used in many studies (Bastiaanssen et al., 2000; Wachendorf et al., 2018). Conversely, in addition to software, it is crucial to identify open-access data to achieve economic results for education and research purposes. This is because high-cost data cannot support many users.

Landsat imagery is preferred for classification and environmental monitoring, because it is freely downloadable and includes multispectral and thermal bands (Narine et al. 2009; Ran et al. 2017). The Copernicus program supplied a free dataset that included sentinel images. Sentinel-2 Level 2A (L2A) is the preferred choice with atmospherically corrected data, and is thus available in a directly analyzable format. The Sentinel-3 satellite is also advantageous owing to its thermal band, which is used for temperature and climate research (García, 2022).

These remote sensing images often prefer many areas, such as grassland monitoring (Potočnik Buhvald et al., 2022), risk management (García-Fernández et al., 2020), land classification and agricultural studies (De Fioravante et al., 2021; Segarra et al., 2020), surface temperature, soil moisture, oil spill detection (Liu et al., 2021; Nie et al., 2021; Zakzouk et al., 2024), NDVI, EVI, and water index (Choudhary and Ghosh, 2022; Peddinti et al., 2021; Ran et al., 2017; Roßberg and Schmitt, 2023). Currently, these analyses, owing to spectral indicators, produce accurate and reliable results in monitoring and detection (Carless et al., 2019), but are still time-consuming and difficult. To overcome these challenges, many software packages and plug-ins have already been used. One of them is QGIS (Quantum GIS), a Geographic Information System software.

Its core team allows many independent organizations to contribute by integrating their own plugins. One of them was the Semi-Automated Classification Plugin (SCP), which is capable of downloading and performing analyses such as the NDVI and the Atmosphere Resistant Vegetation Index (ARVI) (Congedo, 2021). Open-source plugins such as the System for Automated Geoscientific Analyses (SAGA-GIS) (Conrad et al., 2015) and Geographic Resources Analysis Support System (GRASS-GIS) (GRASS, 2025) provide advantages in data filtering, classification, and spatial analysis in this application. However, the use of this popular software requires a high level of expertise and experience. However, most people prefer basic functions, simple calculations, and one-step processes.

To address this, this study aims to introduce a new tool integrated into QGIS, called the Sentinel Vegetation Indices (QSVI). It provides computational simplicity for environmental indices, which are commonly used in most remote-sensing applications. This tool can automatically and quickly calculate many indices, such as NDVI, EVI, Leaf Area Index (LAI), Canopy Vegetation Index (CVI), thermal indices, Urban Thermal Field Variance Index (UTFVI), and Thermal Discomfort Index (TDI), on the same platform, even for large datasets. Owing to its simple and user-friendly interface, it offers an efficient and preferred solution for both beginner and advanced researchers.

2 Material And Methods

2.1 Development of the QSVI plugin

QGIS is a widely used open-~~access~~source GIS platform that ~~provides~~ is recognized for its extensive ~~support for~~ capabilities in monitoring and analyzing geospatial data. Its ability to ~~extend~~enhance GIS functionality ~~and~~combined with the support of a large development community ~~contribute~~contributes to its effectiveness and popularity. The QSVI plugin, developed ~~within~~by the QGIS plugin community, ~~is~~was written in Python 3.9 and designed using Qt Designer, a tool for creating integrated user interfaces within the QGIS. This design does not require ~~additional~~any extra Python packages, making it compatible with the standard desktop versions of QGIS ~~across~~for all operating systems.

~~After installation, the QSVI plugin is accessible from the Raster menu on the main QGIS toolbar (Figure 1a-b).~~

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman), Kalın Değil

Biçimlendirilmiş: Başlık 1

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman), Kalın Değil

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), 11 nk, Türkçe (Türkiye)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

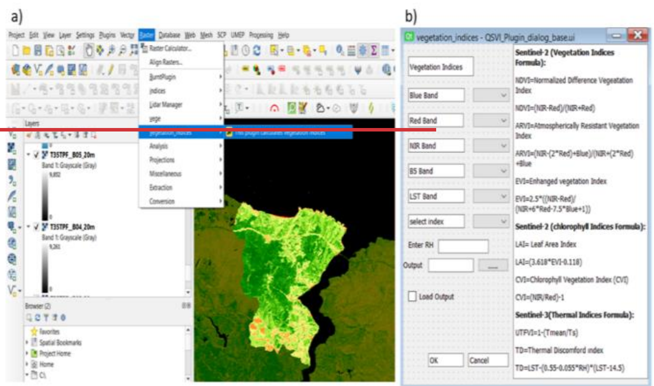


Figure 1. a)Plugin menu tab in Qgis software b) The tabs of QSVI graphical user.

To install the plugin, users simply extract the ZIP file and navigate to "Plugins" -> "Manage and Install Plugins." After installation, the plugin was automatically integrated into the user interface and could be accessed directly from the raster menu in the QGIS toolbar. This allows users to immediately analyze the index data (Fig. 1a-b).The tool simplifies the processing of remote sensing images and allows for the efficient calculation of various indices. For optimal performance, especially with images larger than 1 GB, a computer with a minimum of 8 GB RAM is recommended.

The QSVI plugin requires a remote sensing image as its primary input. Users can load an image either directly from the interface or select it from a list of images already available in QGIS. Supported image formats include tif and jpg. After selecting the image, users can choose the desired index from the provided options, and the calculation process will begin. Once complete, the resulting image is saved in the user-selected output folder.

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), 11 nk, Türkçe (Türkiye)

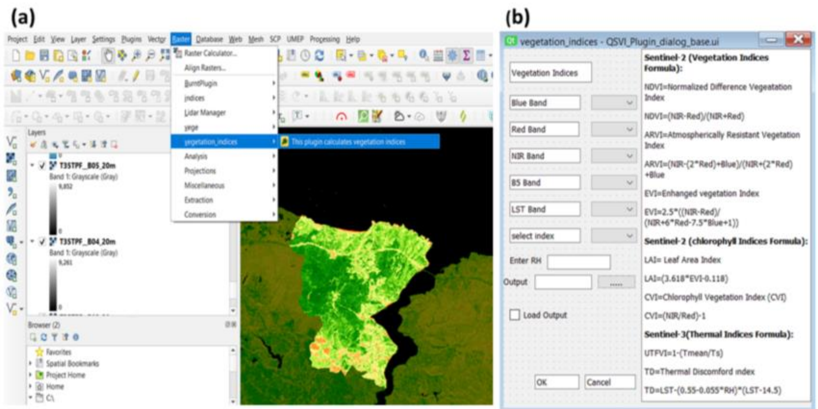


Figure 1. (a) Plugin menu tab on the QGIS platform, **(b)** Tabs of the QSVI graphical user interface.

This tool simplifies the processing of remote sensing images and allows for the effective calculation of different indices. To ensure optimal performance, particularly with images exceeding 1 GB, it is advisable to use a computer with at least 8 GB RAM.

2.2 Process description

The QSVI plugin's processing functionality iswas divided into three categories: vegetation, chlorophyll, and thermal indices, which arewere designed for comprehensive environmental analysis (FigureFig. 2). The QSVI plugin requires a remote-sensing image as its primary input. Users can load an image directly from the interface or select it from a list of images already available in QGIS. The supported image formats include TIFF and JPEG. The calculation process begins after selecting the image and desired index from the provided options. Once completed, the resulting image is saved in the user-selected output folder.

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman), Kalın Değil

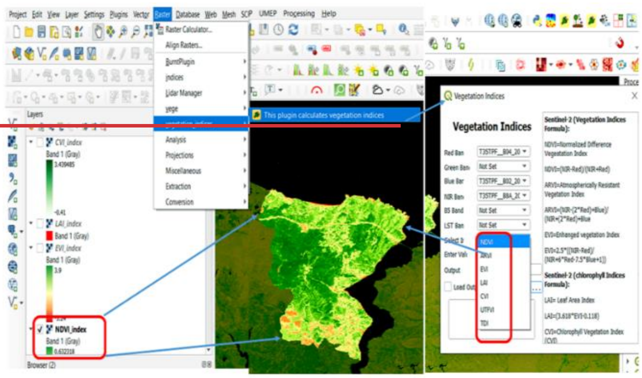
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman), 10 nk

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman), 10 nk, Yazı tipi rengi: Siyah, Aralık 16 nk

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), 11 nk, Türkçe (Türkiye)



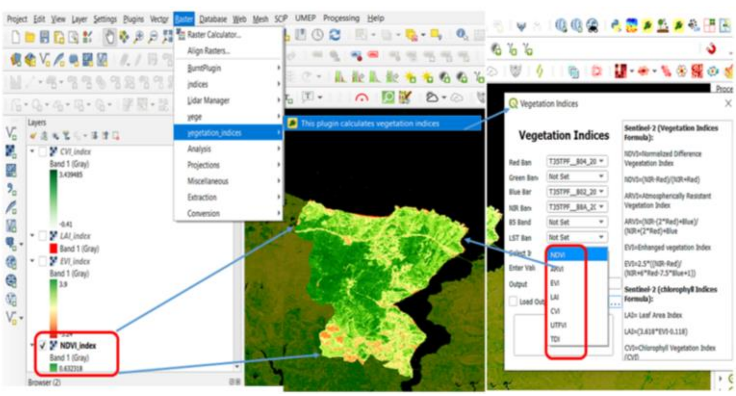


Figure 2. Overview of QSVI plugin functionalities (Developed by Nuray Baş~~)~~)).

