# Monitoring Urban Growth and Vegetation Changes in Al Ain Using Remote Sensing and GIS Techniques, UAE (2017-2023)

GIS & Remote Sensing Approach


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51

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## 1. Introduction

Geographic Information Systems (GIS) and Remote Sensing (RS) have transformed the way we analyze land use and land cover (LULC) changes, providing critical insights into the impacts of urban growth on natural landscapes. As urbanization accelerates, particularly in rapidly developing regions, tracking these changes becomes essential for sustainable urban planning. The city of Al Ain in the UAE, often referred to as the "Garden City" for its extensive green spaces and agricultural lands, offers a unique case study of these dynamics. With its agricultural heritage and proximity to natural desert landscapes, Al Ain has experienced substantial changes due to rapid urbanization and economic development. Understanding these shifts in land use is key to balancing growth with environmental preservation.

This project focuses on assessing LULC changes in Al Ain from 2017 to 2023, expanding on previous research that analyzed similar transformations between 2006 and 2016. The earlier study revealed a notable 8% increase in agricultural land and a 12% expansion in urban areas, primarily at the expense of natural sandy regions. This growth has led to a reduction in green and undeveloped areas, impacting the region's ecosystem and resource availability. By extending the study period to include recent years, this project aims to provide an updated perspective on these trends, helping to determine if the previous patterns of urban expansion have continued or intensified.

To achieve this, we utilize high-resolution satellite imagery from Sentinel-2 and Landsat-8, which offer spatial resolutions of 30m, 15m, and 60m. These satellites provide detailed imagery that allows for a closer examination of land cover changes, particularly in identifying shifts in urban, agricultural, and natural land types. GIS serves as the primary tool for processing and analyzing this data, enabling us to classify and track changes in specific land categories over time. The combination of GIS and RS technology facilitates a comprehensive spatial-temporal analysis, allowing us to visualize, quantify, and interpret these shifts effectively.

Al Ain's location and unique environmental features make it especially vulnerable to the effects of urban expansion. Located inland within the Emirate of Abu Dhabi, Al Ain is the UAE's fourth largest city and the second largest in the Abu Dhabi Emirate. Its geographic position near the Omani border, coupled with its reliance on both agricultural and urban resources, makes it a critical area for study. Highways connecting Al Ain with Dubai and Abu Dhabi have further catalyzed its growth, contributing to an expanding network of infrastructure and residential areas. As these urban areas grow, the pressure on natural landscapes, such as desert and agricultural regions, increases, leading to potential challenges in water management, biodiversity, and soil conservation.

Our study integrates various GIS layers, including vegetation condition indices, soil data, and LULC classifications, to generate a multidimensional view of Al Ain's landscape. Techniques such as the Normalized Difference Vegetation Index (NDVI) allow us to analyze vegetation health, while GIS mapping helps to reveal patterns in urban growth and land conversion. By mapping and analyzing these changes, we can provide valuable insights for policymakers and urban planners, offering a foundation for sustainable development practices in Al Ain.

Ultimately, this study seeks to inform future land management decisions by highlighting areas that are most affected by urbanization and identifying zones with potential for sustainable development. The findings will support Al Ain's urban planning efforts, helping to balance the demands of urban expansion with the need to conserve natural resources. Through this comprehensive analysis, we aim to contribute to the broader understanding of how urban growth impacts semi-arid environments, adding valuable insights to ongoing discussions on sustainable urbanization in the UAE and similar regions.

## 2. Methodology

This study employs Geographic Information Systems (GIS) and Remote Sensing (RS) techniques to analyze land use and land cover (LULC) changes in Al Ain from 2017 to 2023. Our methodology is structured into key stages: data collection, data preparation, data storage, data processing, data querying, and visualization of results. Each step is crucial for accurately tracking and understanding spatial-temporal patterns in urban growth, vegetation changes, and landscape transformations.

1. **Data Collection:**

- **Satellite Imagery:** We collected high-resolution satellite data from Sentinel-2 and Landsat-8. Sentinel-2 provides spatial resolutions of 10m, 20m, and 60m, while Landsat-8 offers resolutions of 15m, 30m, and 100m. This range of resolutions allows for detailed mapping of various land use categories, such as urban areas, agricultural fields, and natural desert regions, giving us a comprehensive spatial dataset for the study period.

- **Supplementary GIS Data:** Additional data was sourced from the Al Ain City Municipality and the Abu Dhabi Agriculture Department. This supplementary data includes historical agricultural records, boundary shapefiles, road networks, and topographic information. Such data provides essential context for the satellite imagery, helping to delineate specific zones and land cover types within the study area.

2. **Data Preparation:**

- **Image Preprocessing:** The satellite images were preprocessed to correct for atmospheric distortion and align spatial coordinates. We used radiometric and geometric correction techniques to ensure that the imagery accurately reflects on-the-ground conditions. Image stacking, resampling, and resolution enhancement were performed to standardize datasets, facilitating consistent comparison between different years.

- **Vegetation and LULC Indices:** Vegetation indices, particularly the Normalized Difference Vegetation Index (NDVI), were calculated to assess vegetation health across the study period. NDVI is particularly useful in this context as it helps distinguish vegetated areas from non-vegetated ones, highlighting areas of vegetation loss or degradation due to urban expansion.

3. **Data Storage Using DBMS:**

- The spatial and attribute data were organized and stored in a Database Management System (DBMS), using a combination of models tailored to handle different data types:

- **Hierarchical DBMS:** Used for structured data that follow a parent-child relationship, such as administrative boundaries and hierarchical land classifications.

- **Network DBMS:** Ideal for managing interconnected spatial elements, such as road networks and utilities, allowing multiple relationships between data points.

- **Relational DBMS:** Employed to store tabular data with spatial attributes, enabling easy querying and retrieval of specific data points related to land use types.

- **Object-Oriented DBMS:** Supports complex spatial data structures, such as polygons representing different land cover types, allowing for more realistic and detailed storage of geographical entities.

4. **Data Processing:**

- **Classification Techniques:** To categorize different land cover types, we applied both supervised and unsupervised classification techniques. Supervised classification uses training samples to classify known land cover types, such as urban, vegetation, and desert, while unsupervised classification identifies natural groupings within the data. This dual approach improves the accuracy of land use classifications, ensuring reliable results.

- **Image Analysis:** ERDAS Imagine software was used to enhance the spatial resolution of Landsat-8 imagery using the HCS (High-Resolution Composite) technique, reducing pixel size from 30m to 15m. Band combinations, such as 5-4-3 for infrared and 4-3-2 for natural color, helped distinguish vegetation, water bodies, and urban areas, aiding in the visual interpretation and analysis of LULC changes.

5. **Data Querying:**

- **Spatial Queries and SQL:** GIS and SQL tools were used to perform spatial queries, allowing us to analyze specific characteristics of land cover changes. For example, we calculated the area of urban expansion and quantified shifts in vegetation by querying data layers that contain attribute information, such as land type, area, and vegetation index values. SQL querying within the GIS environment also enabled us to join various datasets, such as linking Sentinel-2 imagery with municipal boundary shapefiles, to gain a more comprehensive view of land use dynamics.

6. **Results and Visualization:**

- **Mapping and Visualization in ArcGIS:** The processed data was visualized using ArcGIS, generating a series of maps, charts, and graphs that illustrate land use and vegetation changes from 2017 to 2023. NDVI and other vegetation indices were used to create thematic maps, showing areas with healthy vegetation versus those with reduced cover. False-color composites and natural color representations helped highlight specific land cover types, providing a clear picture of Al Ain's landscape transformations.

