ESA satelite analysis of Sentinel-1 and Sentinel-2 images

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Introduction

This project uses satellite imagery from the European Space Agency's Sentinel-1 and Sentinel-2 missions to analyze environmental and geographical characteristics of various European cities. Key components include:

- False-Color Infrared Images: Using near-infrared (NIR) and red bands to assess vegetation health, soil properties, and water bodies.
- K-means Clustering for Color Classification: Classifying pixel colors to identify urban areas, vegetation, and water bodies.
- Height Map Analysis: Analyzing elevation data to understand terrain variations and average heights.

These analyses provide insights for urban planning, environmental conservation, and resource management.

1 ESA - Sentinel-1 and Sentinel-2

1.1 Sentinel-1

Sentinel-1, part of the European Copernicus Program, includes two radar satellites, Sentinel-1A and Sentinel-1B, launched in 2014 and 2016. Using Synthetic Aperture Radar (SAR), it provides high-resolution images of the Earth's surface in all weather conditions and daylight. Applications include land use monitoring, oil spill detection, wildfire mapping, ice sheet monitoring, and disaster management.

1.2 Sentinel-2

Sentinel-2, also part of the Copernicus Program, consists of two optical satellites, Sentinel-2A and Sentinel-2B, launched in 2015 and 2017. Equipped with multi-spectral instruments capturing 13 spectral bands, Sentinel-2 offers high-resolution images for vegetation monitoring, land use mapping, agriculture, water and coastal resource monitoring, and emergency response. It is essential for environmental monitoring and resource management.

2 False-Color Infrared Images

False-color infrared images are particularly useful as they contain information invisible to the human eye in the visible spectrum. These images utilize near-infrared light (NIR), which has different reflection properties than visible light.

2.1 Vegetation Analysis

A significant application area is vegetation analysis. Healthy vegetation reflects strongly in the near-infrared range, while unhealthy or sparse vegetation reflects less strongly. This allows for an accurate assessment of plant health and vegetation density.

2.2 Soil Analysis

Another application area is soil detection. Different soil types and surface structures can be identified by their reflection properties in the infrared range. This enables more precise classification and mapping of soil types.

2.3 Water and Moisture Analysis

Water and moisture analysis also benefit from false-color infrared images. Water absorbs strongly in the near-infrared range and therefore appears dark in these images. This facilitates the identification of water bodies and the determination of soil moisture content.

2.4 Better Differentiation Between Soil and Vegetation Cover

Finally, false-color infrared images help to distinguish different soil and vegetation covers more clearly. Due to their different reflection properties in the near-infrared range, various types of vegetation and soil can be better differentiated. This is particularly useful in land use and land cover mapping as well as environmental monitoring.

3 False-Color Infrared Image

Using the software Snap, provided by ESA, I was able to analyze false-color infrared images from any location in the world. For my analysis, I have chosen to analyze six different cities in Europe:

- Athens, Greece
- Berlin, Germany
- Copenhagen, Denmark
- Amsterdam, Netherlands
- Dublin, Ireland
- Madrid, Spain

4 Ploting the Pixel Color in a 3D scatter plot

4.1 K-means

The goal of K-means is to minimize the following objective function, which is the sum of squared distances between data points and their corresponding cluster centroids:

$$J = \sum_{i=1}^{K} \sum_{x \in C_i} \|x - \mu_i\|^2$$

where:

- K is the number of clusters.
- C_i is the set of points in cluster i.
- x is a data point.
- μ_i is the centroid of cluster i.
- $\|x - \mu_i\|^2$ is the squared Euclidean distance between data point x and centroid μ_i.

4.2 Near-Infrared Band (NIR)

- **Assigned to**: Red Channel
- **Explanation**: High reflection in the near-infrared range is characteristic of healthy, dense vegetation. These areas are likely forest areas, parks, or agricultural lands with good plant growth.
- **Significance**: These areas are ecologically valuable as they represent high biomass and plant activity.

4.3 Red Band

- **Assigned to**: Green Channel
- **Explanation**: This could indicate sparse vegetation, bare soil, or agricultural lands with lower plant growth.
- **Significance**: These areas are potentially prone to erosion and may require measures to improve soil quality and plant cover. They could indicate agricultural lands that are not fully planted or areas in need of regeneration.

4.4 Green Band

- **Assigned to**: Blue Channel
- **Explanation**: These areas may represent transitional regions, such as urban fringes, that contain both natural and anthropogenic elements.
- **Significance**: These clusters identify urban structures and water bodies, which are crucial for urban planning and water management.

4.5 Overlaps

- **Explanation**: These areas may represent transitional regions, such as urban fringes, that contain both natural and anthropogenic elements.
- **Significance**: These areas are interesting for the analysis of land use changes and for planning urban developments.

