Extraction of lake water area by using Multi-source Satellite Data

Peng Zhu¹,², Shifeng Huang¹,²*, Jianwei Ma¹,², Yayong Sun¹,², Jingfeng Xin¹,², Yongmin Yang¹,², He Zhu¹,²

¹China Institute of Water Resources and Hydropower Research, Beijing, 100038, China
²Ministry of Water Resources and Drought Mitigation Engineering Research Centre for flood control, Beijing, 100038, China
*Corresponding author’s e-mail: huangsf@iwhr.com

Abstract. With remote sensing resolution data from Landsat-8, GF-1 and Sentinel-1 as the data sources, we used the object-oriented multi-resolution segmentation method to extract the area of Po Lake in Anhui. First, the multi-resolution segmentation method is used to segment the object, and then rule sets are established to extract areas of water bodies on three maps to calculate the area of lake water. The research result shows that the object-oriented multi-resolution segmentation method can realize efficient extraction of open water areas and facilitate disaster monitoring and emergency response.

1. Introduction

With scientific advancements, natural resources are becoming another area of human attention. Water, as a special resource, plays an indispensable role in social production and lives. In the natural water circulation system, lakes play a crucial role, and are sensitive to changes in the climate and precipitation. They are also an important carrier of information on global climate change and regional response [1]. Therefore, monitoring and supervision of lakes are gathering mounting research attention. Traditional monitoring and management measures, subject to limits in objective conditions, can no longer meet the current needs. The satellite remote sensing technology has many advantages such as large observation range, short cycle and low costs that other technologies cannot match when applied to monitoring and management of lakes.

Many existing studies have made use of satellite data to extract areas of lake water bodies. Zhang Yanchao (2016) used Landsat-8 images as the data source and made use of multiple methods to extract water body information in the last two decades in Qinghai Lake, which provided support for decision-making of management of Qinghai Lake [2]. Zhao Xin and Su Jiakai (2015) used Fengyun No.3 Satellite images as the major data source, extracted water bodies at different time in a year to calculate the area of water bodies in Dongting Lake and realized dynamic monitoring of Dongting Lake in different seasons [3]. Chen Yanfen et al. (2016) took Dongting Wetland as the research area, used MODIS images as the data source, plotted the time-series characteristics curves for different land surface features, and used the minimum distance classification method of spectral matching to classify the wetlands and plot maps for the research area[4]. Li Shengsheng (2018) took Qinghai Lake and lakes in Bellu River Basin as the research object, used Landsat long time-series remote sensing images in the last 30 years, the SPOT-5 and GF-1 satellite images in 2003 and 2015 to realize automatic extraction of water body areas.
Li also referred to the climate data (precipitation and temperature) of these two lakes released on National Meteorological Information Center to analyze the correlation between the temporal-spatial changes and regional climate in these two research areas [5]. Li et al. (2019) conducted long-term monitoring of lake coverage areas in Qaidam Basin by using Landsat images, described the trend of changes in detail, and revealed the influence of human activities on the area of lakes [6]. Wang et al. (2014) conducted long-term monitoring of lake reservoirs along the downstream of Three Gorges in Yangtze River by using MODIS data and analyzed the changes of lake areas in the research area [7]. Feng et al. (2019) conducted water body transparency monitoring of 50 middle- and large-size lakes in the middle and lower reaches of Yangtze River by using MODIS remote-sensing data to analyze the influence of different factors on transparency of lake water [8].

This study takes Po Lake in southern Anhui Province, China, as the research area, and images of Landsat-8, GF-1 and Sentinel-1 satellites as the data source, uses the object-oriented multi-resolution segmentation method, combines optical data and radar data to extract lake water areas. The accuracy of the extract result is also analyzed.

2. Research Area and Data

2.1. Research Area

Po Lake, formerly known as ‘Leichi’, is a relict lake after the Ancient Yantze River changes its course and Lize Lake disintegrates. It belongs to the drainage of Huayang River, a branch of Yangtze River, straddles three counties: Taihu County, Sujiang County, and Wangjiang County. It reaches Huayang and Yangwan water gates eastwards, Susong Xiqiao westwards, Huangpu Bay southwards, and Xuqiao Xiaqiaoba northwards (E116°19′-116°33′, N30°04′-30°15′). The lake is connected with Huayang Lake and joins Yangtze River through Huayang Lake. The lake is subject to the subtropical monsoon climate, with an average annual temperate of 16.6°C, 255 days of frost-free period, and precipitation of 1291.3 mm. Before the gates (Huayang Gate and Yangwan Gate) were built, the lake water level changes with the Yangtze River; after the gates were built, the lake water level shows little and steady changes due to human control. The location of the lake is shown in Figure 1.