- **Temporal Analysis:** By comparing satellite images from different years, we conducted temporal analysis to identify patterns and rates of land cover change. The NDVI maps were particularly valuable in assessing vegetation health over time, revealing areas of significant decline linked to urban encroachment or environmental pressures.

Through this comprehensive methodology, we provide a robust analysis of how urbanization has impacted Al Ain's landscape over time. The integration of high-resolution imagery, DBMS models, and GIS tools enables detailed monitoring of LULC changes, offering insights that can guide sustainable development strategies in Al Ain and similar semi-arid regions.

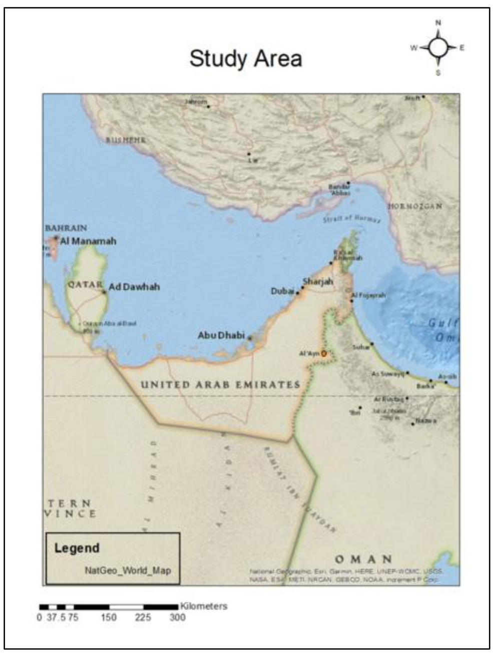
# 3. Materials

## 3.1. Study area

The study examines Al Ain, one of the UAE's rapidly expanding cities, positioned at coordinates around 192,277.55 and 747,547.13. The research focuses on three primary aspects: vegetation condition index, soil, and land use/land cover. Figure 1 illustrates Al Ain's location within the UAE; this city is situated in the Emirate of Abu Dhabi, serving as the administrative center of the Al Ain Region. It borders the Omani town of Al-Buraimi to the east. Al Ain is notable as the UAE's largest inland city, the fourth largest overall (following Dubai, Abu Dhabi, and Sharjah), and the second largest within the Abu Dhabi Emirate. Highways connecting Al Ain with

Abu Dhabi and Dubai create a triangular geographic network, with each city approximately 130 kilometers apart.

The topographic map of Al Ain, shown in Figure 2, provides detailed insights into the city's terrain and elevation. Topography is essential for vegetation studies, as it reveals the elevation, slope, and water flow patterns that affect soil types, moisture levels, and sunlight exposure, all of which are crucial for plant growth. This information is valuable for environmental planning and agricultural management, as it helps identify ideal planting locations, manage forest resources, monitor vegetation health, and preserve biodiversity. Additionally, topographic maps are useful for tracking long-term changes in the landscape, such as deforestation or reforestation, which support ecosystem stability and environmental sustainability.



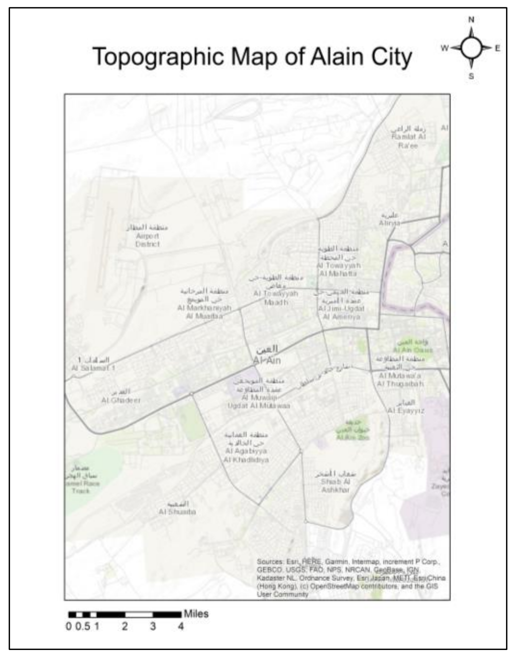




**Figure 1**: Map showing the location of Al Ain within the UAE. **Figure 2**: Map showing Al Ain's terrain and elevation.

## 3.2. Data sets

This study utilized Sentinel-2 satellite images, acquired through the sources indicated in Table 1, to assess land use and vegetation changes in Al Ain, a city in the UAE experiencing rapid growth. The satellite data, spanning from 2017 to 2023, provided crucial spatial insights into the area.

The data collection process was grounded in two main techniques: remote sensing and GIS analysis. By leveraging high-resolution satellite imagery from Google Earth, Landsat-8, and Sentinel-2, the study captured detailed images of various land cover types, including urban areas, agricultural zones, and desert stretches. These images provided spatial resolutions of 30m, 15m, and 60m, offering the clarity needed for accurate mapping of landscape changes. Supplementary GIS data, sourced from Al Ain City Municipality and the Abu Dhabi Agriculture Department, included historical agricultural data, boundary shape-files, and road network information, enriching the overall dataset. Table 1 offers a comprehensive summary of these datasets and sources.

For mapping and visualization, the research utilized ArcGIS and ERDAS Imagine software, which were instrumental in tracking vegetation and land use transformations in Al Ain over the 2017-2023 period. These tools allowed for in-depth analysis and visualization of spatial changes, enhancing the study's ability to capture and interpret significant shifts in land cover. Table 1 consolidates the data sources, resolutions, and analysis tools used, providing a clear overview of the methodologies that supported this thorough examination of land use evolution in Al Ain.

| Data type | Data product | Data source | Data specification | Mapping & Visualization Tools |
|---|---|---|---|---|
| **Satellite data** | 1. Google Earth<br>2. Landsat-8<br>3. Sentinel-2 satellite | https://earthexplorer.usgs.gov/<br>https://earthexplorer.usgs.gov/<br>https://apps.sentinel-hub.com/ | - 30m spatial resolution image<br>- 15m spatial resolution image<br>- 60m spatial resolution image | ArcGIS and ERDAS Imagine for mapping vegetation changes from 2017-2023 in Al Ain City and for visualizing the images |
| **Supplementary data** | - Previous agriculture data<br>- Shape file of study area | - Al Ain City Municipality<br>- Land Use Yearly Bulletin by Central Bureau of Statistics and Abu Dhabi Agriculture Department | - Information regarding agricultural pattern, conventional historical record data and shape files for boundary, roads, etc. | ArcGIS and ERDAS Imagine |
| **Sample** | Ground truthing point used in the study | Google Earth | Land cover & vegetation data | ArcGIS for visualizing ground truthing points and vegetation data |

**Table 1:** Summary of data used in the study.

## 3.3. Vegetation Change Detection and Analysis

An analysis of vegetation and land cover changes in Al Ain city utilized satellite imagery from Landsat 8 and Sentinel-2 for the years 2017 and 2024. Initially, the original images (Image 1) were processed and merged using the HCS resolution merge technique (Image 2). Band combinations 4, 3, and 2 from Landsat 8 were selected to provide a clear visual representation of vegetation, water bodies, and built-up areas. The images were stacked and sampled from a 30-meter resolution to a 15-meter resolution using Erdas Imagine software, enhancing spatial resolution for more precise analysis.

