RESEARCH PROJECT COURSE

[PHYS494]

SPRING 2024

INVESTIGATION OF TEMPORAL VARIATIONS IN VEGETATION IN AL AIN AND ABU DHABI REGIONS USING MODIS DATA

SUPERVISED BY

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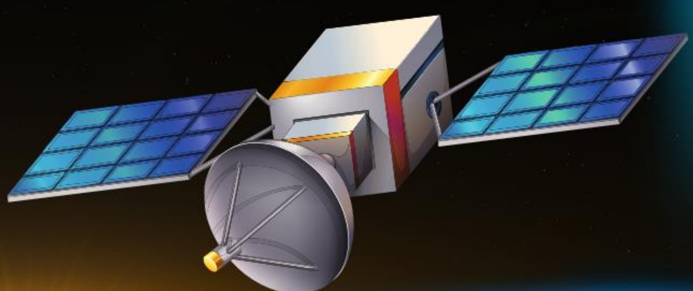

SECTION 51

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Introduction

Satellite remote sensing represents a cutting-edge technological paradigm, offering a panoramic insight into Earth's surface, atmosphere, and oceans through the deployment of sensors aboard orbiting satellites. This sophisticated technology serves as a powerful tool for exploring and comprehending various facets of the environment, ranging from intricate weather patterns to land utilization and environmental dynamics, all on a global scale. At its core, remote sensing entails the meticulous capture of information about distant objects or regions, facilitated by sensors aboard satellites traversing space or airborne platforms. This process hinges upon the intricate interaction between electromagnetic radiation and the features of Earth's surface, with sensors meticulously recording the reflected or emitted radiation for subsequent analysis.

The satellites employed for remote sensing purposes can be broadly categorized into two primary types: passive and active. Passive satellites adeptly capture natural radiation emanating from the Earth's surface or atmosphere through the utilization of optical or thermal sensors. Conversely, active satellites emit their own radiation signals, such as radar pulses, to penetrate through obstructions like clouds and vegetation, effectively measuring surface features with precision.

The applications of satellite remote sensing span a vast spectrum of fields and wield significant impact, encompassing critical domains such as environmental monitoring, weather forecasting, natural resource management, urban planning, and disaster management. However, notwithstanding its transformative potential, satellite remote sensing grapples with a myriad of challenges. These challenges include the complexities inherent in interpreting vast datasets and the pervasive influence of atmospheric interference, necessitating a relentless pursuit of advancements in sensor technology and data processing algorithms to surmount these obstacles and unlock the full potential of remote sensing technologies for the betterment of humankind.