![Figure 1. Location of Po Lake](image-url)
2.2. Data and Pre-processing
Landsat-8 Satellite is the 8th satellite of the Landsat series launched by America, and also the latest one. The spatial resolution of Landsat-8 images is 30 m, and the time resolution is 16 days. GF-1 is the first satellite in China’s high-resolution space-based observation system. One two-meter full-color spectral camera and one 8-meter spectral camera and four 16-meter multi-spectrum large-format cameras. Sentinel-1 is the first of the Copernicus Programme satellite constellation conducted by the European Space Agency. The satellite has one C-band synthetic aperture radar (SAR) instrument and is able to map the entire world once every 12 days.

The data used in this study are Landsat-8 data obtained on 3rd August, 2019, GF-1 data obtained on 6th August, 2019, and Sentinel-1 data obtained on 7th August, 2019.

Data pre-processing in this study consists of two parts: optical data pre-processing (Landsat-8 and GF-1), and radar data pre-processing (Sentinel-1). Two types of data are pre-processed by ENVI. Pre-processing of Landsat-8 data include two steps: radiometric calibration and atmospheric correction. Pre-processing of GF-1 data includes three steps: radiometric calibration, atmospheric correction and orthorectification, according to the multi-spectrum data selected in this study. Pre-processing of Sentinel-1 data has three steps: multi-look, speckle filtering, geocoding, and radiation correction.

3. Research Methodologies

3.1. Image Segmentation
Object-oriented extraction is an image classification method that takes the sets of adjacent pixels as the object to recognize interested spectral elements; it segments and classifies images according to the shape, texture and spectrum of images, and improves the accuracy of outputs. The core idea of this method is to consider the “object” rather than the pixel as the minimum processing unit, that is, the image segmentation object is taken as the research object. In other words, homogeneous objects obtained by image segmentation in the object-oriented image remote-sensing information extraction system, the image object is the basis of theories and a concept in comparison with image pixels, so the object can be understood as object units with certain sizes obtained by clustering image pixels within a certain spatial range according to the principle of “maximum homogeneity, minimum heterogeneity”. Thus, image segmentation is the most crucial step. The accuracy of segmentation is closely related to the classification accuracy [9-12]. On the Easy-Interpretation software platform, this study uses the object-oriented method to extract water bodies.

Production of objects refer to the process of producing meaningful homogeneous objects, including four parts: image segmentation, combination and partitioning, mosaic, and feature computing. In this study, only image segmentation and combination are involved. Image segmentation, in essence, is to segment an M ×N digital image into multiple segments that do not overlap each other. When partitioning the images into segments of certain sizes, we start from areas of random pixels and merge adjacent segments to increase the area. Homogeneity of the image areas can be expressed by computing of heterogeneity. Multi-resolution segmentation can ensure segmentation of objects into proper sizes.

The proper segmentation parameters are chosen according to distribution of water bodies in the study area to realize multi-resolution segmentation of pre-treated images and segment images into homogeneous objects that do not overlap each other. Then, according to the spectral difference of water body objects in different wavebands of images, different spectral indices are established. According to the optical spectra and spatial features of water bodies, the knowledge rule sets are built and the threshold classification method is used to extract the water bodies. Next, the extract results are expressed by charts, the boundary jaggs are removed to smoothen the polygonal contours of the water body vectors. Last, samples are collected according to the geographic range of the study area as the sample testing sites, the manual visual interpretation results of these sampling sites are taken as the reference data to analyze the accuracy of the water body extraction results.

When using the Easy-Interpretation software to segment the images, we controlled the maximum resolution and resolution gap, adjusted three parameters, the maximum resolution
set by users), color (proportion the color factor in segmentation), and smoothness (proportion of the smoothness factor), to control the segmentation result. The maximum resolution selected in this study is 3, the resolution gap is 0.6, the maximum resolution value is 50, the color is 0.7, and the smoothness is 0.5.

3.2. Water Body Extraction

In water body extraction of optical data, the water body index is the most common and efficient extraction method. According to the emission spectra of water bodies, differences in spectrum information of near-infrared band (NIR) and green band (Green) can be used to differentiate the water bodies from other geological features. Thus, the normalized difference water index (NDWI) can be used as an index for water body extraction [13].

\[
\text{NDWI} = \frac{\rho_{\text{Green}} - \rho_{\text{NIR}}}{\rho_{\text{Green}} + \rho_{\text{NIR}}} \quad (1)
\]

On that basis, to avoid the influence of shades (shades of buildings and others) on the extraction result, the near-infrared band (NIR) is replaced by the short wave infrared band (SWIR) to create a new water body index – modified normalized difference water index (MNDWI) [14].

\[
\text{MNDWI} = \frac{\rho_{\text{Green}} - \rho_{\text{SWIR}}}{\rho_{\text{Green}} + \rho_{\text{SWIR}}} \quad (2)
\]

For radar data, the lake water body will have specular reflection to micro waves, so that the emission spectra of the water bodies in radar images can be used to differentiate the water bodies from other features, and are represented by dark colors. The threshold values of backscattering coefficients are used to extract water bodies.

| Data Source | Method | Band Calculation | Rule |
|-------------|--------|------------------|------|
| Landsat-8   | MNDWI  | (B3-B6) / (B3+B6) | \(\text{MNDWI} > 0.5\) |
| GF-1        | NDWI   | (B2-B4) / (B2+B4) | 0 < NDWI < 5 |
| Sentinel-1  | Threshold Backscatter coefficient | -28 < \(\sigma\) < -20 |

The water bodies extracted by rules in Table 1 are shown in Figure 2.