The region of interest, Al Ain city, was selected from the UAE map (Image 3). The 2017 and 2024 images were extracted to focus specifically on vegetation changes within this area. To analyze vegetation, an unsupervised NDVI (Normalized Difference Vegetation Index) technique was applied, utilizing Band 5 (Near-Infrared, NIR) and Band 4 (Red). Vegetation reflects strongly in the NIR spectrum and weakly in the red spectrum, enabling clear differentiation from other land cover types. The formula used was:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}$$

This formula corrected any potential pixel value errors, ensuring the proper assignment of Band 5 as NIR and Band 4 as red. In the resulting NDVI map, bright colors indicate high vegetation cover, while dark colors represent built-up areas or barren land (Image 4). The NDVI map was crucial for identifying vegetation changes in the study area.

Further analysis was conducted using various band combinations in Erdas Imagine. These combinations included:

- Band 5, 4, 3 (Image 5): This combination highlights infrared colors and helps distinguish vegetation, water, and soil based on their spectral reflectance.
- Band 4, 3, 2 (Image 6): This combination produces a natural color representation, aiding visual interpretation of the landscape and vegetation.
- Band 6, 5, 4 (Image 7): A false-color composite, emphasizing vegetation and land cover in a unique color scheme.
- Band 7, 6, 4 (Image 8): Another false-color composite, which is particularly useful for highlighting vegetation and water bodies.
- Band 7, 5, 3 (Image 9): This false-color combination is effective for distinguishing different vegetation types and urban areas.

Additionally, GIS tools were utilized to generate a vegetation distribution map (Image 10) for both 2017 and 2024, comparing vegetation cover across these years. Sentinel-2 satellite images for 2017 and 2023 (Images 11, 12, and 13) were incorporated into the analysis. Image 11 was processed with a false-color combination, Image 12 with NDVI, and Image 13 as a scene classification map, categorizing the land cover into distinct classes. Moreover, Image 14 shows the land use and cover of Al Ain in 2017 and 2023, highlighting the changes in urban expansion and vegetation. Land use and cover classifications are instrumental in identifying vegetation types, allowing for an understanding of the spatial distribution of plant species, their growth patterns, and how these are influenced by human activities or natural environmental factors.

The resolution of these images was enhanced, and the "swipe" tool in Erdas Imagine was used to observe the temporal changes in vegetation. The results revealed significant changes in vegetation between 2017 and 2024, indicating rapid shifts in land cover over the analyzed period.

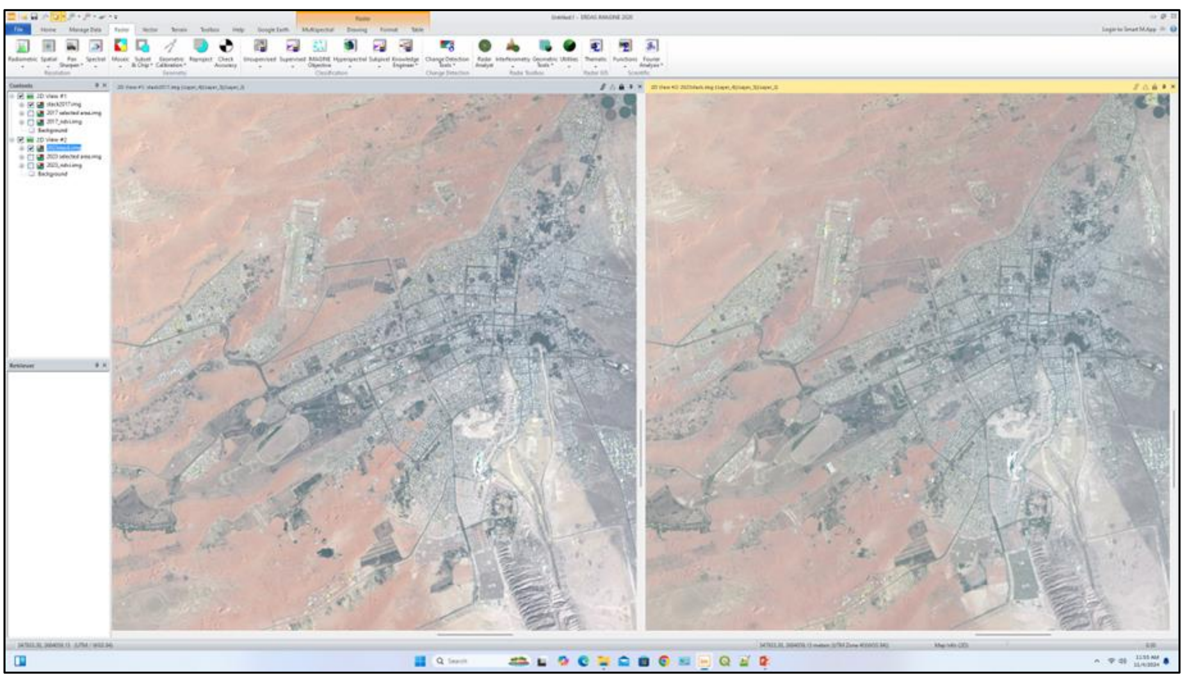


**Image 1**: Left (2017-03-07) - Original satellite image, right (2023-03-16) - Original satellite image.

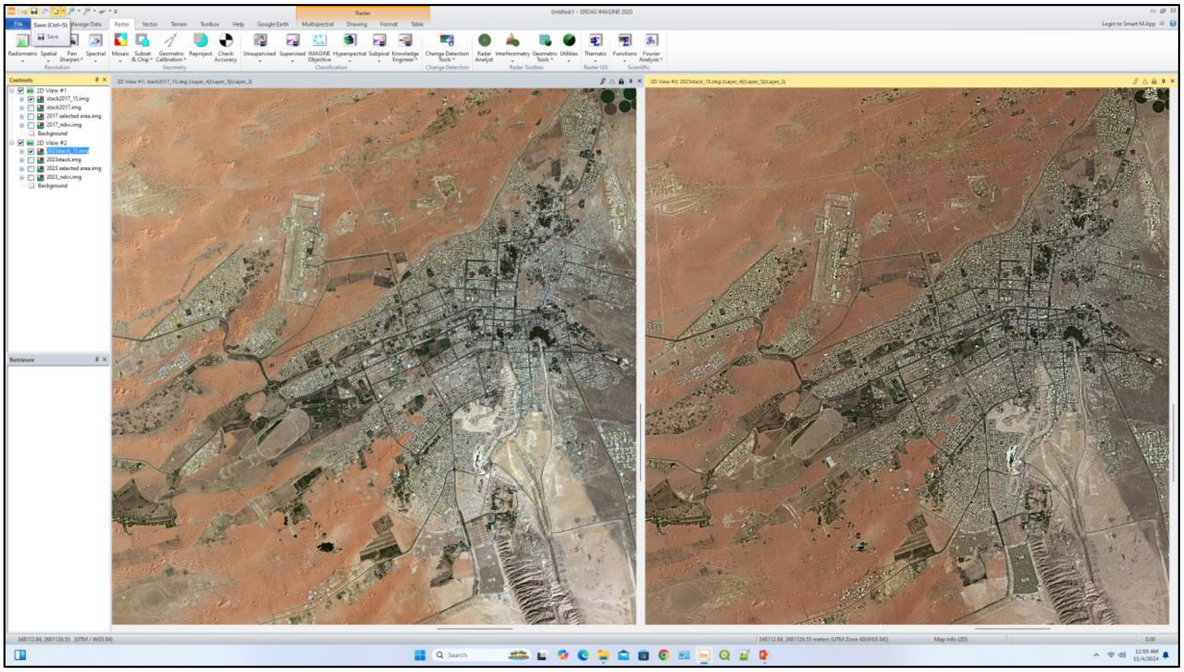


**Image 2:** Left (2017-03-07) - Merged image after HCS resolution merge technique (Bands 4, 3, 2), sampled from 30m to 15m resolution, right (2023-03-16) - Merged image after HCS resolution merge technique (Bands 4, 3, 2), sampled from 30m to 15m resolution.

