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Applied Programming in Forestry

Project Report

NDVI Analysis for Saxon Switzerland National Park
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Content

Introduction

The Saxon Switzerland National Park in eastern Germany is abiologically rich protected landscape that is characterized by its unique sandstone landscapes, diverse forest communities, and high species diversity. However, like all natural landscapes, the park is not invulnerable to environmental perturbations, such as climate change, land use changes instigated by humans, and natural perturbations such as storms, droughts, and fires. Monitoring vegetation health is critical to detecting these environmental changes and formulating effective conservation measures (Walz 2008).
Vegetation health has a direct association with ecosystem stability, carbon sequestration, and wildlife habitat quality. The conventional field-based monitoring techniques, although precise, are often time-consuming, expensive, and spatially restricted (Pettorelli, 2013). Satellite-based vegetation indices using remote sensing technologies provide a cost-effective and scalable means of monitoring vegetation patterns in large regions over time (Huete et al., 2002).One of the most widely used remote sensing tools for vegetation assessment is the Normalized Difference Vegetation Index (NDVI) that quantifies health status based on the spectral reflectance of vegetation in the red and near-infrared bands (Rouse et al, 1974).

Integration of NDVI analysis with the strength of present Python-based geospatial libraries enables efficient remote sensing data processing and visualization. In this regard, here the present work utilizes open-access satellite data such as Sentinel-2 satellite data through the use of Python packages Rasterio, NumPy, and Matplotlib to conduct NDVI-based vegetation research in the Saxon Switzerland National Park. Results from such a study provide useful insights in terms of characterizing seasonwise vegetation patterns, along with environmental stresses that could enable preservation and maintenance activities within the national park region.

Background and Significance

Vegetation is a fundamental component of ecosystems, playing a critical role in maintaining biodiversity, regulating climate, and supporting wildlife. However, forests and natural landscapes are increasingly threatened by climate change, human activities, and natural disturbances. To effectively monitor and manage these ecosystems, advanced remote sensing techniques such as the **Normalized Difference Vegetation Index (NDVI)** have emerged as powerful tools for analyzing vegetation health and detecting environmental changes over time (Pettorelli, 2013).

Importance of NDVI

As a remote sensing statistic, the Normalised Difference Vegetation Index (NDVI) compares the reflectance of satellite data between the red and near-infrared bands in order to determine vegetation health. The formula states that unvegetated areas, sparse vegetation, or stress are indicated by a lower value, while dense, healthy vegetation is indicated by a larger value. Information on vegetation dynamics, the effects of climatic change, and ecological disturbances across time make the NDVI an invaluable tool for land use planning, ecosystem evaluations, and environmental monitoring (Tucker, 1979).

Why Saxon Switzerland National Park?

The Saxon Switzerland National Park in eastern Germany is a protected natural area renowned for its unique sandstone rocks, diverse ecosystems, and thick vegetation cover. This park is vital to biodiversity conservation, climate regulation, and ecotourism. However, it is increasingly being affected by the following factors:

• Climate change (rising temperatures, weather extremes) (IPCC, 2021).
• Land use and deforestation on vegetation cover (Hansen et al., 2013).
• Human activity and tourism on ecosystem stability (Buckley, 2011).
In light of these issues, NDVI-based remote sensing analysis is a reliable way of monitoring the health of vegetation, detecting environmental change, and supporting conservation in the park.

Study Objectives

The objectives of this research are:

1. To calculate and compare NDVI values over varying time intervals to measure vegetation health.

2. To identify seasonal and long-term NDVI trends in order to learn about vegetation dynamics.

3. To map locations of vegetation stress or degradation in the national park.

4. To incorporate NDVI outcomes with spatial data (boundaries, rivers) to improve ecological study.

5. To develop a reproducible process for ongoing remote sensing-based monitoring of Saxon Switzerland National Park.

Research Questions and Problem Statement

Research Questions

This research aims to answer the following most important research questions:

1. How is vegetation health within Saxon Switzerland National Park seasonal?
2. Where does the park display vegetation stress or degradation, and what causes such changes?
3. What can be designed as methodologies for a reproducible, long-term NDVI-based monitoring framework for the park?