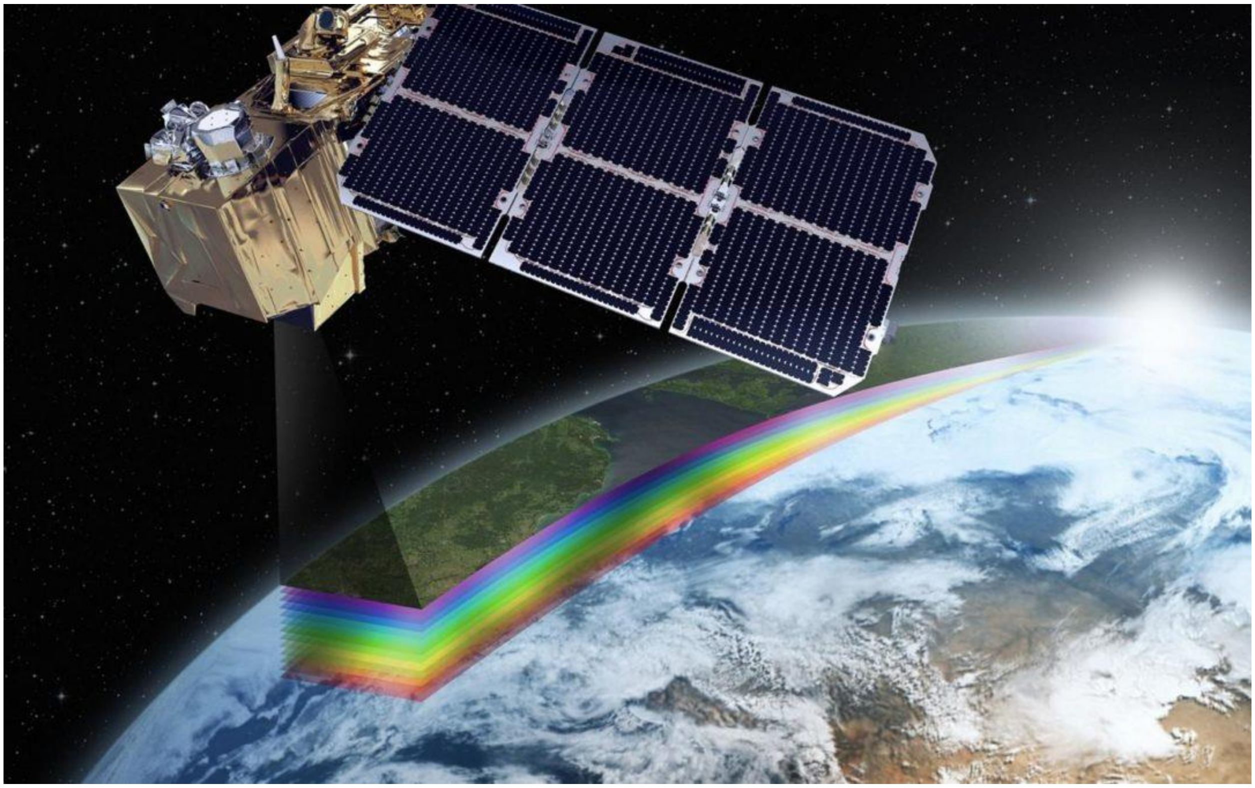

Figure.1 Remote sensing satellite gathering information without any physical contact.

Background

Satellite remote sensing epitomizes a cutting-edge technological frontier, affording an expansive vista into Earth's surface, atmosphere, and oceans by harnessing sensors deployed aboard orbiting satellites. This revolutionary technology serves as a potent instrument for delving into and comprehending various environmental phenomena, spanning intricate weather patterns, land utilization variations, and environmental changes, all on a global scale. At its essence, remote sensing embodies the meticulous capture of information concerning distant objects or regions, facilitated by sensors adorning satellites navigating the vast expanse of space or airborne platforms. This intricate process hinges upon the interplay between electromagnetic radiation and Earth's surface features, with sensors meticulously capturing the reflected or emitted radiation for subsequent analysis.

The satellites employed in remote sensing endeavors can be broadly categorized into two primary types: passive and active. Passive satellites adeptly capture the natural radiation emanating from Earth's surface or atmosphere utilizing optical or thermal sensors. In contrast, active satellites emit their own radiation signals, such as radar pulses, penetrating through obstacles like clouds and vegetation to measure surface features with remarkable precision.

The applications of satellite remote sensing traverse a wide spectrum of fields, yielding profound impacts across critical domains such as environmental monitoring, weather forecasting, natural resource management, urban planning, and disaster management. However, notwithstanding its transformative potential, satellite remote sensing grapples with an array of challenges. These challenges encompass the complexities inherent in interpreting vast datasets and the pervasive influence of atmospheric interference, necessitating a relentless pursuit of advancements in sensor technology and data processing algorithms to overcome these obstacles and unlock the full potential of remote sensing technologies for the betterment of humankind.

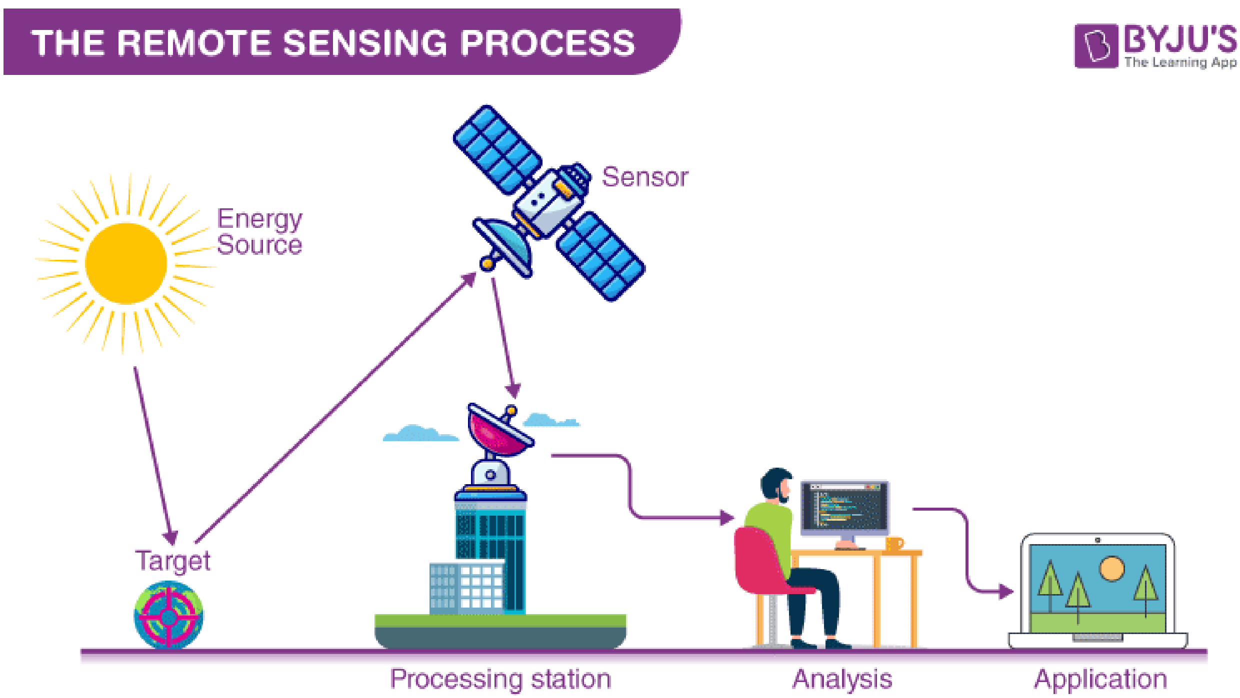

Figure.3 shows the process of remote sensing.

