HACETTEPE UNIVERSITY

GEOMATICS ENGINEERING DEPARTMENT

2024 – 2025 Spring

GMT447 Digital Image Processing

Homework_2

Water Body Extraction and Boundary Detection Using NAIP Imagery on Google Earth Engine

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11.05.2025

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Objective

The objective of this project is to extract water bodies and detect their boundaries using high-resolution NAIP imagery within a selected region in Minnesota.
By employing NDWI calculation, edge-preserving smoothing, Sobel-based gradient detection, and thresholding techniques on the Google Earth Engine platform, the project aims to accurately delineate water surfaces and their edges.

1. Introduction

Accurate identification of water bodies is critical for hydrological studies, environmental management, and disaster response planning. Remote sensing data, particularly high-resolution imagery, provides a valuable resource for large-scale water body detection. The National Agriculture Imagery Program (NAIP) offers 1-meter resolution imagery with Red, Green, Blue, and Near-Infrared bands, making it suitable for such applications.

This project utilizes NAIP imagery from 2019 covering a selected area in Minnesota, "Land of 10,000 Lakes," to extract water bodies and detect their boundaries using a remote sensing-based workflow implemented in Google Earth Engine (GEE).

2. Study Area and Dataset

- Dataset: USDA/NAIP/DOQQ (2019)
- Spectral Bands: Red (R), Green (G), Blue (B), and Near-Infrared (NIR)
- Spatial Resolution: 1 meter
- Study Area:
    - Bottom Left: (-94.92°, 47.48°)
    - Top Left: (-94.92°, 47.56°)
    - Top Right: (-94.80°, 47.56°)
    - Bottom Right: (-94.80°, 47.48°)

The study area is located within Minnesota, a region characterized by a high density of natural lakes, providing an ideal setting for water detection tasks.

2. Methodology

The methodology followed five major steps:

- Clipping the Study Area: The NAIP imagery was first filtered to cover the study area defined by the specified bounding coordinates. Since the NAIP dataset is organized as an ImageCollection consisting of multiple overlapping tiles, the mosaic() function was applied to merge these tiles into a single seamless image. This mosaic was then clipped to the exact extent of the study area to create the base image for subsequent processing steps.

- NDWI Calculation: The Normalized Difference Water Index (NDWI) was computed using the Green and Near-Infrared (NIR) bands to enhance the spectral response of water bodies. The NDWI is calculated based on the following normalized difference formula:

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

Figure 1 Normalized Difference Water Index (NDWI) calculation using Green and Near-Infrared (NIR) bands.

This formulation increases the reflectance of water features while suppressing the reflectance of vegetation and soil backgrounds. To facilitate the visual interpretation of water bodies, the NDWI image was displayed using a color palette where low and negative values are shown in white, and high positive values indicating water surfaces are shown in blue. This ['white', 'blue'] palette allows a clear distinction between non-water features such as soil and vegetation (white) and water bodies (blue), enhancing the effectiveness of the water body extraction process.

- Edge-Preserving Smoothing: A 3×3 mean filter was applied to the NDWI image to reduce random noise while preserving significant edges, such as water-land boundaries. A 3×3 kernel size was specifically chosen to achieve a balance between sufficient noise reduction and minimal spatial blurring, ensuring that fine water body boundaries were maintained during the smoothing process. During the smoothing operation, border effects were considered negligible, and the native behavior of the Google Earth Engine platform, which typically mirrors edge pixels, was utilized to maintain consistency without introducing significant artifacts.

- Gradient Detection with Sobel Operators: Sobel kernels were applied separately in the horizontal (GxG_xGx) and vertical (GyG_yGy) directions to compute the first-order image derivatives. To obtain the horizontal and vertical gradients, the smoothed NDWI image was convolved with the manually defined Sobel kernels using the convolve() function in GEE. Since the Google Earth Engine (GEE) environment does not provide a built-in gradient magnitude function, the overall edge strength was manually calculated using the following standard magnitude formula:

$$M(x, y) = \sqrt{G_x^2(x, y) + G_y^2(x, y)}$$

Figure 2 Mathematical expression for gradient magnitude calculation.