Problem Statement

Saxon Switzerland National Park is a protected area natural reservation area that is famous for its diversity of ecosystems, sandstone ridges, and biodiversity. Like in most natural areas, however, it faces increasing environmental pressures such as:

- Climate change impacts in the form of increased temperatures and altered precipitation patterns that have the potential to alter vegetation health (IPCC, 2021).
- Deforestation and land use changes leading to habitat degradation and loss of biodiversity (Hansen et al., 2013).
- Human use and tourism, which can affect soil stability and forest health (Buckley, 2011).

Given these challenges, there is a requirement for efficient monitoring and evaluation of vegetation health to facilitate sustainable management and conservation planning. Traditional field-based vegetation monitoring methods, although precise, are typically time-consuming, labor-intensive, and spatially limited.

Remote sensing techniques, specifically NDVI analysis, are an inexpensive, effective, and scalable approach to monitor vegetation patterns. Through satellite imagery (Sentinel-2/Landsat-8) and geospatial analysis tools, this study will facilitate holistic estimation of the well-being of vegetation in Saxon Switzerland National Park.

The findings of this research will provide for early detection of vegetation stress, improved ecological management strategies, and development of a reproducible long-term monitoring system for the conservation of the park

Methodology

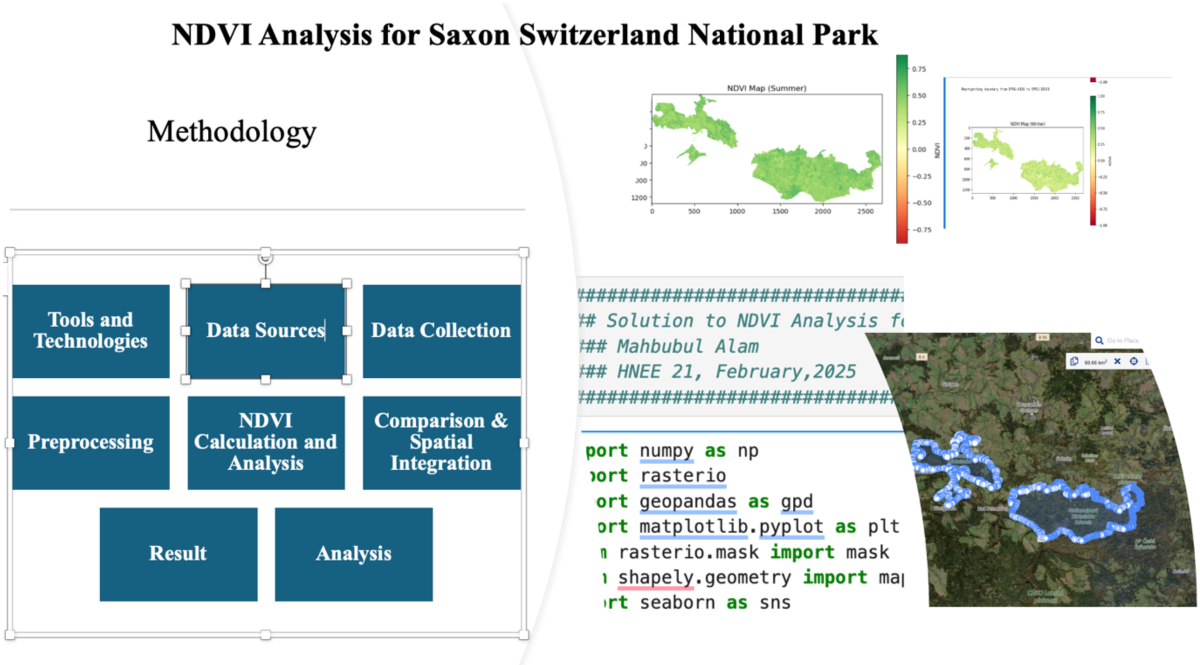


Figure: 1 Methodology

Tools and Technologies

Programming: Python
Data Sources: Sentinel-2 imagery, shapefiles of park boundaries.
Hardware/Software: A computer with GIS capabilities and Python installed.
Data Collection

- Order Sentinel-2 scenes over Saxon Switzerland National Park for winter and summer.
- Summer NDVI: June – August
- Peak vegetation growth.
- Suitable for studying healthy, robust plants.
- Winter NDVI: Dec – Feb
- Low-vegetation or dormant conditions.
- Best to detect seasonal changes.
- Collect vector data of park boundaries to delineate the study area.

