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NDVI Analysis And Visualization Using Sentinel Hub And Streamlit

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Abstract: The Normalized Difference Vegetation Index (NDVI) is widely used for analyzing vegetation health through satellite imagery. It is computed as the normalized difference between red and near-infrared (NIR) spectral bands, allowing per-pixel greenness estimation. NDVI leverages multi-spectral remote sensing data to classify land cover, identify vegetation density, and distinguish features such as water bodies, barren lands, and forested regions.

This study presents a web-based NDVI analysis framework that integrates Sentinel Hub for satellite image acquisition, Streamlit for interactive visualization, and SQLite for structured report storage. The system enables users to dynamically retrieve Sentinel-2 imagery, compute NDVI, EVI, and SAVI in real-time, and visualize results across multiple spectral bands (True Color, Infrared, and Vegetation Indices). A dynamic interactive map powered by OpenStreetMap allows users to intuitively select geographic locations for analysis, enhancing accessibility and user experience. Additionally, the system provides histograms, surface plots, and statistical insights, allowing users to analyze vegetation patterns efficiently. The system also supports data export in CSV format and structured local storage for historical analysis.

By automating NDVI computation and visualization, this research enhances the efficiency of environmental monitoring, reducing the manual effort associated with traditional GIS-based approaches. Future enhancements include cloud deployment for real-time large-scale analysis, integration with a more robust database system, and development of a full-stack web application for expanded functionality and scalability.

***Keywords* - Remote Sensing, NDVI Sentinel Hub, SQLite, Streamlit, Vegetation Index, OpenStreetMap.**

I. INTRODUCTION

The Normalized Difference Vegetation Index (NDVI) is a widely used metric in remote sensing for assessing vegetation health, land cover classification, and environmental monitoring. NDVI is computed using the red and near-infrared (NIR) spectral bands from satellite imagery, where healthy vegetation reflects more NIR light while absorbing red light. This index plays a crucial role in applications such as agriculture, forestry, drought assessment, and climate change analysis【1】.

Traditional NDVI computation methods require manual satellite image processing making large-scale environmental monitoring time-consuming and computationally demanding 【2】. Additionally, cloud-based solutions like Google Earth Engine provide large-scale processing capabilities but lack real-time interactivity and structured local data storage 【3】. To address these limitations, an automated system is required that integrates real-time satellite image retrieval, NDVI computation, interactive visualization, and structured data management.

This research presents a web-based NDVI analysis framework that leverages Sentinel Hub for dynamic satellite image acquisition, OpenStreetMap (OSM) for intuitive geographic selection, Streamlit for interactive visualization, and SQLite for structured report storage. The system allows users to dynamically fetch Sentinel-2 imagery, compute NDVI in real-time, and visualize results across multiple spectral bands (True Color, Infrared, and NDVI). Additionally, users can analyze vegetation trends through histograms, surface plots, and statistical insights and download reports for further analysis.

- **Objectives of the Study**
  The main objectives of this research are:
  1) Develop a real-time, automated NDVI computation system using the Sentinel Hub API, integrated with OpenStreetMap for dynamic location selection and enhanced usability.
  2) Provide an interactive vegetation index visualization interface through Streamlit.
  3) Implement a temporary SQLite database to store NDVI, EVI, and SAVI reports during active sessions.

- **Scope of the Research**
  This study focuses on developing a scalable and efficient NDVI analysis system that provides:
  1) Offer real-time access to Sentinel-2 imagery with multi-spectral analysis (True Color, Infrared, NDVI), integrated with OpenStreetMap for precise, interactive, location-based analysis**.**
  2) Automate data storage and retrieval using SQLite, enabling temporary session-based tracking of vegetation trends**.**
  3) Support future scalability, including potential cloud integration for large-scale remote sensing applications**.**

II. LITERATURE REVIEW

- **NDVI and Its Significance in Remote Sensing**

  The **Normalized Difference Vegetation Index (NDVI)** is an essential metric in remote sensing used to monitor vegetation health and land cover changes. It is calculated using **red and near-infrared (NIR) spectral bands**, where healthy vegetation reflects more NIR light and absorbs more red light. NDVI is widely applied in **agriculture, forestry, drought monitoring, and climate studies**.