~~Table 1 lists these indices along with their corresponding formulas. Once a~~ The process was divided into two main steps: loading the remote sensing image ~~is selected~~ and selecting the necessary indices from the ~~pop-up window, the plugin~~icons at the interface. Users then specify the output folder and the file names. QSVI automatically calculates the ~~chosen~~selected indices~~.~~

~~**Table 1** Environmental~~ and then generates a raster output file, either in the TIFF or JPEG format, containing the calculated indices ~~computed by the QSVI plugin.~~. Table 1 presents all indices, along with their corresponding formulas.

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), 11 nk, Türkçe (Türkiye)

Biçimlendirilmiş: Girinti: Sol: 2.56 cm

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirilmiş: Girinti: İlk satır: 1.27 cm, Aralık Önce: Otomatik, Sonra: Otomatik

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

	Index	Formula	Reference
Vegetation ~~indices~~	NDVI	$NDVI = \frac{NIR-RED}{NIR+RED}$	~~Rouse et al.(1974), Crippen (1990) Houete (1988)~~(Crippen,
	ARVI	$ARVI = \frac{NIR-(2*RED)+Blue}{NIR+(2*RED)+Blue}$	~~Kaufman (1984); Tanre et al., 1992)~~(Kaufman, 1984;
	EVI	$EVI = 2.5\frac{NIR-RED}{(NIR+6*RED-7.5*Blue+1)}$	~~Huete et al.(2002)~~(Huete et al., 2002)
Chlorophyll	LAI	LAI=3.618*EVI-0.118	~~Boegh et al. [60]~~(Boegh et
	CVI	$CVI = \frac{NIR}{RED} - 1$	~~Vincini et al. (2007)~~(Jiang et al., 2006)
Thermal ~~indices~~	UTFVI	UTFVI = 1 - (Tmean/Ts)	~~Zhang et al. (2006)~~(Weng et al., 2004)
	TDI	TDI=LST-(0.55-0.055*RH)*(LST-14.5)	~~Gartland (2011)~~ (Thom, 1959)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirilmiş Tablo
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

The process is divided into two main steps: first, loading the remote sensing image, and second, selecting the necessary indices from the icons in the interface. Users then specify the output folder and file name. Upon completion, the plugin generates a raster output file, either in Tiff or Jpeg format, containing the calculated indices.

In the vegetation category, users can access the NDVI, EVI and ARVI. These indices are an important remote sensing tool for monitoring vegetation health and dynamics. While NDVI is a widely recognized metric for assessing vegetation cover by measuring the difference between near-infrared and red reflectance, its effectiveness is further enhanced within the QSVI plugin through optimized computational processes. This allows the effective management of large datasets, which is essential in studies where rapid and adaptable data analysis is required. EVI is a modification of NDVI that is more sensitive to high biomass concentrations. It accounts for atmospheric conditions and provides a more accurate representation of vegetation density, which is particularly advantageous in regions with dense vegetation. The ARVI is also designed to address the issue of atmospheric disturbance by taking into account the reflectance of blue light, thereby making it an effective method for correcting the potential biases. Together, these vegetation indices not only facilitate the monitoring of ecological health but also contribute to the understanding of plant responses to environmental changes (Lei et al. 2024; Jombo & Adelabu, 2022).

The advanced capabilities of the QSVI plugin allows researchers to apply the indices effectively across extensive geographical areas, facilitating a comprehensive and timely analysis of vegetation dynamics with high accuracy. In addition to the vegetation indices, the chlorophyll indices play a vital role in understanding plant physiology and ecosystem functionality. The CVI and LAI are of great importance in evaluating plant health and photosynthetic capacity at the canopy level. The CVI provides insights into chlorophyll concentration, which is critical for assessing crop health and productivity, while the LAI quantifies leaf area and helps to understand overall plant growth and canopy structure. Furthermore, the thermal indices category, which includes UTFVI and the TDI, is crucial for understanding the thermal dynamics of urban environments. The UTFVI is a valuable tool for urban planners in their efforts to mitigate the Urban Heat Island (UHI) effect, as it allows for the assessment of the intensity of thermal stress on urban vegetation. TDI evaluates thermal discomfort in human populations, informing public health initiatives and urban design strategies aimed at enhancing community well-being. Together, these thermal indices are essential for assessing the impacts of urbanization on ecological health and developing strategies for climate adaptation. (Ren et al. 2023).

3 Study Area and Data

The study area selected is the**Table 1.** The environmental indices were computed using the QSVI plugin.

In the vegetation category, the NDVI, EVI, and ARVI indices can be accessed easily. These indices are important for monitoring the health and dynamics of the vegetation on Earth. NDVI determines vegetation change by calculating the difference between near-infrared and red-band reflections. These analyses were performed quickly and practically, owing to the plugin's integrated calculation processes. Even large raster datasets can be processed within a short time. Different indices showed different sensitivities to environmental variables in the analysis. For example, EVI provides a more accurate representation of vegetation than NDVI, because it focuses more on ground brightness and atmospheric effects. On the other hand, ARVI uses blue light reflectance information, which is advantageous for studies in areas with high atmospheric pollution. In fact, all these indices do more than monitor ecological health. They also measured the responses of plants to environmental changes and presented these changes to researchers and practitioners (Jombo and Adelabu, 2022; Lei et al., 2024).

The QSVI provides a simplified and practical application of these dynamics with remotely sensed imagery over large geographic areas. CVI and LAI, which are partially different and also focus on plants, monitor plant growth and development. Thus, it contributes to the sustainability of agricultural and forestry activities.

3 Study Area and Data

The study area is the Sarıyer, municipality ~~of Sarıyer, covering an area of 177km² on~~, which covers 177 km² of the European side of Istanbul (41°9'44.28″" N 29°2'50.64~~""~~″ E). Sarıyer is bordered by the districts of Beşiktaş and Kâğıthane to the south, Eyüpsultan to the west, ~~the~~ Bosphorus to the east, and the Black Sea to the north (~~Figure~~Fig. 3).

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

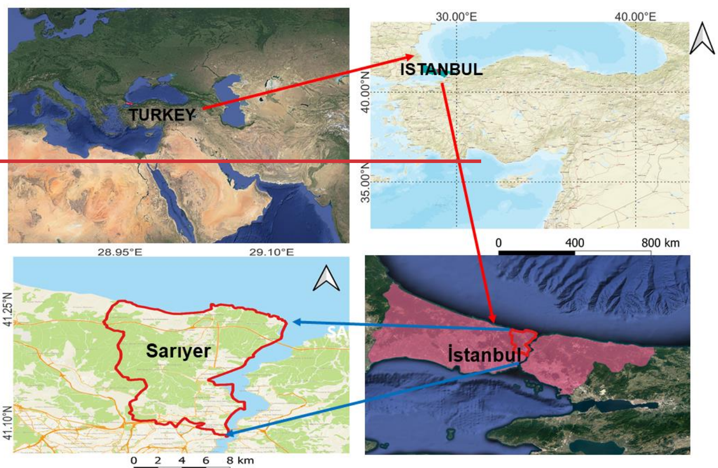


Figure 3. Location of the plugin's testing area (Basemap: Esri ArcGIS Online, 2024).

The coastline along the Bosphorus is ~~characterised~~characterized by steep cliffs and crags, while Sarıyer is ~~known~~renowned for its rich biodiversity, including the eastern end of the Belgrade Forest, which is situated within the

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), 11 nk, Türkçe (Türkiye)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

municipality's boundaries. Furthermore, the area defined by the Rumelikavağı-Rumelifeneri-Kilyos triangle is ~~characterised~~characterized by a high degree of forestation. However, this has been partially affected by the recent construction of residential buildings~~ in recent times.~~. Sarıyer ~~displays~~has a Black Sea climate~~, with temperatures~~ characterized by seasonal variations in temperature and humidity~~ levels that vary seasonally, particularly~~, especially along the coastline.

During the measurement period (1950~~ – ~~–2023), Sarıyer ~~experienced~~recorded its lowest temperature of -9 °C in February and~~ its~~ highest temperature of 40.6 °C in July, with an average annual precipitation of 662.5 mm (Turkish State Meteorological Service, 2023). The majority of Sarıyer's land area is covered by rich natural vegetation ~~(Turkish State Meteorological Service, 2022). As of 2022, the population of Sarıyer is reported to be 350,454 (Turkish Statistical Institute, 2022).~~(Turkish State Meteorological Service Official Web Sites 2025). The image data from Sentinel-2 and Sentinel-3, which were atmospherically corrected and in the TIFF format, were utilized in this study. The data were downloaded from https://scihub.copernicus.eu on July 9, 2022, with a total disk size of 1010 MB.

~~The image data from Sentinel-2 and Sentinel-3, atmospherically corrected and in TIFF format, were used in this study. The data were downloaded from https://scihub.copernicus.eu on 9 July 2022, with a total size on disk of 1010 Mb.~~

4 Results

~~The results obtained in this~~This study ~~provide~~provides important findings regarding the processing and analysis of various environmental indices. ~~The methods and tools used were effectively applied to the calculation of~~Many indices, including vegetation, chlorophyll, and thermal indices, ~~allowing~~have been calculated using the QSVI tool, and their potential applications in research and education have been investigated.