4.6 Scatter plots

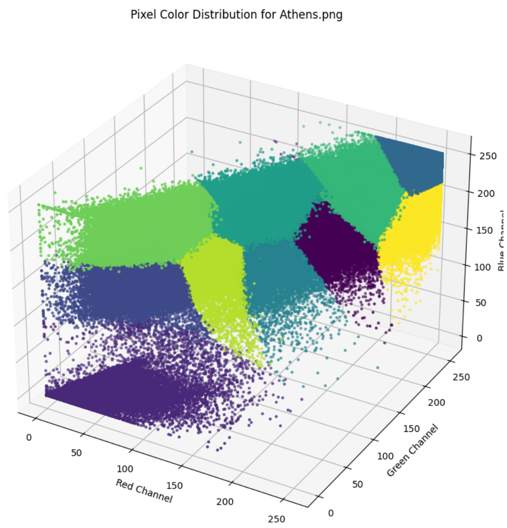

Figure 1: Athens, Greece

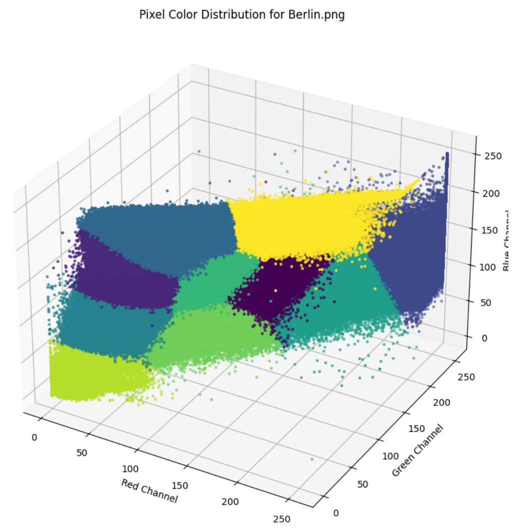

Figure 2: Berlin, Germany

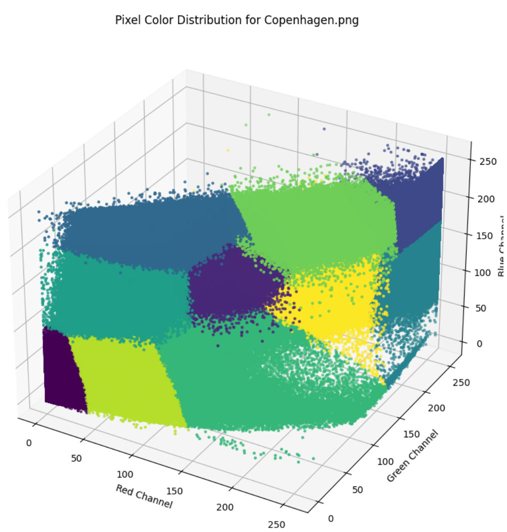

Figure 3: Copenhagen, Denmark

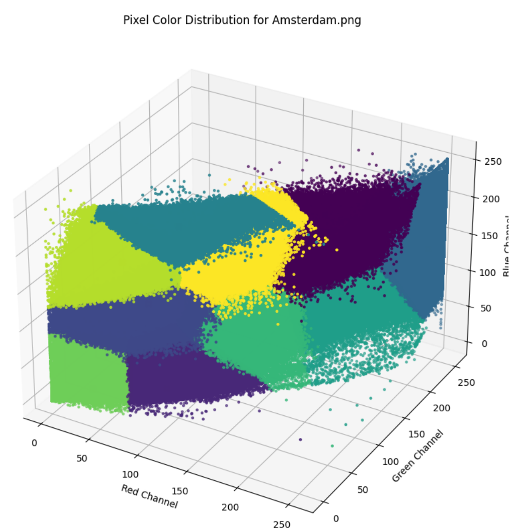

Figure 4: Amsterdam, Netherlands

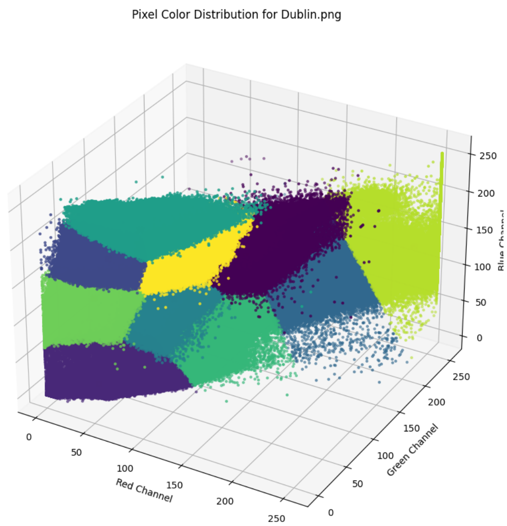

Figure 5: Dublin, Ireland

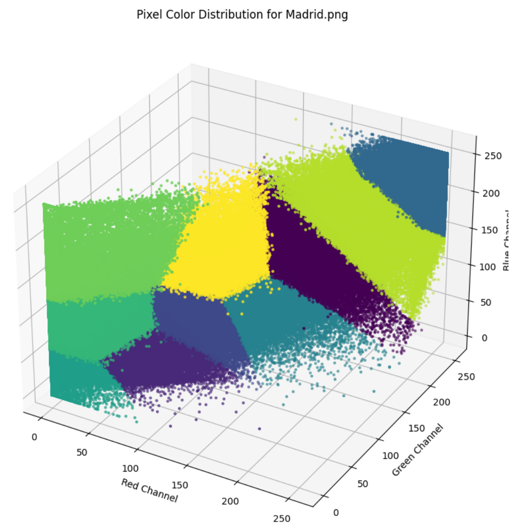

Figure 6: Madrid, Spain

4.7 Amsterdam

The color distribution for Amsterdam shows distinct clusters in the RGB color space, indicating different types of land cover. The clusters representing high reflectance in the red channel typically correspond to healthy, dense vegetation in false-color infrared images. Other clusters represent moderate vegetation, urban areas, and water bodies, suggesting a diverse urban and natural landscape.

4.8 Athens

Athens exhibits clear clusters corresponding to different land cover types. Clusters with high reflectance in the red channel indicate significant vegetation. Clusters with lower reflectance in the red channel represent urban areas and water bodies. This distribution shows a varied landscape with a mix of urban and natural features.

4.9 Berlin

Berlin's color distribution shows strong clustering, with clusters representing high reflectance in the red channel indicating dense vegetation, reflecting high biomass and plant activity. Other clusters suggest a mix of urban areas and water bodies, indicating a heterogeneous landscape with distinct land cover types.

4.10 Copenhagen

Copenhagen's color distribution also shows distinct clusters. Clusters with high reflectance in the red channel indicate dense vegetation, while other clusters represent urban areas and water bodies. This distribution indicates a mix of natural and anthropogenic elements in the city's landscape.

4.11 Dublin

Dublin's plot shows a balanced distribution of clusters. Clusters with high reflectance in the red channel indicate healthy vegetation, while other clusters likely represent urban areas and water bodies. The clustering suggests varied land cover in the region.

4.12 Madrid

Madrid's distribution shows clear clusters indicating different land cover types. Clusters with high reflectance in the red channel suggest dense vegetation, while other clusters represent urban areas and other surfaces. The distribution reflects a mix of natural and urban elements in the city.

5 Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) uses these bands to measure vegetation density and health. The formula is:

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

- **NIR Band**: Sentinel-2 Band B8 (842 nm)
- **Red Band**: Sentinel-2 Band B4 (665 nm)

