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Characterization of Urban Expansion of Dubai

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Abstract

Dubai has experienced rapid urban growth over the past several decades, transforming extensive desert areas into residential, commercial, industrial and tourism developments. The purpose of this study was to characterize the urban expansion of Dubai between 1984 and 2024 using remote sensing techniques and satellite imagery acquired by Landsat 5 TM , Landsat 7 ETM+, and Sentinel-2 MSI. Image preprocessing included atmospheric correction using Dark Object Subtraction method in ENVI. Both unsupervised and supervised classification techniques were applied to evaluate land cover changes over time. The unsupervised methods included ISODATA and K-Means, while the supervised methods consisted of Parallelepiped, Maximum Likelihood, and Minimum Distance classifiers. The results revealed a substantial increase in urbanized areas and significant modifications to the coastline associated with continuous development and the construction of artificial islands. Although all classifications methods were effective in identifying land cover changes, the Minimum Distance classifier produced the most consistent and accurate results. Despite several challenges encountered during the project, including time constraints and limited information associated with the historical images, the analysis was successfully completed. This study demonstrates the value of remote sensing and image classification techniques as effective tools for monitoring urban growth and understanding land cover changes through time.

Introduction

Over the past several decades Dubai has experienced rapid urban growth. Urban expansion has transformed large areas of desert into residential, commercial, and industrial developments. The rapid urban growth started in the early 2000s, with the beginning of the construction of the artificial archipelago. Dubai, part of the United Arab Emirates, launched a

large engineering project to build hundreds of man-made islands along its Persian Gulf coastline in order to increase the potential for beachfront tourism development. The creation of man-made islands, like the World Islands and the Palm Jumeirah, further altered the coastline and opened up new development opportunities. This rapid transition has made Dubai an excellent example for monitoring urban expansion through remote sensing techniques.

The main objective of this research is to analyze the urban expansion of Dubai over several decades, using a combination of satellite images from 1984, 2003, and 2024. To compare these changes, both supervised and unsupervised classification techniques are applied to the satellite images. Understanding these changes is essential for urban planning and environmental management. Remote sensing provides an efficient method for detecting and analyzing land cover changes over time, allowing researchers to evaluate the extent and rate of urban growth.

Methodology

For a better comparison of the urban expansion of Dubai, three images from 1984, 2003, and 2024 were used. The first image was taken by the Landsat 5 TM on April 29, 1984 and the second image by the Landsat 7 ETM+ on May 28, 2003. Both of these images were acquired from the USGS Earthshots website. The third image was taken by the Sentinel-2 MSI satellite on January 23, 2024, and was acquired from the European Space Agency website.The 1984 and 2003 images downloaded are not true color images, but the website does not provide additional information about these images. The 2024 image was downloaded as a false color image since it was the only option provided by the website.

First, the images were downloaded and imported into ENVI. The processing of the three images began with an atmospheric correction using the Dark Object Subtraction tool on

ENVI to remove atmospheric haze. The bands of the three images were kept the same, red, green, and blue.

After this step, both supervised and unsupervised classifications were conducted on the three images. For the unsupervised classification, the ISODATA and K-means methods were applied, both of which group pixels based on their spectral similarity. The classifications were configured using a number of 5 classes, a threshold percentage of 2%, and 10 maximum iterations.

The next step for the processing of these images was the supervised classification, which was performed using multiple classification algorithms including Parallelepiped, Minimum Distance, and Maximum Likelihood methods. Regions of interest (ROIs) were first created to define four land cover classes for the three images: ocean, sand, urban areas (city), and vegetation.

After the classification process was completed, the resulting images were exported from ENVI for visualization and comparison purposes. Final map layouts were then prepared by adding cartographic elements, including legends and north arrows, to improve the interpretation and presentation of the classified images. These final products were used to evaluate land cover changes and to illustrate the urban expansion of Dubai between 1984 and 2024.

Results/Discussion

The classification results revealed a significant increase in urbanized areas in Dubai between 1984 and 2024. In the 1984 images, urban development was limited to a narrow strip along the coastline, while most of the study area consisted of undeveloped desert land. By 2003, the classified images showed considerable expansion of the city and the beginning of major coastal modifications associated with the construction of artificial islands. The 2024

imagery demonstrated extensive urban growth, with a much larger built-up area and a more complex coastline resulting from continued development and land reclamation activities. The original satellite images used in this study are presented in Figure 1.