Various steps were performed to generate output data. After the ~~monitoring of environmental changes over the defined region. The detailed results of these analyses are presented in this section.~~

~~Once the necessary~~ raster remote sensing data ~~has been uploaded to~~are displayed on the screen, the QSVI algorithm ~~proceeds to calculate~~computes the indices and ~~thus generate~~generates the ~~related results as output~~corresponding result files. The processing tab ~~are categorized~~is divided into three ~~sections~~categories: vegetation, chlorophyll, and thermal indices. Users must select a preferred category before proceeding with ~~the~~ index calculation. ~~Under~~The NDVI, ARVI, and EVI indices were generated within the vegetation category~~, NDVI, ARVI, and EVI indices are generated~~ to assess vegetation greenness. In this ~~paper, to test the QSVI plugin outputs~~study, Sentinel-2 Level 2A products were used as a real data source~~. Thanks~~ to test the QSVI plugin outputs. Owing to its open-access data policy, users ~~have~~can access ~~to~~ four spectral bands (~~10m~~10 m resolution) and six spectral bands (~~20m~~20 m resolution).

NDVI and EVI are valuable for monitoring vegetation status, especially in areas characterized by high biomass densities. EVI, which is more sensitive than NDVI, especially in densely vegetated areas, offers nuanced insights because it is less susceptible to atmospheric conditions. (Bounoua et al., 2000; Huang et al., 2021; Xiao et al., 2003). These differences

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), 11 nk, Türkçe (Türkiye)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), 11 nk, Türkçe (Türkiye)
Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), 10 nk
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman), 10 nk, Kalın Değil
Biçimlendirilmiş: Başlık 1, Sekme durakları: 15.7 cm, Sola
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

provide EVI preferences for agricultural and forest health applications. The results are illustrated in Figure 4a-b, which shows that the NDVI vegetation spectral reflectance range was smaller than that of the EVI (Tucker, 1977),(Figure 4a-b). Additionally, ARVI corrects for atmospheric scattering effects by utilizing blue-light reflectance, thereby influencing red-light reflectance (Fig. 4c).

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

NDVI and the EVI are of significant value in the monitoring of vegetation status, particularly in areas characterised by high biomass densities. EVI, being more sensitive in densely vegetated areas compared to NDVI, offers nuanced insights due to its lesser susceptibility to atmospheric conditions (Xiao et al., 2003; Bounoua et al., 2000; Huang et al., 2021). This difference is illustrated in Figure 4a-b and NDVI vegetation spectral reflectance range is smaller than EVI (Tucker, 1977);(Figure 4b).

Additionally, ARVI corrects for atmospheric scattering effects by utilizing blue light reflectance, thereby influencing red light reflectance as well (

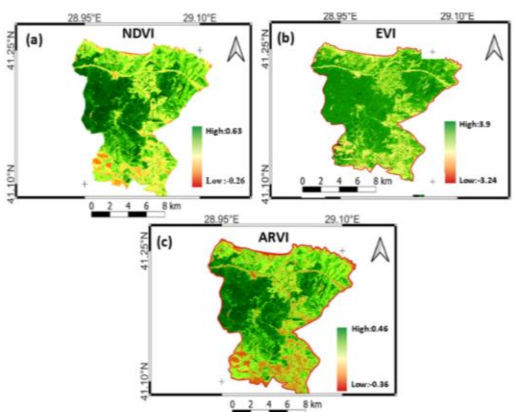


Figure 4c).

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman), Kalın

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

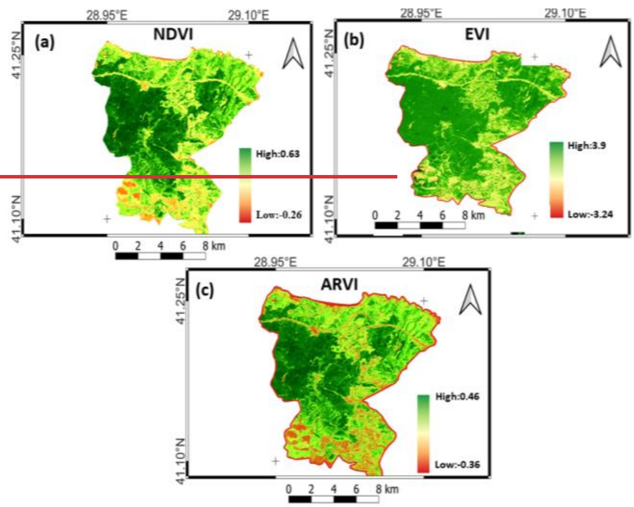


Figure 4. Calculated from Sentinel-2 images with pluginplugins (a) NDVI indices, (b) EVI indices, and (c) ARVI indices.

In the second category which is, the CVI and LAI index were generated in to quantify the chlorophyll index, which are particularly providingprovides information at the canopy scale. These indexindices can be estimated from the overall photosynthetic capacity of athe canopy (Broge and Leblanc, 2000); (Figure 5b-c). Figure(Broge and Leblanc, 2001) (Fig. 5a depicts the study area as observed through Google imagery. -b).

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirilmiş: Girinti: Sol: 2.54 cm

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirilmiş: Girinti: İlk satır: 1.27 cm

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi:

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

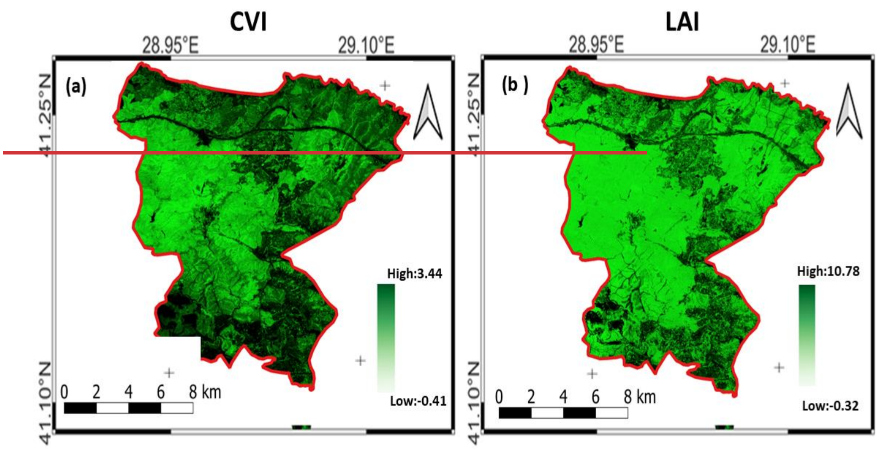
Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), Desen:Yok



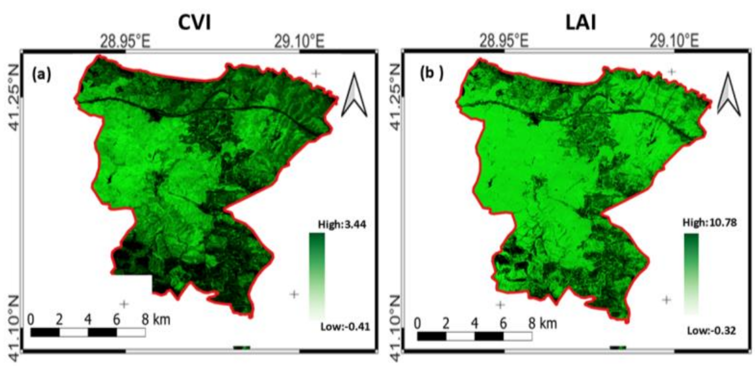


Figure 5. Calculated from Sentinel-2 images with pluginplugins (a) Google image (b) CVI indices (cand (b) LAI indices.

The addition of a thermal band to the Sentinel-3 satellite, which is not present in the Sentinel-2, makes it an optimal choice for the calculation of thermal indices such as UTFI and TDI. The UTFVI is a frequently used method in ecological thermal studies due to its correlation with Land Surface Temperature (LST) and its consideration of thermal impact. This index is designed to assess environmental well-being by evaluating the UHI effect across the whole study area, categorizing pixels into six levels ranging from excellent to worst (Sharma et al., 2021; Naim et al., 2021). The ecological conditions are represented visually through a colour gradient, with red representing the most severe conditions and green representing the

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

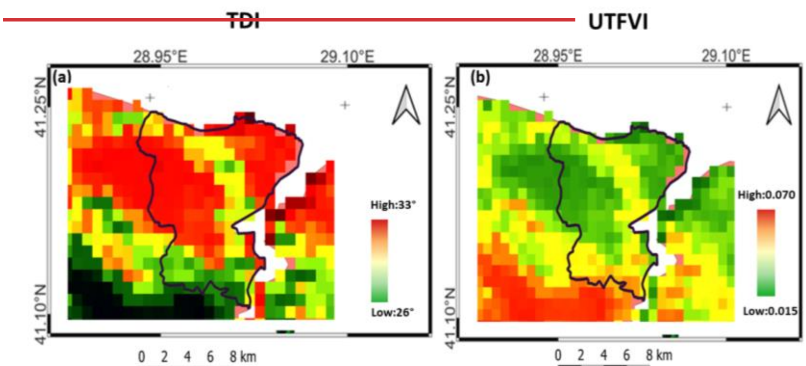
Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirilmiş: Girinti: Sol: 1.27 cm

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), 11 nk, Türkçe (Türkiye)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman) least severe conditions (Figure 6c). Moreover, the monitoring of the intensifying UHI impact provides valuable data for the development of urban planning and public health strategies. UHI refers to the rising temperatures experienced in urban areas relative to surrounding rural areas due to human activities and infrastructure. These effects have been found to have significant impacts on human health.

