Article

Mapping Lake-water area at sub-pixel scale using Suomi NPP-VIIRS imagery

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Abstract: Capturing the variation of lake-water area using remotely sensed imagery is an essential topic in many related fields. There are a variety of remote sensing data that can serve this purpose. Generally speaking, higher spatial resolution data are able to derive better results. However, most high spatial resolution data are sometimes defective because of their low temporal resolution and limited scene coverage. Visible Infrared Imaging Radiometer Suite onboard Suomi National Polar-orbiting Partnership (Suomi NPP-VIIRS) provides a newly-available and appropriate manner for monitoring large lakes, thanks to its frequent revisit and wide breadth. But its spatial resolution is relatively low, from 375m to 750m. This study introduces a two-step method that integrates spectral unmixing and sub-pixel mapping to map lake-water area at sub-pixel scale from NPP-VIIRS imagery. Accuracy was assessed by employing corresponding Landsat images as the reference. Five plateau lakes in Yunnan province, China, were selected as the case study areas. Results suggest that the proposed method is able to derive finer resolution lake maps that show more details of the shoreline. Analysis also reveals that errors and uncertainties also exist in this method. Most of them come from the spectral unmixing procedure that retrieve water fraction from NPP-VIIRS data.

Keywords: linear spectral unmixing; sub-pixel mapping; Suomi NPP-VIIRS; plateau lakes; water fraction

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1. Introduction

Lakes play a significant role in maintaining regional water balance of ecosystems. Sometimes, lake-water area could change dramatically because of climate change, irregular precipitation, and various consumptions in arid and semi-arid regions[1,2]. Therefore, intensive monitoring is necessary to capture the variation of lake-water area for water resource balance analysis[3,4].

Remote sensing technique is an effective way of monitoring lake water area variation due to its wide coverage and repeated observations[5]. Various types of remotely sensed data have been used for this purpose, such as Landsat Thematic Mapper (TM)/Enhanced Thematic Mapper plus (ETM+)/Operational Land Imager (OLI)[6-8], Moderate Resolution Imaging Spectroradiometer (MODIS)[9-11], and also Visible Infrared Imaging Radiometer Suite onboard Suomi National Polar-orbiting Partnership (Suomi NPP-VIIRS)[12], which is a generation of moderate multispectral sensor. Suomi NPP-VIIRS provides a range of visible and infrared bands at a moderate resolution to observe the earth surface. It is considered as an upgrade and replacement of MODIS as a wide-swath and multispectral sensor[13]. Like MODIS, Suomi NPP-VIIRS has high temporal resolution, but its spatial resolution is 375m to 750m, which would hamper the correct mapping of lake water area.

This study aims to propose a two-part method, including spectral unmixing and sub-pixel mapping, in order to produce finer resolution lake maps from Suomi NPP-VIIRS data. The results were evaluated using water maps derived from the Landsat image that was acquired on the same day.

2. Materials and Methods

2.1. Study area and materials

Dianchi Pool, Fuxian Lake, Yangzong Sea, Xingyun Lake and Qilu Lake were selected as study areas. They are five of the largest plateau lakes in Yunnan Province, China, all located between 24.0°-25.1° N and 102.5° -103.1° E (Figure 1).

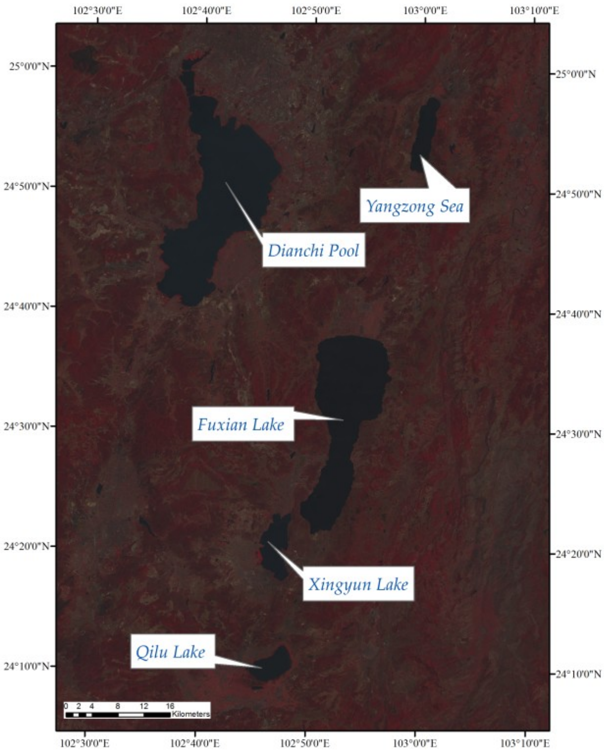

Figure 1. A map of study area showing the locations of the five plateau lakes

Two sets of image data, namely Suomi NPP-VIIRS and Landsat OLI, were used in this study. The selected materials were listed in Table 1. The time lag between the acquisition of NPP-VIIRS and Landsat is about 3 hours. Band 6 of Landsat OLI has a wavelength range from 1.56 to 1.66 μm, which is close to that of the NPP-VIIRS I3 band. Both images had been atmospherically corrected and co-registered with each other.

Table 1. Materials used in this study.

Image type	Image date	Acquisition time	Path/Row	Spatial resolution
NPP-VIIRS	02/02/2014	06:39:57	--	375m
Landsat OLI	02/02/2014	03:36:02	129/43	30m

2.2. Methods

The methodology of this study includes two parts, water fraction retrieval using pixel unmixing, and sub-pixel mapping based on water fraction. The water fraction retrieval part introduces a moving window based histogram method [12], which is based on the theory of Linear Spectral Mixture Model, to estimate water fraction of mixed pixels along the lake shorelines. Sub-pixel mapping procedure adopts a popular method called pixel swapping algorithm [14].