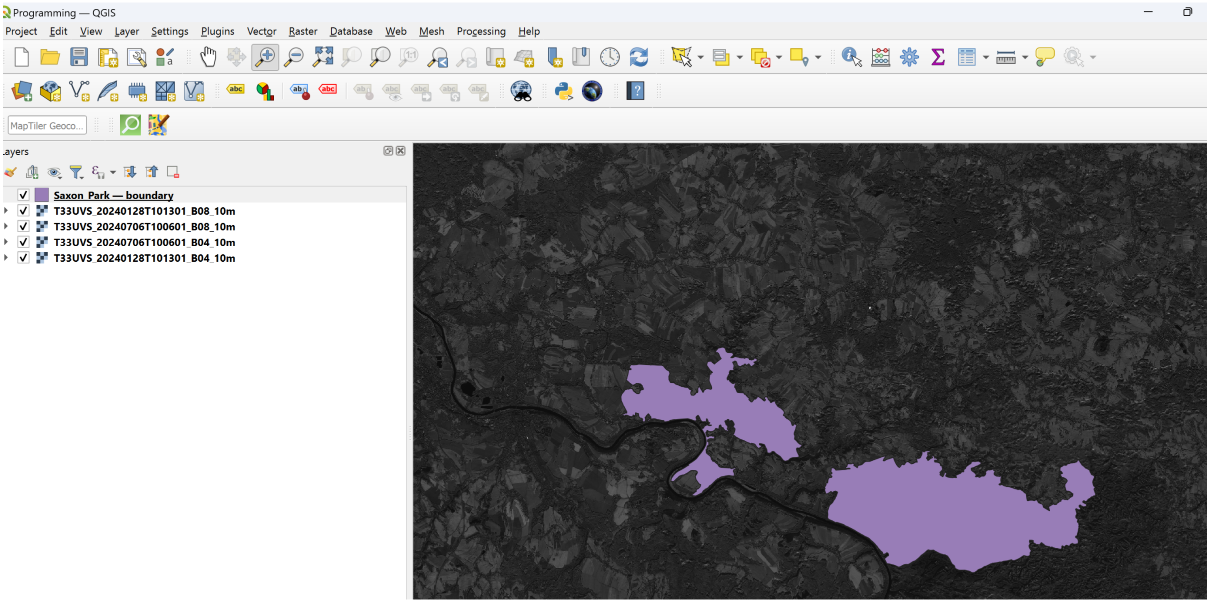


Figure: 2 Study area processing from QGIS

Preprocessing

Cloud Masking & Image Correction: Remove cloud-covered pixels to improve accuracy. Here cloud masking consider below 10%

Clipping to Study Area: Clip the NDVI data only within the park boundary.

Projection Standardization: Verify that all datasets have the same coordinate reference system (CRS) for spatial consistency.

NDVI Calculation and Analysis

ComputeNDVI from the equation:

NDVI=NIR−Red/ NIR+RedNDVI

Seasonal Analysis:

Generate Summer NDVI and Winter NDVI maps to monitor vegetation change

Vegetation Health Analysis

Determine areas of potential vegetation stress or decline using NDVI values.

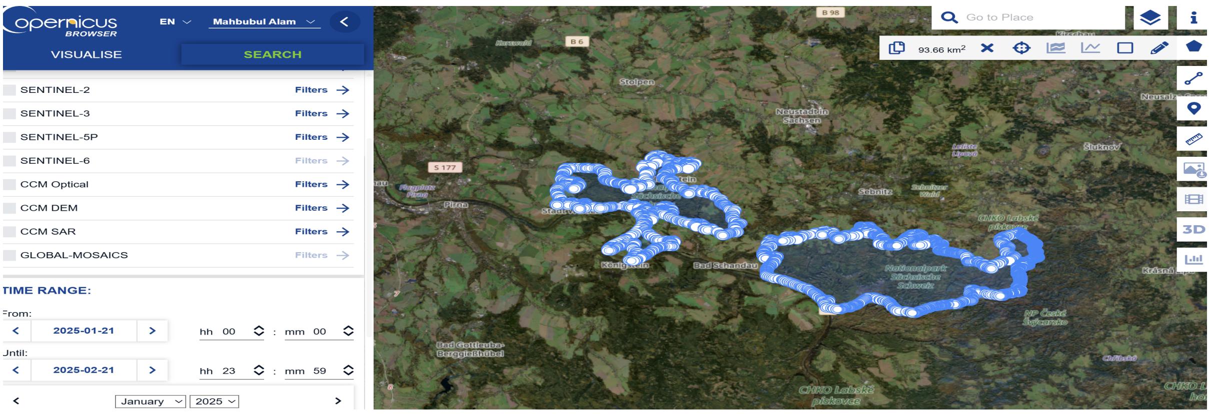


Figure : 3 data preprocessing from Copernicus

Result and analysis (Workflow in jupyter notebook)