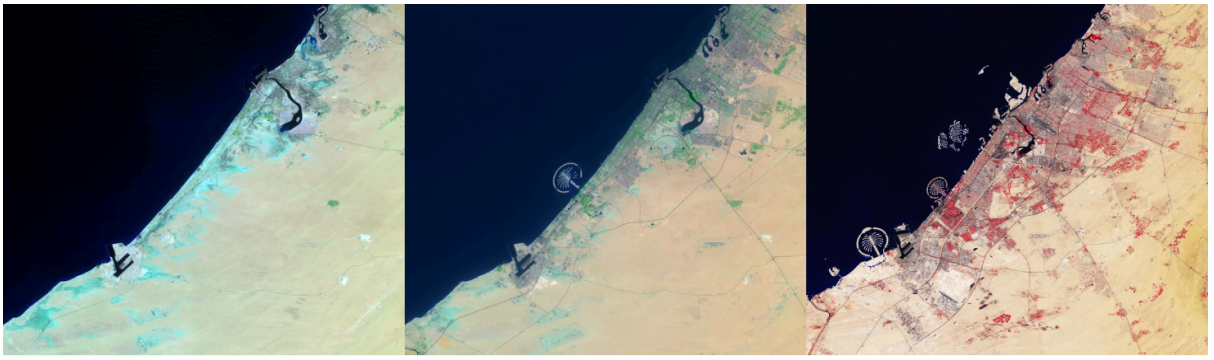

Figure 1: Original images 1984/2003/2024

Both unsupervised classification methods, ISODATA and K-Means, were effective in separating the major spectral classes and identifying general land cover patterns. However, these methods produced some inconsistencies and mixed classes, particularly in transition zones between urban areas and desert surfaces. Despite these limitations, they provided a useful overview of land cover distribution and highlighted the progressive increase in developed areas through time. The classification results obtained using the ISODATA and K-Means methods are presented in Figures 2 and 3, respectively.

