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Urban Hydrological Extraction Based on Otsu Threshold: A Case Study in Zhejiang Province, China

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Abstract: This work uses advanced remote sensing to precisely extract hydrological information, supporting transmission network planning. High-resolution water body mapping lets designers optimize routes to avoid ecologically sensitive areas, achieving environmental protection, cost efficiency, and enhanced operational safety. The methodology provides a scalable, replicable framework for intelligent obstacle avoidance in power grid development, applicable to other regions and sectors with similar planning needs.

Keywords: Water extraction; Power transmission system; Intelligent decision

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1. Introduction

In power grid line planning, avoiding obstacles like water bodies (rivers, lakes, reservoirs, wetlands) is crucial due to environmental regulations and the need to minimize ecological disruption [1]. Therefore, intelligently extracting water body information using remote sensing imagery is vital [2]. This study focuses on Zhejiang Province, China, which has a diverse hydrological system. We used the Google Earth Engine (GEE) platform and the Modified Normalized Difference Water Index (MNDWI) method to create an accurate water body map [3, 4]. This map will aid power grid planning by reducing construction costs and environmental impact [5]. The methodology can be applied to other regions facing similar challenges.

2. Methods

2.1. Water body information extraction platform

The Google Earth Engine (GEE) platform, with its global open-source satellite imagery and cloud computing power, greatly speeds up large-scale remote sensing data analysis. In this study, the GEE platform was used to efficiently obtain and preprocess 2022 Sentinel-2 satellite imagery of Zhejiang Province [6]. The Modified Normalized Difference Water Index (MNDWI) was also computed on the platform, which enhanced computational efficiency and streamlined the analysis.

2.2. Sentinel-2 satellite data

The Sentinel-2 satellite, comprising 2A and 2B, has a 10 - day revisit period per satellite, but together, they can reduce it to 5 days. It carries a multispectral imager (MSI) covering 13 spectral bands , with ground resolutions of 10 m, 20 m, and 60 m [6]. The main spectral bands are shown in **Table 1**.

Table 1. Main bands of sentinel-2

Band	Description	Spatial resolution	Wavelength
B2	Blue	10m	496.6 nm(S2A) / 492.1 nm(S2B)
B3	Green	10m	560 nm(S2A) / 559 nm(S2B)
B4	Red	10m	664.5 nm(S2A) / 665 nm(S2B)
B8	NIR	10m	835.1 nm(S2A) / 833 nm(S2B)
B11	SWIR1	20m	1613.7 nm(S2A) / 1610.4nm(S2B)
B12	SWIR2	20m	2202.4 nm(S2A) / 2185.7 nm(S2B)

2.3. Water body index method

The NDWI method uses the ratio of band differences to extract water body information, highlighting the contrast between water bodies (with strong absorption in the near-infrared band) and other land features (with enhanced reflectance in the near-infrared band). The MNDWI method replaces the near-infrared band in the NDWI with the short-wave infrared band (SWIR), enhancing the distinction between water bodies and buildings and reducing confusion in urban areas [7]. The MNDWI method was used in this study, and its calculation formula is as follows:

$$MNDWI = \frac{\rho_{\mathrm{Green}} - \rho_{SWIR}}{\rho_{\mathrm{Green}} + \rho_{SWIR}} \quad (1)$$

In this equation, $_{\mathrm{Green}}$ and $_{\mathrm{SWIR}}$ are the reflectance values in bands B3 and B12 of Sentinel-2 imagery, respectively.

2.4. Otsu's thresholding method

The complexity of the Earth's surface and spectral variability can lead to incorrect water body extractions or omissions. To address this, the Otsu method, an adaptive thresholding technique, is used. It divides image pixels into background and target pixels, using variance as a measure of grayscale distribution uniformity. A larger variance indicates greater differences between image parts [8]. By maximizing between-class variance, the algorithm determines the threshold that minimizes misclassification probability, subsequently enabling robust image binarization. Within this framework, consider an image with grayscale intensities spanning the interval[0, K], where n_i denotes the pixels count at grayscale level i and N representing the total number of pixels in the image and its corresponding occurrence probability is defined as follows:

$$P_i = \frac{n_i}{N}, i = 0,1,2,\ldots K, \sum_{\mathrm{i}=0}^{K} P_i = 1 \tag{2}$$

Divide the pixels in the image into two categories, A and B, based on a grayscale threshold value t. Category A consists of pixels with grayscale values between 0 and t, while category B consists of pixels with grayscale values between $t + 1$ and K. The probabilities of categories A and B are as follows:

$$\omega_0 = \sum_{i=0}^{t} P_i, \omega_1 = \sum_{i=t+1}^{K} P_i = 1 - \omega_0 \tag{3}$$

The mean grayscale values of categories A and B are as follows:

$$\mu_0 = \sum_{i=0}^{t} \frac{iP_i}{\omega_0}, \mu_1 = \sum_{i=t+1}^{K} \frac{iP_i}{\omega_1} \tag{4}$$

The overall mean grayscale value of the entire image is:

$$\mu = \omega_0 \mu_0 + \omega_1 \mu_1 \tag{5}$$

The between-class variance is defined as:

$$\sigma^2 = \omega_0 (\mu_0 - \mu)^2 + \omega_1 (\mu_1 - \mu)^2 \tag{6}$$

Let t vary in the range [0, K] with a step size of 1, and the optimal threshold value corresponds to the value of t that maximizes the between-class variance.