![Figure 2. Water Body Extraction Result (borders of red are the boundaries of the lake)](image)

4. Result and Analysis

The lake area obtained by three methods are shown in Table 2. When calculating the area of extracted water areas, only the areas within the borders of yellow are calculated to extract the pixels. According to Table 2, the area of water bodies extracted by Landsat-8 images is the largest, reaching 137.74 km²; the area extracted by GF-1 images is the smallest of 118.83 km².

| Data Source | Landsat-8 | GF-1  | Sentinel-1 |
|-------------|-----------|-------|------------|
| Result      | 137.74    | 118.83| 135.21     |

Visual interpretation of the images are performed to analyze the accuracy of extraction results by the three types of data. Extraction results by using Landsat-8 images and GF-1 images show losses on the
northwestern corner, but the results on the southern areas are accurate. The Sentinel-1 images can accurately extract areas on the northwestern areas, but the northern farmlands are mistaken as water bodies. Meanwhile, the southeastern area of the lake are considered not as water bodies by these three images, so this area is no longer the lake area.

5. Conclusion
By using object-oriented method, this study uses Landsat-8, GF-1 and Sentinel-1 remote sensing data, computes the water body index and the backscattering coefficient and threshold of radar images, to extract water bodies in Po Lake area in Anhui Province. The advantages of this method include quick extraction, suitability for disaster monitoring and emergency response. It also has drawbacks such as low automation level and unsuitability for water body extraction in large areas. Subsequent research will focus on automatic water body extraction and water extraction methods that are suitable for large areas of water.

Acknowledgments
This work was jointly supported in part by the National Key R&D Program of China under Grant 2017YFB0503005, 2017YFC0405803 and 2017YFC1502704, in part by National Natural Science Foundation of China under Grant 41701431 and 51420105014, in part by the Civil Space Land Water Resource Satellite System Technology, and in part by the IWHR Research & Development Support Program under Grant JZ0145B032017 and JZ0145B032019.

References
[1] Wang S, Dou H. (1998) Annals of China Lakes. Science Press.
[2] Zhang Y. (2016) Research on the method of water body extraction based on remote sensing image-The case of Qinghai Lake. Northwest University.
[3] Zhao X, Su J. (2015) Dynamic monitoring of Dongting lake water based on remote sensing data. Heilongjiang Science and Technology of Water Conservancy. 43(08). 139-140.
[4] Chen Y, Niu Z, Hu S, Zhang H. (2016). Dynamic monitoring of Dongting Lake wetland using time-series MODIS imagery. Journal of Hydraulic Engineering. 47(09). 1093-1104.
[5] Li S. (2018) Spatial and temporal variation characteristics of the typical lake and lake group in Tibetan Plateau under climate change. China University of Geosciences for Master Degree.
[6] Li H, Mao D, Li X, Wang Z, Wang C. (2019) Monitoring 40-Year Lake Area Changes of the Qaidam Basin, Tibetan Plateau, Using Landsat Time Series. Remote Sensing. 11(3). 343.
[7] Wang J, Sheng Y, Tong T. (2014) Monitoring decadal lake dynamics across the Yangtze Basin downstream of Three Gorges Dam. Remote Sensing of Environment. 152. 251-269.
[8] Feng L, Hou X, Zheng Y. (2019) Monitoring and understanding the water transparency changes of fifty large lakes on the Yangtze Plain based on long-term MODIS observations. Remote Sensing of Environment. 221. 675-686.
[9] Yong W. (2016) The Research of Multi-scale Segmentation, Object-oriented Extraction of Target Information. Lanzhou Jiaotong University.
[10] Li Y, Ding J, Yan R. (2015) Extraction of small river information based on China-made GF-1 remote sense images. Resource Science. 37(02). 408-416.
[11] Zhao W, Yang X. (2018) Study on Water Bodies Extraction Method of Xianyang Lake Based on Object-Oriented. Anhui Agricultural Science Bulletin. 24(16). 146-149.
[12] Jiang D, Yuan J, Wu W, Gu X. (2019) Object-oriented Urban Water Body Extraction Based on Sentinel-2 Satellite Imagery. Geospatial Information. 17(05). 10-1344.
[13] McFEEETERS S. (1996) The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. International Journal of Remote Sensing. 17(7). 1425-1432.
[14] Xu H. (2006) Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. International Journal of Remote Sensing. 27(14). 3025-3033.