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Review of Remote Sensing Satellite in Surface Water Extraction

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Abstract

Rapid and accurate extraction of water information from remote sensing satellite images is of great significance for water resources investigation, watershed planning, monitoring and protection of water resources. On the basis of extensive literature investigation, this study systematically expounds the basic idea and development process of water extraction from remote sensing images, and comprehensively summarizes the basic methods and current situation of scholars in water extraction, analyzes the advantages and disadvantages of various methods, explains the existing problems of current water extraction, and finally looks forward to the development trend of remote sensing water information extraction.

Keywords

Water Extraction; Remote Sensing Satellite; Water Index; Threshold Method.

1. Research Progress of Multi-spectral Image in Water Extraction

Different ground objects have different laws of electromagnetic wave radiation due to their different composition, structure and environment, which are mainly shown in the different characteristics of emitting, absorbing and reflecting electromagnetic waves [1]. The same ground object has different reflection ability in different electromagnetic wave bands; different ground objects also have different reflection ability in the same wave band; the reflectivity of the same ground object has similar rules with the change of incident electromagnetic wave wavelength [2]. Therefore, it can be identified and classified according to the differences of spectral characteristics between different ground objects. The water body is in the visible band, the reflectivity is higher in the blue and green bands, and lower in the red band. In the near-infrared and short-wave infrared bands, the reflectivity of the water body is low, and almost all the incident energy is absorbed. The reflectivity of water body shows a decreasing trend, that is, blue band > green band > red band > near infrared band > short wave infrared band. According to the spectral characteristics of water bodies in different bands, water bodies can be extracted effectively, such as single-band threshold method, water body index method and so on. The texture features of satellite images reflect the internal structure of natural landscape and target objects, which is one of the important bases for feature recognition and information extraction. Different from other features, the surface of the water body is smooth and continuous, the fluctuation is small, and the texture is dense, while the surface of other features outside the land water body is relatively rough. According to the texture features of the water body in the optical image, the water body can also be effectively extracted.

In recent years, scholars have carried out extensive research on water extraction from different sensor data. The methods of surface water extraction using multi-spectral images can be divided into three methods: single-band or multi-band threshold method, water index method

(Table 1) and classifier-based method [3,4]. Bartocci et al. found that the near infrared band is the best band for water information recognition [5]. Shih and others based on Landsat MSS images, using density segmentation method, effective plain water information [6]. Zhou et al. found that water bodies in TM images have unique characteristics of spectral relationship, namely: (TM2+TM3) > (TM4+TM5), this method is especially suitable for the extraction of mountain water bodies [7]. According to the relationship between the second and fourth bands of TM images, Mcfeeters et al proposed a normalized water index (NDWI) model. This model can effectively suppress soil and vegetation information, but the inhibition effect on building information is poor, and there is some mixed separation of building and water information in the extraction results [8]. On the basis of NDWI model, Xu Hanqiu proposed an improved normalized water body index (MNDWI). Especially in the extraction of urban water information, MNDWI shows a good effect [9]. Zhang et al. proposed a surface water extraction model based on LBV transform for Landsat-8 OLI images, and compared with NDWI, MNDWI and AWEI extraction results, it has better accuracy [10]. Jiang et al applied multi-layer perceptual neural network to the extraction of surface water in Landsat 8 OLI image, which effectively suppressed the influence of shadow and ice and snow on water extraction results [11]. Zhang et al. combined Sentinel-2 images and OpenStreetMap data, proposed a water extraction model based on existence and background learning algorithm, and proved that the model has higher accuracy than water index method and random forest classifier [12].

Table 1. Water index and calculation formula

Water index	Formula
NDVI	$\mathrm{NDVI} = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}$
NDWI	$\mathrm{NDWI} = \frac{\rho_{Green} - \rho_{NIR}}{\rho_{Green} + \rho_{NIR}}$
MNDWI	$\mathrm{MNDWI} = \frac{\rho_{Green} - \rho_{SWIR}}{\rho_{Green} + \rho_{SWIR}}$
EWI	$\mathrm{EWI} = \frac{\rho_{Green} - \rho_{NIR} - \rho_{SWIR}}{\rho_{Green} + \rho_{NIR} + \rho_{SWIR}}$
AEWI_{nsh}	$\mathrm{AEWI}_{nsh} = 4 \times (\rho_{Green} - \rho_{SWIR1}) - (0.25 \times \rho_{NIR} + 2.75 \times \rho_{SWIR2})$
AEWI_{sh}	$\mathrm{AEWI}_{sh} = \rho_{blue} + 2.5 \times \rho_{Green} - 1.5 \times (\rho_{NIR} + \rho_{SWIR1}) - 0.25 \times \rho_{SWIR2}$
WNDWI	$\mathrm{WNDWI} = \frac{\rho_{Green} - \alpha \times \rho_{NIR} - (1-\alpha) \times \rho_{SWIR}}{\rho_{Green} + \alpha \times \rho_{NIR} + (1-\alpha) \times \rho_{SWIR}} \quad \alpha \in [0,1]$
WRI	$\mathrm{WRI} = \frac{\rho_{Green} + \rho_{Red}}{\rho_{NIR} + \rho_{SWIR}}$
NDFI	$\mathrm{NDFI} = \frac{\rho_{NIR} - \rho_{SWIR}}{\rho_{NIR} + \rho_{SWIR}}$
Sum_{457}	$\mathrm{Sum}_{457} = \rho_{NIR} + \rho_{SWIR1} + \rho_{SWIR2}$

Spectral water index method is widely used because of its good applicability and high accuracy. The classifier-based method uses supervised or unsupervised classification algorithms to extract surface water, which is better than the spectral water index method in some cases. However, the method based on classifier is complex and time-consuming, so it is not suitable for rapid extraction of surface water.