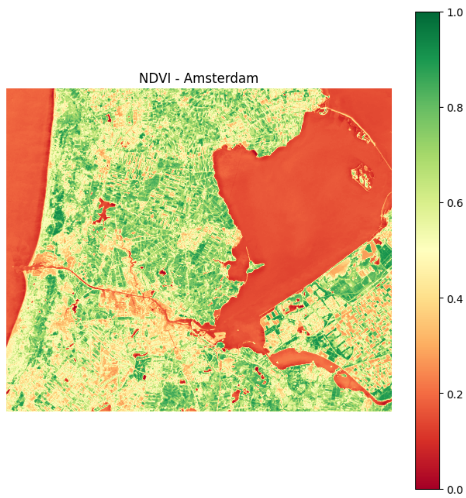

Figure 7: NDVI - Amsterdam

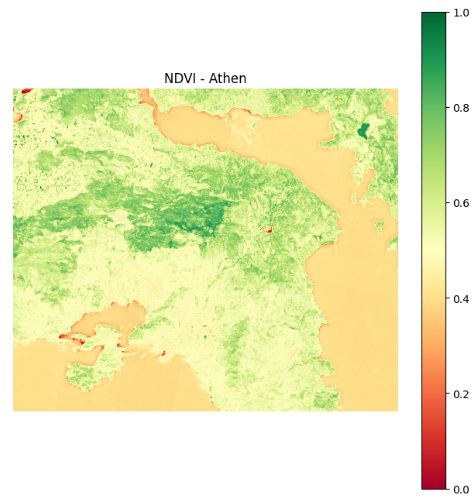

Figure 8: NDVI - Athens

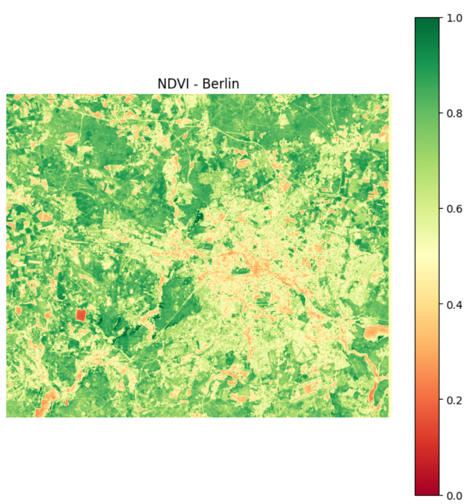

Figure 9: NDVI - Berlin

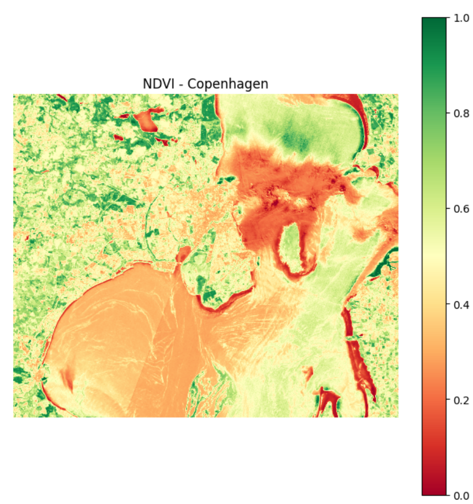

Figure 10: NDVI - Copenhagen

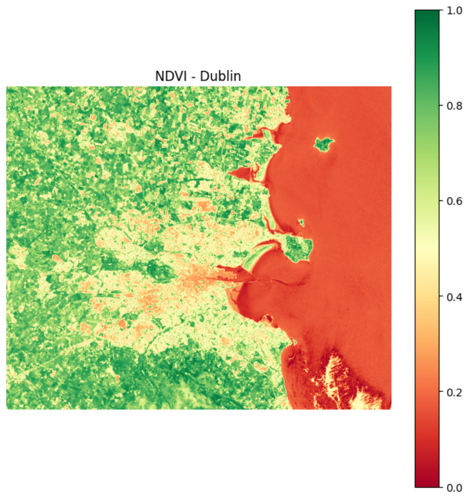

Figure 11: NDVI - Dublin

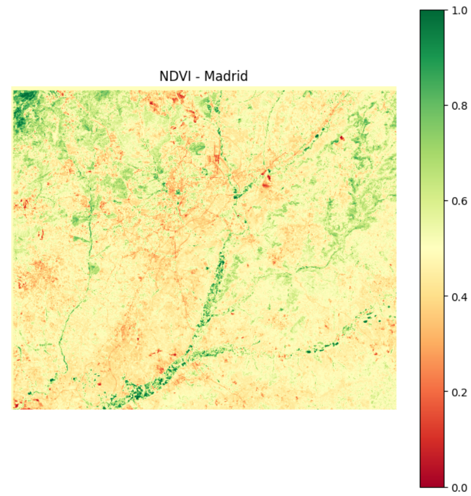

Figure 12: NDVI - Madrid

6 Interpretation of NDVI

6.1 Healthy Vegetation (NDVI between 0.6 and 1)

- **Identification**: These areas are characterized by dark green to light green colors in the plot.
- **Description**: Large contiguous green areas are visible in the plot, indicating dense and healthy vegetation.
- **Significance**: These areas could be forests, dense grasslands, or agricultural fields with good plant growth.

6.2 Moderate Vegetation (NDVI between 0.4 and 0.6)

- **Identification**: These areas are characterized by orange to yellow-green colors in the plot.
- **Description**: These NDVI values indicate moderate vegetation, typically found in agricultural fields, grasslands, or urban green spaces.
- **Significance**: These areas appear as transitional regions between dense vegetation areas (green) and sparsely vegetated or urban areas (yellow to red).

6.3 Low Vegetation (NDVI between 0.4 and 0)

- **Identification**: These areas are characterized by orange to red colors in the plot.
- **Description**: These low NDVI values indicate sparse or disturbed vegetation. These could be fallow lands, urbanized areas, or regions with insufficient vegetation cover.

7 Interpretation of Each City

7.1 Amsterdam

The NDVI plot for Amsterdam shows a mix of green, indicating healthy vegetation, and orange/red areas, suggesting urban regions and water bodies. The dense vegetation is likely found in parks and surrounding rural areas.

7.2 Athens

Athens displays significant green areas in the NDVI plot, indicating healthy vegetation in parks and rural surroundings. The presence of orange/red areas suggests urban regions and sparse vegetation.

7.3 Berlin

Berlin's NDVI plot reveals extensive green areas, highlighting healthy vegetation in parks, forests, and agricultural fields. The urban areas are indicated by orange/red patches.

7.4 Copenhagen

Copenhagen's plot shows a mix of green and orange/red regions. The healthy vegetation is seen in parks and outskirts, while urban areas and water bodies are indicated by red and orange patches.

7.5 Dublin

Dublin's NDVI plot features substantial green areas, suggesting healthy vegetation in parks and rural surroundings. The red and orange patches denote urban regions and sparse vegetation.

7.6 Madrid

Madrid's NDVI plot shows a mix of green, indicating healthy vegetation, and yellow/orange areas, suggesting sparse vegetation and urban regions. The distribution reflects the city's arid climate and dense urban areas.

