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Multi-temporal Landsat ETM+ Image Fusion Based on ARW for Improved Water Extraction

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Abstract: Rapid and accurate extraction of water is important for investigation and macroscopic monitoring of water resources, wetland protection, coastal line change, and flood inundated area evaluation and flood disaster evaluation. In recent years, more and more researches focus on water extraction using images such as multi-spectral images and achieved good results. However, when using multi-spectral images, as they are affected by weather (such as heavy rain, snow, and clouds), the precipitation of wet and dry seasons, as well as the growing and withering of vegetation planting in water area, single multi-spectral image can hardly acquire water information as complete as possible even though high level image processing and interpretation technologies are available. Therefore, it is necessary to merge multi data sources with different features together to take use of their complementary information so as to improve water extraction results. A multi-temporal image fusion method based on accuracy-ratio weight is proposed. We analyze the water extraction result of Landsat ETM+ images collected in spring, summer, autumn, and winter respectively, and find out their advantageous and disadvantageous information for water extraction, based on which, a multi-temporal image fusion method is designed, which successfully solves the problem of extraction of plant growing water area and water filling and loss in wet and dry seasons. The proposed multi-temporal image fusion method is proved to have the highest water extraction accuracy in this study.

Keywords: *Water extraction, Multi-temporal, Image Fusion, Landsat ETM+, Accuracy Ratio Weight*

1. Introduction

Fast and accurate extraction of water body is very important for water resources investigation, management, and micro monitoring, wetland protection, lake/coastline change detection, flood prediction and evaluation. This task is difficult, time-consuming, and sometimes impossible for a huge region such as an entire country or continent, when using traditional ground survey techniques [1]. The introduction of remote sensing provides a new way to manage and utilize water resources. Using remote sensing data to extract water is a research hotspot. Currently, there are a lot of researches focusing on water extraction using remote sensing data [2]. Since the first launch of Landsat-1 in 1970s, a series of advanced satellites have been launched, providing multi spectral images(MSI) for a long time, and largely used in land use/land-cover [3] as well as water extraction researches[4][5][6][7][8]. Compared to traditional measuring techniques, remote sensing technology has advantages like convenience, safety, quickness, and cost-effectiveness. Besides, with satellite instruments it is also possible to observe a target repeatedly, in some cases every day or even several times per day. However, current researches on water extraction are mainly based on single-source images, which can hardly reflect the integrity and the present situation of water area. For water, the size of water area is affected by the following factors:

(1) Human factors, including man-made destruction of water (such as filling lakes).
(2) Natural factors, including water change caused by geologic hazard and climatic variation, as well as the amount of precipitation in wet and dry seasons.

When using MSIs to extract water, except for natural disaster and human destruction, the integrity and accuracy of water extracted is also affected by the following factors:
(1) Bad weather (such as heavy rain and snow) and clouds. The ground objects covered by snow and clouds can be hardly identified. Rain, especially heavy rain can also affect the identification of ground objects.
(2) The growth and withering of vegetation planting (such as lotus planting). In the growing season of vegetation, water area is invisible in optical images, while during the withering days of vegetation, water is visible.

Due to the above factors, water area is not changeless, but is dynamic. That's to say, water area changes dynamically with time. The single sensing element could only provide partial and inaccurate information [9]. When extracting water, the above factors should be taken into account. Single image, as it records water status at a moment, and can't reflect the overall perspective of water, even though the extraction method is perfect, it cannot solve the incompleteness problem of water extraction caused by the above factors. Image fusion, as a new technology, can combine the remarkable information from single image to acquire more complete information related to the recognized targets, and improve the accuracy, certainty and rapidness of target recognition [10].