Moreover, a thorough comprehension of remote sensing technology forms the cornerstone of this research endeavor. It mandates a comprehensive understanding of the principles, methodologies, and applications intrinsic to remote sensing. This encompasses familiarity with a plethora of satellite imagery platforms, encompassing their respective sensors, spectral bands, and spatial resolutions. Additionally, a nuanced understanding of data processing techniques is indispensable, spanning from image pre-processing and calibration to advanced spectral and spatial analysis methods. Concurrently, a robust foundation in environmental science provides the necessary context for interpreting vegetation variations within broader ecological frameworks. This involves grasping the multifaceted interactions between vegetation health and various environmental factors such as climate, soil composition, land use, and human activities. Proficiency in data analysis methodologies and tools is fundamental for extracting meaningful insights from remote sensing data. This entails expertise in statistical analysis techniques, time series analysis, and spatial statistics, alongside proficiency in software packages commonly employed in environmental research, such as R, Python, and MATLAB. Furthermore, a deep understanding of geospatial analysis techniques is indispensable, encompassing knowledge of geographic information systems (GIS), spatial interpolation methods, and spatial modeling approaches. Programming skills, particularly in Java for developing custom scripts and algorithms tailored to specific data analysis tasks, are highly advantageous. Additionally, proficiency in scripting languages like Python facilitates workflow automation, data manipulation, and interaction with remote sensing libraries and application programming interfaces (APIs). Given the centrality of the Normalized Difference Vegetation Index (NDVI) in quantifying vegetation variations, a thorough understanding of NDVI principles, calculation methodologies, and interpretation nuances is critical. Equally important are strong analytical and interpretive skills, enabling researchers to discern temporal vegetation variations, identify meaningful patterns, and derive actionable insights from remote sensing datasets.

$$\text{NDVI} = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})}$$

The NDVI (Normalized Difference Vegetation Index) formula calculates a pixel's index value in a satellite image, incorporating two key elements: NIR (Near-Infrared) for reflectance in the near-infrared band and Red for reflectance in the red band. This index ranges from -1 to 1, with higher NDVI values typically indicating healthier or denser vegetation, while lower values suggest sparse or stressed vegetation, as well as bare soil or urban
areas.

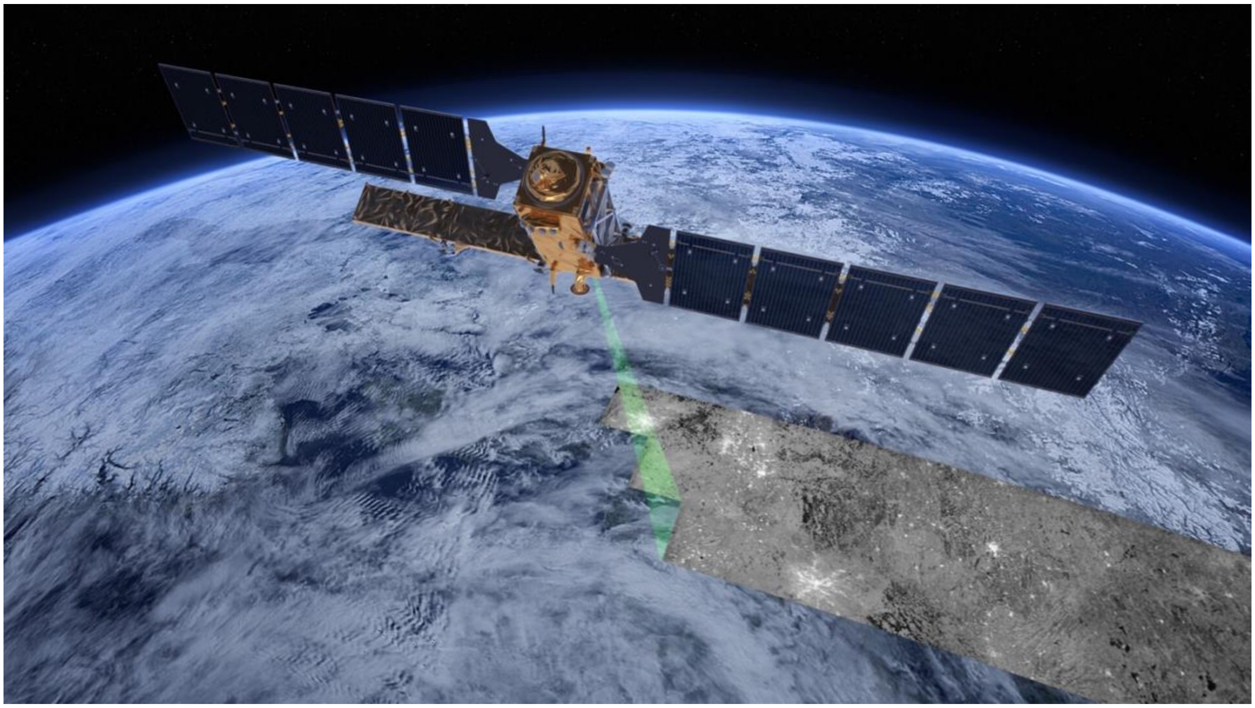
Figure.3 Conceptual image of the Sentinel 1 satellite collecting radar imagery as it orbits Earth.