2. Research Progress of SAR Image in Water Extraction

SAR image has the characteristics of all-time and all-weather observation to the earth, and is not affected by clouds, so it is a powerful tool to obtain the submerged area and evaluate the flood disaster [14]. SAR images generally contain few bands, which are mainly identified according to the backscattering coefficient, texture and other features of ground objects [15]. SAR transmits electromagnetic signals at certain time intervals through the antenna. With the movement of the platform, it receives and records the echo signals of ground targets in different positions, and carries out coherent processing to achieve high-resolution imaging in range and azimuth directions. SAR measures the distance by the time difference between transmitting and receiving signals, and the range resolution is mainly related to the bandwidth of the radar signal. The greater the bandwidth, the narrower the pulse width, the lower the resolution; the directional resolution is mainly related to the beam width of the radar azimuth, and the smaller the beam width is, the higher the resolution is. If the echo signal of the ground target is weak, the gray value of the corresponding pixel of the SAR image is lower; if the echo signal is strong, the gray value of the corresponding pixel of the SAR image is higher. Compared with other rough ground objects, the surface of the water body is smooth, the electromagnetic wave signal emitted by SAR is reflected back less on its surface, and the reflection is similar to the specular reflection, so the echo signal received by SAR is weaker, and the gray value of the pixel of the water body in the SAR image is lower.

Scholars at home and abroad have carried out extensive research on the use of SAR images for water information extraction and flood monitoring. The main models of water body information extraction using SAR images include threshold segmentation, independent component analysis, object-oriented segmentation and terrain-aided information extraction [16]. Hess et al. proved through experiments that SAR image can quantify the inundation degree of forest floodplain area and can be applied to real-time flood monitoring [17]. By improving OTSU algorithm and based on Envisat ASAR image, Li et al. achieved high accuracy of water information extraction and greatly promoted the automatic extraction level of water body [18]. An et al. improved the CV model and proposed a fusion segmentation algorithm combined with OTSU algorithm, which can effectively extract the boundary of water body in radar image, and has the characteristics of accurate location and efficient operation [19]. Based on Envisat ASAR images, Maurizio et al analyzed the backscattering characteristics of water, ice and land at different incident angles and different ground cover, and counted the threshold range of water extraction [20]. Because of the long revisit period of the satellite, it is difficult to apply to the emergency response of disasters. Based on mathematical morphology and supervised image classification, Klemenjak S et al proposed a method of automatically extracting river structure from TerraSAR-X data, which achieved good results [21]. Zeng Lingfang and others are using Sentinel-1 data to monitor the flood inundation in Sri Lanka, extracted the water cover area before and after the disaster based on the single threshold method, and made a flood inundation area map [22]. Compared with ERS-1 SAR and ENVISAT ASAR satellites, Sentinel-1 double satellite cooperation has shorter revisit period and larger coverage area. Its wide range, multi-application and multi-mode characteristics make it quickly applied to the research of surface water body and flood monitoring.

In the actual situation, the vegetation or other ground objects in the water will scatter the electromagnetic wave signal emitted by SAR, enhance the backscattering signal of the surrounding water body, and affect the roughness of the water surface; the water surface will also be affected by the wind, resulting in waves, so that the surface becomes rough, and the corresponding backscattering signal is stronger. Due to the increase of the surface roughness of the water body, the reflection of the electromagnetic wave emitted by SAR can not be similar to the specular reflection after it reaches the water surface, which is similar to that of other rough ground objects, and the degree of differentiation decreases, which increases the difficulty of water information extraction. In addition, the shadow will also have a certain impact on the accuracy of water extraction from SAR images. SAR is generally side-looking imaging, and the electromagnetic wave signal emitted by radar antenna has a radiation blind zone. When the angle of the slope of the ground target is less than the incident angle of the emitted electromagnetic wave signal, such as part of the hillside, there will be a shadow area in the SAR image, and the gray value is very low, which is close to the backscattering coefficient of the water body.

3. Conclusion

The extraction of water body information from remote sensing images provides important support for water area dynamic change monitoring and water environment protection, and will get more attention and application. With the rapid development of satellite remote sensing with "high space, high time and hyperspectral" resolution, the free opening and acquisition of multi-source data, the available data will become more and more diversified. In the future, the comprehensive application of multi-source data, a variety of methods and technologies will bring greater opportunities for the extraction of water information from remote sensing images. The introduction of multi-source data can make up for the shortcomings of single optical remote sensing data, such as slope map and terrain shading map generated by DEM data, which can reduce the interference of mountain shadow; radar data has the ability to obtain all-weather data, and is not disturbed by cloudy and cloudy weather, and has a significant effect in overcoming the interference of cloudy and mountain shadow. The fusion of multi-source data can make full use of the spectral, spatial structure and texture features of remote sensing images. The combination of threshold method, water index method, classifier method and popular deep learning method can provide an idea for large-scale, systematic and fine water information extraction.

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