The introduction of Satellite remote sensing system provides repeat coverage of the majority regions of the Earth. It is very valuable to analyze time series images. Time series analysis is successfully applied in wetland deneation. Lunetta and Balogh uses two Landsat 5 scenes, one with leaves coverage, the other without leaves, to map wetland successfully, and the accuracy is up to 88%. The image with leaves is to draw land cover, while the image without leaves is to identify watery soil [11]. Time series Landsat data are also used to analyze texture. Arai extracted texture from Landsat TM and MSS multi-temporal data [12], evaluated the possibility of classifying Landsat images using textures extracted from images collected in different time periods, and proved that multi-temporal data are useful for his analysis. Munez-Villiers and Lopez-Blanco successfully used Landsat and ETM+ data spanning 13 years to acquire land cover types after forest has being changed into grassland and agricultural district [13]. Some projects put emphasis on analyzing how long a period is needed to maximize land cover and vegetation classification. Price, etc. used 3 Landsat 5 images from different time periods to determine the optimal number of spectral bands of one image and the combined images to classify the grassland types for a grassland ecosystem [14]. Their study verified images captured in different time are very valuable, and found that two or three MSIs together are enough to accurately classify plant community. Similar researches used 4-date TM images of an agricultural district in Argentina to determine the ideal number of images and the acquisition time interval between images [15]. The result showed that only two-date images can successfully classify land cover types, and if the acquisition time interval is appropriate, more useful information can be obtained. In Wang's research, he used a series of images captured in 9 months, and found that 4 to 5 images are necessary for successful classification. More images are unnecessary, but fewer images are insufficient [16].

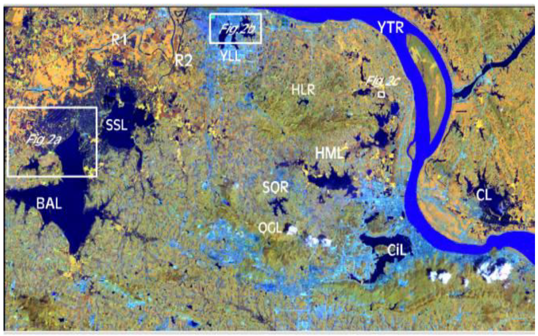
Obviously, multi-temporal images provide a kind of valuable dimension for classification. For water, the morphology of water area is a random process of time. Therefore, time series data are especially important for extracting water with seasonal variation. This paper aims at merging multi-temporal Landsat ETM+ images to extract water to explore the value of fusion of multi-temporal images in water extraction. We extract water from images collected from spring, summer, autumn, and winter in a subtropical area at the same place and make accuracy evaluation. Based on the accuracy evaluation, we propose a multi-temporal image fusion method based on accuracy ration weight (ARW). By ARW, we merge images from spring, summer, autumn, and winter, and extract water from the fused image and carry out accuracy evaluation.

2. Study Area and Data

2.1. Study Area

The study area is located in Southeast of Hubei Province with a total size of 157,380 hectares. The study site is characterized by such classes as built-up area, suburban area, farmland area, mountain area, and water area. Hubei has a sub-tropical humid monsoon climate, with high annual rainfall up to 1600 mm/year and two distinct seasons, namely, a wet season from March to September, and a dry season from October to February of next year. Figure 1(b) shows Landsat ETM+ image dated on 19 August 2008 of the test site. The study area has rich water resources, including several lakes, reservoirs, part of Yangtze River, and some small water bodies like rivers and ponds (Figure 1(b)). Around some lakes, especially the northeastern area to Baoan Lake, there is a large area of ponds for fish farming. In part of Baoan Lake and Huama Lake, there is a large area of lotus planting.

(a) Location map of our study area in Hubei Province, China



(b) Landsat ETM+ image (band453) of the study area

Figure 1: *The study area*

Note: BAL-Baoan Lake QGL-Qinggang Lake CL-Chao Lake HML-Huama Lake HLR-Huanglong Reservoir SQR-Shiqiao Reservoir YTR-Yangtze River R1-small River 1 R2-small River 2.

2.2. Data

In the present study, 4 dates Landsat ETM+ images (Path 122, Row 39) have been used, as shown in table

1. The Landsat ETM+ image consists of eight spectral bands, with a spatial resolution of 30 meters for bands 1 to 5 and band 7. The resolution of band 6H/6L (thermal infrared) is 60 meters or 30 meters. The resolution of band 8 (panchromatic) is 15 meters. The approximate scene size is 170 km north-south by 183 km east-west (106 mi by 114 mi).

In this study, band 1-5 and 7 are used. The thermal band (band 6) was not utilized due to its coarser spatial resolution (approximately 60 meters) and little spectral signature difference between different surface features.