2.5. Water body extraction accuracy verification

We choose the confusion matrix based on Python language to evaluate the classification results. The binary confusion matrix consists of TP (True Positive), FP (False Positive), TN (True Negative), and FN (False Negative) [9]. F1-score is calculated using the constructed confusion matrix. Precision represents the proportion of true water bodies among the extracted water bodies, while recall represents the proportion of extracted water bodies among all true water bodies. The calculation formulas are as follows:

$$Precision = \frac{TP}{TP + FP} \tag{7}$$

$$Recall = \frac{TP}{TP + FN} \tag{8}$$

$$F_1 score = \frac{2 \times Precision \times Recall}{Precision + Recall} \tag{9}$$

3. Results

3.1. Water area analysis

Applying the methodology described in this study, the total water surface area in Zhejiang Province is estimated to be approximately 4500.67 square kilometers. The areas of water bodies in cities of Zhejiang Province are shown in **Table 2**.

Table 2. Water area of each city in Zhejiang Province (Unit: square kilometers)

Region	Huzhou	Ningbo	Taizhou	Shaoxing	Wenzhou	Jiaxing	Hangzhou	Jinhua	Lishui	Quzhou	Total
Area	466.3902	699.4834	324.3846	404.7413	301.6418	790.6482	920.3597	236.2061	186.887	169.9326	4500.67

In this paper, we select one region in Zhejiang Province to verify the accuracy of water body extraction, using visual interpretation results as the evaluation standard for model accuracy, and calculating the F1-score. In this demonstration area, the F1-score value of water extraction was 0.87.

3.2. Research analysis and implications for power grid line planning

The extraction of water bodies using remote sensing techniques, as demonstrated in this study, serves as a critical foundation for power grid line planning. The accurate identification and mapping of water bodies are essential for several reasons:

3.2.1. Minimizing environmental impact

Water bodies, especially those in ecologically sensitive areas, are subject to strict environmental regulations. By accurately identifying water bodies, planners can design power grid routes that avoid these areas, thereby minimizing ecological disruption and ensuring compliance with environmental laws. For example, avoiding wetlands and coastal areas can prevent habitat destruction and protect biodiversity.

3.2.2. Optimizing construction costs and logistics

Water bodies pose significant challenges for the construction of power lines. Crossing rivers, lakes, or wetlands often require specialized infrastructure such as bridges, elevated lines, or underwater cables, which can be costly and technically complex. By identifying water bodies in advance, planners can optimize routes to avoid such areas, thereby reducing construction costs and simplifying logistics.

3.2.3. Enhancing operational safety and maintenance

Water bodies can impact the operational safety of power lines. For instance, proximity to water bodies may increase the risk of flooding, which can damage power infrastructure and disrupt service. By identifying water bodies and planning routes to avoid them, power grid operators can enhance the resilience of their infrastructure against natural disasters and reduce the frequency of maintenance interventions.

3.2.4. Supporting sustainable development goals

The integration of water body information into power grid planning aligns with broader sustainability goals. By minimizing the impact on water bodies and surrounding ecosystems, power grid projects can contribute to the preservation of natural resources and the promotion of sustainable development practices.

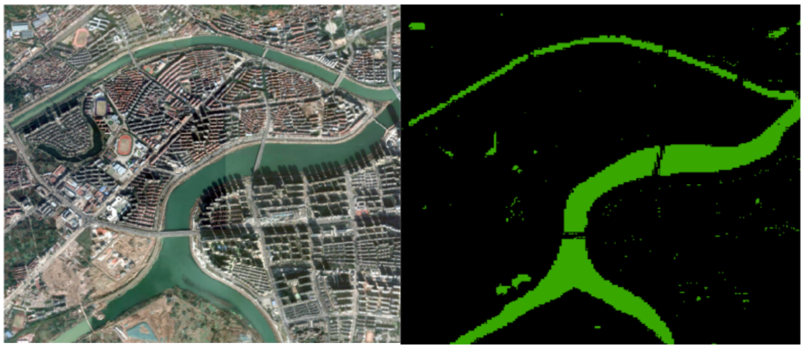

Figure 1. Water extracted by the threshold method

3.3 Case study analysis: power grid line planning in Zhejiang Province

In this study, the water body map was overlaid with proposed power grid routes in Zhejiang Province, leading to several important findings. In Huzhou, the original route intersected small lakes and wetlands; by leveraging the water body data, planners successfully adjusted the route to avoid these areas, thereby reducing both infrastructure demands and environmental impact. In Ningbo, the initial plan involved crossing a major river, but with the aid of water body mapping, an alternative route was identified that eliminated the need for a river-crossing bridge and shortened the power line, significantly lowering construction costs. Similarly, in Hangzhou, the extraction of water bodies revealed the presence of protected wetlands, enabling planners to reroute the grid to avoid these sensitive areas, thus ensuring compliance with environmental regulations and preventing potential legal disputes.

4. Conclusions

Advanced remote sensing techniques, like those in this study, provide a strong framework for better power grid line planning. By identifying and mapping water features, planners can design routes that avoid ecologically sensitive areas, achieving environmental preservation, cost efficiency, and enhanced safety. The methodology offers a scalable solution for intelligent obstacle avoidance in power grid development and has potential for use in other regions. Future research may involve improving extraction algorithms, using multi-temporal data analysis and integrating additional environmental data to enhance the precision and sustainability of power grid planning.

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Data availability

The dataset supports the findings of the study are available from the corresponding author upon request.

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