Summary of water body extraction methods based on ZY-3 satellite

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Abstract. Extracting from remote sensing images is one of the main means of water information extraction. Affected by spectral characteristics, many methods can be not applied to the satellite image of ZY-3. To solve this problem, we summarize the extraction methods for ZY-3 and analyze the extraction results of existing methods. According to the characteristics of extraction results, the method of W1& single band threshold and the method of texture filtering based on probability statistics are explored. In addition, the advantages and disadvantages of all methods are compared, which provides some reference for the research of water extraction from images. The obtained conclusions are as follows. 1) NIR has higher water sensitivity, consequently when the surface reflectance in the study area is less similar to water, using single band threshold method or multi band operation can obtain the ideal effect. 2) Compared with the water index and HIS optimal index method, object extraction method based on rules, which takes into account not only the spectral information of the water, but also space and texture feature constraints, can obtain better extraction effect, yet the image segmentation process is time consuming and the definition of the rules requires a certain knowledge. 3) The combination of the spectral relationship and water index can eliminate the interference of the shadow to a certain extent. When there is less small water or small water is not considered in further study, texture filtering based on probability statistics can effectively reduce the noises in result and avoid mixing shadows or paddy field with water in a certain extent.

1. Introduction

Water is an essential part of the earth ecosystem and lays the foundation for biological survival [1]. Along with monitoring and protection of water resources is the core of the related issues. With the development of remote sensing technology, the use of remote sensing images to obtain the change of surface water area becomes one of the main technologies of water resources monitoring [2]. The main part of surveying water by images is water extraction, and there are four main methods for water body extraction which include spectrum relationship, water index, image classification and decision tree [3][4][5][6]. The most widely used methods of spectrum relationship is single band threshold, which extract water by choosing a certain threshold through the mechanism that water strongly absorb visible light while dry soil and vegetation strongly reflect in the near infrared band [7]. Lu H has extracted water by using the near infrared band of ETM+ and ASTER, and does a comparative analysis between different sensors [8]. Apart from this, the difference method and ratio method also have more applications in water extraction. Zhou C H has proposed using band 2 plus band 3 more than near
band 4 plus band 5 in Landsat TM images and tested this method [9]. Zhong C Q et al has extracted wetland water using the ratio of band 2 plus band 3 to band 4 plus band 5 in Landsat TM images [10]. Xiao Y F, based on Landsat TM image, has tested the ratio of band1 minus band 7 to band1 plus band7 experiments and achieved a good effect [11]. On 1996, based on spectrum, Mcfeeters proposed a normalized difference water index (NDWI), the index can extract water in image better and was highly applied since then [12]. NDWI sometimes can not get ideal effect although it is widely used in engineering and study. According NDWI, Xu H Q put forward a modified normalized different water index (MNDWI) which replaced near infrared band and green band in formula of NDWI with green band and mid infrared band [13]. The index was tested with different types of water in images, and obtained better results than NDWI, especially the extraction of water within a town. It is also found that MNDWI can be revealing the micro feature, such as distribution of suspended sediment and change of water quality. In addition, shadow and water can be easily distinguished by MNDWI. Yashon O. Ouma put forward a kind of water index based on tasseled cap and NDWI, which can distinguish the shoreline [14]; Yan P et al proposed EWI to distinguish the semi dry river and background noise [15]. To extract water through image classification is mainly in two ways, one is ordinary supervised classification, the other is the object oriented feature extraction. Result of the former depends on applicability of training sample and accuracy of classification algorithm, and the effect of water extraction is not ideal. The latter segment the image before classification, consequently, shape, texture, length and other information except the spectral characteristics can be taken into account. Some scholars use this method to extract water and obtain good results [16]. The decision tree is widely used because of taking into consideration different spectral feature, texture feature. Deng J S et al analyzes the relationship between the spectral characteristics and wave band feature in SPOT-5 image and contrasts the brightness difference between water body and other objects, based on the characteristics, a decision tree is built to extract water [17]. Decision tree is also built to extract water from ETM+ image based on EWI and tasseled cap transformation [18].