  Several methods have been developed for NDVI computation and visualization, including **desktop GIS tools, cloud computing platforms, and web-based applications**. The table below presents a **comparative review of existing NDVI analysis methods** based on various technological approaches, highlighting their advantages and limitations.

  Google Earth Engine (Gorelick et al., 2017) utilizes the Landsat, MODIS, and Sentinel-2 datasets through a cloud-based computing platform. It enables large-scale NDVI processing and time-series analysis, and offers a powerful API for custom applications. However, it requires coding expertise and does not provide local data storage options, posing challenges for nontechnical users.

QGIS and ArcGIS (Neteler et al., 2012) are popular desktop GIS software that support Landsat, MODIS, and Sentinel-2 imagery. They allow advanced geospatial analysis and customizable NDVI computations. Nevertheless, these tools involve manual data handling and do not support real-time dynamic visualization, limiting their efficiency in fast analysis workflows.

MODIS NDVI Web Portals (Didan et al., 2015) offer long-term vegetation monitoring using MODIS datasets through web-based tools. These portals enable users to analyze NDVI trends over extended periods; however, they are restricted to preprocessed datasets and lack the capabilities for on-demand data retrieval and flexible analysis.

Sentinel Hub (Belgiu & Csillik, 2018) provides API-based processing for Sentinel-2 imagery, allowing for fast satellite data retrieval and automated NDVI computation. Despite its efficiency in image fetching and vegetation monitoring, it does not include built-in structured storage for preserving historical NDVI reports, which requires external integration for complete report management.

The NDVI Viewer by IndigoWizard (2023) introduced a user-centric approach using Streamlit to visualize Sentinel-2 based NDVI changes over time. While offering better accessibility compared to traditional systems, it suffers from limitations, such as the absence of local storage for analysis reports and restricted interactivity for complex or multi-index comparisons.

Paddy Field Mapping by PrashanthReddy47 (2023) utilizes machine learning models with Sentinel-2 data and Streamlit to perform NDVI-based classification, focusing primarily on crop monitoring. However, this tool is specifically optimized for agricultural applications and lacks flexibility for broader vegetation or environmental analysis tasks.

Satellite NDVI Analysis by YSYVon (2023) offers a standalone Python-based GUI that enables users to upload images and manually compute NDVI values. Although the application supports shapefile export, it lacks API integrations for dynamic image retrieval, requiring users to source and upload imagery separately, thereby reducing operational efficiency.

In contrast, the **proposed system (this research)** integrates Sentinel Hub, Streamlit, and SQLite to create a seamless, automated NDVI retrieval and analysis platform. It supports the real-time visualization of NDVI, EVI, and SAVI indices, structured local storage of reports, and dynamic geographic selection via OpenStreetMap.

Although currently designed for local execution, it provides scalable architecture that can be expanded to cloud-based deployment for large-scale vegetation monitoring.

III. METHODOLOGY

- **Data Acquisition**

The system utilizes Sentinel Hub API to dynamically fetch Sentinel-2 satellite images based on user-specified geographic coordinates. To enhance usability, OpenStreetMap (OSM) is integrated, allowing users to select a region interactively rather than manually entering coordinates.

The following parameters are used for satellite image retrieval:

1) Satellite Source: Sentinel-2
2) Geolocation Source: OpenStreetMap's Nominatim API (for location-to-coordinate conversion)
3) Spectral Bands: Red (B4), Near-Infrared (B8)Resolution: 10m per pixel
4) Temporal Selection: User-defined date range

- **Vegetation Index Computation**

The system computes three key vegetation indices:

1) The **Normalized Difference Vegetation Index (NDVI)** is calculated using the standard formula:

NDVI = (NIR−Red) / (NIR+Red)

where:
(a) NIR (Near-Infrared Band, B8)**:** High reflectance in healthy vegetation.
(b) Red Band (B4)**:** High absorption in healthy vegetation.