Calculation of NDVI using Sentinel-2 data for summer and winter

Calculation of NDVI using Sentinel-2 data for summer and winter his section discusses how NDVI from Sentinel-2 images of Saxon Switzerland National Park is calculated for summer and winter in order to examine seasonal differences in vegetation.

Project Dependencies

```
import numpy as np
import rasterio
import geopandas as gpd
import matplotlib.pyplot as plt
from rasterio.mask import mask
from shapely.geometry import mapping
import seaborn as sns
```

Figure 4 : Project Dependencies

These libraries facilitate effective geospatial data analysis, manipulation, and visualization

1. **numpy:** Effects huge arrays and matrices, which are beneficial for lots of numerical work and data manipulation.
2. **rasterio:** For reading and writing geospatial raster data (e.g., GeoTIFF), which is useful for lots of work with satellite or aerial imagery.
3. **geopandas :** Extends `pandas` for spatial data. This package enables manipulation of vector data, like shapefiles.
4. **matplotlib.**pyplot: Effects static, animated, and interactive visualizations to display data or geospatial maps.
5. rasterio.mask: Masks or clips raster data using vector boundaries for region-based analysis.
6. shapely.geometry : Offers geometric functions to operate onshapes (points, lines, polygons) in spatial analysis.
7.seaborn: Adds data visualization with good-looking statistical plots.

Define file path

File paths for Sentinel-2 imagery are stored in a dictionary. This dataset includes both summer and winter bands for Red (B4) and NIR (B8).
Here
Summer data: "SB04.tif" (Red) and "SB08.tif" (NIR).
Winter data : "WB04.tif" (Red) and "WB08.tif" (NIR).
A boundary shapefile (Boundary.shp) is used for clipping the NDVI data into the area of interest.

```
[2]: # Define file paths for summer and winter datasets
seasonal_paths = {
    "Summer": {"red": "/Users/mahbubulalam/Desktop/Project_Folder/D/SB04.tif", "nir": "/Users/mahbubulalam/Desktop/Project_Folder/D/SB08.tif"},
    "Winter": {"red": "/Users/mahbubulalam/Desktop/Project_Folder/D/WB04.tif", "nir": "/Users/mahbubulalam/Desktop/Project_Folder/D/WB08.tif"}
}
boundary_shp = "/Users/mahbubulalam/Desktop/Project_Folder/D/Boundary.shp"
```

Figure: 5 Define file path

Hrere is used absolute path but in code will show the relative path.

