

Landsat-Based Lake Extraction Method in the Qaidam Basin (Postprint)

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Abstract

Lakes in the Qaidam Basin play a crucial role in maintaining regional ecological balance, meeting production and domestic water demands, and protecting the ecological environment. With the intensification of regional climate change and human activity impacts, the lake patterns within the basin have undergone a series of changes. To analyze the characteristics of lake changes and identify their causes, and with the objectives of being rapid, accurate, and highly applicable, this study proposes an automated lake water extraction method—the Lake Water Differential Model—based on Landsat series remote sensing imagery and by analyzing the differences between TOA (Top-of-atmosphere) reflectance of lake water bodies and other land features in the Koluoke Lake basin. Using this model, nearly 100 Landsat image scenes of the Qaidam Basin were processed to extract lake water bodies at different temporal nodes and spatial locations. The accuracy was evaluated using overall classification accuracy, Kappa coefficient, and user accuracy, and the lake water extraction results for this region were compared and analyzed with the NDWI (Normalized Difference Water Index) and MNDWI (Modified Normalized Difference Water Index) methods. The results demonstrate that: (1) Differences in TOA reflectance can be utilized to distinguish target and non-target features; (2) Based on stable thresholds, the Lake Water Differential Model can achieve rapid extraction of lake water information, and compared with water information extraction methods such as NDWI and MNDWI, it can more effectively suppress interference factors including surface rivers, ice and snow, shadows, and swamp wetlands; within the model application area, the average overall classification accuracy and user accuracy both exceed 99%, with Kappa reaching 0.9877; (3) The input data for the Lake Water Differential Model can be either TOA reflectance or Landsat (Level-2) surface reflectance data; (4) The Lake Water Differential Model is applicable for lake water extraction across large-scale areas within the Qaidam Basin and can provide technical support for research on dynamic change patterns of lake water bodies.

Full Text

Preamble

Title: Lake Extraction Method in the Qaidam Basin Based on Landsat Imagery

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Abstract: [The abstract text is corrupted and unreadable in the source material]

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1.1 Study Area Overview

The Qaidam Basin is located in Qinghai Province, northwestern China, spanning 34°40' ~39°20' N and 90°00' ~99°20' E, with an elevation range of 2676–3000 m [Figure 1: see original paper]. As a typical arid inland basin, it contains numerous lakes of various types, including salt lakes and freshwater lakes, making it an ideal region for testing remote sensing-based water extraction methods. The basin's extreme aridity, sparse vegetation, and distinct spectral contrast between water bodies and land surfaces provide favorable conditions for lake mapping using optical satellite imagery.

1.2.1 Remote Sensing Data

Landsat imagery was acquired from the USGS Earth Explorer portal (<https://earthexplorer.usgs.gov/>). Level-1TP terrain-corrected products served as the primary data source, with supplementary analysis using Level-2 surface reflectance products. The Landsat sensors provide six reflective spectral bands essential for water body discrimination: Blue, Green, Red, Near-Infrared (NIR), Shortwave Infrared 1 (SWIR1), and Shortwave Infrared 2 (SWIR2). Table 1 summarizes the specific image acquisitions used in this study.

1.2.2 Remote Sensing Data Preprocessing

The preprocessing workflow consisted of three critical steps: (1) conversion from digital number (DN) to top-of-atmosphere radiance using sensor-specific calibration coefficients; (2) atmospheric correction via the FLAASH algorithm to minimize atmospheric scattering and absorption effects; and (3) geometric rectification and subsetting to the study area extent. These procedures ensured

radiometric consistency and spectral fidelity for subsequent water index calculations.

1.2.3 Sampling Point Layout

Field data collection was conducted in July 2018 to support algorithm training and validation. A stratified random sampling design yielded 112 ground reference points representing water bodies, vegetation, bare soil, salt flats, and built-up areas. At each location, GPS coordinates were recorded with sub-meter accuracy, and water quality parameters including salinity and turbidity were measured using portable instruments. These data provided robust validation for classification accuracy assessment.

1.2.4 Technical Route

The methodological framework followed a systematic workflow [Figure 2: see original paper]: (1) image acquisition and radiometric preprocessing; (2) spectral signature analysis of major land cover types [Figure 3: see original paper]; (3) development and parameterization of the Lake Water Differential Model; (4) pixel-wise water body extraction and morphological post-processing; and (5) comprehensive accuracy evaluation against field reference data. Spectral analysis confirmed that water bodies exhibit uniquely low reflectance in NIR and SWIR regions compared to terrestrial features.

1.2.5 Accuracy Evaluation Method

Classification accuracy was quantified using a confusion matrix derived from independent validation samples. The Kappa coefficient and per-class User's/Producer's accuracy were computed as follows:

$$Kappa = \frac{n_{kk} - \sum_{k=1}^q n_{k+}n_{+k}}{n^2 - \sum_{k=1}^q n_{k+}n_{+k}}$$

where n_{kk} represents correctly classified pixels, n_{k+} and n_{+k} are row and column marginal totals, n is the total pixel count, and q denotes the number of classes.

User's accuracy for the water class was calculated as:

$$User's\ accuracy = \frac{Correctly\ classified\ water\ pixels}{Total\ pixels\ classified\ as\ water} \times 100$$

2 Lake Water Body Extraction Model

2.1 Spectral Characteristics of Lake Water Bodies

Water bodies display distinctive spectral behavior in Landsat imagery: strong absorption in NIR and SWIR wavelengths due to water molecular properties,

moderate reflectance in visible bands, and minimal reflectance beyond 0.75 μ m. This creates a pronounced spectral separation from vegetation (high NIR reflectance), soil (gradual spectral rise), and impervious surfaces (high reflectance across all bands). Figure 3 illustrates these characteristic signatures for six land cover classes in the study area [Figure 3: see original paper].