The computation is performed pixel-wise, generating an NDVI image where:

(a) **NDVI > 0.5**: Dense vegetation
(b) **0.2 ≤ NDVI ≤ 0.5**: Moderate vegetation
(c) **0.1 ≤ NDVI < 0.2**: Sparse vegetation
(d) **NDVI < 0.1**: Barren land or water bodies

2) **Enhanced Vegetation Index (EVI)**

EVI is designed to improve vegetation monitoring by reducing atmospheric and soil influences. It incorporates the blue band to correct for aerosol scattering effects and is calculated as:

EVI = G×(NIR−Red)(NIR+C1×Red−C2×Blue+L)

where:

(a) **NIR (B8)**: Near-infrared band.
(b) **Red (B4)**: Red band.
(c) **Blue (B2)**: Blue band (used for atmospheric correction).
(d) **G = 2.5**: Gain factor.
(e) **C_1 = 6, C_2 = 7.5**: Aerosol correction coefficients.
(f) **L = 1**: Canopy background adjustment.

3) **Soil-Adjusted Vegetation Index (SAVI)**

SAVI is useful in semi-arid and arid regions, where bare soil significantly affects vegetation indices. It includes a soil brightness correction factor (L) to compensate for soil reflectance variations. It is calculated as:

$$SAVI=(NIR-Red)(NIR+Red+L)\times(1+L)$$

where:

(a) **L (Soil Factor)**: Typically 0.5 for moderate vegetation.
(b) **NIR (B8)**: Near-infrared band.
(c) **Red (B4)**: Red band.

- **Data Storage & Report Management**

The proposed system leverages SQLite, a lightweight relational database, to efficiently manage and store data related to user queries, computed results, and graphical analysis. The database records user-selected locations, image retrieval dates, and processing parameters, ensuring structured storage of input data. Computed NDVI, EVI, and SAVI values for selected regions are stored for further analysis. Additionally, histogram and line chart values are saved to facilitate vegetation trend analysis. The system also supports exporting computed vegetation index values as CSV files, allowing users to retain analysis results for further study.

- **Visualization & User Interaction**

A Streamlit-based web application provides an interactive user interface (UI) that enables:

1) **Dynamic Geographic Selection**: OpenStreetMap allows users to select areas of interest.
2) **Multi-Mode Visualization**: Users can toggle between True Color, Infrared, and NDVI views**.**
3) **Histogram & Statistical Analysis**: Graphical representation of NDVI distribution.
4) **Surface Plots**: 3D visualization of NDVI values across selected regions.
5) **KDE Graphs:** Kernel Density Estimation (KDE) charts provide a smooth probability distribution of NDVI, EVI, and SAVI values, offering insights into vegetation index density and comparison.
6) **CSV Report Downloads**: Users can export computed NDVI data and analysis results.

IV. System Architecture

The proposed system consists of multiple components that work together to automate NDVI, EVI, and SAVI computation, visualization, and data storage.