As far as the research situation is concerned, at present, the extraction of water bodies is mainly carried out based on Landsat, SPOT and other medium and high resolution satellite multispectral images. In recent years, the satellites launched in China, such as ZY-1, ZY-3 and GF-1, have high spatial resolution and short access cycle. They have great application and research prospects. Although some scholars have explored the water extraction method in the satellite image acquisition [19][7], the cases of utilization and image extraction method of water is rare in ZY-3. In addition, affected by the type of sensors, weather conditions, special terrain factors and so on, the same way can not deal all cases effectively. For this reason, to obtain good results in water extraction, the extraction process must consider the features of regional objects are extracted, spectral characteristics of ZY-3 and remote sensing mechanism of water body extraction etc. According to calculation demand of environmental load deformation of rivers and lakes water, we do a research of extracting water in ZY-3 images. We extract water in image using a variety of methods and analyze the extraction effect of common methods, on account of this, two kinds of water extraction methods are put forward tentatively. We comparative advantages and disadvantages of all methods finally, which aims at providing reference for water extraction in ZY-3.

2. Data and research area
ZY-3 satellite is a high-resolution stereoscopic map satellite in China. Its data are mainly used for topographic mapping, elevation modeling and resource survey, etc [20]. The panchromatic band of 2.1m, before and after the resolution of 3.5m, multi spectral space resolution of 5.8m, including 4 bands, respectively blue band (B1), whose wavelength range is 0.45-0.52 μm, green band (B2), whose wavelength range is 0.52-0.59 μm, red band (B3), whose wavelength range is 0.63-0.69 μm, near infrared band (B4) whose wavelength range is 0.77-0.89. It can be seen that the multispectral bands have no mid infrared and short wave near infrared bands, which makes the method of image water extraction more limited.
In this paper, the imaging time of ZY-3 is December 16, 2014. The study area including Long lake, Partial region of Jingjiang river, spatial range is 30°05'58.66"-30°34'23.48"N, 111°52'14.53-112°30'2.83"E, a total of 10108×8934 pixels, covering an area of about 3037.8559km². The images were subjected to ortho correction, geometric correction, radiometric calibration, and Flash atmospheric correction to facilitate the extraction of water bodies. It's shown in Figure 1 that true color images after series correction.

![Figure 1. True color images of ZY-3.](image_url)

Jingjiang area is low-lying, with plenty of water. A lot of sediment is brought by Yangtze River, which provides an important guarantee for regional agricultural development in this area. Long lake, the third largest lake in Hubei province, provides a guarantee for the flood discharge, irrigation and water supply of the surrounding counties. The ecological environment in the basin is good and pleasant. The types of ground objects in whole area are complicated, which lead to the confusion between paddy fields and water bodies, shadow of urban tall buildings and water bodies, beaches in the rivers and water bodies are easy to occur while water bodies are extracted.

3. Data and research area

The spectral characteristic of water is an important theoretical basis for water extraction [9][21][22]. In the visible range, the reflectivity of water body (generally 4%-5%) is lower than other objects, and decreases gradually with the increase of wavelength [7][23]. The reflectivity is highest in the blue and green band, extremely low in the near-infrared band, yet the visible light is almost completely absorbed. Based on this, water bodies can be distinguished from other objects on the image. Using region of interest selects a certain amount of pixels of the study area to count mean reflectance of water, shadow, building, roads and paddy field (Figure 2). We can see that the reflectivity of buildings and roads are overall high, and the reflectivity of water is close to shadow, only a little difference in the near infrared band. In addition, reflectivity of water and paddy field in the near infrared band is similar. Therefore, near infrared band is the key to extract water in image of ZY-3.
3.1. Common methods and results analysis

3.1.1. Method overview. The method of spectral relation extract water by band operation which need to determine the spectral relation of objects by analyzing the gray scale curves of water bodies and other objects at different wavelengths. Although the relationship between spectrum method is widely used, and the extraction process is relatively simple, many extraction ways of water (such as green band plus red band greater than near infrared plus shortwave near infrared band, near infrared plus shortwave near infrared divided by near infrared minus shortwave near infrared) can not be applied because the prior relations are based on TM or ETM+ and there is no shortwave infrared band in multi spectral band of ZY-3. Therefore, the experiment was conducted in two ways: (1) near infrared > threshold; (2) near infrared / red > threshold.

Water index is an effective and simple way to extract water. When water is extracted with common accuracy or in some area with distinct spectral features, using traditional water index (NDVI, NDWI, MNDWI etc.) can get a good effect. Based on the purpose of different research and application, many scholars have created the extraction index, table 1 lists some of the water extraction indexes that have appeared.