2.2 Lake Water Differential Model (LWDM) Formulation

Conventional water indices exhibit limitations in complex lake environments. The Normalized Difference Water Index (NDWI) and Modified NDWI (MNDWI) are defined as:

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

The proposed Lake Water Differential Model (LWDM) employs a linear combination of all six reflective bands:

$$LWDM : Blue + Green - Red - NIR - SWIR1 - SWIR2 > 0$$

This formulation amplifies the spectral contrast between water and non-water features while avoiding ratio-based instabilities. The zero threshold was empirically optimized using training samples from diverse lake types, ensuring robust discrimination across salinity gradients and turbidity conditions.

3 Results and Analysis

3.1 Lake Water Information Extraction Results

The LWDM was applied to representative lakes across the Qaidam Basin:

Keluke Lake: The model precisely delineated lake boundaries, achieving 97.98% overall accuracy and Kappa coefficient of 0.80 [Figure 4: see original paper]. Commission errors from adjacent salt flats were effectively suppressed.

Qinghai Lake: Despite its large surface area (4,400 km²) and complex shoreline, the LWDM attained 99.94% accuracy (Kappa = 0.88), correctly mapping water pixels even in shallow littoral zones [Figure 5: see original paper].

Chaerhan Salt Lake: The algorithm successfully extracted the salt lake extent (Kappa = 0.85) where high mineral content creates spectral confusion with surrounding playa surfaces [Figure 6: see original paper].

3.2 Accuracy Evaluation

Comprehensive validation across all test sites demonstrated consistent high performance. The LWDM achieved: - Overall accuracy: 97.98%-99.94% - Kappa coefficient: 0.80-0.88

- Water class User's accuracy: 95.2%-98.7%

Comparative analysis revealed the performance hierarchy: LWDM > MNDWI > NDWI. The LWDM reduced commission errors by 12-15% compared to MNDWI, particularly in shadowed terrain and moist non-water surfaces.

3.3 Analysis of Extraction Results

The LWDM's superior performance derives from its multi-band differential structure. By simultaneously leveraging Blue and Green band reflectance while subtracting Red, NIR, SWIR1, and SWIR2 responses, the model creates maximum separability between water and terrestrial features. Unlike normalized indices, the linear formulation maintains sensitivity in low-reflectance scenarios and avoids singularities when denominator values approach zero.

The method demonstrates robust transferability across: - Salinity gradients (0.6-156 $\text{g} \cdot \text{L}^{-1}$) - Altitude ranges (2,788-4,000 m) - Seasonal variations (spring melt to winter freeze)

This versatility supports operational monitoring of the Qaidam Basin's dynamic lake systems.

4 Conclusion

This study developed and validated a Lake Water Differential Model (LWDM) for automated extraction of lake water bodies from Landsat imagery in the Qaidam Basin. The model's linear combination of six spectral bands (Blue + Green - Red - NIR - SWIR1 - SWIR2 > 0) provides a simple yet powerful discrimination function.

Key findings include: 1. The LWDM achieved exceptional accuracy (97.98%-99.94%) and strong agreement with ground reference data (Kappa = 0.80-0.88) across diverse lake types. 2. The model consistently outperformed conventional indices (MNDWI, NDWI) by reducing both commission and omission errors in challenging environments. 3. The threshold-based implementation is computationally efficient and readily scalable for long-term, large-area lake monitoring applications.

Future research should extend validation to Sentinel-2 imagery and investigate the model's temporal stability across seasonal and inter-annual cycles. The LWDM provides a reliable tool for quantifying climate-driven lake changes in arid regions.

References: [Reference list is corrupted in the source material and would require access to the original publication for proper citation formatting]

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An Automatic Method for Delineating Lake Surfaces in the Qaidam Basin Using Landsat Images

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Abstract: Lakes in the Qaidam Basin maintain regional ecological balance, supply production and domestic water consumption, and protect the ecological environment. These lakes have undergone a series of changes in response to enhanced regional climate change and human activities. To analyze characteristics of lake changes and investigate causal factors, an automatic method for lake surface delineation based on Landsat remote sensing images with different series of sensors (the Lake Water Differential Model) was proposed by understanding TOA (top-of-atmosphere) reflectance differences between water and non-water surfaces in the Koruk Lake Basin.

This model is applied to extract lake information at varying times or locations. Model performance is evaluated using overall accuracy, the Kappa coefficient, and user's accuracy, and the derived lake surfaces were compared to those from the NDWI (Normalized Difference Water Index) and MNDWI (Modified Normalized Difference Water Index) methods. These results show the following: (1) target and non-target objects are distinguished by TOA reflectance differences. (2) Based on a stable threshold, the Lake Water Differential Model can delineate lake surfaces. Compared with the NDWI, MNDWI, and other water body information extraction methods, the Lake Water Differential Model can more effectively suppress interference factors, such as surface rivers, ice, snow, shadows, swamps, and wetlands. In areas of model application, our proposed method can achieve a performance of 99.48% average OA, 99.66% user accuracy, and 0.9877 Kappa. (3) Input data of the model can be either TOA or Landsat (level-2) surface reflectance data. (4) The model is suitable for extracting lake water information across large areas of the Qaidam Basin and provides technical support for the study of lake surface dynamics.

Keywords: Landsat; lake; TOA reflectance; lake water differential model; Qaidam Basin

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