Table 1 : *Landsat ETM+ data specifications (Path/Row: 122/39)*

Date(time period)	Landsat sensor	Cloud cover (%)	Wet/Dry season
20080515(Spring: Mar.-May)	ETM+(SLC-off)	9.63	wet
20080819(Summer : Jun.-Aug.)	ETM+(SLC-off)	5.35	wet
20091025(Autumn : Sep.-Nov.)	ETM+(SLC-off)	0.01	dry
20080209(Winter: Dec.-Feb.)	ETM+(SLC-off)	0.17	dry

4. 2.3. The properties of MSIs in water extraction

MSIs are widely used in water extraction applications [17][18][19]. It has the following advantages in water extraction.

①As the spectral feature of water in MSI is unique, to set an appropriate threshold for some distinct band can successfully extract water.

(a) Yangtze River in TM432

(b) Yangtze River in TM453

Figure 2: *The composition color of Yangtze River in different band combinations*

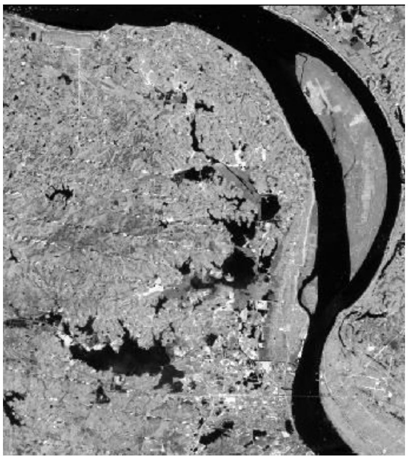
②Except for single band, band combinations can also be used to successfully extract water. Compared to single band grey image, multi band combination shows more color information, which provides higher differentiation degree for water identification. Figure 2 (a), (b) shows ETM+ 432 bands combination and 453 bands combination of part of Yangtze River, which has great differentiation degree.

Researchers have proposed a lot of water extraction methods, including single band threshold, multi-band enhance threshold method, and classification method [20][21] [22][23][24], all of them have good results in water extraction. However, limited to the imaging mechanism of MSIs, and due to human and natural factors, there are the following problems during water extraction.

①Affected by weather, MSIs often have clouds. Clouds and cloud shadows possibly cover true water body, and cloud shadows tend to be regarded as water body. The existence of clouds and cloud shadows interfere the identification of water. The ground objects covered by snow and clouds can be hardly identified. Rain, especially heavy rain can also affect the identification of ground objects.

②Affected by the amount of precipitation in wet and dry seasons, in wet seasons, there is more water, while in dry seasons, there is less water. Even some rivers or branches dry up. Figure 3 (a) and (b) show the water area of part of Yangtze River in wet season and dry season respectively. Water in (a) is plump, while in (b), is slimmer.

③Affected by the growth and withering of vegetation planting (such as lotus planting), in the growing season of vegetation, water area is invisible in optical images, while during the withering days of vegetation, water is visible. Figure 4 (a) and (b) shows Baoan Lake in lotus growing season (August) and withering season (February) respectively. The area marked by a red circle is the lotus planting area. We can see that there is no water observed in the lotus planting area in the August image, while in the February image, we can observe water clearly because lotus is withering.



(a) Yangtze River in wet season (summer image)

(b) *Yangtze River in dry season (winter image)*

Figure 3: *Yangtze River in wet and dry season*

(a) Baoan lake in summer (lotus growing)

(b) Baoan lake in winter (lotus withering)

Figure 4: *Baoan Lake in lotus growing and withering season*

3. Methodology

Figure 5 shows the whole processing framework.

3.1. Preprocessing of Landsat ETM+ data

All the Landsat ETM+ data were acquired from http://datamirror.csdb.cn/ with stripes. For each band, the strip was successfully removed by multi-image adaptive local regression method (RGF) provided on http://datamirror.csdb.cn/. As can be seen form table 1, most of the images are covered by clouds which will greatly affect water extraction result. To improve classification accuracy, clouds and cloud shadows should be removed beforehand. In this paper, clouds and cloud shadows were successfully removed using the method proposed by Xiao [25].