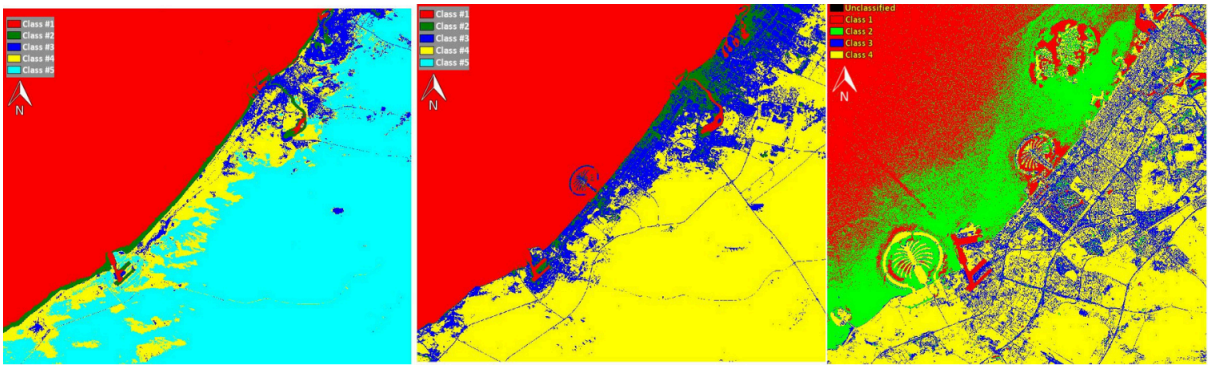

Figure 2: ISODATA classification results for Dubai 1984/2003/2024

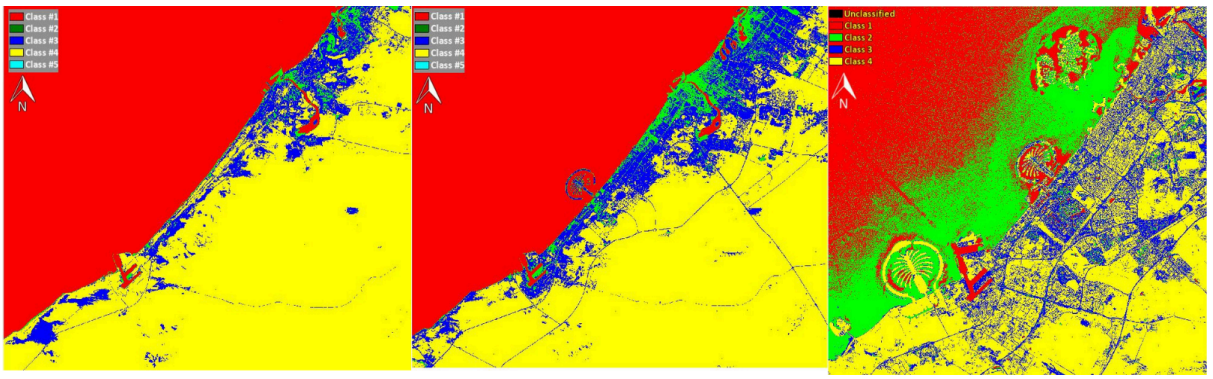

Figure 3: K-Means classification results for Dubai 1984/2003/2024

The supervised classification methods produced more detailed and interpretable results because the use of regions of interest (ROIs) allowed the land cover classes to be defined more accurately. The Parallelepiped classifier generated a large number of unclassified pixels and showed lower performance compared to the other methods. Maximum Likelihood provided satisfactory results, although some confusion between urban areas and surrounding land cover classes was observed. Among all methods evaluated, the Minimum Distance classifier produced the most consistent results and the clearest separation between water, urban areas, sand, and vegetation. Therefore, it was considered the most accurate method for representing land cover changes in Dubai. The classification results obtained using the Parallelepiped, Maximum Likelihood, and Minimum Distance methods are presented in Figures 4, 5, and 6, respectively.