8 Interpretation of Mean NDVI Values for Each City

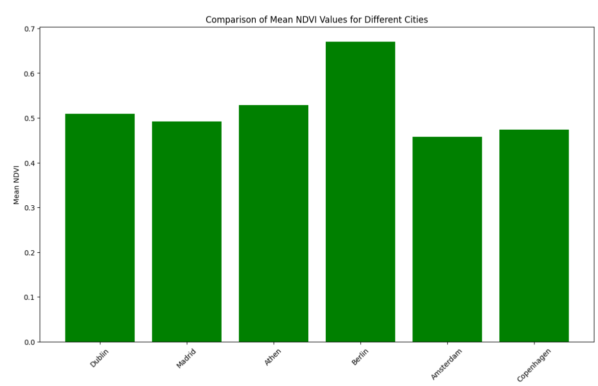

Figure 13: Comparison of Mean NDVI Values

- **Dublin**: 0.5097
- **Madrid**: 0.4923
- **Athens**: 0.5287
- **Berlin**: 0.6702
- **Amsterdam**: 0.4573
- **Copenhagen**: 0.4741

City with the Highest Mean NDVI: Berlin (0.6702)

8.1 Dublin

Dublin has a mean NDVI value of 0.5097, indicating moderately healthy vegetation. This suggests that the city has a fair amount of green spaces such as parks and gardens, contributing to its overall vegetation health.

8.2 Madrid

Madrid's mean NDVI value of 0.4923 suggests that the city has slightly less healthy vegetation compared to Dublin and Athens. This could be due to its drier climate and extensive urban areas, which reduce the overall vegetation density.

8.3 Athens

Athens has a mean NDVI value of 0.5287, indicating a relatively healthy level of vegetation. This suggests that Athens has significant green areas and vegetation, possibly in the form of parks and surrounding rural areas.

8.4 Berlin

Berlin stands out with the highest mean NDVI value of 0.6702. This high value indicates very healthy and dense vegetation, reflecting the city's extensive green spaces, parks, and surrounding forests. Berlin's urban planning likely emphasizes the inclusion of green areas, contributing to this high NDVI value.

8.5 Amsterdam

Amsterdam's mean NDVI value of 0.4573 is the lowest among the cities analyzed, indicating less healthy vegetation. This might be due to the dense urban environment and extensive water bodies, which reduce the overall vegetation density.

8.6 Copenhagen

Copenhagen has a mean NDVI value of 0.4741, suggesting moderately healthy vegetation. The city's parks and green areas contribute to this value, but the extensive urban regions might lower the overall NDVI.

8.7 Conclusion

Berlin has the highest mean NDVI value, indicating the healthiest and densest vegetation among the analyzed cities. This highlights Berlin's emphasis on maintaining green spaces within the city. In contrast, Amsterdam has the lowest mean NDVI, suggesting less healthy vegetation, likely due to its dense urban structure and extensive waterways. The other cities, Dublin, Madrid, Athens, and Copenhagen, have moderate NDVI values, reflecting a balanced mix of urban areas and vegetation.

9 Height Map Analysis

These maps provide a visual representation of the elevation variations within each city, highlighting both natural and man-made features.