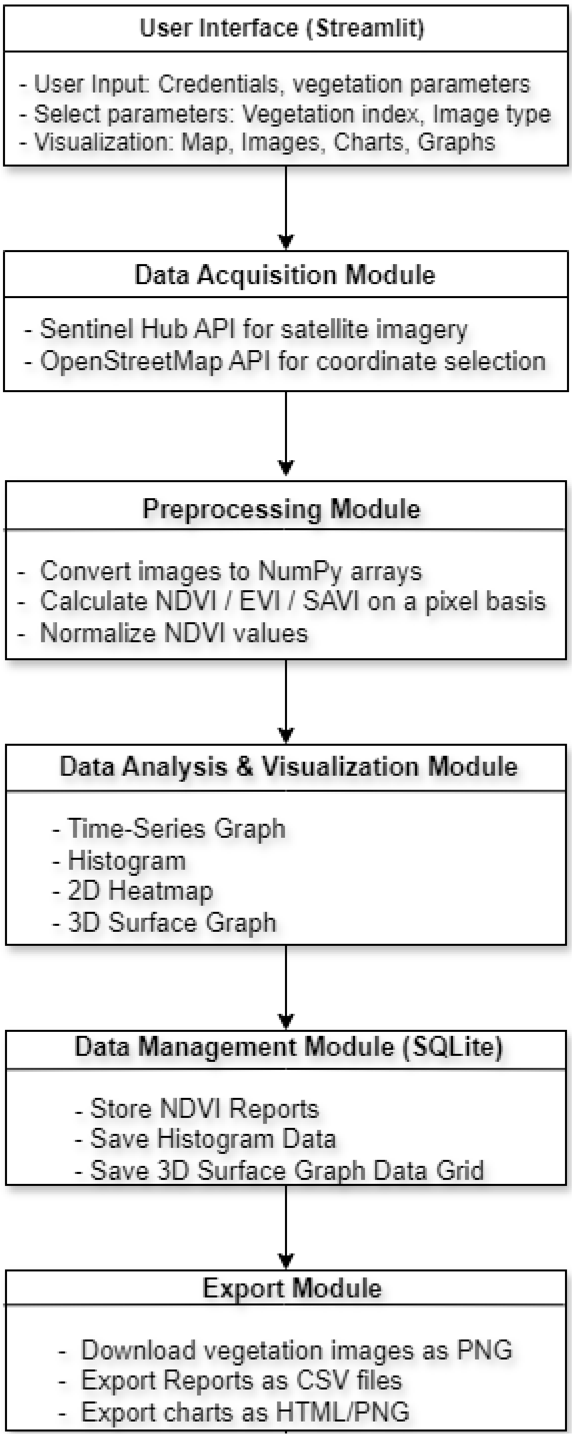

Figure 1: System Architecture of the Vegetation Analysis Framework

V. RESULTS AND DISCUSSION

The proposed system was tested using Sentinel-2 satellite imagery retrieved via Sentinel Hub API, with geographic locations selected through OpenStreetMap's Nominatim API. The system successfully computed NDVI, EVI, and SAVI, providing a comparative vegetation analysis through interactive visualizations and statistical insights.

1) Vegetation Index Image Analysis

The computed NDVI, EVI, and SAVI vegetation index values for selected regions were visualized as color-coded raster images, revealing variations in vegetation density.

a) **NDVI Visualization:** Clearly differentiates between healthy vegetation (high NDVI values) and barren land/water bodies (low NDVI values).
b) **EVI Visualization:** Showed enhanced contrast in areas with high atmospheric influence, making vegetation features more distinct.
c) **SAVI Visualization:** Provided better vegetation representation in regions with sparse greenery and exposed soil, improving accuracy where NDVI alone may be unreliable.

2) Statistical Insights and Trend Analysis

a) **Histogram Analysis:** Histogram Analysis: The distribution of vegetation indices showed a strong peak in moderate-to-dense vegetation areas (NDVI > 0.2, EVI > 0.3, SAVI > 0.2), with lower values indicating non-vegetated regions.

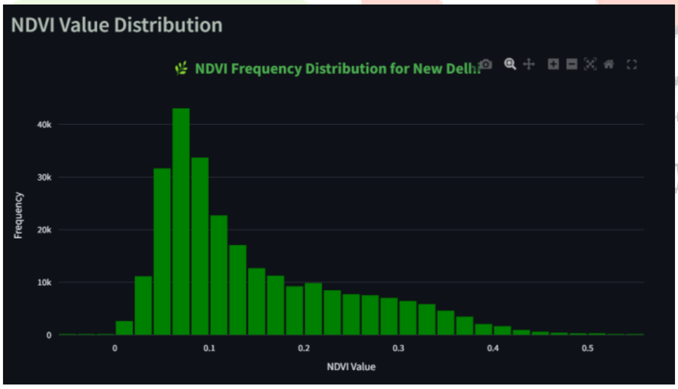

Chart-1: Histogram Distribution

b) **Time-Series Trend:** By analyzing multiple datasets over different time periods, the system demonstrated seasonal variations in vegetation health, indicating potential applications for crop monitoring and climate impact studies.