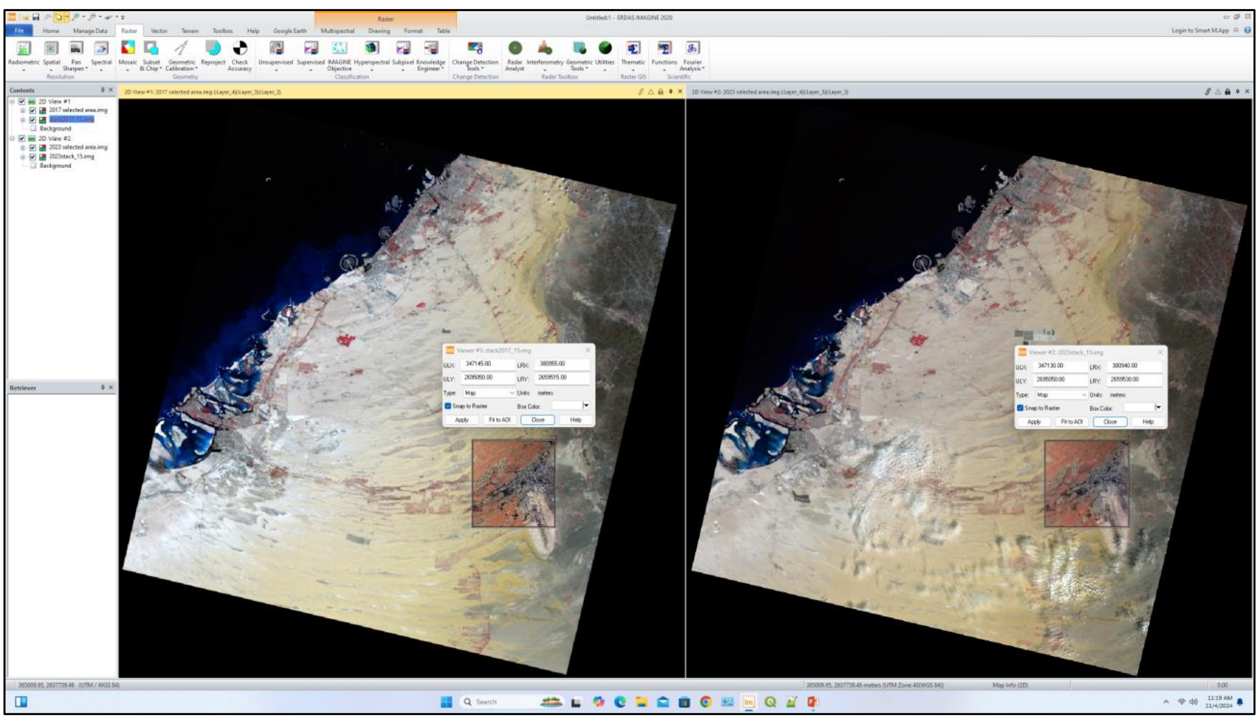


**Image 3:** Left (2017-03-07) - Selected area of Al Ain city using Band 5, 4, 3 combinations, right (2023-03-16) - Selected area of Al Ain city using Band 5, 4, 3 combinations.

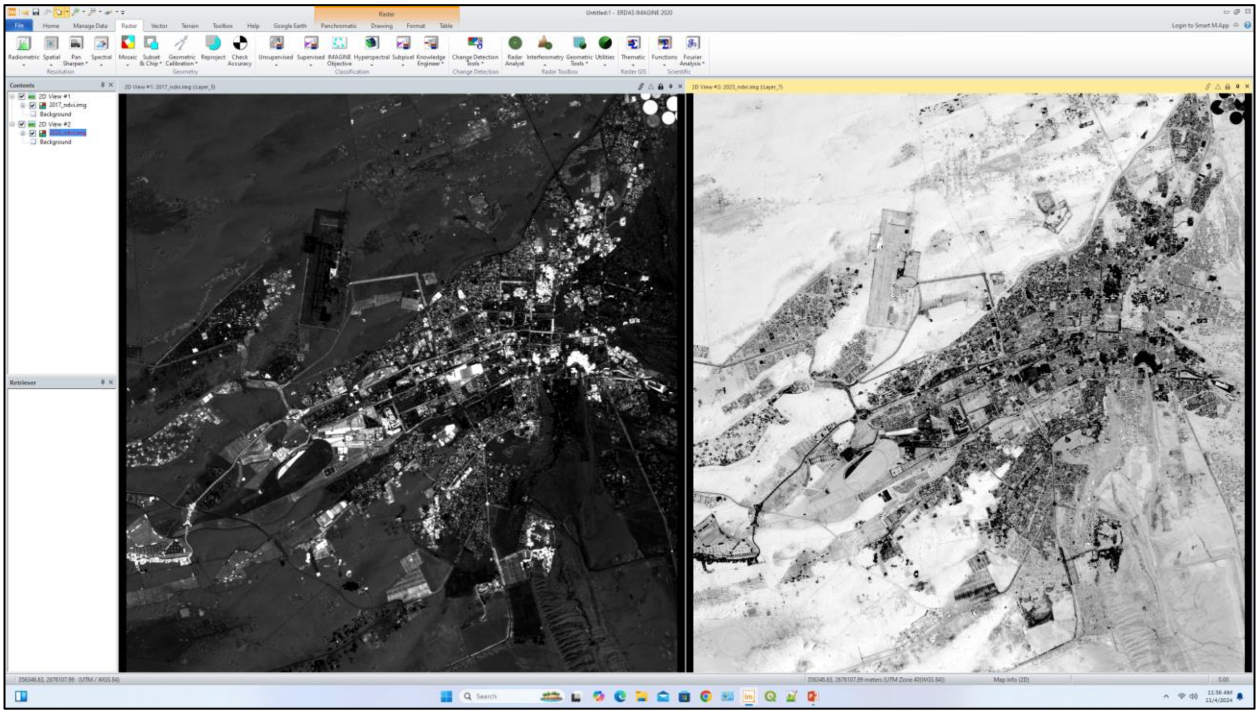


**Image 4:** Left (2017-03-07) - NDVI result map showing vegetation (bright colors) and built-up areas (dark colors), Right (2023-03-16) - NDVI result map showing vegetation (bright colors) and built-up areas (dark colors)