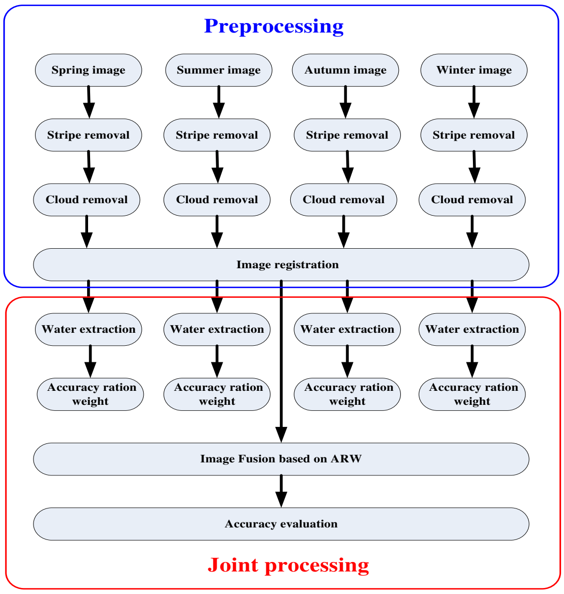


Figure 5: *Data processing flow of water extraction*

4. Water extraction from four-season images

As single Landsat ETM+ image can hardly reflect the real condition of water area, it is necessary to analyze images captured in different times. To evaluate the influence of plant growing as well as the precipitation of wet and dry seasons on water extraction accuracy, we select four images from four seasons, as shown in table 1. The classification of seasons is based on the weather bureau in China. In this paper, all images adopt the same extraction method based on the threshold of the first component of PCA transformation of these images. The threshold is taken much bigger to avoid the confusion with other ground objects. As a result, some small water bodies like small ponds are ignored.

4.1 Spring water extraction

Spring includes March, April and May. It's a rainy season and a wet season in Hubei. Here, we take the image (20080515) captured on May 15 2008 as a sample. In May, lotus is growing, but not reaches its flourishing period, thus, some water area in the lotus area can be observed, and some cannot be observed on the image, see the marked area in Baoan Lake in figure 6. Water in Yangtze River basin is plump, so do some small branches and rivers, which can be observed clearly. The water extraction result is given in figure 7. (represented by red color).

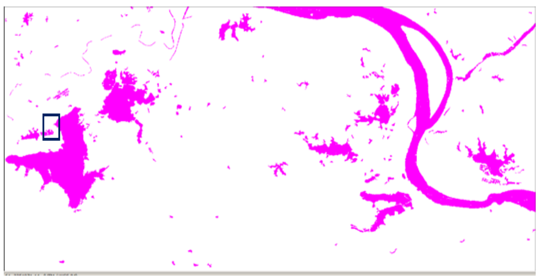


Figure 6: *Water extraction result of spring image*

4.2 Summer water extraction

Summer includes June, July and August. It's also a rainy season and a wet season in Hubei. Here, we take the image (20080819) captured on August 19 2008 as a sample. In summer, lotus reaches its flourishing period. Lotus leaves cover their underlying water tightly, and water in lotus area cannot be observed at all on the image. See the marked square area in Baoan Lake in figure 7. As summer is still a wet season, water in Yangtze River basin is still plump, and so do some small branches and rivers, which can be observed clearly. The water extraction result is given in figure 8. (represented by yellow color).

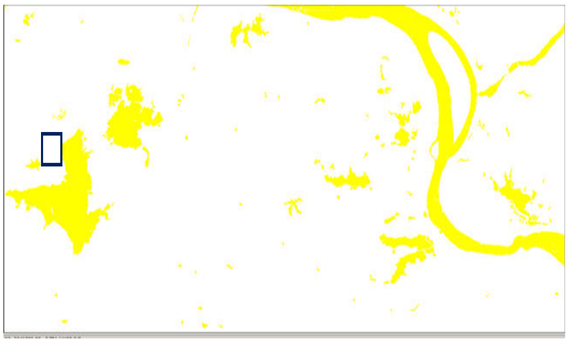


Figure 7: *Water extraction result of summer image*

4.3 Autumn water extraction

Autumn includes September, October and November. It's a dry season in Hubei. Here, we take the image (20091025) captured on October 25 2009 as a sample. In autumn, lotus is withering. However, as the image is captured in October, Lotus leaves don't die away completely; their underlying water is still covered. Water body in lotus area cannot be observed on the image either. As autumn is a dry season, water in Yangtze River basin is not intact. It shrinks and some part doesn't have water. See the marked square area in figure 8. Branches and small revers can be faintly observed. The water extraction result is given in figure 9 (represented by dark blue color).