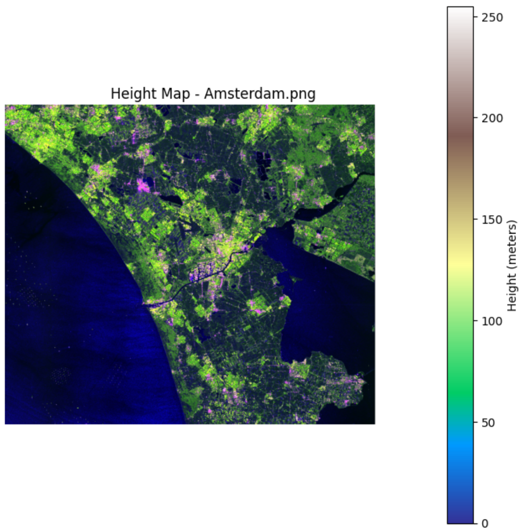

Figure 14: Height Map - Amsterdam

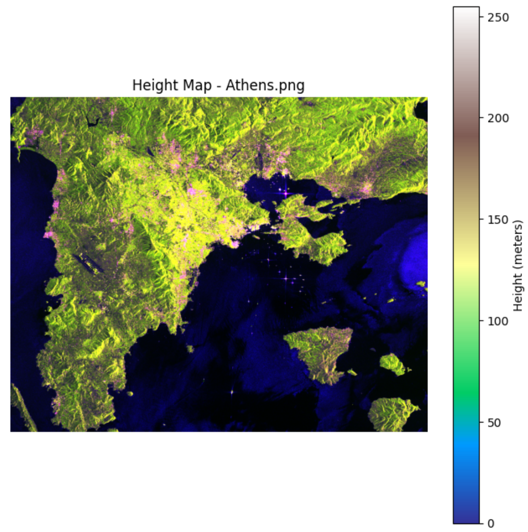

Figure 15: Height Map - Athens

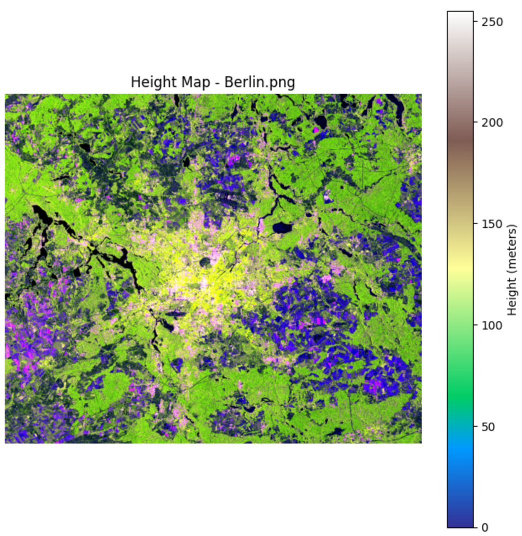

Figure 16: Height Map - Berlin

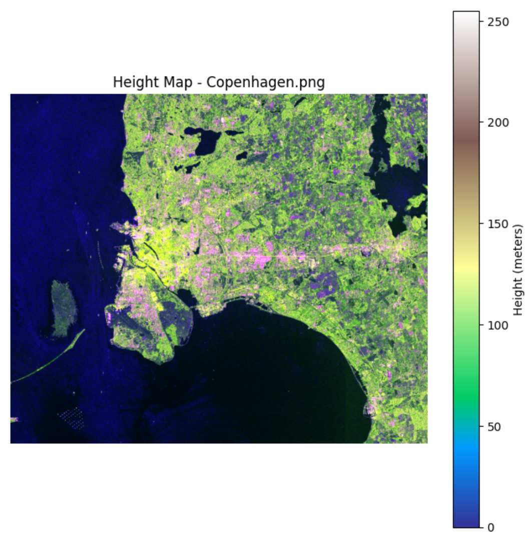

Figure 17: Height Map - Copenhagen

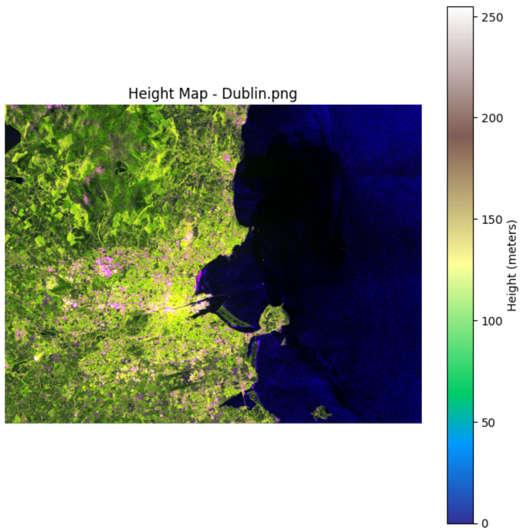

Figure 18: Height Map - Dublin

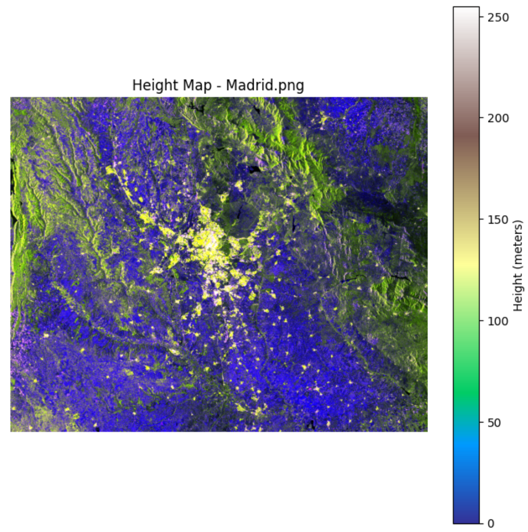

Figure 19: Height Map - Madrid

9.1 Amsterdam

The height map of Amsterdam shows uniform low elevations, characteristic of the city's flat terrain. Lower regions, depicted in darker shades, highlight Amsterdam's location below sea level or the ocean surrounding the city and it's intricate canal system.

9.2 Athens

Athens' height map reveals varied topography with significant elevation changes. High elevations, indicated by brighter colors, correspond to surrounding mountainous regions, while lower elevations represent urban and coastal areas or the surrounding Ocean.

9.3 Berlin

Berlin's height map displays predominantly flat terrain with some variation. Central areas are uniform, while outskirts show more elevation changes, including small hills and forests, capturing Berlin's mix of urban and natural landscapes.

9.4 Copenhagen

Copenhagen's height map shows flat terrain with slight elevation variations. Coastal areas are visible, with the city itself lying at low elevations. Subtle height variations depict the city's landscape, including its waterfront.

9.5 Dublin

Dublin's height map reveals a mix of low-lying areas and higher elevations in surrounding regions. The city center is flat, while outskirts show more significant elevation changes, highlighting Dublin's coastal proximity and surrounding hills.

9.6 Madrid

Madrid's height map shows considerable elevation differences, reflecting its location on the Spanish plateau. Higher elevations are prevalent in the north and west, with varied terrain surrounding the central urban area.