Research Methodology

The research methodology centers on employing remote sensing techniques, specifically utilizing MODIS NDVI data, to analyze vegetation variations in the Al Ain and Abu Dhabi regions. The study initiates with meticulous data collection and preprocessing, facilitated using Google Earth Engine (GEE) code. This involves specifying the geographical coordinates for Al Ain ([55.470, 24.045], [55.470, 24.285], [55.890, 24.285], [55.890, 24.045]) and Abu Dhabi ([54.122899, 24.605935], [54.122899, 24.148549], [54.842656, 24.148549], [54.842656, 24.605935]) and acquiring MODIS NDVI imagery spanning from 2010 to 2022. Preprocessing activities entail filtering the MODIS data by date and region utilizing GEE, a powerful cloud-based platform for planetary-scale geospatial analysis.

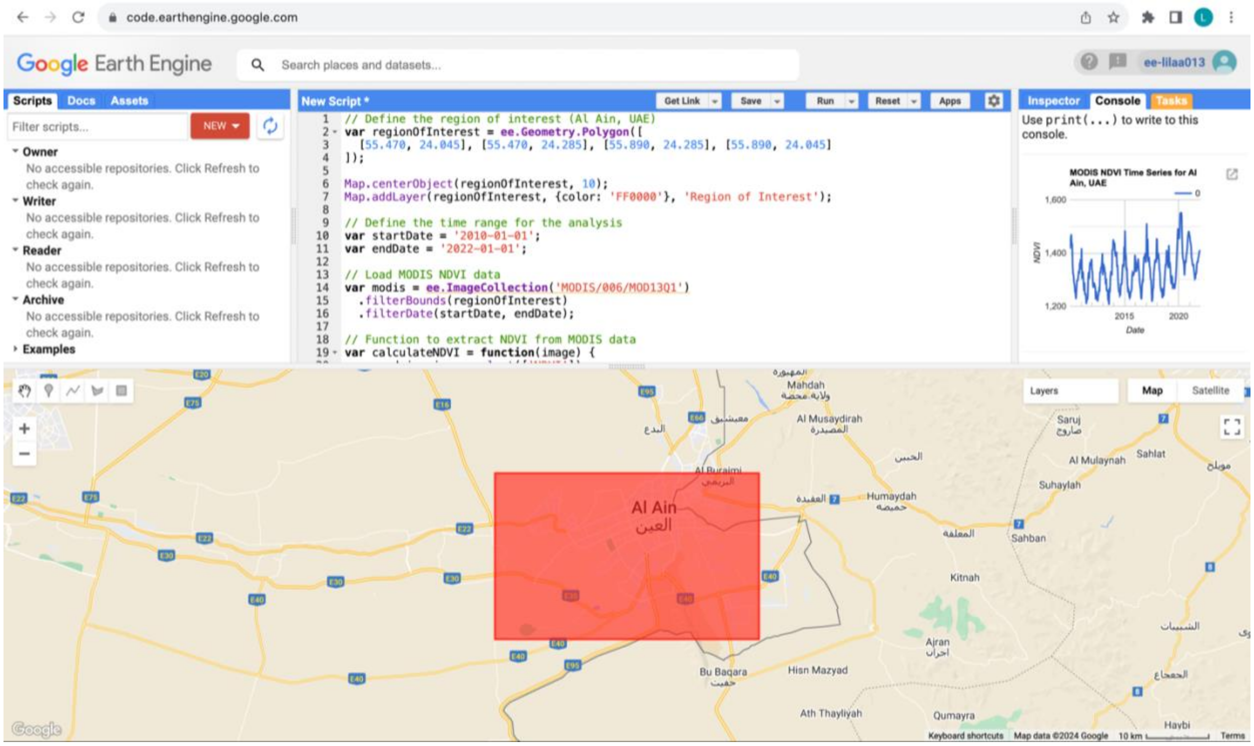

Figure.4 Screenshot of Google Earth Engine window in which we loaded the MODIS data estimated the NDVI and processed data to produce the time series.

MODIS (Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard NASA's Terra and Aqua satellites, providing global coverage of land surface dynamics, vegetation health, and climate variables at moderate spatial resolutions. The MODIS NDVI data, derived from the ratio of near-infrared and red reflectance measurements, offers valuable insights into vegetation variations over large geographic areas. With its daily revisit capability and extensive historical archives, MODIS NDVI data enables long-term monitoring of vegetation phenology, ecosystem productivity, and land surface changes. The MODIS sensor's spectral bands, calibrated radiometric measurements, and data processing algorithms ensure high-quality and consistent imagery suitable for a wide range of environmental applications.

Following data preprocessing, the calculation of NDVI values from the MODIS imagery ensues. This involves a well-established formula wherein the near-infrared (NIR) band is subtracted from the red band and divided by the sum of both bands. GEE provides a robust environment for executing these calculations efficiently across large spatial and temporal extents.