This approach allowed the integration of horizontal and vertical edge information to highlight water body boundaries more accurately.

- Thresholding for Edge Extraction: A threshold value was applied to the gradient magnitude image using the greater-than (.gt()) function to extract strong edges corresponding to water body boundaries. Based on visual inspection, a threshold value of 0.1 was selected to achieve an optimal balance between sensitivity and specificity. Lower threshold values resulted in excessive noise and detection of irrelevant edges, while higher threshold values led to the omission of fine water boundary details. Thus, 0.1 was determined to be the most effective threshold for accurately delineating water body edges while minimizing noise.

4. Results

Each processing step resulted in a distinct visual and analytical output. The outputs and corresponding observations are detailed below:

4.1 Output 1 - NAIP RGB Image

Figure 3 NAIP RGB image clipped to the Minnesota study area, showing natural color composition at 1-meter spatial resolution.

The clipped NAIP RGB image clearly shows the study area, including a large water body surrounded by urban settlements and vegetated regions. The high spatial resolution (1 meter) allows fine discrimination of land cover features such as roads, buildings, and vegetation patches.

Water surfaces appear darker compared to the surrounding land areas, but without spectral indices, distinguishing narrow or shallow water features remains challenging in true color imagery.

4.2 Output 2 - NDWI Image

Figure 4 NDWI image computed from Green and Near-Infrared (NIR) bands, highlighting water surfaces with positive index values.

The NDWI image significantly enhances the distinction between water and non-water surfaces. Water bodies exhibit high positive NDWI values (displayed in dark blue), while vegetation and built-up areas appear with lower or negative values. Small ponds and narrow water channels, which were difficult to identify in the RGB image, become distinctly visible. However, some shadowed areas and wet soils may show mildly positive NDWI values, potentially causing minor confusion in strict water segmentation tasks.

4.3 Output 3 - Smoothed NDWI Image

After applying a 3×3 edge-preserving smoothing filter, the NDWI image shows reduced pixel-level noise while retaining the integrity of water body shapes. The water surfaces appear more continuous, minimizing isolated noisy pixels that could mislead edge detection algorithms. Edges between water and land remain relatively sharp, validating the effectiveness of smoothing in enhancing segmentation quality without sacrificing spatial detail.

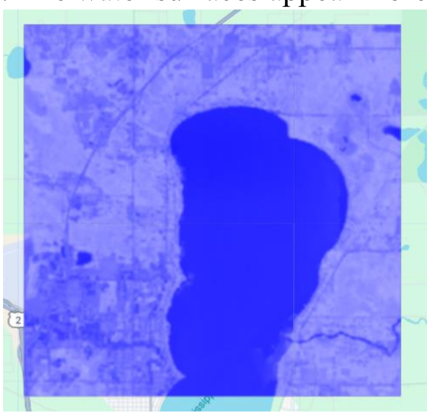

Figure 5 Smoothed NDWI image after applying a 3×3 edge-preserving mean filter to reduce noise while maintaining water-land boundaries.

4.4 Output 4 - Gradient Magnitude

The gradient magnitude image highlights transition zones between water and non-water areas by emphasizing strong changes in NDWI values. Clear, sharp boundaries are visible around the water bodies, while relatively homogeneous regions exhibit low gradient magnitudes. This step enables the identification of actual water boundaries independently of the absolute NDWI values. Some gradient noise is still present in highly heterogeneous land cover regions, particularly urbanized zones with mixed spectral signatures.

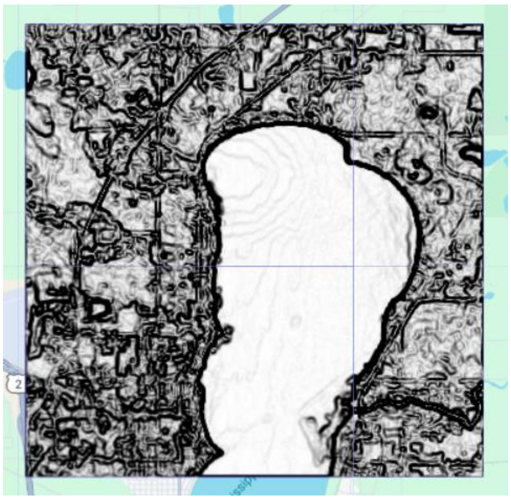

Figure 6 Gradient magnitude image obtained by combining horizontal and vertical Sobel operators to detect edge strengths around water bodies.