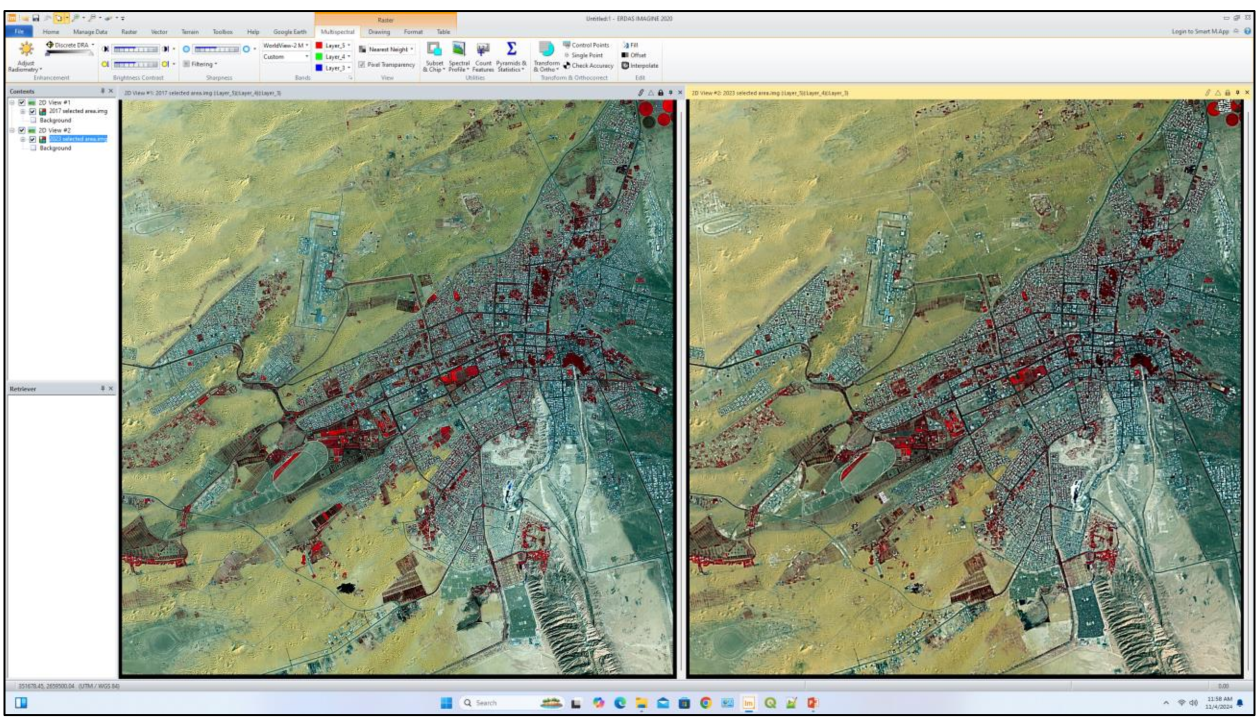


**Image 5:** Left (2017-03-07) - Band 5, 4, 3 combinations (infrared colors), Right (2023-03-16) - Band 5, 4, 3 combinations (infrared colors).

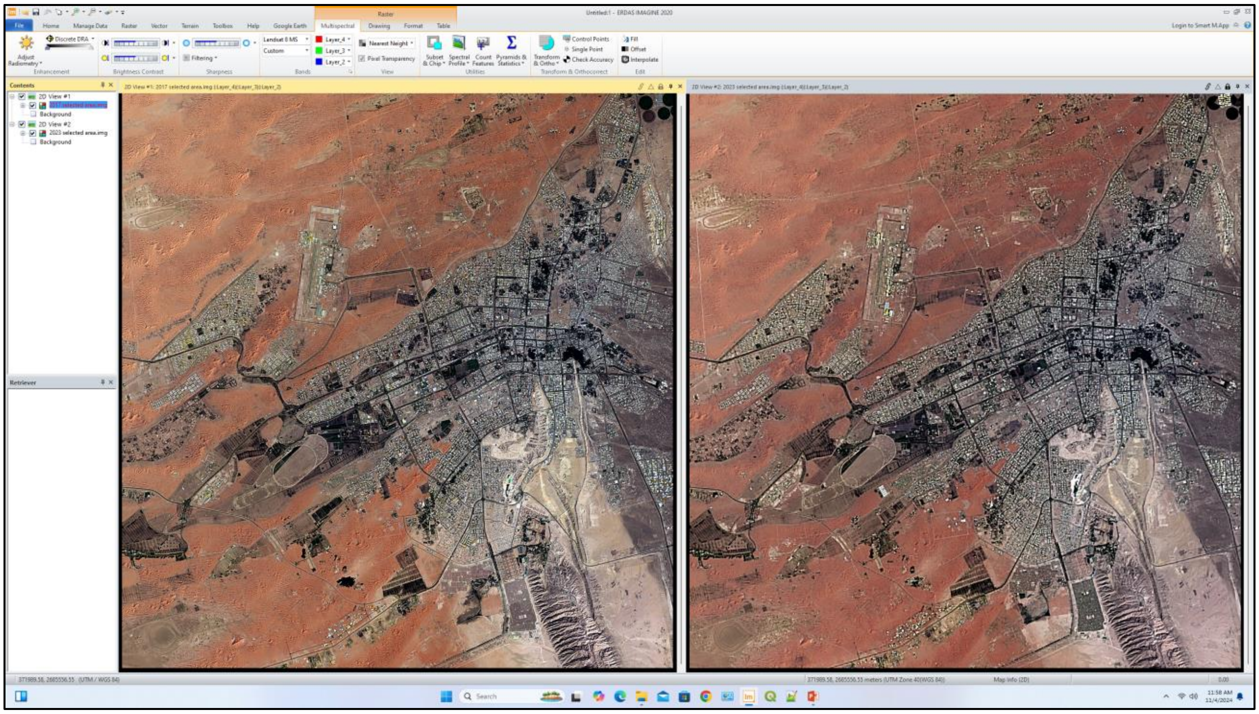


**Image 6:** Left (2017-03-07) - Band 4, 3, 2 combinations (natural color representation), Right (2023-03-16) - Band 4, 3, 2 combinations (natural color representation).