TDI is a psychophysical measure used to assess how individuals experience and perceive a combination of heat and humidity. It quantifies the discomfort experienced by individuals in different environmental conditions. Figure 6b in the study illustrates the estimated thermal comfort levels (in °C) based on these conditions. Additionally, psychological parameters play a role in influencing thermal comfort, as noted by De Dear et al. (1998). TDI categories define comfort levels as follows: temperatures ranging from 15 to 19.9°C are considered comfortable, temperatures between 26.4 and 29.9°C are categorized as very hot, and temperatures exceeding 30°C are classified as torrid, according to Thom (1959). The combined impact of these factors serves to underscore the necessity of comprehending and mitigating UHI effects for human well-being.



Plants on Earth are often subjected to stress owing to environmental factors. As a result, vegetation changes have occurred. The LAI, which is used to detect these changes, was designed to monitor and analyze this negativity in plants (De Bock et al., 2023). CVI measures chlorophyll content in plants under stress (Broge and Leblanc, 2001; Poletaev and Lisetskii, 2024). LAI provides information on the density and distribution of plants, whereas CVI identifies changes in plant health and chlorophyll content. The CVI is an important index that assesses the level of physiological stress induced by chlorophyll reduction in plants, thereby enabling timely intervention in plant management (Vijayalakshmi et al. 2024).

Unlike Sentinel-2, the Sentinel-3 satellite includes a thermal band obtained with a Sea and Land Surface Temperature Radiometer (SLSTR) sensor, which enables the acquisition of detailed information about the Earth's temperature. Thus, owing to the strong correlation between UTFVI and Land Surface Temperature (LST), thermal effects in urban areas can be identified (Naim and Kafy, 2021; Sharma et al., 2021). This process is performed by grouping all pixel values in the image according to the thermal stress level. Another extremely important thermal index is the TDI. This index was used to assess the combination of heat and humidity perceived by the individuals. It is a psychophysical measure of the discomfort experienced by individuals under different environmental conditions. The TDI categories define comfort levels as follows: temperatures ranging from 15 to 19.9°C are considered comfortable, temperatures between 26.4 and 29.9°C are categorized as very hot, and temperatures exceeding 30°C are classified as torrid, according to TDI . Additionally, psychological parameters play a role in influencing thermal comfort, as noted by de Dear and Brager (1998). The combined impact of these factors underscores the need to comprehend and mitigate the effects of Urban Heat Islands (UHI) on human well-being. The UHI effect negatively affects the quality of life in cities and increases energy consumption due to high temperatures, especially during summer months. The UTFVI measures the UHI effect on the surface and helps reduce its negative impacts on the city (Degerli and Cetin, 2023). The relationship between the UTFV and UHI provides important data for urban planning and public health strategies. Moreover, it can help assess ecosystem health by monitoring vegetation changes. Bu olumsuzlukların yanında bitki örtüsünde zamanla beklenemdik değişimler meydana gelebilir. Figure 6a illustrates the thermal stress (TDI, °C), whereas Figure 6b displays the UTFVI thermal comfort levels. Red indicates the highest level of thermal stress, whereas green indicates the lowest level of thermal discomfort.

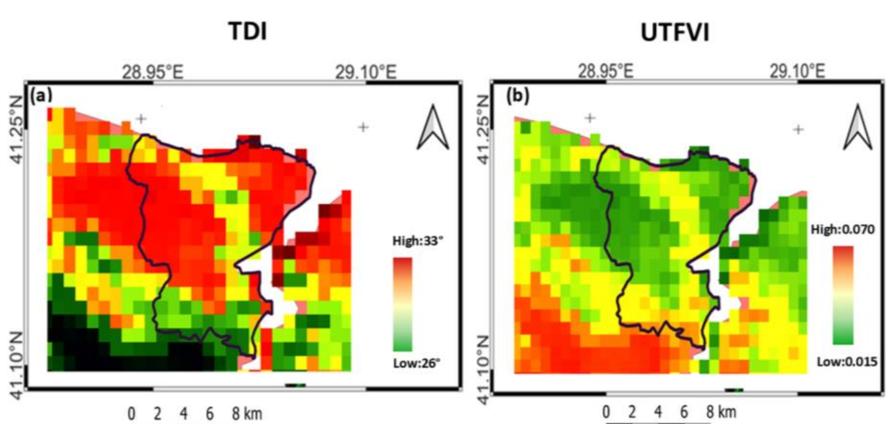


Figure 6. Calculated from Sentinel-3 images with ~~plugin~~plugins (a) TDI ~~indices~~ thermal stress and (b) UTFVI ~~indices~~thermal comfort level.

~~These calculated indices can contribute to assessing ecosystem health by monitoring changes in vegetation. Since environmental factors have the potential to induce stress and result in alterations to vegetation, as well as affect plant growth patterns, LAI is designed to monitor plant density and growth. This allows for the detection and analysis of these changes.~~

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi:

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirilmiş: Girinti: İlk satır: 1.25 cm

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), 11 nk, Türkçe (Türkiye)

The CVI measures the amount of chlorophyll in plants and can be used to detect and manage stress in plants (Broge and Leblanc, 2000; Xu et al., 2023). The analysis of temporal variations in LST using the UTFVI can help reduce the impact of urban heat islands (UHI) by providing a means of quantifying the UHI effect (Çevik Degerli, B., & Cetin, M., 2023).

QSVI was compared to other widely used applications, such as

The study also compared the raster calculation menu in other popular GIS software (SAGA-GIS, GRASS-GIS, ArcGIS, and the QGIS raster calculator menu, in order to assess its) to determine the performance. The computations were conducted on a computer with 8 GB of RAM and for a 500 MB Sentinel-2 dataset and a 510 MB Sentinel-3 dataset.

of the QSVI (Table 2).

Table 2. Comparison of computation times between QSVI and other popular software.

Comparison of Index Calculation Times between QSVI and different Software

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), Kalın Değil, Desen:Yok

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), Desen:Yok

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

~~As shown in Table 2, the QSVI plugin~~

	Indices	Data-Size	QGIS raster calculator	ArcGIS raster calculator	GRASS GIS	SAGA GIS	QSVI-plugin
		(mb)	(sn)				
Vegetation	NDVI	Sentinel-2 (500)	21.2	20.5	23.4	24.4	4.2
	ARVI		26.7	25.8	25.2	26.8	5.5
	EVI		25.1	26.3	25.8	24.1	5.2
Chlorophyll	CVI		21.2	20.2	22.5	21.5	4.5
	LAI		18.3	19.3	23.7	22.7	4.2
Thermal	UTFVI	Sentinel-3 (510)	17.6	16.2	19.3	20.3	4.3
	TDI		17.9	18.2	19.4	20.4	4.2
	Total:	1010	148	146.5	159.3	160.2	32.1

The calculations were performed on a PC with 8 GB of RAM using a 500 MB Sentinel-2 dataset and a 510 MB Sentinel-3 dataset. The results indicated that QSVI significantly ~~faster in calculating certain indices compared to~~outperformed other ~~popular~~ GIS software ~~when considering total calculation times. For instance~~in terms of the overall processing time. At the end of the process, the QGIS raster calculator ~~required a total of~~ took 148 ~~seconds~~s to complete ~~the calculations~~, whereas ~~the~~ QSVI ~~plugin~~ finished in ~~just~~ 32.1 seconds~~, resulting in a~~. Thus, QSVI reduced the processing time ~~reduction of~~by approximately 116 seconds or approximately 1.93 minutes.

Similarly, the ArcGIS raster calculator ~~required~~takes 146.5 seconds~~, with QSVI saving around 1~~ to complete, whereas QSVI reduces this time by approximately 1.90 minutes~~. The~~ (114 seconds). GRASS GIS ~~process took~~required 159.3 seconds, while QSVI ~~reduced~~cut this time by ~~approximately~~about 2.12 minutes~~.~~ (127 seconds). Similarly, while SAGA GIS ~~required~~took 160.2 seconds, ~~and~~ QSVI saved ~~about~~approximately 2.14 minutes. In ~~total~~particular, for 1 GB datasets, QSVI ~~reduces computation~~decreases the processing time by ~~about~~an average of 2.1 minutes compared ~~to~~with other popular software~~, particularly for 1 GB datasets.~~

. These results demonstrate that the QSVI plugin not only ~~offers significant time savings but also enhances overall~~ provides high processing efficiency ~~in processing remote sensing data. Its ability to significantly reduce computation time makes it~~ but also greatly simplifies the workflow for users by saving time when analyzing large datasets. QSVI is a valuable tool for both academic research and educational ~~and practical~~ applications.

5. Discussion

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirilmiş Tablo

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), Vurgulu Değil

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

In this study, a new plugin was introduced to assess the calculation of vegetation indices more practically and quickly. These indices are widely used in environmental monitoring ~~and analysis.~~

~~5~~ using remote sensing technology. While they can be calculated on various platforms, the new plugin (QSVI) is designed to allow for a simpler solution. Simultaneously, its open-source code makes it accessible to a large number of users, making it an alternative study with large datasets.

The primary contribution of this research is not the development of new environmental indices; rather, it is faster and easier to use all the indices on the same platform. This provides an easily accessible choice for both beginners and experts studying vegetation dynamics.