Subsequently, a time series analysis approach is adopted to map NDVI values over time. GEE enables the implementation of complex spatial and temporal analyses, allowing for the extraction of NDVI values over the regions of interest (Al Ain and Abu Dhabi) for each time step. This facilitates the visualization of temporal trends in vegetation variations and streamlines the generation of time series charts.

The methodology then progresses to comparison and analysis. NDVI trends between Al Ain and Abu Dhabi are meticulously compared, with a particular focus on identifying and analyzing peaks in NDVI values, indicative of periods of heightened vegetation growth. Statistical methods may be utilized to quantitatively assess differences in NDVI trends between the two regions.

Interpretation and discussion of the findings follow, wherein observed differences in NDVI trends are contextualized within environmental factors such as climate, land use, and agricultural practices. The implications of the findings for agricultural management and environmental monitoring are thoroughly explored, providing valuable insights into the variations of vegetation in the study areas.

Finally, the research methodology concludes by summarizing key findings and emphasizing the significance of remote sensing in agriculture. Suggestions for future research directions or refinements to the methodology are also provided, ensuring a robust framework for ongoing investigation and analysis. Throughout the methodology, rigorous validation and quality control measures are implemented to ensure the accuracy and reliability of the results, underscoring the methodological rigor of the research.

Data analysis

For the data analysis section, we utilized Google Earth Engine to extract MODIS NDVI (Normalized Difference Vegetation Index) data for the Al Ain and Abu Dhabi regions in the United Arab Emirates. The provided code delineates the steps involved in retrieving and visualizing the vegetation variations over a specified period, from January 2010 to January 2022. Let's delve into the details of the analysis and its implications.

Firstly, we defined the region of interest, which in this case, is the Al Ain area, using geographic coordinates to create a polygon geometry. This region was selected due to its significance in agricultural activities and vegetation cover within the UAE. The time range for analysis was set from January 2010 to January 2022 to capture vegetation variations over a span of 12 years.

We then loaded the MODIS NDVI data for the specified region and time range. MODIS imagery is renowned for its global coverage and moderate spatial resolution, making it suitable for monitoring vegetation variations over large areas.

A key step in the analysis was to calculate the NDVI values from the MODIS data. NDVI is a widely used index for quantifying vegetation greenness and health based on the difference in reflectance between near-infrared and red wavelengths. The provided code includes a function to extract NDVI values from each MODIS image in the collection.

Subsequently, we mapped the NDVI function over the MODIS image collection to generate a time series chart depicting the temporal variation of NDVI values for the Al Ain region. The chart visualizes the average NDVI values over time, providing insights into seasonal and long-term vegetation variations.

Upon visual inspection of the time series chart, it is evident that both the Al Ain and Abu Dhabi regions exhibit notable fluctuations in NDVI values over the study period. Interestingly, the highest peak in NDVI values occurs around the year 2020 for both regions. This observation raises intriguing questions about the potential drivers behind this vegetation surge, particularly in the context of the COVID-19 pandemic, which significantly impacted human activities and environmental conditions globally.

Further analysis is warranted to explore the potential connection between the observed increase in vegetation and the COVID-19 pandemic. Hypotheses could include reduced anthropogenic activities leading to improved air quality and reduced pollution, thereby benefiting vegetation health. Additionally, factors such as changes in land use practices, climate variability, and natural disturbances may contribute to the observed vegetation variations.

Moreover, comparisons between Al Ain and Abu Dhabi reveal distinct patterns in vegetation variations, with Al Ain exhibiting higher NDVI values compared to Abu Dhabi, particularly in the years preceding 2020. This discrepancy could be attributed to differences in land cover, agricultural practices, and water availability between the two regions. Future research could delve deeper into these factors to elucidate the drivers of vegetation variations and inform sustainable land management practices.

In conclusion, the analysis of MODIS NDVI data provides valuable insights into the temporal variation of vegetation variations in the Al Ain and Abu Dhabi regions. The observed increase in vegetation around 2020 warrants further investigation to elucidate potential drivers, including the impact of the COVID-19 pandemic. Additionally, comparisons between regions highlight the importance of considering local environmental factors in understanding vegetation variations. Overall, this analysis underscores the utility of remote sensing data in monitoring and understanding ecosystem dynamics and informs decision-making for sustainable land management and environmental conservation efforts.