NDVI Computation Process

The load_and_compute_ndvi function processes Sentinel-2 imagery to compute the Normalized Difference Vegetation Index (NDVI) for Saxon Switzerland National Park.
Load Spatial Data
Reads the **study area boundary** from a shapefile.
Reads **Red (B4) and Near-Infrared (NIR/B8) bands** from Sentinel-2 imagery.
Reproject: Ensures the boundary shapefile matches the raster's **Coordinate Reference System (CRS)** to prevent misalignment.
Clip Image to Study Area:
Masks the **Red** and **NIR bands** to only include pixels within the study boundary.
Handles division by zero using a small constant (epsilon)
The NDVI map and the processed boundary are returned as output for additional examination.
By calculating the NDVI values during summer and winter, this function serves the purpose of accurately monitoring vegetation, allowing for seasonal comparison and the detection of changes in vegetation health over time.

```python
def load_and_compute_ndvi(red_path, nir_path, boundary_shp):
    """
    Load red and NIR bands, clip to boundary, compute NDVI, and handle division by zero errors.
    """
    # Load the boundary shapefile
    boundary = gpd.read_file(boundary_shp)

    # Reproject if necessary
    with rasterio.open(red_path) as src:
        raster_crs = src.crs
    if boundary.crs != raster_crs:
        print(f"Reprojecting boundary from {boundary.crs} to {raster_crs}")
        boundary = boundary.to_crs(raster_crs)

    # Convert boundary to GeoJSON format
    boundary_geom = [mapping(geom) for geom in boundary.geometry]

    # Load and mask the Red band
    with rasterio.open(red_path) as red_src:
        red_band, _ = mask(red_src, boundary_geom, crop=True)
        red_band = red_band[0].astype(float)  # Extract first band and convert to float

    # Load and mask the NIR band
    with rasterio.open(nir_path) as nir_src:
        nir_band, _ = mask(nir_src, boundary_geom, crop=True)
        nir_band = nir_band[0].astype(float)  # Extract first band and convert to float

    # Ensure no NaN or Inf values
    red_band = np.nan_to_num(red_band, nan=0.0, posinf=0.0, neginf=0.0)
    nir_band = np.nan_to_num(nir_band, nan=0.0, posinf=0.0, neginf=0.0)
```

```python
    # Compute NDVI while avoiding division by zero
    epsilon = 1e-10  # Small value to prevent division errors
    with np.errstate(divide='ignore', invalid='ignore'):
        ndvi = np.where((nir_band + red_band) < epsilon, np.nan, (nir_band - red_band) / (nir_band + red_band))

    return ndvi, boundary
```

Figure:6 NDVI Computation Process

Interpretation and visualisation:

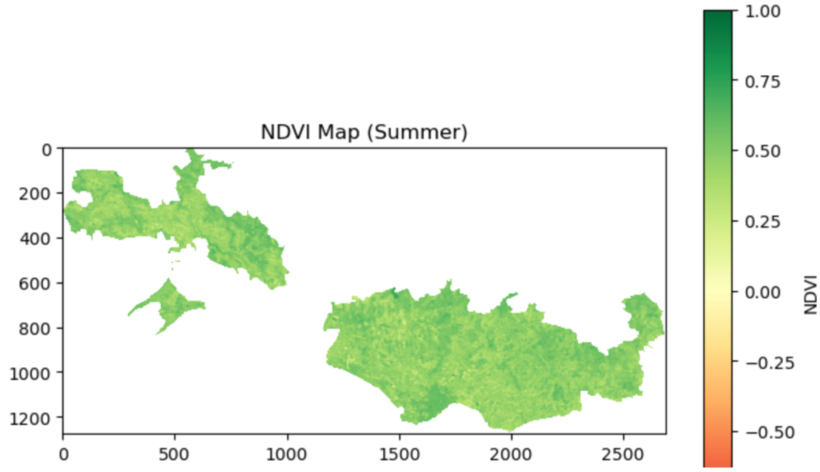
Colour-coded NDVI maps can be used to visualise the NDVI after it has been calculated. This section summer and winter NDVI displayed.Sentinel-2 Red (B4) and NIR (B8) bands were used to construct the NDVI maps of Saxon Switzerland National Park in the summer and winter. To match the raster data, the border shapefile was reprojected from EPSG:4326 to EPSG:32633. Green denotes healthy plants, whereas yellow to red denotes bare ground or poor vegetation. NDVI values can range from -1 to 1. In contrast to the winter NDVI image, which shows more open vegetation reflecting seasonal variations in plant activity, the summer NDVI map shows somewhat denser vegetation.

```python
# Process NDVI for each season
for season, paths in seasonal_paths.items():
    red_path, nir_path = paths["red"], paths["nir"]

    # Compute NDVI for the given season
    ndvi_map, boundary = load_and_compute_ndvi(red_path, nir_path, boundary_shp)

    # Plot the NDVI map
    plt.figure(figsize=(8, 6))
    plt.imshow(ndvi_map, cmap='RdYlGn', vmin=-1, vmax=1)
    plt.colorbar(label='NDVI')
    plt.title(f'NDVI Map ({season})')
    plt.show()
```

```
Reprojecting boundary from EPSG:4326 to EPSG:32633
```




```
Reprojecting boundary from EPSG:4326 to EPSG:32633
```