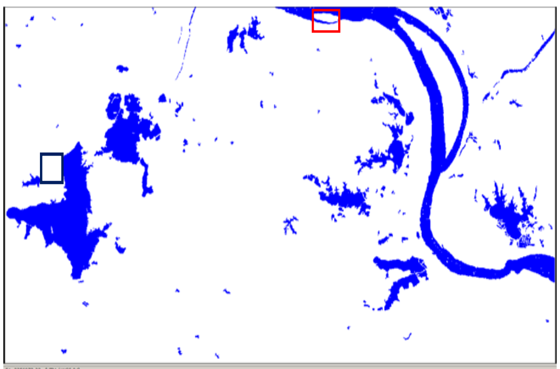


Figure 8: *Water extraction result of autumn image*

4.4 Winter water extraction

Winter includes December, January and February. It's also a dry season in Hubei. Here, we take the image (20080209) captured on February 9 2008 as a sample. In winter, lotus dies away completely. Their underlying water appears. Thus, Baoan Lake and Huama Lake are intact. As winter is a dry season, water in Yangtze River basin is not intact. It shrinks and some part doesn't have water. See the marked square area in figure 9. Branches and small revers can be faintly observed. The water extraction result is given in figure 10.(represented by light blue color).

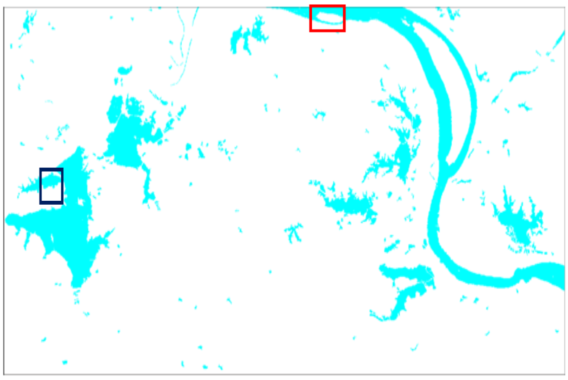


Figure 9: *Water extraction result of winter image*

4.5 Analysis of water extraction results of four seasons

Combine water extracted from four seasons, we can obtain a combination image shown as figure 10. The black area represents the common part of water extracted. For lakes, water area extracted from autumn and winter image is intact. The main reasons are: water area in lake is affected by lotus' growing status. As in autumn and winter, lotus is withering, water becomes visible. Besides, most lakes store water in dry seasons. For Yangtze River, the status is just the other way. Water extracted from spring and summer is intact, and branches are clearly visible as spring and summer are wet seasons in Hubei. A lot of rainfall makes Yangtze River full of water, so do small rivers.

Table 2 gives the extracted water area of four seasons and the total extracted water area. The extracted water area reflects the ability of water extraction of each image. From table 2, we can see that spring image obtains the best water extraction result, then followed by winter, autumn and summer. The area of water extracted is affected by two main factors, that's, vegetation growing in water and the amount of precipitation. Spring is full of rainfall. Besides, in May, lotus is growing, but not completely covers water, which can be observed from the image of May. In autumn and winter, lotus is withering, and lakes store water. Some part of Yangtze River is cutoff. The fact that water extracted from autumn and winter images is bigger than water extracted from summer image shows that lakes take up the leading role in water extraction result. Table 3 gives the water extraction accuracy of four seasons respectively, which is in accordance with table 2.