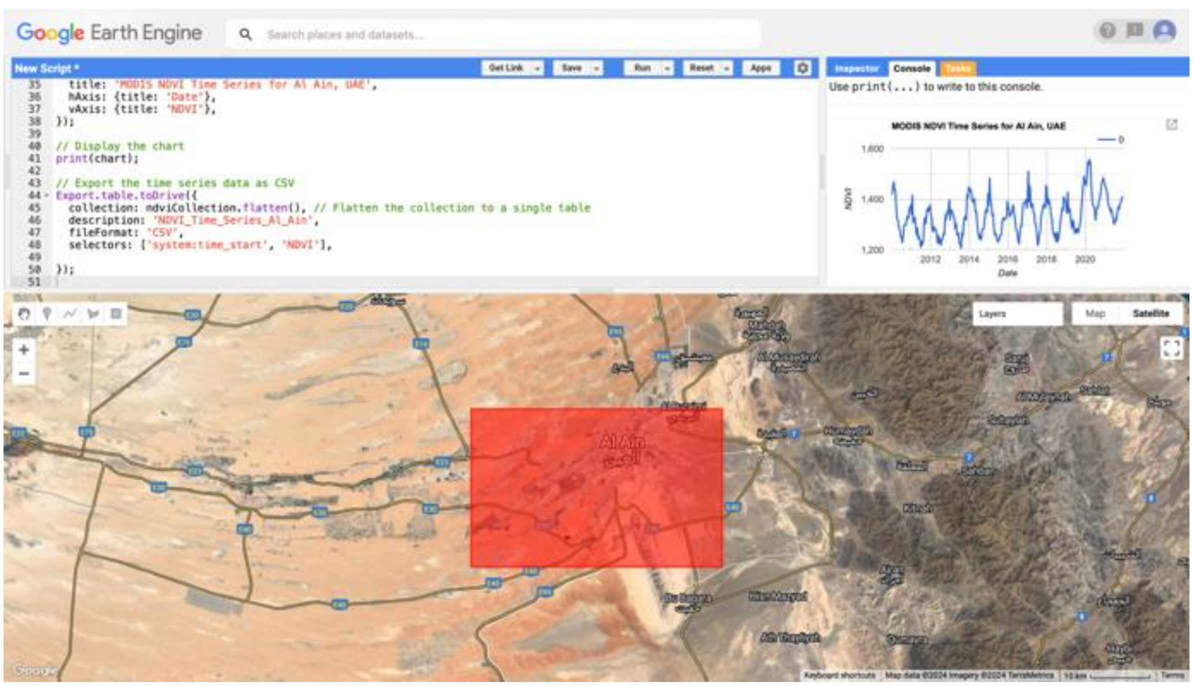

Figure.5 The region in Al Ain that we chose to see how the vegetation changed in that specific region.

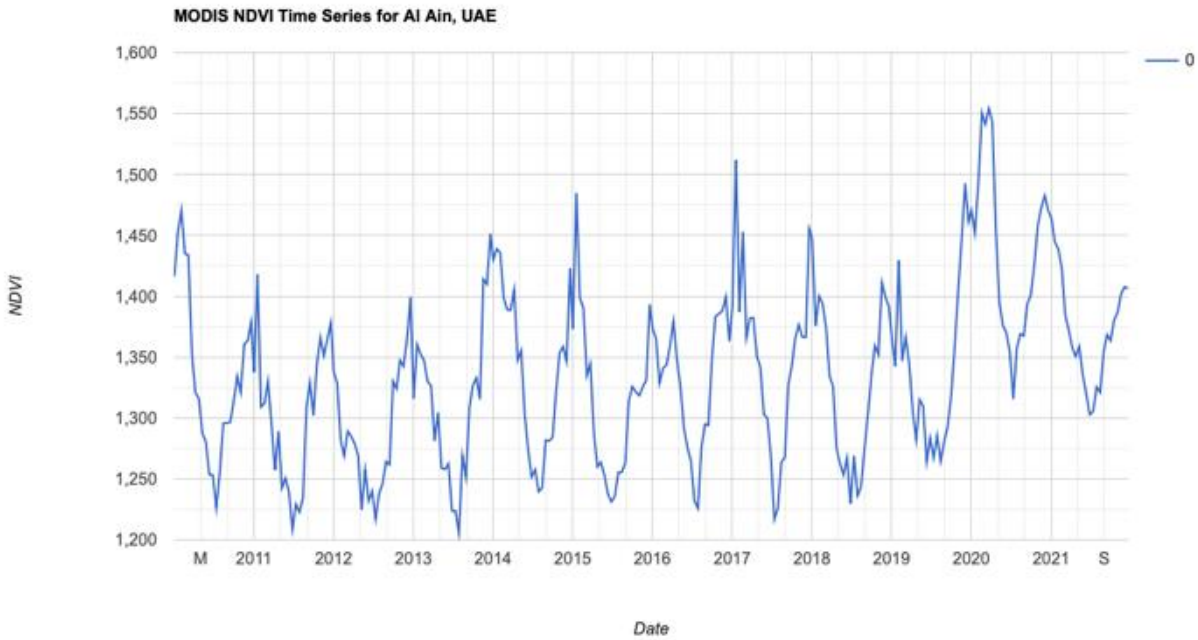

Figure.6 This is the variation in NDVI for 12 years in Al Ain region.