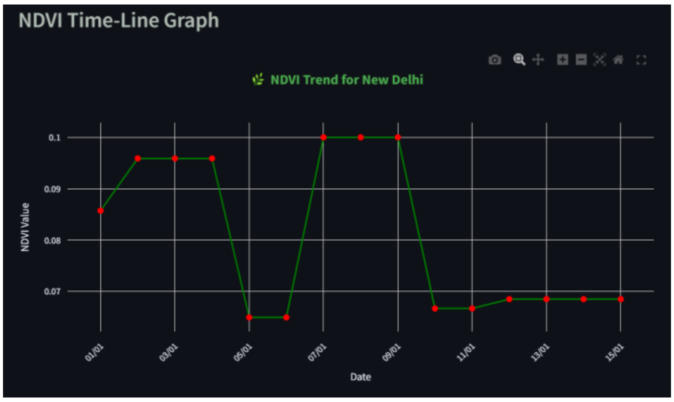

Chart-2: Time Line Chart

c) **Heatmap Analysis:** Heatmaps provided a spatial density representation of vegetation indices, highlighting areas with high and low vegetation coverage. The Folium Heatmap overlay on OpenStreetMap enabled interactive exploration of vegetation patterns.

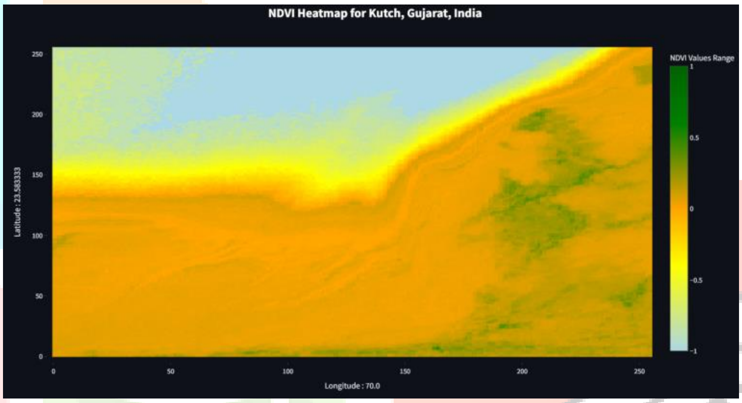

Chart-3: Heatmap

d) 3D Surface Plot: The elevation-based 3D surface visualization mapped NDVI, EVI, and SAVI values in a topographic format, where higher peaks represented dense vegetation and lower valleys indicated barren lands or water bodies. This visualization helps in terrain-based vegetation analysis, making it useful for geospatial studies and precision agriculture.

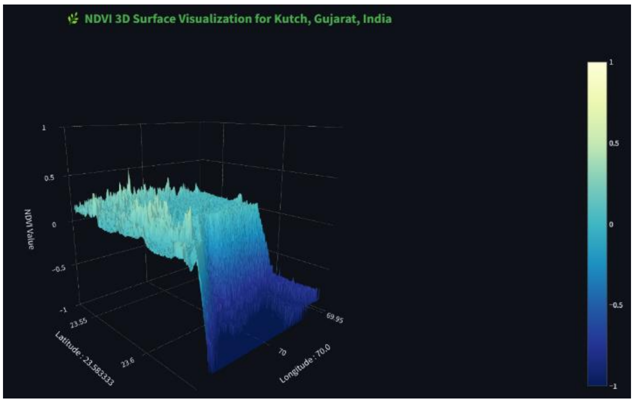

Chart-4: 3D Surface Pot

e) KDE Chart (Kernel Density Estimation): Provides a smoothed probability distribution of NDVI, EVI, and SAVI values, enabling comparison of vegetation indices and identifying dominant value ranges.