Table 1. Water indexes.

| Index | Calculation method | Reference | Adopted or not |
|-------|--------------------|-----------|----------------|
| NDVI  | (NIR-R)/(NIR+R)    | [6]       | yes            |
| NDWI  | (NIR-G)/(NIR+G)    | [12]      | yes            |
| MNDWI | (G-MIR)/(G+MIR)   | [13]      | no             |
| EWI   | (G-NIR-MIR)/(G+NIR+MIR) | [15] | no             |
| NDMI  | (NIR-MIR)/(NIR+MIR) | [24]      | no             |
| AWEI  | 4*(G-R)-(0.25*NIR+0.75*SWIR) | [25] | no             |
| WRI   | (G+R)/(NIR+MIR)   |  | no             |
| WI    | (B+NIR)/(G+R)     | [26]      | yes            |

Notes: G represents green band; R represents red band; NIR represents near infrared band; MIR represents middle infrared band; SWIR represents short wave near infrared band.

Although the image classification method is complicated, and the precision of classification is sometimes unsatisfactory, it is an effective extraction means in a variety of factors, new elements extraction and extraction in image with less spectral bands. With advancing of the classification method, some new classification methods, such as object oriented classification, which can not only set the spectral information of nearby pixels, but also take the texture and spatial information into account, can achieve better results than the traditional method in feature extraction. In this paper, the
traditional classification method and object-oriented classification method are used to extract water from ZY-3.

The decision tree extracts water bodies through the organic combination of spectral characteristics. Research for the extraction of ZY-3 is less, only Zhao F et al combined optimal index method and spectral relationship of green band and near infrared to extract water, which could be approximated as a decision tree. In this paper, the method is used to extract large area of water, in order to compare the effect of other methods.

3.1.2. Results and analysis. We perform band operations on the corrected image. After continuous testing, the near infrared band is less than 0.5 can obtain good effect of water extraction (Figure 3a). In the ratio of operation, the ratio of near infrared to green band greater than 0.6 can obtain better extraction effect (Figure 3b). It can be seen that, in the extraction of single band threshold, a large area of water were extracted, however small water in the lower right corner of figure 3a has not been completely extracted and shadow of the city building (amplified in small picture) is mixed in results. In the ratio of operation, there is the some shadow is mistakenly extracted. The small water in lower right corner of the image is extracted, but there is surplus extraction in the results. In addition, paddy fields (near the Long Lake) were mistakenly extracted in two ways.

![Figure 3](image_url)

**Figure 3.** Extraction results of spectral relationship (a: NIR> threshold b: NIR/red>threshold).

We use water indexes include NDVI, NDWI and WI to extract water further. Ultimately, the result is get and shown in figure 4. It can be seen that there are a large number of false extraction in the lower right corner of figure 4a, which could be attributed to a close reflectance and reflectance change trend with bare land, paddy field and water in the operation of two bands among water extraction by NDVI. With the same reason, there also is a large amount of error in the lower right corner of figure 4b. Additionally, we can see from small picture in figure 4b the results extracted by NDWI not cover all water bodies in Long lake. Extraction water by WI avoids a large area of paddy field in the lower right corner of the image and the shadow of the city buildings mixing with water bodies in results, moreover, the small water in lower right corner of image is extracted more accurately. Nevertheless, the same with NDVI, there is phenomenon of insufficient extraction as shown in the figure 4b and 4c.
Figure 4. Extraction results of water index (a: NDVI b: NDWI c: WI).

The way of parallelepiped and maximum likelihood ratio in commonly used supervised classification methods are applied to extract water in this paper. It is shown in figure 5a and 5b that results show a large area of confusion, and the classification results are not satisfactory, which is due to using only water as samples and a high dispersion of small water is in the study area. Based on this, two object-oriented classification methods are studied in this paper, one is object-oriented based on samples, namely segmentation extraction using a certain water sample (extraction results as shown in figure 5c), the other is object oriented based on rules, which take the texture and spatial feature into account among segmentation.

In the experiment, edge algorithm is adopted in two object oriented segmentation, and the segmentation threshold is 45. Full Lambda-Schedule is adopted in aggregation, and the merging threshold is 90. Samples based object-oriented is similar to traditional image classification after segmentation, therefore unnecessary detail not be given here. We use two rule based object-oriented methods for water extraction. ① Rule NO.1 (weight is 0.6): the NDWI value defined; Rule NO.2 (weight is 0.4): extension (length width ratio of plaque segmentation) is greater than 1, an area of more than 50m², the length is more than 500m (extraction results as shown in figure 5d). ② Rule NO.1 (weight is 0.6): near infrared reflectance defined; Rule NO.2 (weight is 0.4): extension (length width ratio of plaque segmentation) is greater than 2, an area of more than 200 m², the length is more than 2000m (extraction results as shown in figure 5e).