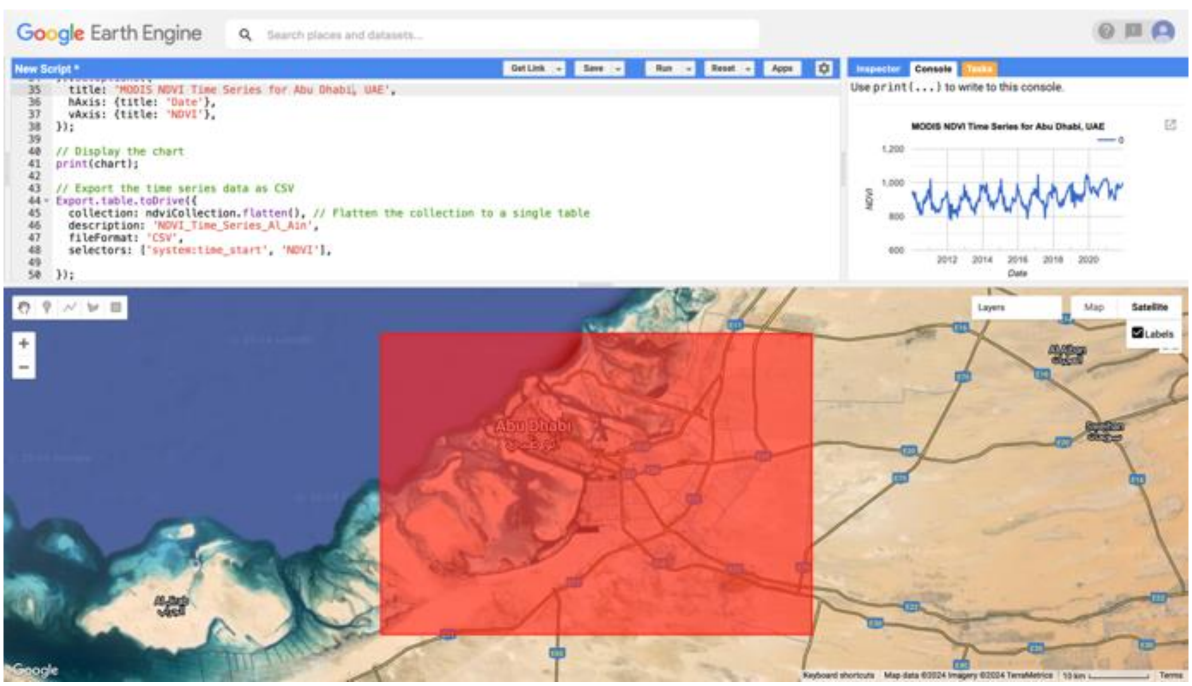

Figure.7 The region in Abu Dhabi that we chose to see how the vegetation changed in that specific region.

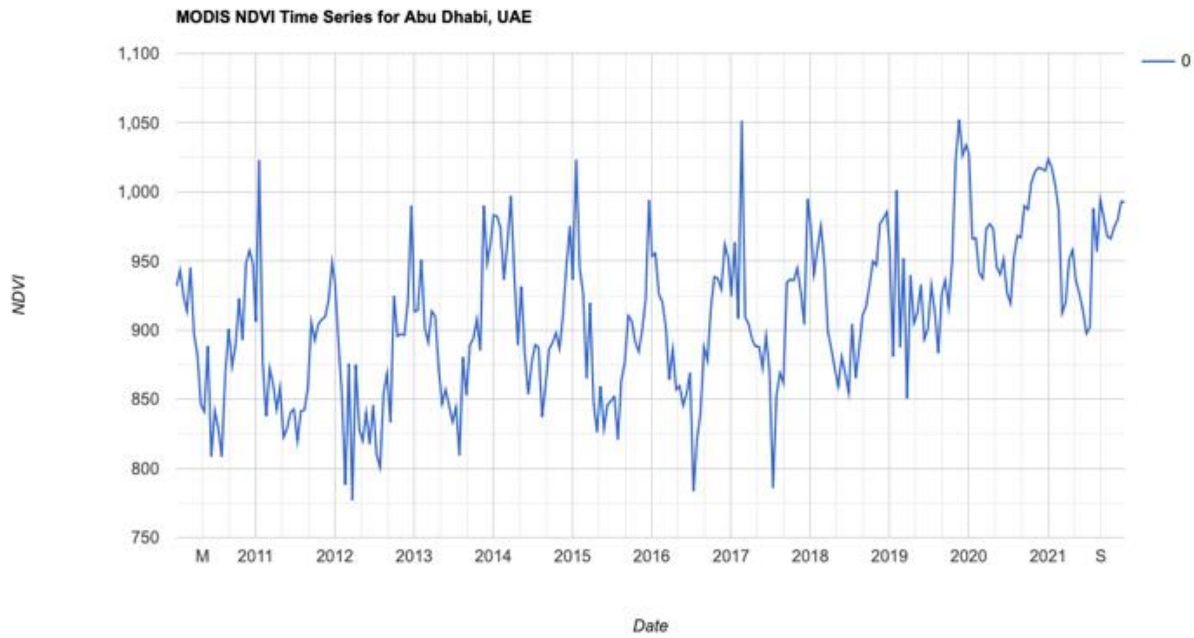

Figure.8 This is the variation in NDVI for 12 years in Abu Dhabi region.