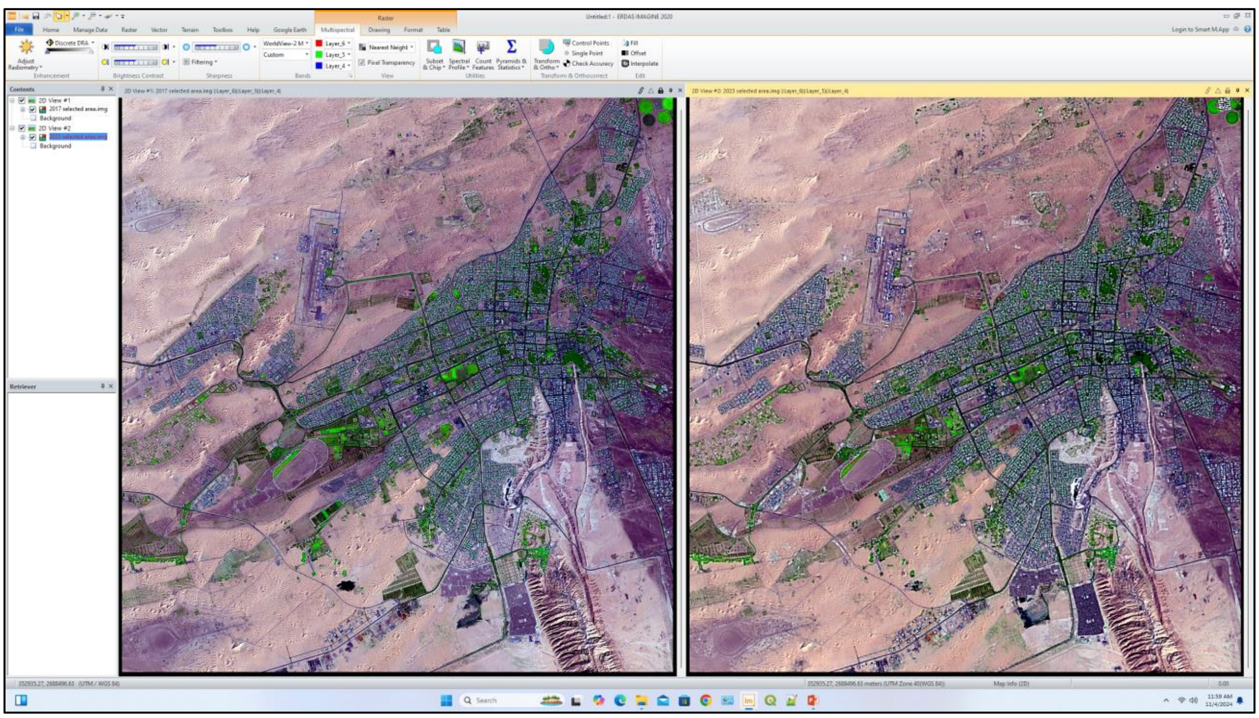


**Image 7:** Left (2017-03-07) - Band 6, 5, 4 combinations (false-color composite), Right (2023-03-16) - Band 6, 5, 4 combinations (false-color composite).

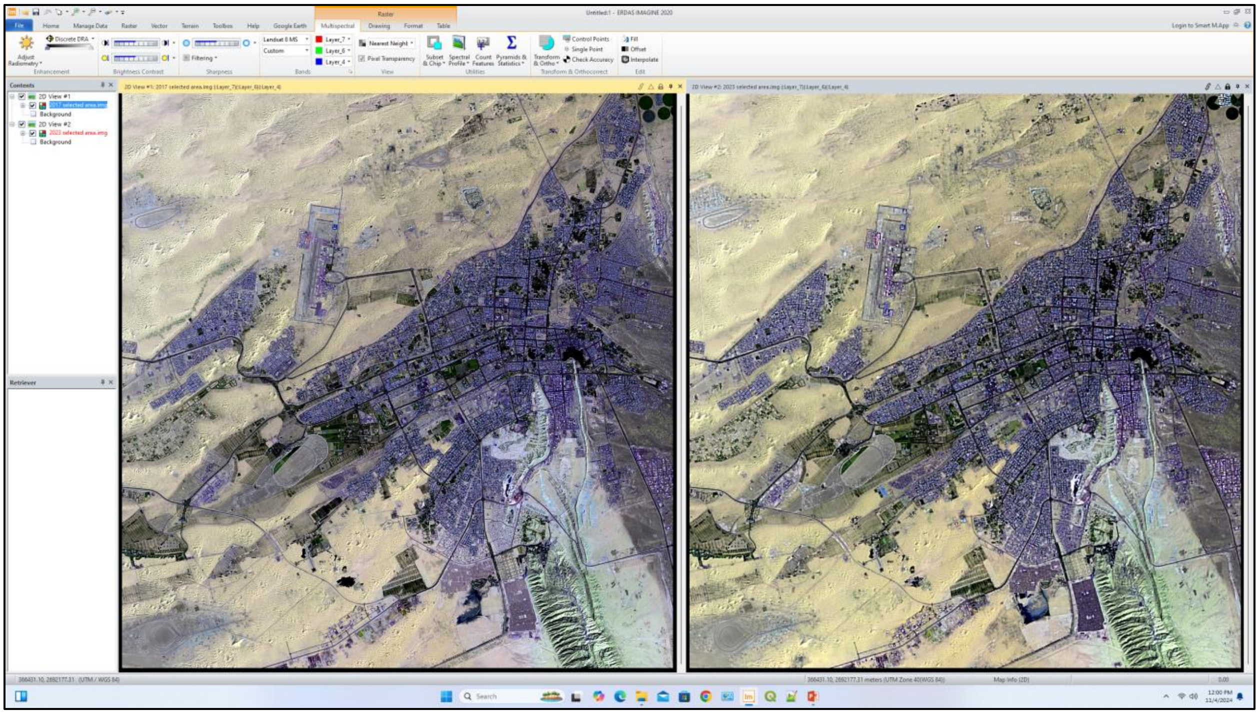


**Image 8:** Left (2017-03-07) - Band 7, 6, 4 combinations (false-color composite), Right (2023-03-16) - Band 7, 6, 4 combinations (false-color composite).

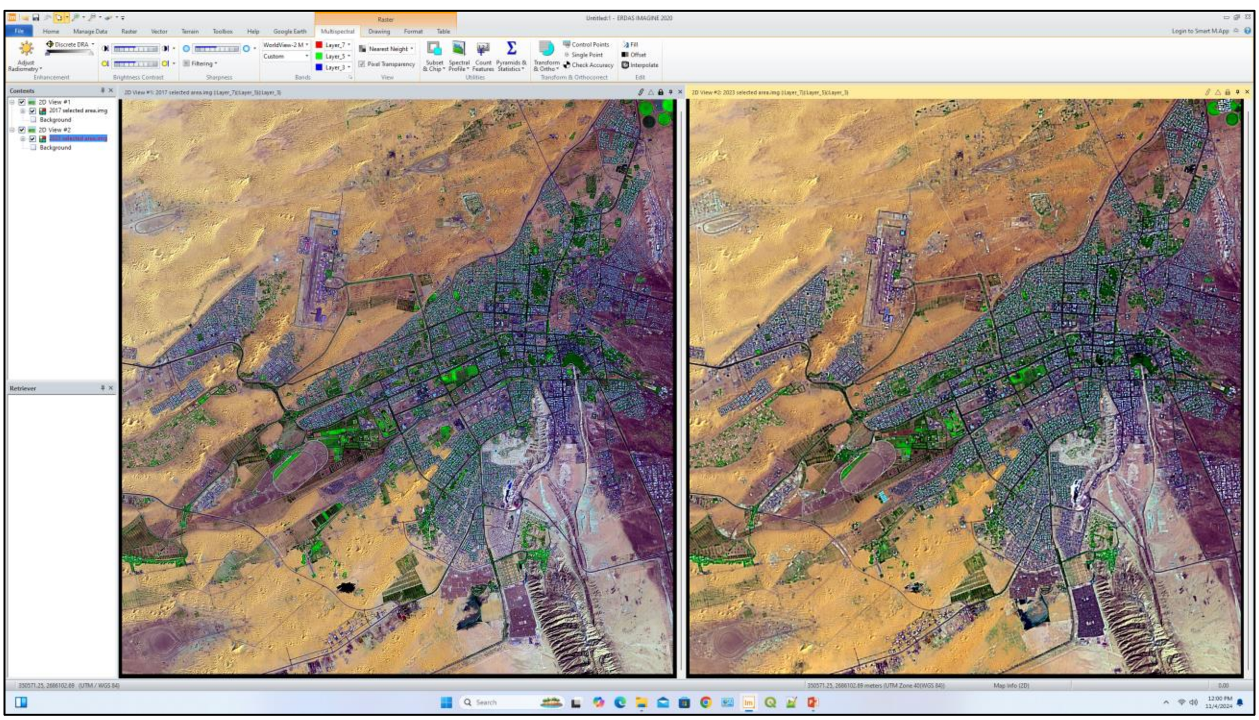


**Image 9:** Left (2017-03-07) - Band 7, 5, 3 combinations (false-color composite), Right (2023-03-16) - Band 7, 5, 3 combinations (false-color composite)