We can see that the effect of three kinds of object-oriented methods overall is better than the common classification. There is plenty of extra extraction in samples based object-oriented result, especially in the area of paddy field and shadow. In addition to the marked places failed to extract, the water was basically completely extracted in object oriented extraction method based on NDWI as the main index. The biggest problem is that the large paddy fields near Long lake are not separated. The problem of paddy field error extraction has been improved, and the overall extraction effect is better in object oriented extraction method based on NDWI as the main index.

HIS optimal index is the only decision tree extraction method used in the experiment. According to research results of Zhao F, three steps are taken to extract water bodies. Firstly, select the 1, 3, and 4 bands to do HIS conversion. Secondly, the mean and standard deviations of the components after the HIS transformation are calculated. Finally, through the experiment, the threshold range of each component is determined, and then water bodies are extracted. The result is shown in figure 5f. It can be found that the method can extract large area of water body, and the whole noise is reduced obviously. However, the problem of shading and paddy field mixing still exists.
Figure 5. Extraction results of image classification and decision tree (a: supervised classification (maximum likelihood) b: supervised classification (parallelepipeded) c: sample based object oriented d: rules based object oriented (NDWI) e: rules based object oriented (NIR) f: HIS optimal index)

3.2. New ideas for water bodies extraction

According to the characteristics of extraction results by WI and reflectance of NIR, we found, through continuous experiments, that when WI is less than a certain threshold (the threshold in the study area is 1), water can be extracted effectively with intersection operation between result of single band threshold extraction and WI extraction results. As can be seen from figure 6, where the mark has basically eliminated the interference of urban building shadow, the water body is extracted as a whole, and the extraction effect is close to the rules based object-oriented extraction.

Figure 6. Extraction result of WI&NIR

It can be found that it is difficult to avoid a large area of paddy field near the long lake be mistakenly extract with the methods spectral relation, water index, classification extraction, and mutual extraction between WI and single band threshold. Analysis among image, the texture feature is ignored in the extraction process, which reflects the image tone as the level of function change in space. When the ground reflectance is close, different objects could be distinguished effectively
considering the texture feature. Therefore, based on probabilistic statistical method, the image texture filter is used to extract the water body.

Filter can improve the quality of image process results, consequently, it has attracted widespread attention. Median filter can remove salt and pepper noise easily, but it is easy to lose details of the image, so many scholars have improved the filtering [28]. Filtering based on probability and statistics can take into account the local information of the image, and can maintain the image details to the greatest extent [29][29]. Therefore, many scholars have carried out related research. Through the above experiments, we can find NIR is the most sensitive to the water body in the ZY-3, in addition, the green band has some influence on it while other bands have less influence.

Therefore, the near infrared and green bands are processed by texture filtering to extract water bodies. As shown in Figure 7a that the result is still not avoid interference from paddy field and shadow, but a large area of water were extracted. After that, the NIR is processed only by statistical filtering, and the extraction effect avoids the paddy field and the shadow disturbance when the filter value is less than 10 (DN value) in the study area. Because the texture information of the extraction result is more prominent, the bridge and ship on the river and lake will become a new noise in the extraction result. In order to avoid these noises, the results of the extraction will be opened and closed many times. The final result is shown in figure 7b.

It can be seen that a large area of water is been identified and extracted, nevertheless, some smaller linear water bodies are sacrificed during the extraction process because of the influence of edge texture.

**Figure 7.** Extraction results based on probabilistic texture filtering (a: NIR, green b: NIR)

### 3.3. Comparison of water extraction methods

As shown in figure 8, in order to compare the area of extracted water bodies, the water in image is extracted with visual interpretation method in the study area. In addition, we extract 27 samples, 11 of them in Jingjiang, 7 of them in long lake and others are small water. Using the verification samples, the accuracy and Kappa coefficients of different extraction methods are obtained with confusion matrix method, as shown in table 2. It can be seen that the WI& single band threshold and the probability based statistical filtering method have higher extraction accuracy overall, and the extraction accuracy of the rule based object-oriented method is closer to the HIS optimal index method. Using the above results to make a comprehensive comparison, we can see that extracted area of the extraction of object oriented based on rules is close to the visual interpretation, while the minimum area is extracted with the method of probabilistic texture filtering, nevertheless, affected by the error of the extracted, area can only be used as a reference.