Today, ~~**Discussion**~~

~~This study introduces the QSVI plugin, a novel tool designed for integration with QGIS, which facilitates the calculation of a variety of indices related to vegetation, chlorophyll, and thermal characteristics. While vegetation indices such as NDVI, EVI and ARVI are well established in remote sensing for monitoring ecological health, the QSVI plugin differs by simplifying the computational processes required to calculate them. This makes it much more efficient to use with large datasets, allowing users to perform fast, scalable analyses that are particularly useful in environmental monitoring applications.~~

~~The main contribution of this paper is not in the novelty of the indices themselves, but in the improvement of their computational efficiency. By facilitating the processing of multiple indices, the plugin provides both beginners and experts with an accessible and effective tool for large-scale data analysis. Furthermore, the open-source nature of QSVI allows for continuous adaptability and ensures its long-term applicability in the changing field of environmental monitoring.~~

~~In the field of~~ remote sensing digital software, which is widely used ~~packages available~~by researchers such as ArcGIS (~~Redlands, C.E.S.R.I. (2011~~ArcGIS Desktop, ArcMap & ArcCatalog | Esri's Legacy GIS Software, 2025), SAGA-GIS, and GRASS GIS ~~are~~, is known to be very provisional and for ~~their~~its sophisticated algorithms in data processing and analysis. However, ~~there is a need for an easy interface and shorter~~not all users can perform powerful computational ~~times. Consequently,~~processes. QSVI ~~offers advantages in terms of processing time and ease of use. Its user-friendly interface~~ facilitates the automation of calculations and ~~the~~ implementation of a simplified~~-~~ set of functions, making it accessible to non-expert users. ~~While there~~There is potential for further improvement by incorporating additional functionalities ~~in the future, it is crucial~~ to maintain the current ~~concise and~~ logical structure of the plugin. For ~~instance, considering the addition of~~example, adding a new function ~~to download satellite data alongside calculation tools could~~ can enhance its utility.

~~In a comparative context, QSVI can be compared with other existing remote sensing plugins, such as PI2GIS (Correia et al., 2018). While QSVI shares similarities with PI2GIS in terms of its learning strategy, it distinguishes itself by incorporating not only vegetation indices but also chlorophyll and thermal indices within its user interface. There is potential for further development, particularly by developing the range of available indices.~~

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirilmiş: Normal, Sola, Satır aralığı: tek

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

However, QSVI can be compared with the existing remote sensing plugins, PI2GIS, which is very convenient for processing remote sensing data. (Correia et al. 2017). QSVI shares similarities with PI2GIS in terms of its learning strategies. OSVI distinguishes them by incorporating not only vegetation indices, but also chlorophyll and thermal indices. In the future, different indices could be added to the QSVI for further development.

It is also worth mentioning that the Q-LIP add-on, is designed for users with limited remote sensing experience in remote sensing.. Furthermore, the plugin developed by Sebbah et al. (2021)(Sebbah et al., 2021) for downloading and calculating various environmental indices using Landsat images is notable for its efficiency; it can process a 1.73 GB Landsat-8 image in just 3 minutes, whereas QSVI demonstrates its capabilities by processing an approximately 1 GB image in a total of 2.1 minutes for Sentinel-2 and Sentinel-3 datasets.

After comparing QSVI with other pluginsAs a result, QSVI is a newcan be an alternative, particularly in for education and research, especially because of its basicsimple interface and index calculationscomputational capability. Additionally, QSVI have aalso reduced the processing time of approximatelyfor Sentinel-2 images by about 2.1 minutes for Sentinel images on standard systems (8 GB RAM, 1 GB disk space). UsingFor Sentinel-3, the time was reduced by 13.6 seconds. The QSVI is available without additional installation using GDAL/OGR and NumPy, QSVI minimizes installation requirements by forgoing external dependencies, enhancing accessibility. Although. However, QSVI is aimed at basic environmental analysis and is not intended to replace ARC-GIS, SAGA-GIS, and GRASS GIS-specialized platforms, QSVI consistently delivers reliable, compatible results, supporting its use in environmental monitoring and analysis..

6. CONCLUSIONS

In both higher education and research, the use of computational tools in remote sensing**6 Conclusion**

In particular, high-resolution remote sensing imagery requires extensive analysis and data processing. The complex interfaces and sophisticated algorithms of digital tools used for this purpose, can be challenging, especially for beginners. The complex interfaces of these tools can make visualisation, analysis and experimentation difficult for students and early career researchers too. In addition, the detailed set of tasks involved in remote sensing applications often requires considerable time and effort, which can further affect accessibility and ease of learning in the field

The primary objective of this study was to develop a new plugin for QGIS with a user-friendly interface, specifically designed for beginners. Aimed at university students and researchers, thisbeginner researchers or users from different disciplines. This study developed an innovative evaluation methodology and introduced a new Python plugin within the existing QGIS software. This plugin provides a graphical user interface (GUI) with a simple interface and practical computational capability that enablesallows users from variousdifferent disciplines to perform remote sensing taskscompute various environmental vegetation indices, without needingthe need for extensive background knowledge in the field.

This study introduces QSVI, a plugin for QGIS that is designedIn this respect, the tool is not only as an educational tool but also as a practical applicationtool for researchers interested in the environmental monitoring and analysisproblems of

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman), Kalın Değil

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirilmiş: Normal, Sola, Satır aralığı: tek

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Varsayılan Paragraf Yazı Tipi, Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Varsayılan Paragraf Yazı Tipi, Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirilmiş: Girinti: İlk satır: 0 cm

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

the Earth. Unlike standard tools, QSVI includes calculations for vegetation, chlorophyll, and thermal indices, streamlining their use through a user-friendly interface while significantly reducing processing time. While NDVI is a well-established index, the QSVI plugin distinguishes itself by also offering chlorophyll and thermal indices, which are crucial for comprehensive environmental assessments. These additional indices make it particularly useful for tracking vegetation health and thermal patterns, areas of significant importance in environmental research. This combination of functions makes QSVI a valuable tool for environmental researchers who need an efficient, open-source solution for remote sensing analysis. With processing times as low assupports researchers working on vegetation health and thermal models with the ability to calculate the well-known NDVI index, as well as chlorophyll and thermal indices on a single platform. Compared with other GIS software, QSVI reduced the processing time for Sentinel-2 and Sentinel-3 data by 2.1 minutes for Sentinel data on standard systems, QSVI offers a practical alternative to more complex software by enabling the efficient calculation of indices across diverse environmental applications. In conclusion, integrating open-source, computer-based tools into university education provides essential resources for both teaching and research, especially in the field of remote sensing. QSVI not only serves as an accessible and practical option for educational purposes but also as a reliable tool for researchers focused on environmental monitoring and index calculation. Its simple interface and efficient processing make it a promising alternative for users interested in studying a wide range of environmental indices using remote sensing data.datasets ranging from 500 MB to 1 GB in the study area. With this performance, users can be provided with practicality and ease of use for large datasets.

Code and data availability. All Sentinel-2 and Sentinel-3 imageryimages used in this study were obtained from the Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus). The Python code for the QGIS Sentinel Indices -plugin (QSVI) is not yet publicly available, but will be provided as supplementary material upon request.

Author contributions. Nuray Baş conducted all stages of the study, including conceptualization, design, Python -plugin development, data analysis, and manuscript preparation.

Competing interests. The contact author has declareddeclares that none of the authors hashave any competing interests.

REFERENCES

Aldhebiani, A. Y., Elhag, M., Hegazy, A. K., Galal, H. K., and Mufareh, N. S.: Consideration of NDVI thematic changes in density analysis and floristic composition of Wadi Yalamlam, Saudi Arabia, Geosci. Instrum. Method. Data Syst., 7, 297–306, doi:10.5194/gi-7-297-2018, 2018.

Esri. (2024). *ArcGIS Online Basemap*. Retrieved from https://www.arcgis.com

Bastiaanssen, W. G. M., Molden, D. J., and Makin, I. W.: Remote sensing for irrigated agriculture: examples from research and possible applications, Agr. Water Manage., 46, 137–155, doi:10.1016/S0378-3774(00)00080-9, 2000.

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman), Kalın

Biçimlendirilmiş: Girinti: İlk satır: 0 cm

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), 11 nk, Türkçe (Türkiye)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), 11 nk, Türkçe (Türkiye)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Biçimlendirdi: Yazı tipi: (Varsayılan) +Gövde (Times New Roman), 11 nk, Türkçe (Türkiye)

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman)

Bernard, R. M., Borokhovski, E., Schmid, R. F., Tamim, R. M., and Abrami, P. C.: A meta-analysis of blended learning and technology use in higher education: From the general to the applied, J. Comput. High. Educ., 31, 173–199, doi:10.1007/s12528-019-09298-1, 2019.

Boegh, E., Soegaard, H., and Thomsen, A.: Evaluating evapotranspiration rates and surface conditions using Landsat TM to estimate atmospheric resistance and surface resistance, Remote Sens. Environ., 79, 329–343, doi:10.1016/S0034-4257(02)00086-8, 2002.

Bounoua, L., Collatz, G. J., Los, S. O., Sellers, P. J., Dazlich, D. A., Tucker, C. J., and Randall, D. A.: Sensitivity of climate to changes in NDVI, J. Climate, 13, 2277–2292, doi:10.1175/1520-0442(2000)013, 2000.

Broge, N. H., and Leblanc, E.: Comparing prediction power and stability of broadband and hyper-spectral vegetation indices for estimation of green leaf area index and canopy chlorophyll density, Remote Sens. Environ., 76, 156–172, doi:10.1016/S0034-4257(00)00197-8, 2000.