Discussion

The notable increase in vegetation in the Al Ain and Abu Dhabi regions around the year 2020 raises intriguing questions about the potential drivers behind this surge, particularly in the context of the COVID-19 pandemic. While the direct causal relationship between the pandemic-related disruptions and the observed vegetation growth requires further investigation, it's plausible to hypothesize that reduced human activities during the lockdown periods may have played a role. The decrease in vehicular traffic, industrial emissions, and agricultural activities might have alleviated environmental stressors and contributed to improved air quality and reduced pollution levels, thereby creating favorable conditions for vegetation growth. However, it's essential to exercise caution in attributing the observed vegetation changes solely to the pandemic, as other factors such as climate variability and natural disturbances could also influence vegetation variations.

Moreover, the comparison between the Al Ain and Abu Dhabi regions reveals intriguing differences in vegetation patterns. Al Ain consistently exhibits higher NDVI values compared to Abu Dhabi, suggesting variations in land cover, land use practices, and environmental conditions between the two regions. Al Ain's status as an agricultural hub with abundant oases and green spaces likely contributes to its higher vegetation cover compared to the more urbanized landscape of Abu Dhabi.

Relating our findings to existing literature in remote sensing and environmental science, our study contributes to the growing body of knowledge on ecosystem dynamics and the impact of human activities on vegetation health. By leveraging satellite remote sensing data, we gain valuable insights into long-term vegetation trends and their underlying drivers, providing valuable information for land management and environmental conservation efforts.

However, it's essential to acknowledge the limitations of our study. While satellite remote sensing offers a powerful tool for monitoring large-scale vegetation variations, it has inherent limitations such as spatial and temporal resolution constraints. Additionally, the absence of ground truth validation and the complexity of interpreting remote sensing data pose challenges in accurately attributing observed changes to specific causal factors.

In conclusion, the discussion section offers critical insights into the implications of the research findings, proposes potential explanations for observed trends, and highlights avenues for further investigation. By elucidating the complex interplay between human activities, environmental factors, and vegetation variations, our study contributes to advancing our understanding of ecosystem dynamics and informs evidence-based decision-making for sustainable land management and environmental conservation.

Conclusion

To sum up, this research utilizes satellite remote sensing, particularly MODIS NDVI data, to analyze vegetation variations in the Al Ain and Abu Dhabi regions of the United Arab Emirates. Through meticulous data collection, preprocessing, and analysis, we have gained valuable insights into temporal variations in vegetation cover and identified intriguing patterns in NDVI values over the study period. The observed increase in vegetation around 2020 prompts questions about potential drivers, notably in the context of the COVID-19 pandemic, underscoring the utility of remote sensing in monitoring ecosystem dynamics. Comparisons between regions reveal distinct vegetation patterns, emphasizing the influence of local environmental factors. While our study contributes to understanding ecosystem dynamics, limitations such as data constraints warrant future research enhancements. Overall, this research underscores the transformative potential of remote sensing technologies in informing evidence-based decisions for sustainable land management and environmental conservation.

Appendix

In this section of our research, we provide the code that was used in Google Earth Engine for data acquisition, preprocessing, analysis, and visualization. These code snippets, implemented in Google Earth Engine (GEE), facilitated the extraction of MODIS NDVI data, calculation of vegetation indices, generation of time series charts, and comparison of vegetation variations between study areas. By ensuring transparency and reproducibility, the code snippets in the appendix serve as a valuable resource for researchers seeking to replicate or build upon the methodologies employed in this study.

```
// Define the region of interest (Al Ain, UAE)
var regionOfInterest = ee.Geometry.Polygon([
  [55.470, 24.045], [55.470, 24.285], [55.890, 24.285], [55.890, 24.045]
]);


Map.centerObject(regionOfInterest, 10);
Map.addLayer(regionOfInterest, {color: 'FF0000'}, 'Region of Interest');


// Define the time range for the analysis
var startDate = '2010-01-01';
var endDate = '2022-01-01';


// Load MODIS NDVI data
var modis = ee.ImageCollection('MODIS/006/MOD13Q1')
  .filterBounds(regionOfInterest)
  .filterDate(startDate, endDate);


// Function to extract NDVI from MODIS data
var calculateNDVI = function(image) {
  var ndvi = image.select(['NDVI']);
  return ndvi.rename('NDVI');
};


// Map the NDVI function over the MODIS collection
var ndviCollection = modis.map(calculateNDVI);
```

```
// Create a time series chart for the region
var chart = ui.Chart.image.seriesByRegion({
  imageCollection: ndviCollection,
  regions: regionOfInterest,
  reducer: ee.Reducer.mean(),
  scale: 250, // The scale of MODIS data
  xProperty: 'system:time_start'
}).setOptions({
  title: 'MODIS NDVI Time Series for Al Ain, UAE',
  hAxis: {title: 'Date'},
  vAxis: {title: 'NDVI'},
});


// Display the chart
print(chart);


// Export the time series data as CSV
Export.table.toDrive({
  collection: ndviCollection.flatten(), // Flatten the collection to a single table
  description: 'NDVI_Time_Series_Al_Ain',
  fileFormat: 'CSV',
  selectors: ['system:time_start', 'NDVI'],

});
```

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