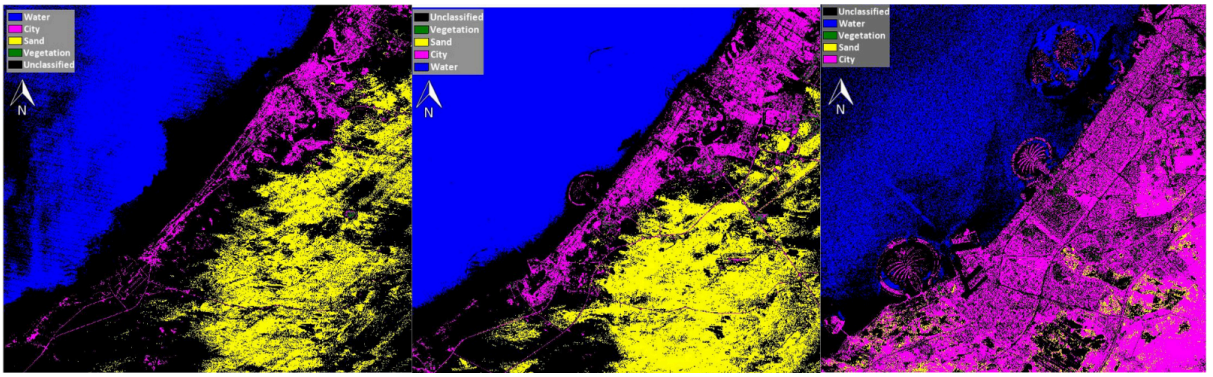

Figure 4: Parallelepiped classification results for Dubai 1984/2003/2024

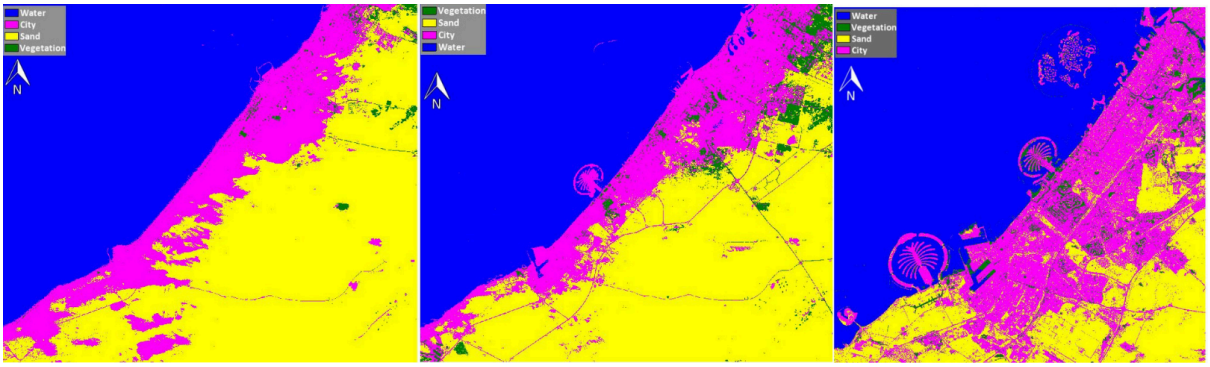

Figure 5: Maximum Likelihood classification results for Dubai 1984/2003/2024

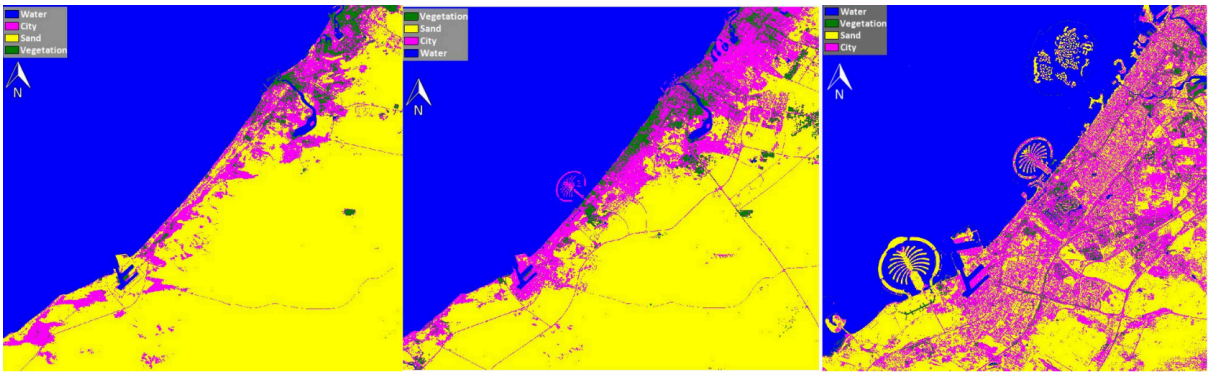

Figure 6: Minimum Distance classification results for Dubai 1984/2003/2024

Several challenges were encountered throughout the development of this project. One of the major difficulties was the university strike, which reduced the time available to work on the analysis. In addition, the original project had to be changed at the last minute because suitable images for the initial study area could not be obtained. Consequently, a new study area and dataset had to be selected within a limited time frame.

Another challenge was that the entire image acquisition and processing workflow had to be completed within only a few hours. This included downloading the satellite images, performing atmospheric correction, generating both supervised and unsupervised classifications, and comparing the results obtained from the different methods. Despite these time constraints, the analysis was successfully completed and produced meaningful results.

Additional limitations were associated with the use of images acquired from different satellites and different years, since they have different spatial resolutions and image characteristics. Furthermore, the historical images obtained from the USGS Earthshots website provided limited information regarding the image composition and spectral bands, making it more difficult to describe and compare the datasets. Spectral similarities between urban areas and surrounding desert surfaces also caused some confusion during the classification process. These challenges affected the performance of some classification methods and required careful selection of regions of interest and comparison of the different classification methods to determine the most suitable approach.

Overall, the results demonstrate how remote sensing techniques can effectively monitor urban expansion and land cover changes through time. The comparison of satellite images from different decades highlights the rapid transformation of Dubai and illustrates the usefulness of image classification methods for studying urban growth and supporting future land management and planning efforts.

Conclusion

The purpose of this study was to demonstrate the significant urban expansion that has occurred in Dubai between 1984 and 2024, and our results demonstrated this growth conclusively. Satellite imagery revealed a substantial increase in urbanized areas and major modifications to the coastline resulting from continuous development and land reclamation activities. These changes illustrate the rapid transformation of Dubai from a predominantly desert environment into a highly developed urban center.

Both supervised and unsupervised classification methods proved to be effective for identifying land cover patterns and evaluating changes through time. While each method presented advantages and limitations, the Minimum Distance classifier produced the most

accurate and consistent results for distinguishing water, sand, vegetation, and urban areas. The comparison of different classification techniques provided a better understanding of their performance and their suitability for land cover mapping.

Despite several challenges encountered during the development of this project, including the university strike, the need to change the original study area, limited information associated with the historical images, and the short time available for image acquisition and processing, the analysis was successfully completed. These difficulties highlighted the importance of adaptability and efficient data processing in remote sensing studies.

Overall, this study demonstrates the value of remote sensing and image classification techniques as useful tools for monitoring urban growth and land cover changes over time. The information obtained from this analysis can contribute to a better understanding of landscape evolution and provide valuable support for future urban planning and environmental management efforts.

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