Carless, D., Luscombe, D. J., Gatis, N., Anderson, K., and Brazier, R. E.: Mapping landscape-scale peatland degradation using airborne Lidar and multispectral data, Landsc. Ecol., 34, 1329–1345, doi:10.1007/s10980-019-00827-3, 2019.

Choudhary, S. S., and Ghosh, S. K.: Surface water area extraction by using water indices and DFPS method applied to satellites data, Sens. Imaging, 23, 33, doi:10.1007/s11220-022-00403-4, 2022.

Conrad, O., Bechtel, B., Bock, M., Dietrich, H., Fischer, E., Gerlitz, L., Wehberg, J., Wichmann, V., and Böhner, J.: System for Automated Geoscientific Analyses (SAGA) v. 2.1.4, Geosci. Model Dev., 8, 1991–2007, doi:10.5194/gmd-8-1991-2015, 2015.

Correia, R., Duarte, L., Teodoro, A. C., and Monteiro, A.: Processing Image to Geographical Information Systems (PI2GIS) — A Learning Tool for QGIS, Educ. Sci., 8, 83, doi:10.3390/educsci8020083, 2018.

Congedo, L.: Semi-Automatic Classification Plugin Documentation, doi:10.13140/RG.2.2.29474.02242/1, 2016.

Congedo, L.: Semi-Automatic Classification Plugin: A Python tool for the download and processing of remote sensing images in QGIS, J. Open Source Softw., 6, 3172, doi:10.21105/joss.03172, 2021.

Crippen, R. E.: Calculating the vegetation index faster, Remote Sens. Environ., 34, 71–73, doi:10.1016/0034-4257(90)90085-Z, 1990.

Cevik Degerli, B., and Cetin, M.: Evaluation of UTFVI index effect on climate change in terms of urbanization, Environ. Sci. Pollut. Res., 30, 75273–752801, doi:10.1007/s11356-023-25513-0, 2023.De Dear, R.J. and Brager, G.S. (1998) Developing an Adaptive Model of Thermal Comfort and Preference. ASHRAE Transactions, 104, 145-167.

De Fioravante, P., Luti, T., Cavalli, A., Giuliani, C., Dichicco, P., Marchetti, M., Chirici, G., and Congedo, L.: Multispectral Sentinel-2 and SAR Sentinel-1 integration for automatic land cover classification, Land, 10, 611, doi:10.3390/land10060611, 2021.

Dinçer, S.: Effects of computer literacy, motivation and self-efficacy on learning success in computer assisted instruction: Investigation of the variables with study duration, Int. J. Curric. Instruc. Stud., 7, 147-162, doi:10.31704/ijocis.2017.009, 2017.

García-Fernández, A. J., Espín, S., Gómez-Ramírez, P., and Martínez-López, E.: Wildlife sentinels for human and environmental health hazards in ecotoxicological risk assessment, In: Roy, K. (Ed.) Ecotoxicological QSARs, Methods in Pharmacology and Toxicology, Humana, New York, NY, doi:10.1007/978-1-0716-0150-1_4, 2020.

Gartland, L.: Ilhas de calor: Como mitigar zonas de calor em áreas urbanas, 1st edn., Oficina de Textos, São Paulo, Brazil, 2011.

Gomez, E. A., Wu, D., and Passerini, K.: Computer-supported team-based learning: The impact of motivation, enjoyment and team contributions on learning outcomes, Comput. Educ., 55, 378–390, doi:10.1016/j.compedu.2010.02.003, 2010.

GRASS GIS community: GRASS GIS - Bringing advanced geospatial technologies to the world, https://grass.osgeo.org, 2018.

Houete, A. R.: A soil-adjusted vegetation index (SAVI), Remote Sens. Environ., 25, 53-70, 1988.

Huete, A., Didan, K., Miura, T., Rodriguez, E. P., Gao, X., and Ferreira, L. G.: Overview of the radiometric and biophysical performance of the MODIS vegetation indices, Remote Sens. Environ., 83, 195-213, doi:10.1016/S0034-4257(02)00096-2, 2002.

Huang, S., Tang, L., Hupy, J. P., Wang, Y., and Shao, G.: A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing, J. For. Res., 32, 1–6, doi:10.1007/s11676-020-01155-1, 2021.

Jombo, S., & Adelabu, S. A. Spatiotemporal Variations of Land Surface Temperature and Vegetation Coverage in Free State Province, South Africa. *IGARSS 2022 - 2022 IEEE International Geoscience and Remote Sensing Symposium*, Kuala Lumpur, Malaysia, 2022, pp. 2414–2417. https://doi.org/10.1109/IGARSS46834.2022.9884372

Kulik, J. A., Kulik, C.-L. C., and Cohen, P. A.: Effectiveness of computer-based college teaching: A meta-analysis of findings, Rev. Educ. Res., 50, 525, doi:10.2307/1170294, 1980.

Kalacska, M., Arroyo-Mora, J. P., and Lucanus, O.: Comparing UAS Lidar and Structure-from-Motion photogrammetry for peatland mapping and virtual reality (VR) visualization, Drones, 5, 36, 2021.

Kaufman, Y. J.: Atmospheric effects on remote sensing of surface reflectance, Remote Sens.: Crit. Rev. Technol., doi:10.1117/12.966238, 1984.

Kolokoussis, P., and Karathanassi, V.: Oil spill detection and mapping using Sentinel-2 imagery, J. Mar. Sci. Eng., 6, 4, doi:10.3390/jmse6010004, 2018.

Lei, J., Wang, S., Wang, Y. *et al.* Determining the planting year of navel orange trees in mountainous and hilly areas of southern China: a remote sensing based method. *J. Mt. Sci.* **21**, 3293–3305 (2024). https://doi.org/10.1007/s11629-024-8673-1

Liu, Y., Qian, J., and Yue, H.: Combined Sentinel-1A with Sentinel-2A to estimate soil moisture in farmland, IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens., 14, 1292–1310, doi:10.1109/JSTARS.2020.3043628, 2021.

Naim, M., Huda, N., and Kafy, A.: Assessment of urban thermal field variance index and defining the relationship between land cover and surface temperature in Chattogram City: A remote sensing and statistical approach, Environ. Chall., 4, 100107, 2021.

Narine, L. L., Popescu, S., Zhou, T., Srinivasan, S., and Harbeck, K.: Mapping forest aboveground biomass with a simulated ICESat-2 vegetation canopy product and Landsat data, Ann. For. Res., 62, 69–86, https://doi.org/10.15287/afr.2018.1163, 2019.

Nepita-Villanueva, M. R., Berlanga-Robles, C. A., Ruiz-Luna, A., and others: Spatio-temporal mangrove canopy variation (2001–2016) assessed using the MODIS enhanced vegetation index (EVI), J. Coast. Conserv., 23, 589–597, https://doi.org/10.1007/s11852-019-00689-9, 2019.

Nie, J., Ren, H., Zheng, Y., Ghent, D., and Tansey, K.: Land surface temperature and emissivity retrieval from nighttime middle-infrared and thermal-infrared Sentinel-3 images, IEEE Geosci. Remote Sens. Lett., 18, 915–919, https://doi.org/10.1109/LGRS.2020.2986326, 2021.

Peddinti, V. S. S., Mandla, V. R., Mesapam, S., and others: Selection of optimal bands of AVIRIS – NG by evaluating NDVI with Sentinel-2, Earth Sci. Inform., 14, 1285–1302, https://doi.org/10.1007/s12145-021-00662-x, 2021.

Potočnik Buhvald, A., Račič, M., Immitzer, M., Oštir, K., and Veljanovski, T.: Grassland use intensity classification using intra-annual Sentinel-1 and -2 time series and environmental variables, Remote Sens., 14, 3387, https://doi.org/10.3390/rs14143387, 2022.

Ram B. Gurung, F. J., Breidt, A. D., Dutin, S. M., and Ogle, S. M.: Predicting enhanced vegetation index (EVI) curves for ecosystem modeling applications, Remote Sens. Environ., 113, 2186–2193, https://doi.org/10.1016/j.rse.2009.05.015, 2009.

Ran, L., Zhang, Y., Wei, W., and Zhang, Q.: A hyperspectral image classification framework with spatial pixel pair features, Sensors, 17, 2421, https://doi.org/10.3390/s17102421, 2017.

Redlands, C. E. S. R. I.: ArcGIS Desktop: Release 10, 2011.

Ren, J., Shi, K., Li, Z., Kong, X., & Zhou, H. (2023). A Review on the Impacts of Urban Heat Islands on Outdoor Thermal Comfort. *Buildings*, *13*(6), 1368. DOI: 10.3390/buildings13061368.

Roßberg, T., and Schmitt, M.: A globally applicable method for NDVI estimation from Sentinel-1 SAR backscatter using a deep neural network and the SEN12TP dataset, PFG, 91, 171–188, https://doi.org/10.1007/s41064-023-00238-y, 2023.

Rouse, J. W., Haas, R. H., Scheel, J. A., and Deering, D. W.: Monitoring vegetation systems in the Great Plains with ERTS, Proc. 3rd Earth Resour. Technol. Satell. Symp., 1, 48–62, https://ntrs.nasa.gov/citations/19740022614, 1974.