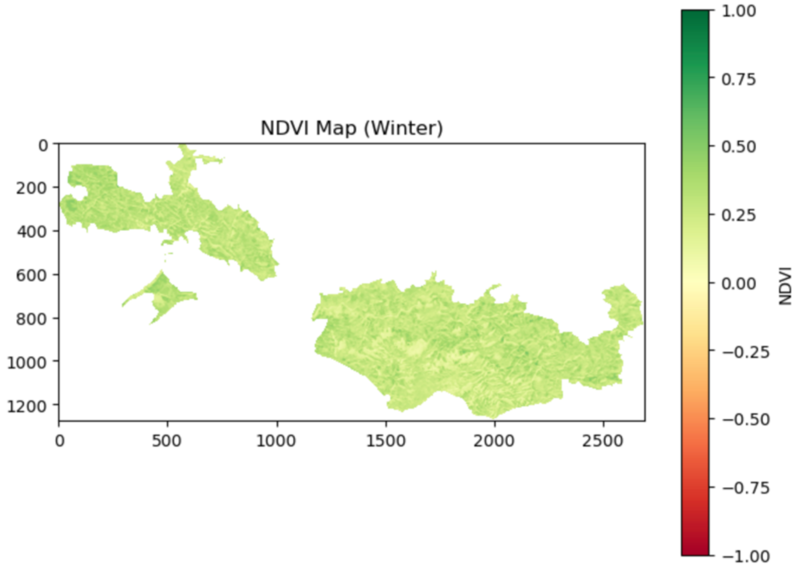


Figure: 7 Summer and winter NDVI

NDVI distribution Analysis:

Summer and winter NDVI histograms are produced to compare the seasonal NDVI distribution.

[29]:

```
# Compute NDVI for each season
ndvi_data = {season: load_and_compute_ndvi(paths["red"], paths[
             for season, paths in seasonal_paths.items()}

# Plot Side-by-Side Histograms
fig, axes = plt.subplots(1, 2, figsize=(12, 5), sharex=True, sh

for ax, (season, color) in zip(axes, [("Summer", "green"), ("Wi
    sns.histplot(ndvi_data[season], bins=30, kde=True, color=co
    ax.set_title(f"NDVI Distribution: {season}")
    ax.set_xlabel("NDVI Value")
    ax.grid(True)

plt.tight_layout()
plt.show()
```

```
Reprojecting boundary from EPSG:4326 to EPSG:32633
Reprojecting boundary from EPSG:4326 to EPSG:32633
```

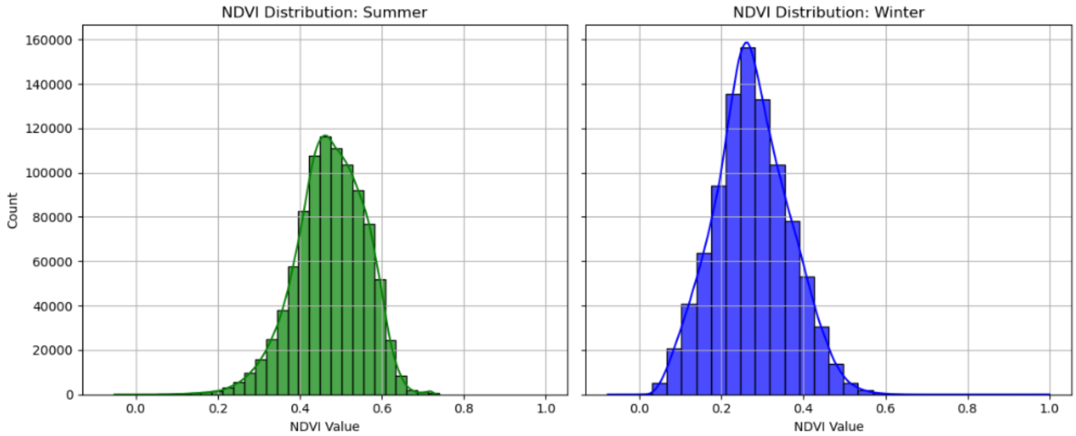


Figure: 8 **NDVI distribution summer and winter**

In Saxon Switzerland National Park, the summer NDVI (green) and winter NDVI (blue) histograms are exhibited alongside each other. Summer NDVI is often higher and peaks around 0.5, indicating more active vegetation. In contrast, the winter NDVI is slightly lower, peaking at around 0.3, indicating that there is less vegetation activity during the winter months. The two seasons are quantitatively compared using histograms.