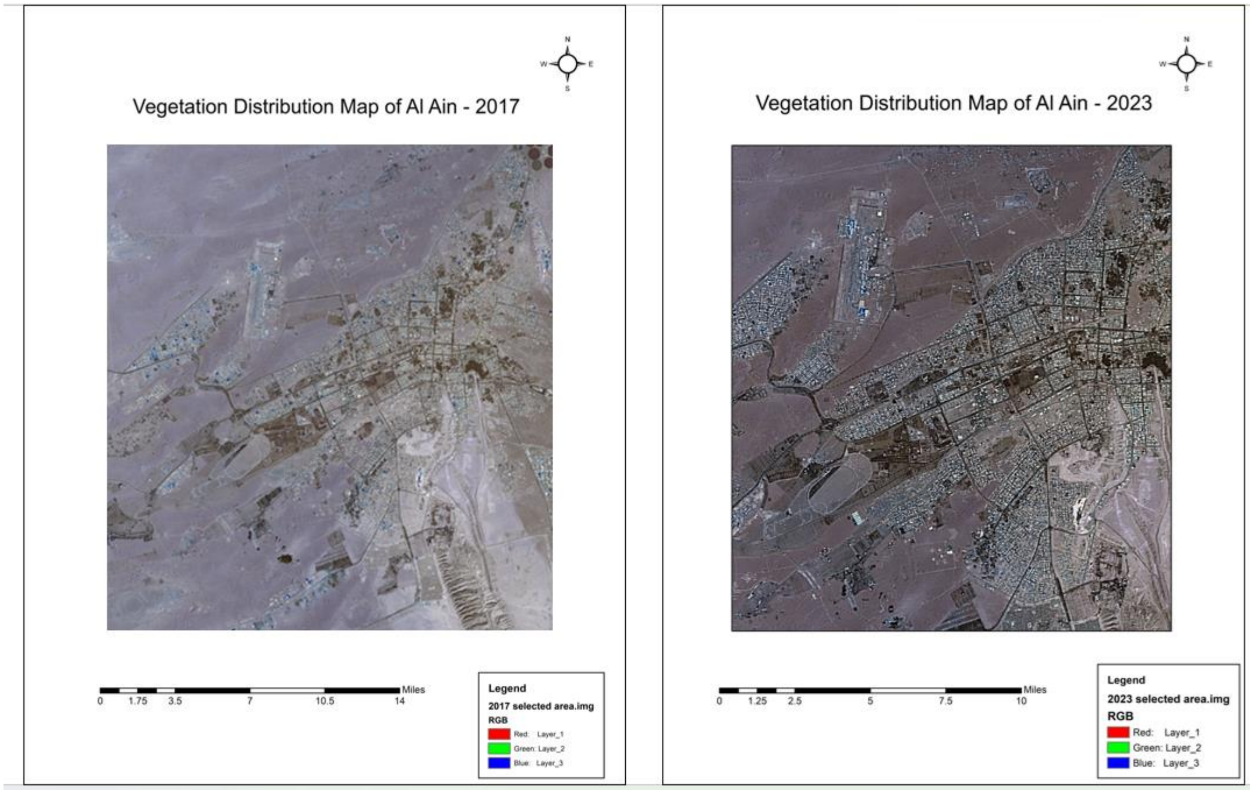



**Image 10:** Left (2017-03-07) - Vegetation distribution map, right (2023-03-16) - Vegetation distribution map.

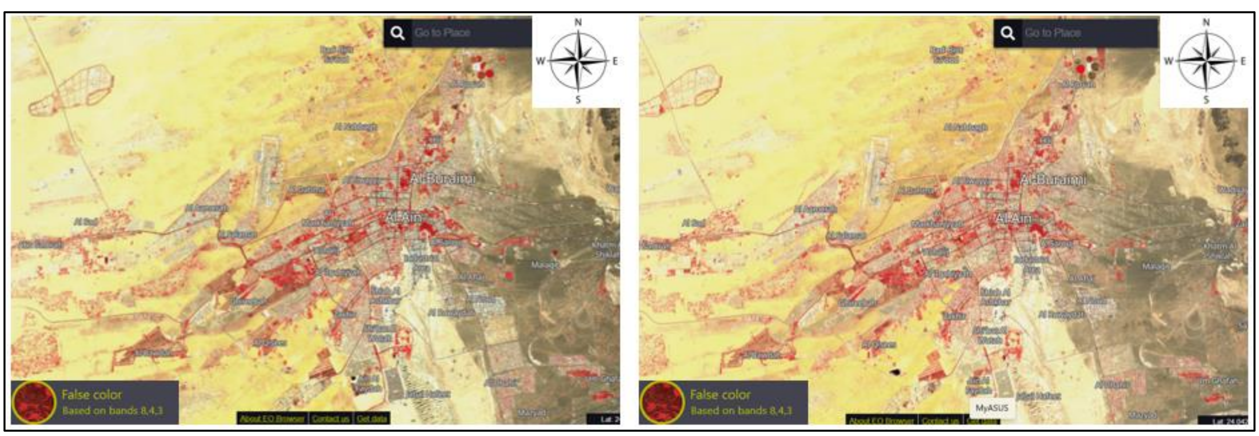



**Image 11:** Left (2017-10-26) - Sentinel-2 false-color image, right (2023-10-30) - Sentinel-2 false-color image.

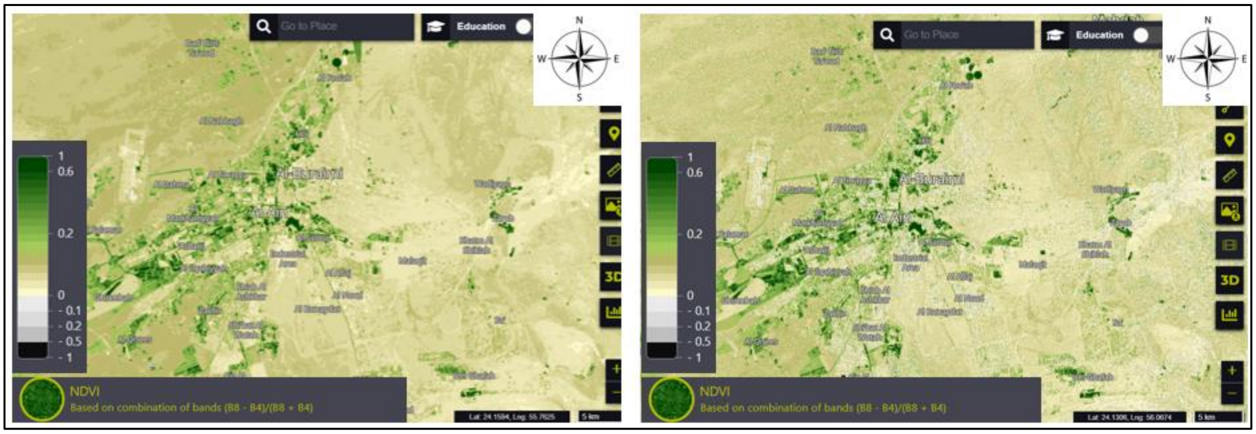



**Image 12:** Left (2017-10-26) - Sentinel-2 NDVI image, right (2023-10-30) - Sentinel-2 NDVI image.

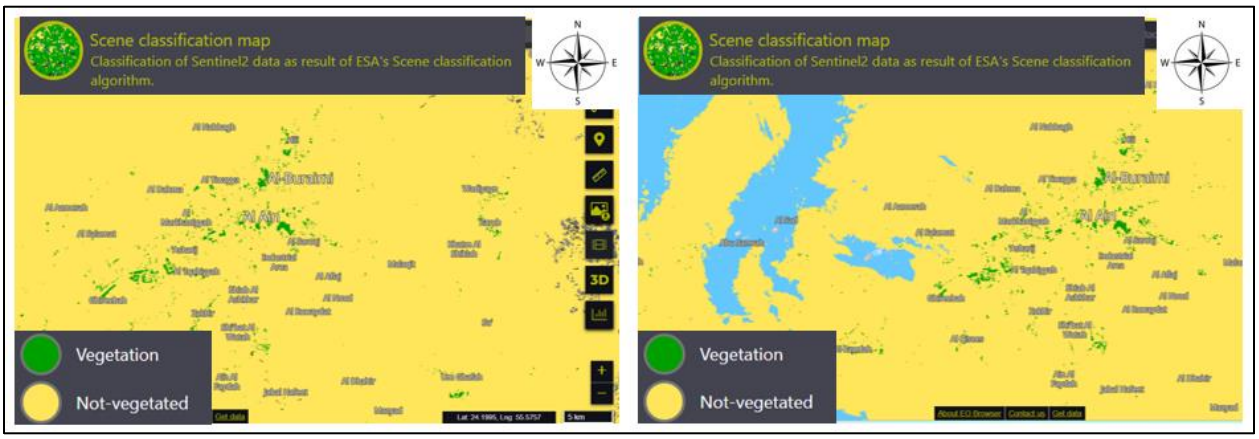



**Image 13:** Left (2017-10-26) - Sentinel-2 scene classification map, right (2023-10-30) - Sentinel-2 scene classification map.

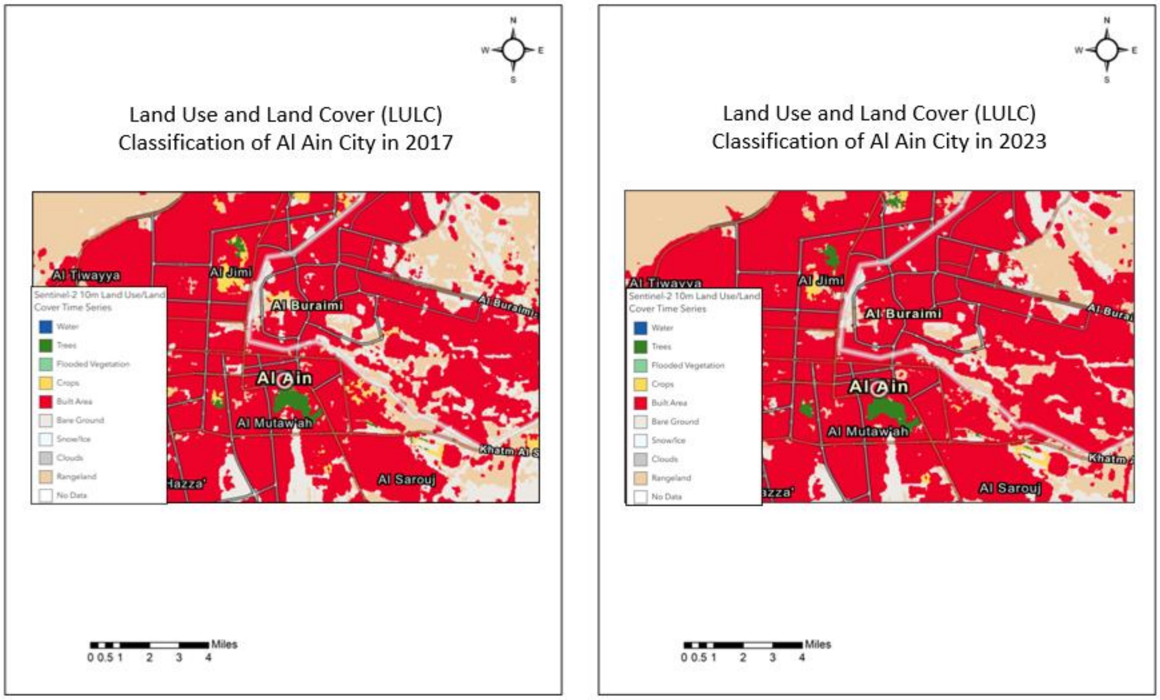



**Image 14:** Left (2017-10-26): Land Use and Land Cover (LULC) classification of Al Ain City in 2017. Right (2023-10-30): Land Use and Land Cover (LULC) classification of Al Ain City in 2023.

# 4. Conclusion

This study examines the patterns of land use and land cover changes in the Al Ain region of the UAE from 2017 to 2023, using a GIS and Remote Sensing (RS) approach to gain insights into its spatial-temporal dynamics. The primary goal of this project is to assess urban growth and land use changes over the six-year period, focusing on the identification of key drivers of urban expansion and the impact on natural resources. Through the integration of remote sensing data (such as satellite imagery) and GIS techniques, this study provides an in-depth analysis of how land use in Al Ain has evolved, particularly in terms of urban sprawl, infrastructure development, and shifts in vegetation cover.

The findings reveal significant patterns of urban growth, especially the expansion of built-up areas and a corresponding decline in agricultural and green land cover. The rapid urbanization observed in certain areas has led to a marked reduction in vegetation and agricultural land, which are critical to maintaining the region's environmental balance. Additionally, the study highlights changes in the spatial distribution of water bodies, desertification, and land degradation in certain areas. These shifts in land cover are essential for local authorities to understand, as they can have long-term impacts on biodiversity, water management, and ecosystem services.