Segarra, J., Buchaillot, M. L., Araus, J. L., and Kefauver, S. C.: Remote sensing for precision agriculture: Sentinel-2 improved features and applications, Agronomy, 10, 641, https://doi.org/10.3390/agronomy10050641, 2020.

Sharma, R., Pradhan, L., Kumari, M., and Bhattacharya, P.: Assessing urban heat islands and thermal comfort in Noida City using geospatial technology, Urban Climate, 35, 100751, 2021.

Sebbah, B., Yazidi Alaoui, O., Wahbi, M., Maâtouk, M., and Ben Achhab, N.: QGIS-Landsat indices plugin (Q-LIP): Tool for environmental indices computing using Landsat data, Environ. Model. Softw., 137, 104972, https://doi.org/10.1016/j.envsoft.2021.104972, 2021.

Sung, Y. T., Chang, K. E., and Liu, T. C.: The effects of integrating mobile devices with teaching and learning on students' learning performance: A meta-analysis and research synthesis, Comput. Educ., 156, 103935, https://doi.org/10.1016/j.compedu.2020.103935, 2021.

Surampalli, R. Y., Zhang, T. C., Goyal, M. K., Brar, S. K., & Tyagi, R. D. (Eds.). (2020). *Sustainability: Fundamentals and Applications*. Wiley. ISBN: 978-1-119-43401-6.

Tanre, D., Holben, B. N., and Kaufman, Y. J.: Atmospheric correction algorithm for NOAA–AVHRR products: Theory and application, IEEE Trans. Geosci. Remote Sens., 30, 231–248, https://doi.org/10.1109/36.134074, 1992.

Thom, E. C.: The discomfort index, Weatherwise, 12, 57–61, 1959.

Tucker, C. J.: Asymptotic nature of grass canopy spectral reflectance, Appl. Opt., 16, 1151–1156, 1977.

Turkish State Meteorological Service: https://www.mgm.gov.tr/tahmin/il-ve-ilceler.aspx?il=%C4%B0stanbul&ilce=Sar%C4%B1yer, last accessed: July 25, 2024.

Turkish Statistical Institute: [URL], last accessed: July 25, 2024.

Xiao, X., Braswell, B., Zhang, Q., Boles, S., Frolking, S., and Moore, B.: Sensitivity of vegetation indices to atmospheric aerosols: Continental-scale observations in Northern Asia, Remote Sens. Environ., 84, 385–392, https://doi.org/10.1016/s0034-4257(02)00129-3, 2003.

Xu, H., Tan, J., Li, C., Niu, Y., and Wang, J.: Exploring the dynamic impact of extreme climate events on vegetation productivity under climate change, Forests, 14, 744, https://doi.org/10.3390/f14040744, 2023.

Vincini, M., Frazzi, E., D'alessio, P., and Stafford, J. V.: Comparison of narrow-band and broad-band vegetation indexes for canopy chlorophyll density estimation in sugar beet, Precis. Agric., 7, 189–196, https://doi.org/10.3920/978-90-8686-603-8, 2007.

Wachendorf, M., Fricke, T., and Möckel, T.: Remote sensing as a tool to assess botanical composition, structure, quantity and quality of temperate grasslands, Grass Forage Sci., 73, 1–14, https://doi.org/10.1111/gfs.12312, 2018.

Zhang, Y., Yu, T., Gu, X., Zhang, Y., Chen, L. F., Yu, S. S., Zhang, W. J., and Li, X. W.: Land surface temperature retrieval from CBERS-02 IRMSS thermal infrared data and its applications in quantitative analysis of urban heat island effect, J. Remote Sens., https://doi.org/10.1016/S0379-4172(06)60102-9, 2006.

Zheng, B., Ward, A., and Stanulis, R.: The effectiveness of online learning in graduate education: A meta-analysis, Educ. Technol. Res. Dev., 70, 1–25, https://doi.org/10.1007/s11423-021-09902-2, 2022.

References

Aldhebiani, A. Y., Elhag, M., Hegazy, A. K., Galal, H. K., and Mufareh, N. S.: Consideration of NDVI thematic changes in density analysis and floristic composition of Wadi Yalamlam, Saudi Arabia, Geoscientific Instrumentation, Methods and Data Systems, 7, 297–306, https://doi.org/10.5194/gi-7-297-2018, 2018.

Bastiaanssen, W. G. M., Molden, D. J., and Makin, I. W.: Remote sensing for irrigated agriculture: examples from research and possible applications, Agricultural Water Management, 46, 137–155, https://doi.org/10.1016/S0378-3774(00)00080-9, 2000.

Bernard, R. M., Borokhovski, E., Schmid, R. F., Tamim, R. M., and Abrami, P. C.: A meta-analysis of blended learning and technology use in higher education: from the general to the applied, J Comput High Educ, 26, 87–122, https://doi.org/10.1007/s12528-013-9077-3, 2014.

Boegh, E., Soegaard, H., Broge, N., Hasager, C. B., Jensen, N. O., Schelde, K., and Thomsen, A.: Airborne multispectral data for quantifying leaf area index, nitrogen concentration, and photosynthetic efficiency in agriculture, Remote Sensing of Environment, 81, 179–193, https://doi.org/10.1016/S0034-4257(01)00342-X, 2002.

Bounoua, L., Collatz, G. J., Los, S. O., Sellers, P. J., Dazlich, D. A., Tucker, C. J., and Randall, D. A.: Sensitivity of Climate to Changes in NDVI, 2000.

Broge, N. H. and Leblanc, E.: Comparing prediction power and stability of broadband and hyperspectral vegetation indices for estimation of green leaf area index and canopy chlorophyll density, Remote Sensing of Environment, 76, 156–172, https://doi.org/10.1016/S0034-4257(00)00197-8, 2001.

Carless, D., Luscombe, D. J., Gatis, N., Anderson, K., and Brazier, R. E.: Mapping landscape-scale peatland degradation using airborne lidar and multispectral data, Landscape Ecol, 34, 1329–1345, https://doi.org/10.1007/s10980-019-00844-5, 2019.

Cevik Degerli, B. and Cetin, M.: Evaluation of UTFVI index effect on climate change in terms of urbanization, Environ Sci Pollut Res, 30, 75273–75280, https://doi.org/10.1007/s11356-023-27613-x, 2023.

Choudhary, S. S. and Ghosh, S. K.: Surface Water Area Extraction by Using Water Indices and DFPS Method Applied to Satellites Data, Sensing and Imaging, 23, 33, https://doi.org/10.1007/s11220-022-00403-4, 2022.

Congedo, L.: Semi-Automatic Classification Plugin: A Python tool for the download and processing of remote sensing images in QGIS, Journal of Open Source Software, 6, 3172, https://doi.org/10.21105/joss.03172, 2021.

Conrad, O., Bechtel, B., Bock, M., Dietrich, H., Fischer, E., Gerlitz, L., Wehberg, J., Wichmann, V., and Böhner, J.: System for Automated Geoscientific Analyses (SAGA) v. 2.1.4, Geoscientific Model Development, 8, 1991–2007, https://doi.org/10.5194/gmd-8-1991-2015, 2015.

Correia, R., Teodoro, A., and Duarte, L.: PI2GIS: processing image to geographical information systems, a learning tool for QGIS, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, ADS Bibcode: 2017SPIE10428E..1HC, 104281H, https://doi.org/10.1117/12.2277952, 2017.

Crippen, R. E.: Calculating the vegetation index faster, Remote Sensing of Environment, 34, 71–73, https://doi.org/10.1016/0034-4257(90)90085-Z, 1990.

De Bock, A., Belmans, B., Vanlanduit, S., Blom, J., Alvarado-Alvarado, A. A., and Audenaert, A.: A review on the leaf area index (LAI) in vertical greening systems, Building and Environment, 229, 109926, https://doi.org/10.1016/j.buildenv.2022.109926, 2023.

De Fioravante, P., Luti, T., Cavalli, A., Giuliani, C., Dichicco, P., Marchetti, M., Chirici, G., Congedo, L., and Munafò, M.: Multispectral Sentinel-2 and SAR Sentinel-1 Integration for Automatic Land Cover Classification, Land, 10, 611, https://doi.org/10.3390/land10060611, 2021.

De Dear, R. and Brager, G. S.: Developing an adaptive model of thermal comfort and preference, 1998.

Dinçer, S.: Effects of computer literacy, motivation and self-efficacy on learning success in computer assisted instruction: Investigation of the variables with study duration, Uluslararası Eğitim Programları ve Öğretim Çalışmaları Dergisi, 7, 147–162, https://doi.org/10.31704/ijocis.2017.009, 2017.

García, D. H.: Analysis of Urban Heat Island and Heat Waves Using Sentinel-3 Images: a Study of Andalusian Cities in Spain, Earth Syst Environ, 6, 199–219, https://doi.org/10.1007/s41748-021-00268-9, 2022.

García-Fernández, A., Espin, S., Gómez-Ramírez, P., Martínez-López, E., and Navas, I.: Wildlife Sentinels for Human and Environmental Health Hazards in Ecotoxicological Risk Assessment, 77–94, https://doi.org/10.1007/978-1-0716-0150-1_4, 2020.

Gomez, E. A., Wu, D., and Passerini, K.: Computer-supported team-based learning: The impact of motivation, enjoyment and team contributions on learning outcomes, Computers & Education, 55, 378–390, https://doi.org/10.1016/j.compedu.2010.02.003, 2010.

GRASS - Bringing advanced geospatial technologies to the world: https://grass.osgeo.org/, last access: 25 May 2025.