NDVI Difference (Summer - Winter)

To detect vegetation changes, **NDVI difference (Summer - Winter)** is calculated and visualized:

```
# Compute NDVI for Summer and Winter
ndvi_summer, _ = load_and_compute_ndvi(seasonal_paths["Summer"]["red"], seasonal_paths["Summer"]["nir
ndvi_winter, _ = load_and_compute_ndvi(seasonal_paths["Winter"]["red"], seasonal_paths["Winter"]["nir

# Compute NDVI Difference (Summer - Winter)
ndvi_diff = ndvi_summer - ndvi_winter


# --- Compute NDVI Difference Statistics ---
stats = {
    "Mean NDVI Difference": np.nanmean(ndvi_diff),
    "Standard Deviation": np.nanstd(ndvi_diff),
    "Minimum NDVI Difference": np.nanmin(ndvi_diff),
    "Maximum NDVI Difference": np.nanmax(ndvi_diff),
    "Total Pixels Analyzed": np.count_nonzero(~np.isnan(ndvi_diff))
}

# Print NDVI Difference Statistics in a Clear Format
print("\n=== NDVI Difference Statistics (Summer - Winter) ===")
for key, value in stats.items():
    print(f"{key}: {value:.4f}")
```

```
Reprojecting boundary from EPSG:4326 to EPSG:32633
Reprojecting boundary from EPSG:4326 to EPSG:32633

=== NDVI Difference Statistics (Summer - Winter) ===
Mean NDVI Difference: 0.2003
Standard Deviation: 0.1150
Minimum NDVI Difference: -0.6330
Maximum NDVI Difference: 0.6801
Total Pixels Analyzed: 937214.0000
```

```
=== NDVI Difference Statistics (Summer - Winter) ===
Mean NDVI Difference: 0.2003
Standard Deviation: 0.1150
Minimum NDVI Difference: -0.6330
Maximum NDVI Difference: 0.6801
Total Pixels Analyzed: 937214.0000
```

[31]:

```
# --- Plot NDVI Difference Map ---
plt.figure(figsize=(6, 4))
plt.imshow(ndvi_diff, cmap='coolwarm', vmin=-0.5, vmax=0.5)
plt.colorbar(label="NDVI Difference (Summer - Winter)")
plt.title("NDVI Difference Map")
plt.show()
```