10 Height Distribution Analysis

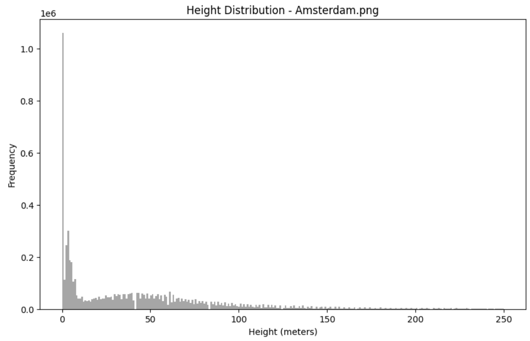

Figure 20: Height Distribution - Amsterdam

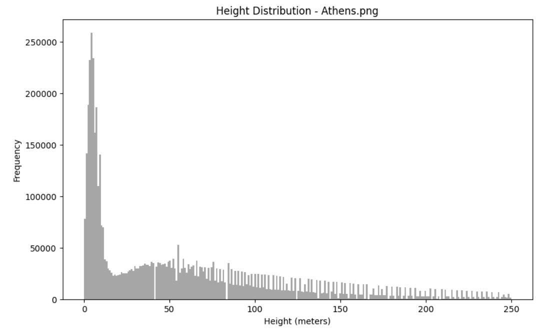

Figure 21: Height Distribution - Athens

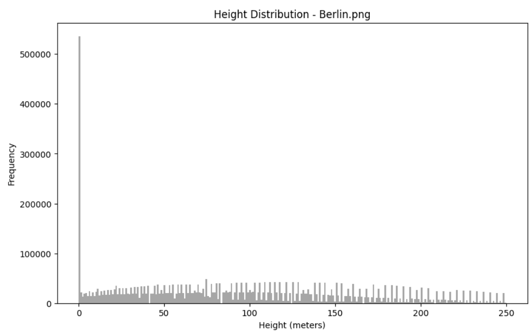

Figure 22: Height Distribution - Berlin

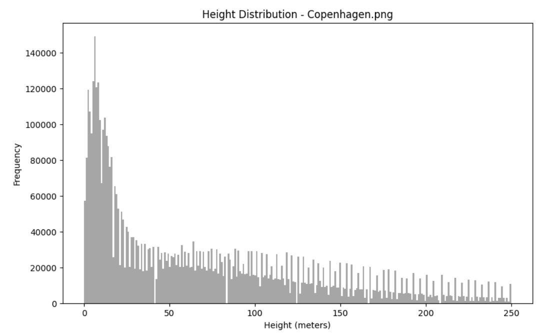

Figure 23: Height Distribution - Copenhagen

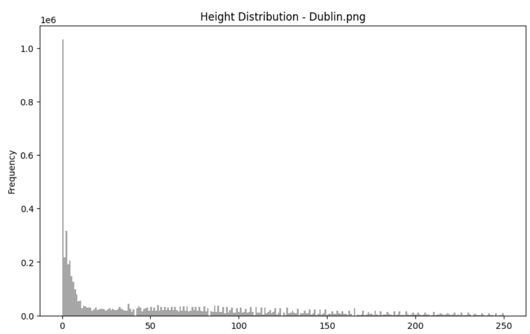

Figure 24: Height Distribution - Dublin

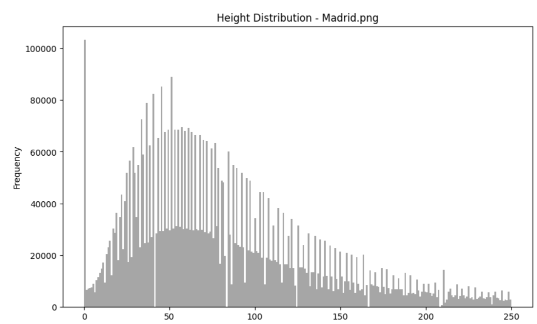

Figure 25: Height Distribution - Madrid

11 Interpretation of Height Distribution

11.1 Amsterdam

The height distribution of Amsterdam shows a high frequency of low elevations, indicating the city's predominantly flat terrain. The peak at 0 meters corresponds to areas at or below sea level, typical for this city. The presence of a few higher elevations may be due to infrastructure such as buildings and bridges.

11.2 Athens

Athens has a more varied height distribution, with a significant frequency of higher elevations. This reflects the city's mountainous surroundings and varied topography. The peak in the lower height range represents the urban areas, while the gradual decline in frequency with increasing height highlights the surrounding hills and mountains.

11.3 Berlin

Berlin's height distribution shows a high frequency of low to moderate elevations, indicating its relatively flat landscape. The peak at 0 meters and a uniform distribution across other heights suggest a mix of urban flat areas and small natural elevations such as parks and minor hills.

11.4 Copenhagen

Copenhagen exhibits a height distribution similar to Amsterdam, with a high frequency of low elevations. The peak at 0 meters reflects the city's coastal and flat landscape. The gradual decline in frequency with increasing height indicates the presence of some low hills and built-up areas.