3. Results

The I3 band of Suomi NPP-VIIRS image acquired on 2/2/2014 (Figure 2(a)) was employed as the input of the water fraction retrieval method. A value of 0.007 was finally served as the threshold for the extraction of pure water pixels after careful visual inspection. A water fraction map (Figure 2(b)) at a spatial resolution of 375m was thus derived based on the aforementioned water fraction retrieval method. This fraction map was then used as the input of sub-pixel mapping algorithm with a scale factor of 25. a downscaled lake map with a spatial resolution of 15m was produced and presented in Figure 2(c). Reference lake map was derived from the 30m resolution Landsat OLI image of the same date and also resampled to 15m resolution (Figure 2(d)).

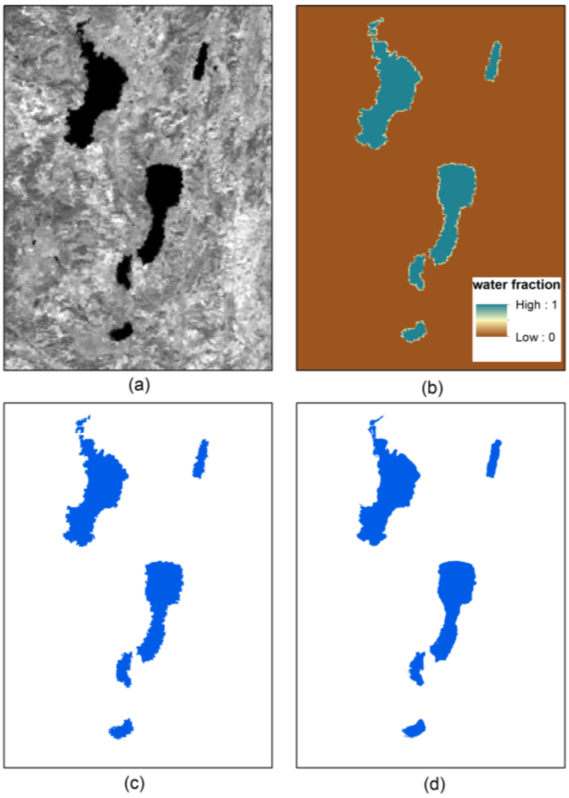

Figure 2. (a) Suomi NPP-VIIRS I3 band, (b) water fraction map from (a), (c) sub-pixel mapping result of (b), (d) referencing lake map from Landsat

It can be observed from Figure 2 that the general shapes of these five lakes have been generated appropriately through the downscaling method. Some subtle parts of the shorelines can even be restored. However, it has also to be noted that the downscaled lake shorelines are not as smooth as the actual shorelines portrayed by Landsat image. Some delicate areas, such as the inner lake on the north of Dianchi Pool and the wetland on the south of Qilu Lake, have not been mapped reasonably. The boundaries of these areas are obviously incorrect comparing with those observed from Landsat image.

The downscaled map and reference map were overlaid on a pixel-by-pixel basis to achieve a quantitative accuracy assessment. Percentage of errors, as well as overall accuracy and Kappa coefficient, were calculated based on the overlaying map. These indices were calculated for each lake individually and listed in Table 2.

It is obvious from Table 2 that the accuracy of downscaled map is not bad but also not ideal. Fuxian Lake has a relatively higher accuracy. Its overall accuracy is approximately 79.26%, with a commission error of 13.85% and omission error of 6.89%. It has a Kappa coefficient of 0.59, which, according to Landis and Koch [15], is a moderate agreement. The accuracy of the other lakes is a little bit worse, indicating that the method of downscaling NPP-VIIRS for lake-water mapping is applicable, but still needs to be improved. The commission errors are much higher that the omission errors, which implies that the water fraction has not been retrieved accurately. Water fraction coverage has been overestimated from the NPP-VIIRS image.

Table 2. Accuracy indices showing the evaluation result of mapping different lakes

Lake	Commission error (%)	Omission error (%)	Overall accuracy (%)	Kappa coefficient
Dianchi Pool	14.31	7.28	78.41	0.57
Yangzong Sea	15.30	7.58	77.12	0.54
Fuxian Lake	13.85	6.89	79.26	0.59
Xingyun Lake	16.81	6.38	76.81	0.54
Qilu Lake	21.56	2.12	76.32	0.54

4. Discussion and conclusion

Results of this study has revealed that through the two-step process, lake map could be downscaled from NPP-VIIRS image and achieve a moderate accuracy. This is a feasible and promising approach to improve the detection resolution of coarse-resolution sensors while keeps their high temporal resolution. However, it is also noticed that the accuracy of sub-pixel scale lake mapping is not high. It is noted that the co-registration between the NPP-VIIRS and referencing Landsat, as well as resampling process during the data preparation, would also affect the accuracy assessment result inevitably. However, the main reason for the low accuracy is that the pixel unmixing procedure overestimated the water fraction, which also affects the sub-pixel mapping result seriously. Further work of sub-pixel scale lake mapping should concentrate more on improving the unmixing procedure.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:
Suomi NPP-VIIRS: Visible Infrared Imaging Radiometer Suite onboard Suomi National Polar-orbiting Partnership
TM: Thematic Mapper
ETM+: Enhanced Thematic Mapper Plus
OLI: Operational Land Imager
MODIS: Moderate Resolution Imaging Spectroradiometer

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