By utilizing GIS and remote sensing technologies, this study underscores the importance of spatial data for understanding the geological and environmental factors that influence land use changes. The integration of high-resolution satellite imagery and GIS analysis has allowed for precise mapping of land cover changes and the identification of areas that are most vulnerable to the impacts of urbanization. This includes the identification of areas with high potential for sustainable development, as well as those that face environmental constraints such as erosion, vegetation loss, or water scarcity.

The use of NDVI (Normalized Difference Vegetation Index) and other remote sensing indices has provided critical insights into vegetation health and land degradation trends, further contributing to the understanding of how land use changes are affecting the region's ecosystem. Moreover, by examining both the current and historical data (2017 and 2023), the study reveals a clear trajectory of urban expansion, highlighting the need for more strategic and environmentally conscious urban planning.

The comprehensive monitoring provided by this study offers valuable support for informed decision-making, enabling stakeholders such as urban planners, environmental managers, and policymakers to implement strategies that balance urban growth with the preservation of natural resources. It advocates for sustainable land management practices that consider environmental, social, and economic factors in tandem. Furthermore, the study emphasizes the need for continuous monitoring using GIS and remote sensing technologies, which are essential tools for adaptive management in the face of rapid urbanization.

In conclusion, this project serves as a vital resource for understanding the dynamics of urban growth and land use change in Al Ain, offering a foundation for future urban development that aligns with sustainability goals. By identifying trends, assessing potential environmental risks, and suggesting areas for sustainable development, the findings contribute to ensuring that Al Ain's urbanization is managed in a way that supports long-term ecological health, resource conservation, and quality of life for residents.

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