11.5 Dublin

Dublin's height distribution shows a significant peak at 0 meters, representing the flat urban center and coastal areas. The extended tail towards higher elevations reflects the city's hilly outskirts, indicating a mix of low-lying urban areas and surrounding elevated regions.

11.6 Madrid

Madrid's height distribution is distinct, with a higher frequency of moderate to high elevations. The peak around 50 meters represents the city's plateau location. The distribution reflects Madrid's complex topography, with urban areas at moderate elevations surrounded by higher terrains.

11.7 Analysis of Frequency Differences

The differing frequencies in height distributions across these cities can be attributed to their unique geographical settings:

- **Amsterdam and Copenhagen**: Predominantly flat and coastal, resulting in high frequencies of low elevations.
- **Athens and Madrid**: Located in mountainous and plateau regions, leading to more varied height distributions and higher frequencies of moderate to high elevations.
- **Berlin and Dublin**: Mixed urban and natural landscapes, showing moderate frequencies across a range of elevations due to urban flat areas and surrounding natural elevations.

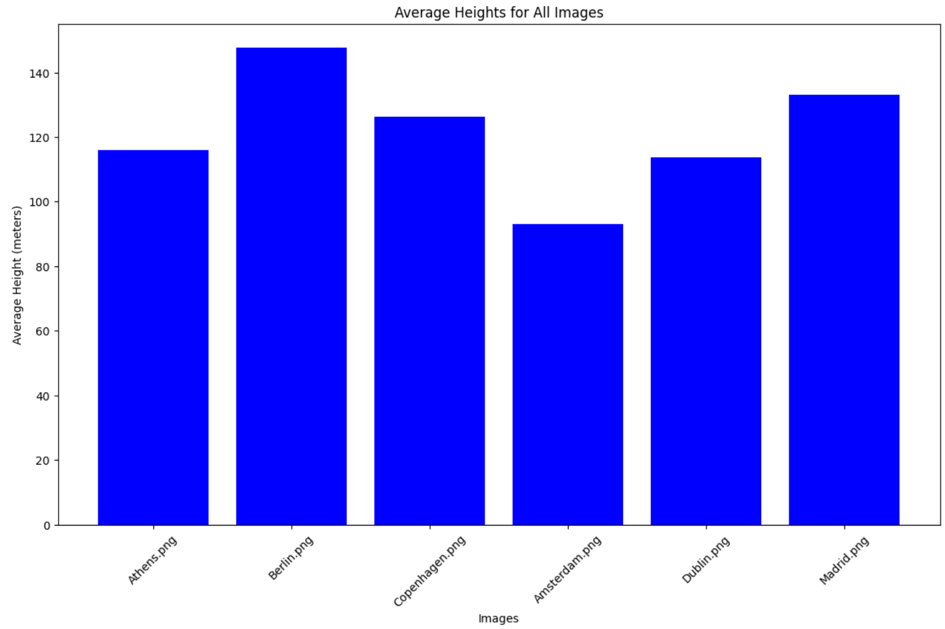

Figure 26: Average Heights for All Images

12 Average Height Analysis

Interpretation of Average Heights

Athens

The mean height for Athens is 115.87 meters. This reflects the city's varied topography, including the urban areas and the surrounding mountainous regions. The relatively high average height indicates significant elevation changes.

Berlin

Berlin has a mean height of 147.64 meters, the highest among the analyzed cities. This high average is due to Berlin's natural elevations scattered throughout the city.

Copenhagen

Copenhagen's mean height is 126.28 meters. The city's coastal and relatively flat landscape contributes to this moderate average height, with slight variations due to built-up areas and low hills.

Amsterdam

Amsterdam has a mean height of 93.12 meters, the lowest among the cities. This low average reflects Amsterdam's flat terrain and low-lying areas, characteristic of its location below sea level.

Dublin

Dublin's mean height is 113.68 meters. The average height indicates a mix of low-lying urban areas and higher elevations in the outskirts, capturing the city's diverse geographical setting.

Madrid

Madrid's mean height is 133.08 meters. The relatively high average height is due to the city's location on the Spanish plateau, with urban areas surrounded by varied terrain and higher elevations.

13 Conclusion

This analysis of Sentinel-1 and Sentinel-2 satellite imagery provides valuable insights into the environmental and geographical characteristics of various European cities. By utilizing false-color infrared images, I assessed vegetation health, soil properties, and water bodies, highlighting the importance of vegetation monitoring in urban planning and environmental conservation.

The application of K-means clustering allowed for effective classification of different land cover types, enabling the identification of urban areas, vegetation, and water bodies. This classification is crucial for urban planning and resource management, ensuring sustainable development and efficient use of natural resources.

The height map analysis revealed the elevation variations within each city, offering a comprehensive understanding of their topography. The comparison of average heights across cities highlighted the diverse geographical settings and their implications on urban infrastructure and planning.

Overall, the knowledge gained from this analysis emphasizes the importance of remote sensing technologies in monitoring and managing urban environments. The ability to analyze and interpret satellite data aids in informed decision-making, promoting sustainable urban development and environmental stewardship.