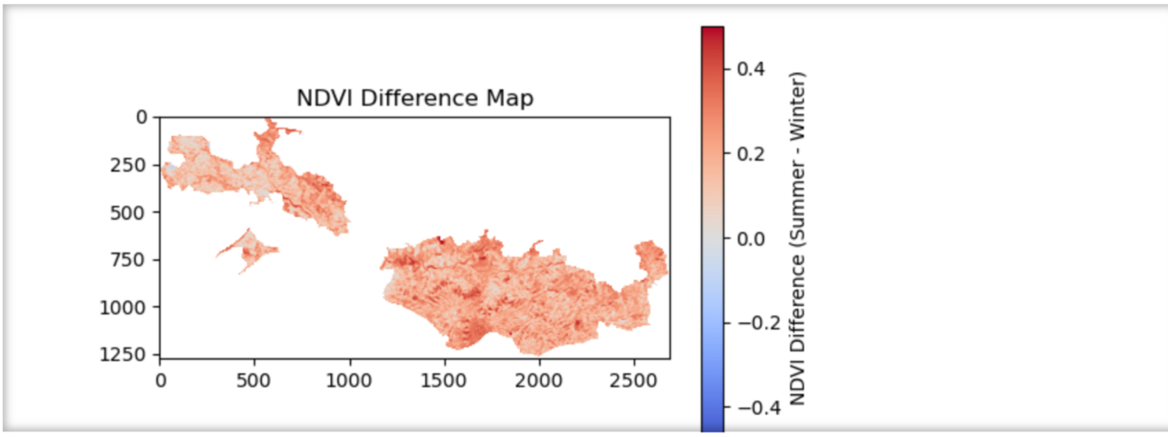


Figure: 9 **NDVI Difference (Summer - Winter)**

```
plt.show()
```

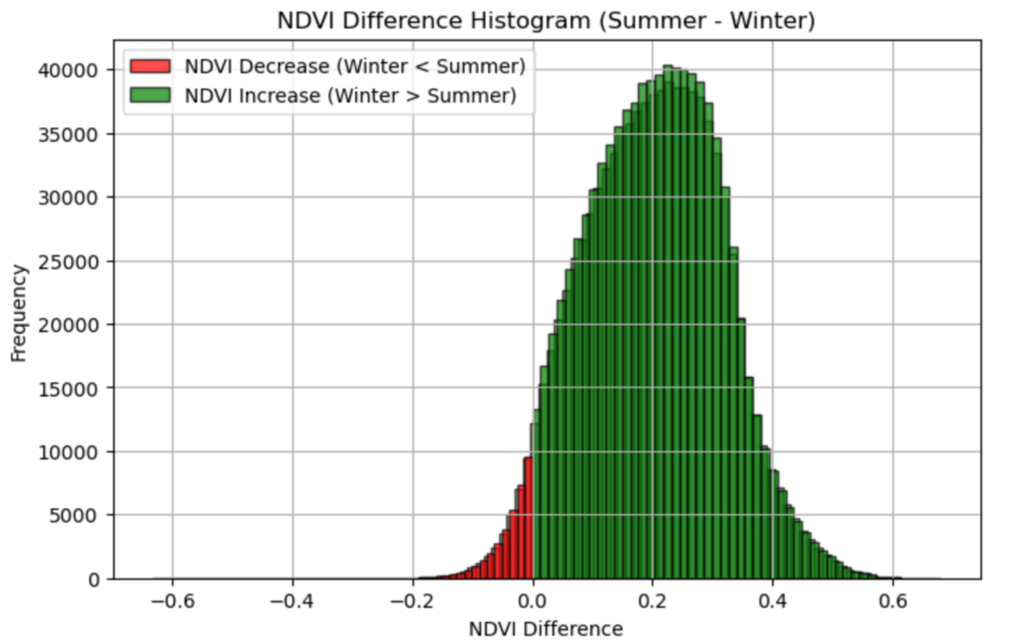


Figure: 10 NDVI Difference (Summer - Winter), Histogram

```
[24]: # Plot NDVI Boxplot
plt.figure(figsize=(3, 2))
sns.boxplot(data=[ndvi_data["Summer"], ndvi_data["Winter"]], palette=["green", "blue"])
plt.xticks([0, 1], ["Summer", "Winter"])
plt.ylabel("NDVI Value")
plt.title("NDVI Distribution (Boxplot)")
plt.grid(True)
plt.show()
```

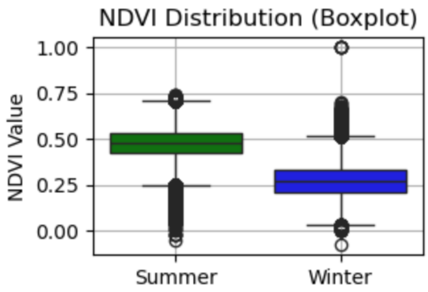


Figure 11.

NDVI Difference Map (Winter–Summer)

The NDVI Difference Map illustrates the vegetation change across seasons in Saxon Switzerland National Park. Red is utilized to indicate NDVI decline (less green in summer compared to winter), and blue indicates an increase. The average NDVI difference of 0.2003 illustrates a general rise in vegetation activity.activity, illustrating a general rise in vegetation activity during summer.

NDVI Difference Histogram.

The histogram also indicates the spread of the NDVI differences. The majority of the pixels (green bars) are positive, indicating the park has a greater NDVI during summer. There are zero pixels (red bars) with negative NDVI values, indicating there are no areas of higher NDVI in winter, which can be attributed to evergreen vegetation or seasonal landscape change.

NDVI Boxplot (Summer vs. Winter)

The boxplot is contrasting summer (green) and winter (blue) NDVI distributions. The Summer NDVI has a higher median (~0.5) and fewer outliers, indicating dense vegetation. The Winter NDVI is lower in median (~0.3) with higher variability, indicating less vegetation activity and bare grounds. These graphs summarize seasonal vegetation trends, which can be used to track environmental change and plan conservation.

Conclusion

This research will add a scientific, data-driven approach to the monitoring of the vegetation health of Saxon Switzerland National Park. With the application of NDVI and geospatial technology, the study aims to help support conservation activities, detect environmental changes, and establish a long-term ecological monitoring system for the park.

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