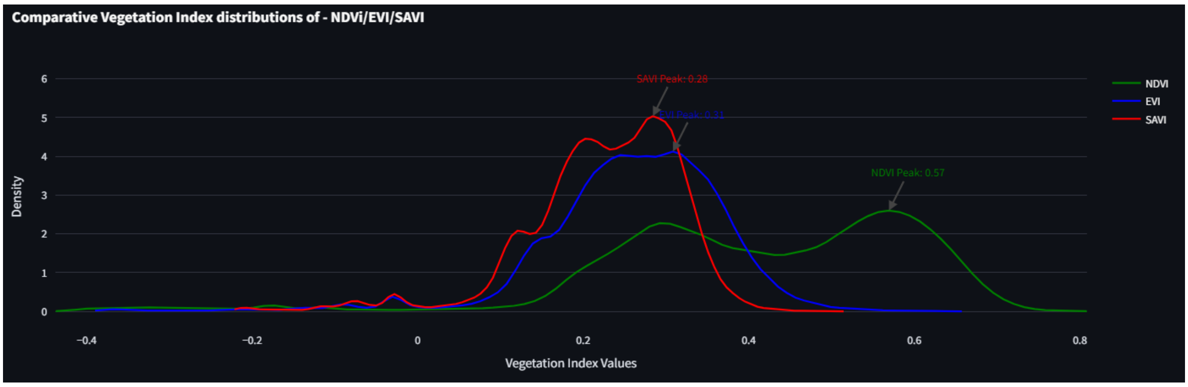

Chart-5: KDE Plot

3) **System Performance and Efficiency**

a) **Processing Time:** The Sentinel Hub API efficiently retrieved satellite images within seconds, significantly reducing manual effort compared to traditional GIS tools.
b) **Temporary Storage Management:** SQLite was successfully used for session-based temporary storage, allowing users to generate reports without long-term database overhead. CSV export functionality enabled users to store and analyze vegetation data externally.
c) **User Interaction:** The integration of OpenStreetMap's API streamlined location selection, making the system more intuitive and user-friendly.

4) **System Performance and Efficiency**

Despite the successful automation of NDVI, EVI, and SAVI computation, certain limitations persist. The system currently employs SQLite for temporary storage, restricting user access to historical reports, necessitating the transition to a full-scale relational database for long-term data retention and comparative analysis. Sentinel Hub's free-tier constraints limit data access, processing requests, and historical retrieval, thereby restricting large-scale, high-frequency vegetation analysis. Furthermore, high-resolution imagery below 10 meters requires a paid subscription, impacting detailed vegetation assessments. The system is presently deployed in a local environment, and future iterations will explore cloud-based deployment to facilitate real-time large-scale processing. Another limitation is the absence of a user authentication mechanism, which will be addressed by implementing a secure login system, allowing users to store, manage, and retrieve historical vegetation analyses. Additionally, expanding the system's capabilities by integrating other vegetation indices, such as the Green Chlorophyll Index (GCI) and the Atmospherically Resistant Vegetation Index (ARVI), will further enhance environmental assessments and improve overall analytical accuracy.

VI. Conclusion

This project effectively illustrates the potential of combining satellite remote sensing with computational techniques to monitor vegetation health through indices like NDVI, EVI, and SAVI. By automating the process of fetching, analyzing, and visualizing Sentinel-2 satellite data, the system offers an intuitive platform for users across technical backgrounds to explore vegetation dynamics.The use of a Streamlit-based interface, enriched with OpenStreetMap interactivity and diverse visualization tools—including histograms, KDE plots,

3D surface maps, and heatmaps—ensures accessibility and user engagement. Additionally, the provision to download analysis results as CSV files supports further offline exploration and documentation.
The system's modular structure and the lightweight implementation of SQLite for temporary data storage contribute to its adaptability and maintainability, forming a solid base for ongoing development and enhancements.

VII. Future Scope

Looking ahead, the application can be significantly extended through cloud-based deployment to enable high-speed, real-time processing of satellite data on a larger scale. Future improvements will include integrating a persistent database to retain user-generated reports, enabling secure user authentication, and offering personalized dashboards for historical vegetation insights.
Transforming this tool into a full-fledged, full-stack application could greatly benefit stakeholders in agriculture, environmental science, and urban planning by providing scalable, continuous vegetation monitoring capabilities. These enhancements aim to make the system more robust, user-centric, and suitable for wide-scale adoption in both research and operational domains.

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