4.5 Output 5 - Detected Edges

By applying a threshold value of 0.1 to the gradient magnitude image, the major water body boundaries were successfully extracted. The binary edge map accurately outlines the perimeter of the main lake and several small water features across the study area. Although most water edges are correctly detected, minor noise remains in certain non-water regions, especially where strong land cover changes occur (e.g., forest to urban transitions). Further post-processing, such as morphological cleaning, could further refine the edge map if needed for operational applications.

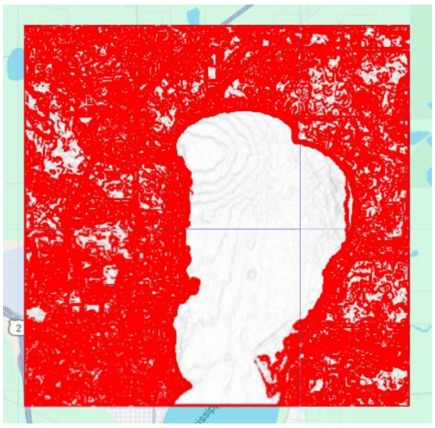

Figure 7 Binary edge map showing the detected water body boundaries after applying a threshold value of 0.1 on the gradient magnitude image.

5. Discussion

This study successfully applied a combination of spectral index enhancement, smoothing, gradient-based edge detection, and thresholding to delineate water bodies in high-resolution NAIP imagery. While the workflow produced promising results, several aspects merit further discussion regarding method efficiency, limitations, and potential improvements.

5.1 Edge-Preserving Filter

The application of a 3×3 edge-preserving smoothing filter significantly improved the continuity of water surfaces in the NDWI image. Noise due to pixel-level spectral variations, particularly in vegetated and urban fringe areas, was effectively reduced without blurring critical boundaries. However, some minor smoothing artifacts were observed along very narrow water features, suggesting that an adaptive filter size based on local image characteristics could yield better performance in complex landscapes.

5.2 Sobel Edge Detection

The use of Sobel operators in both the horizontal and vertical directions allowed robust detection of water-land boundaries, irrespective of their orientation. The gradient magnitude effectively emphasized sharp spectral transitions associated with true water edges. Nonetheless, non-water edges caused by sharp land cover changes (e.g., urban-to-vegetation interfaces) were also highlighted, introducing minor noise into the edge maps. Future applications might benefit from combining Sobel operators with more advanced edge detectors (e.g., Canny edge detector) or integrating contextual information to suppress irrelevant edges.

5.3 Thresholding

Thresholding the gradient magnitude image was a crucial step for isolating true water boundaries. The selected threshold value of 0.1 provided a good balance between sensitivity and specificity, as visually validated. However, the choice of a global threshold may not fully accommodate spatial variability in edge strength across heterogeneous landscapes. Adaptive thresholding approaches (e.g., Otsu's method, percentile-based thresholding) could further improve segmentation accuracy by dynamically adjusting to local conditions.

5.4 General Observations

Overall, the integration of NDWI-based enhancement and gradient analysis proved effective for water body boundary detection using NAIP data. The 1-meter spatial resolution of NAIP imagery enabled detailed edge extraction but also increased sensitivity to fine-scale land cover variations, necessitating robust smoothing and edge-cleaning procedures. Despite minor limitations, the developed workflow demonstrates strong potential for operational water monitoring applications, especially when combined with automated post-processing techniques such as morphological filtering or object-based image analysis.

6. Conclusion

This study successfully demonstrated a simple yet effective workflow for water body extraction and boundary detection using high-resolution NAIP imagery. Combining NDWI analysis, edge-preserving smoothing, gradient magnitude computation, and thresholding provided reliable delineation results. The approach can be further enhanced in future work through adaptive thresholding or additional spectral feature integration.

References

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