Huang, S., Tang, L., Hupy, J. P., Wang, Y., and Shao, G.: A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing, J. For. Res., 32, 1–6, https://doi.org/10.1007/s11676-020-01155-1, 2021.

Huete, A., Didan, K., Miura, T., Rodriguez, E. P., Gao, X., and Ferreira, L. G.: Overview of the radiometric and biophysical performance of the MODIS vegetation indices, Remote Sensing of Environment, 83, 195–213, https://doi.org/10.1016/S0034-4257(02)00096-2, 2002.

Huete, A. R.: A soil-adjusted vegetation index (SAVI), Remote Sensing of Environment, 25, 295–309, https://doi.org/10.1016/0034-4257(88)90106-X, 1988.

Jaud, M., Agranier, A., Graindorge, D., Kernec, M., and Delacourt, C.: Combining remote sensing surveys, digital and in situ field trips in higher education geology classroom, BSGF - Earth Sci. Bull., 196, 2, https://doi.org/10.1051/bsgf/2024029, 2025.

Jiang, Z., Huete, A. R., Chen, J., Chen, Y., Li, J., Yan, G., and Zhang, X.: Analysis of NDVI and scaled difference vegetation index retrievals of vegetation fraction, Remote Sensing of Environment, 101, 366–378, https://doi.org/10.1016/j.rse.2006.01.003, 2006.

Jombo, S. and Adelabu, S. A.: Spatiotemporal Variations of Land Surface Temperature and Vegetation Coverage in Free State Province, South Africa, in: IGARSS 2022 - 2022 IEEE International Geoscience and Remote Sensing Symposium, IGARSS 2022 - 2022 IEEE International Geoscience and Remote Sensing Symposium, 2414–2417, https://doi.org/10.1109/IGARSS46834.2022.9884372, 2022.

Kaufman, Y. J.: Atmospheric effects on remote sensing of surface reflectance, NTRS Author Affiliations: NASA Goddard Space Flight CenterNTRS Document ID: 19860034741NTRS Research Center: Legacy CDMS (CDMS), 1984.

Lai, J., Wang, S., Wang, Y., and Luo, W.: Determining the planting year of navel orange trees in mountainous and hilly areas of southern China: a remote sensing based method, J. Mt. Sci., 21, 3293–3305, https://doi.org/10.1007/s11629-024-8673-1, 2024.

Liu, Y., Qian, J., and Yue, H.: Combined Sentinel-1A With Sentinel-2A to Estimate Soil Moisture in Farmland, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, https://doi.org/10.1109/JSTARS.2020.3043628, 2021.

Naim, Md. N. H. and Kafy, A.-A.: Assessment of urban thermal field variance index and defining the relationship between land cover and surface temperature in Chattogram city: A remote sensing and statistical approach, Environmental Challenges, 4, 100107, https://doi.org/10.1016/j.envc.2021.100107, 2021.

Narine, L. L., Popescu, S., Zhou, T., Srinivasan, S., and Harbeck, K.: Mapping forest aboveground biomass with a simulated ICESat-2 vegetation canopy product and Landsat data, Annals of Forest Research, 52, 69–86, https://doi.org/10.15287/afr.2018.1163, 2009.

Nie, J., Ren, H., Zheng, Y., Ghent, D., and Tansey, K.: Land Surface Temperature and Emissivity Retrieval From Nighttime Middle-Infrared and Thermal-Infrared Sentinel-3 Images, IEEE Geoscience and Remote Sensing Letters, 18, 915–919, https://doi.org/10.1109/LGRS.2020.2986326, 2021.

Peddinti, V. S. S., Mandla, V. R., Mesapam, S., and Kancharla, S.: Selection of optimal bands of AVIRIS – NG by evaluating NDVI with Sentinel-2, Earth Sci Inform, 14, 1285–1302, https://doi.org/10.1007/s12145-021-00662-x, 2021.

Poletaev, A. and Lisetskii, F.: Using vegetation indices to identify high chlorophyll tree cover in floodplains for carbon sequestration, E3S Web Conf., 486, 07013, https://doi.org/10.1051/e3sconf/202448607013, 2024.

Potočnik Buhvald, A., Račič, M., Immitzer, M., Oštir, K., and Veljanovski, T.: Grassland Use Intensity Classification Using Intra-Annual Sentinel-1 and -2 Time Series and Environmental Variables, Remote Sensing, 14, 3387, https://doi.org/10.3390/rs14143387, 2022.

Ran, L., Zhang, Y., Wei, W., and Zhang, Q.: A Hyperspectral Image Classification Framework with Spatial Pixel Pair Features, Sensors (Basel), 17, 2421, https://doi.org/10.3390/s17102421, 2017.

Redlands, C. E. S. R. I.: ArcGIS Desktop: Release 10, 2011

Roßberg, T. and Schmitt, M.: A Globally Applicable Method for NDVI Estimation from Sentinel-1 SAR Backscatter Using a Deep Neural Network and the SEN12TP Dataset, PFG, 91, 171–188, https://doi.org/10.1007/s41064-023-00238-y, 2023.

Rouse, J. W., Haas, R. H., Schell, J. A., and Deering, D. W.: Monitoring vegetation systems in the Great Plains with ERTS, NTRS Author Affiliations: Texas A&M Univ.NTRS Report/Patent Number: PAPER-A20NTRS Document ID: 19740022614NTRS Research Center: Legacy CDMS (CDMS), 1974.

Sebbah, B., Yazidi Alaoui, O., Wahbi, M., Maâtouk, M., and Ben Achhab, N.: QGIS-Landsat Indices plugin (Q-LIP): Tool for environmental indices computing using Landsat data, Environmental Modelling & Software, 137, 104972, https://doi.org/10.1016/j.envsoft.2021.104972, 2021.

Segarra, J., Buchaillot, M., Araus, J., and Kefauver, S.: Remote Sensing for Precision Agriculture: Sentinel-2 Improved Features and Applications, Agronomy, 10, 641, https://doi.org/10.3390/agronomy10050641, 2020.

Sharma, R., Pradhan, L., Kumari, M., and Bhattacharya, P.: Assessing urban heat islands and thermal comfort in Noida City using geospatial technology, Urban Climate, 35, 100751, https://doi.org/10.1016/j.uclim.2020.100751, 2021.

Sung, Y.-T., Chang, K.-E., and Liu, T.-C.: The effects of integrating mobile devices with teaching and learning on students' learning performance: A meta-analysis and research synthesis, Computers & Education, 94, 252–275, https://doi.org/10.1016/j.compedu.2015.11.008, 2016.

Tanre, D., Holben, B. N., and Kaufman, Y. J.: Atmospheric correction algorithm for NOAA-AVHRR products: theory and application, IEEE Transactions on Geoscience and Remote Sensing, 30, 231–248, https://doi.org/10.1109/36.134074, 1992.

Thom, E. C. (1959). The Discomfort Index. *Weatherwise*, *12*(2), 57–61. https://doi.org/10.1080/00431672.1959.9926960

Tucker, C. J.: Asymptotic nature of grass canopy spectral reflectance, Appl. Opt., AO, 16, 1151–1156, https://doi.org/10.1364/AO.16.001151, 1977.

Turkish State Meteorological Service Official Web Sites: https://www.mgm.gov.tr/eng/forecast-cities.aspx, last access: 25 May 2025.

Vijayalakshmi, D., Jeevitha, R., Gowsiga, S., Vinitha, A., and Soumya, R.: Evaluation of chlorophyll index as indicators to screen sorghum genotypes for drought stress tolerance, CEREAL RESEARCH COMMUNICATIONS, 52, 1511–1525, https://doi.org/10.1007/s42976-024-00494-7, 2024.

Wachendorf, M., Fricke, T., and Möckel, T.: Remote sensing as a tool to assess botanical composition, structure, quantity and quality of temperate grasslands, Grass and Forage Science, 73, 1–14, https://doi.org/10.1111/gfs.12312, 2018.

Weng, Q., Lu, D., and Schubring, J.: Estimation of land surface temperature–vegetation abundance relationship for urban heat island studies, Remote Sensing of Environment, 89, 467–483, https://doi.org/10.1016/j.rse.2003.11.005, 2004.

Wulandari, F., Anika Marhayani, D., Setyowati, R., Anitra, R., Sulistri, E., and Mursidi, A.: The Effectiveness of Study Online in Higher Education, in: Proceedings of the 6th International Conference on Information and Education Innovations, New York, NY, USA, 41–45, https://doi.org/10.1145/3470716.3470724, 2021.

Xiao, X., Braswell, B., Zhang, Q., Boles, S., Frolking, S., and Moore, B.: Sensitivity of vegetation indices to atmospheric aerosols: continental-scale observations in Northern Asia, Remote Sensing of Environment, 84, 385–392, https://doi.org/10.1016/S0034-4257(02)00129-3, 2003.

Zakzouk, M., El-Magd, I. A., Ali, E. M., Abdulaziz, A. M., Rehman, A., and Saba, T.: Novel oil spill indices for sentinel-2 imagery: A case study of natural seepage in Qaruh Island, Kuwait, MethodsX, 12, 102520, https://doi.org/10.1016/j.mex.2023.102520, 2024.

Biçimlendirdi: Yazı tipi: +Gövde (Times New Roman), Desen:Yok

Biçimlendirilmiş: Girinti: Sol: -1 cm, Asılı: 1 cm