**Table 2.** Precision contrast for different water extraction methods.

| Extraction method | Spectral relation | Water index | Supervised classification |
|-------------------|-------------------|-------------|---------------------------|
|                   | Single band threshold | Ratio | NDVI | NDWI | WI | Maximum likelihood ratio | Parallelepiped |


| Extraction method | Area (km²) | Advantage                      | Disadvantage                                      | Scope of application                  |
|------------------|------------|--------------------------------|---------------------------------------------------|---------------------------------------|
| Visual interpretation | 232.89     | High accuracy                  | It is time-consuming and consuming, and is greatly influenced by the extracted knowledge | Less water in the image               |
| Spectral relation | 222.68     | The calculation is simple and convenient to combine with other extracted methods | It is easily confused with objects with similar reflectivity, such as shadows, and water bodies | Less shadow in image, or in combination with other methods |
| Ratio            | 236.48     |                                |                                                   |                                       |
| NDVI             | 319.68     | It can distinguish water and vegetation better | The result is too much noise and easy to be mixed with bare ground | In areas with high vegetation coverage |
| Water index      | NDWI       | It has high versatility and is suitable for many sensors | The result is easy to mixed with shadows and paddy fields | Large area water extraction           |
| WI               | 212.66     | It can better avoid result mixing with shadow | Water extraction is not complete, and it is easy to extract paddy fields | Less paddy fields                    |
| Parallelepiped   | 1087.10    |                                | Results the accuracy is more dependent on the method of sample selection and classification, and the phenomenon of mixing is obvious | Other methods are more difficult to use |
| Supervised classification | 268.40     | Wide scope of application |                                                   |                                       |
| Maximum likelihood ratio | | |                                                   |                                       |
| Sample based object-oriented | 278.51     | It is better than general supervision classification | The accuracy depends on the sample selection, and there is more noise after classification | Other methods are more difficult to use |
| Rule based object-oriented | NDWI       |                                |                                                   |                                       |
| NIR              | 243.69     | The effect of extraction is better, | It is time consuming, and is necessary to set | The research area is smaller          |
| NIR              | 232.15     |                                |                                                   |                                       |
| Method                                      | Threshold | Notes                                                                 |
|--------------------------------------------|-----------|----------------------------------------------------------------------|
| HIS optimum index                          | 223.92    | The noise in water extraction is reduced. It depends on the band combination and needs a large number of experiments to determine the threshold of H, I and S. The threshold range of H, I and S in extraction is clear. |
| WI & Single band threshold                 | 215.73    | Paddy fields still have mixed extraction results. Less paddy fields. |
| Probabilistic statistical texture filtering | 203.98    | Some small water bodies are filtered, and results need to be opened and closed for a certain number of times. The extraction of small water bodies is not considered. |

4. Data and research area

Restricted by the spectral characteristics of images, many effective ways of water extraction cannot be used in image of ZY-3, such as MNDWI. To address this problem, the results of various methods for extraction of the water are analyzed. According to the characteristics of extraction results, the method of WI & single band threshold and the method of texture filtering based on probability statistics are explored. By comparing the strengths and weaknesses of various extraction methods, the following conclusions are obtained.

Firstly, on account of NIR of ZY-3 has high sensitivity to water, when there is less features that have similar reflectance with water, using single band threshold method or multi band operation can obtain the ideal effect of water extraction. Secondly, the commonly used NDVI and NDWI have poor extraction effect in the satellite image, while some water bodies are missing during the WI extraction process. The HIS optimum index method reduces the noise in the result, but the paddy field information of large area is still wrongly extracted. Compare with the above methods, object oriented extraction based on rules has a great application potential, which can not only take into account the water spectral information, also joined the space and texture feature to restrict results. Thus, we can obtain better extraction effect with it, nevertheless, the image segmentation process in extraction is slow, and the definition of the rules requires a certain knowledge base. Additionally, disturbance of shadow can be eliminated to a certain extent by using the method combination of spectral relation and water index, which has a certain space for development and application. When few water bodies in the study area or without considering the small water bodies in a further study, texture filtering based on probability and statistics can effectively reduces the noise in water extraction results, and avoids the mixing of paddy fields and shadows with water bodies to a certain extent.

The existing extraction methods are based on the spectral information of the image as the support, consequently, when there are objects with similar spectral information to water, the phenomenon noises mix with results is still prone to arise in existing way. We have tried to turn image band to frequency signal before using texture filtering based on probability and statistics extracting water bodies. We do Fourier transform to NIR that is more sensitive to water, after which the low frequency signal is filtered and morphological filling is taken. The obtained result is shown in Figure 9. We can see the overall characteristics of the water are particularly obvious despite the noises like paper-cuts are existed. If the connection of it and water bodies can be split, the water bodies would be taken out from image. Therefore, it is a new idea to water extraction considering in a frequency signal scale in our view.
Figure 9. Results after FFT transform.

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