Figure 10: *Combination of water extraction results of four seasons (Combination1)*

Table 2: *Water extraction area of four seasons*

Season	Color	Water extracted Area(ha)	Percentage of total area (%)
Spring(20080515)	red	17,109.27	10.87
Summer(20080819)	yellow	15710.76	9.98
Autumn(20091025)	dark blue	16389.45	10.41
Winter(20080209)	grey blue	17037.27	10.83
Combination1		19909.8	12.65
Total area		157,380.57	

Table 3: *Water extraction accuracy of four seasons*

Season	Water	Non water	Accuracy (%)
Spring(20080515)	458	42	91.6
Summer(20080819)	424	76	84.8
Autumn(20091025)	437	63	87.4
Winter(20080209)	454	46	90.8
Combination1	473	27	94.6

5. Water extraction of ARW-based multi-temporal image fusion

Based on the above analysis, we known the single image from one season can hardly reflect the entire water status. Therefore, it is necessary to combine images from four seasons together to improve water extraction accuracy. As all of these images are optical images, the imaging principle is just the same, and the spectral signature is also similar. Here, we use a weighted average method. By analyzing the extraction result of each image and their water extraction accuracy, the weight of each image is set. The computation equation of weight is given by equation (1), and the fusion rule is based on equation (2). $image_{seasoni}$ represents the accuracy of one season. The higher the accuracy, the higher is the weight. The final multi-temporal fused image is shown as figure 11, and the extraction result is shown as figure 12.

$$w_i = \frac{image_{seasoni}}{image_{spr} + image_{sum} + image_{aut} + image_{win}} \quad (1)$$

$$F(m,n) = w_{spr} * image_{spr} + w_{sum} * image_{sum} + w_{aut} * image_{aut} + w_{win} * iamge_{win} \quad (2)$$

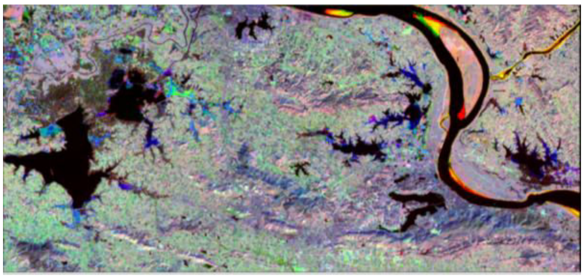


Figure 11: *ARW-based Multi-temporal image fusion*

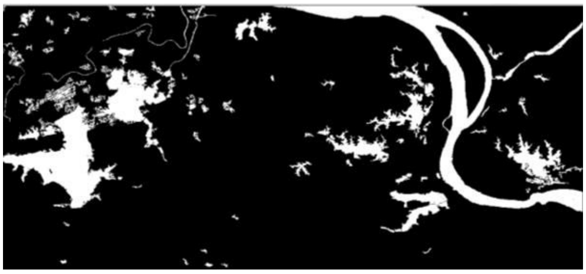


Figure 12: *Water extraction result of ARW-based Multi-temporal image fusion*

6. Results

From figure 12, we can see that the water extracted from the fused image is intact, the lotus area is extracted, small rivers are clearly visible, the North part of Baoan Lake is also extracted, the cutoff area of Yangtze River in dry season is also extracted, and mountain shadow is clearly distinguished from other objects. Table 4 gives the water extraction accuracy and extraction area of the ARW-based fusion image. The overall water extraction accuracy is much higher than a single season image. As the fused image combines images from four seasons, it has higher water extraction accuracy.

Table 4: *Water extraction area and accuracy of ARW-based Multi-temporal fusion image*

	Pixels extracted	Area extracted	Percentage of total area (%)
ARW_image	231848	17,109.27	13.26
	Water	Non water	Accuracy (%)
ARW_image	491	9	98.2

7. Conclusions

A multi-temporal image fusion method based on accuracy-ratio weight is proposed. We analyze the result of water extraction of Landsat ETM+ images collected in spring, summer, autumn, and winter respectively, and find out their advantageous and disadvantageous information in water extraction, based on which, a multi-temporal image fusion method based on ARW is designed, which can better highlight the role of images with more accurate and complete water information and successfully solves the difficulty of extraction of plant growing water area and water filling and loss in wet and dry seasons. The proposed ARW-based multi-temporal image fusion method is proved to have the highest water extraction accuracy in this study, much higher than the accuracy of single image. Based on this study, we will continue with a water change detection study in our future research, and explore possible factors that possibly cause water changes.

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