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Exploring the Current Status of Multispectral Data Application in Water Quality Monitoring of Rivers and Lakes

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Abstract:

Water quality monitoring provides a foundation for managing pollution in the water environment by analyzing pollution sources, concentrations, and trends in water bodies. Traditional water quality monitoring methods are expensive and can be insufficient for the demands of large-scale real-time monitoring; meanwhile, multispectral remote sensing can quickly gather expansive data from water areas and has become widely used in quality of water monitoring. This paper aims to examine the current application of multispectral remote sensing data in monitoring water quality pollution in rivers and lakes. The study reveals that the application of multispectral remote sensing in water quality monitoring has indeed been extensive. Firstly, while multispectral remote sensing data is relatively easy to obtain, its precision is limited; there are challenges regarding low accuracy in water quality parameter inversion models, necessitating its integration with hyperspectral data and drone remote sensing. Secondly, current methods for remote sensing of water quality still depend heavily on a big volume of measured data and face spatiotemporal limitations; thus, it is recommended to optimize modeling techniques to reduce regional constraints and reliance on measured water quality data. Lastly, this research summarizes applications of more readily obtainable multispectral data in monitoring water quality in rivers and lakes for researchers encountering challenges in data acquisition, analyzing both the advantages and shortcomings of the data and methods, and providing recommendations for researchers in selecting remote sensing water quality monitoring data.

Keywords: River and lake water quality monitoring, multispectral remote sensing, remote sensing

1. Introduction

The whole world is increasingly concerned about the ecological protection of water resources, and water pollution has become an important issue affecting the process of sustainable development of mankind. Rivers and lakes are an important part of the water ecological environment. They can regulate local climate change, maintain regional biodiversity and ecological balance, and have a great impact on the living environment of residents in coastal areas, industrial and agricultural production, etc. [1]. In the long term human production and life, the water environment of rivers and lakes has been severely damaged, and the restoration of water ecosystems has become a key issue.

In the management of river and lake environments, water quality monitoring provides a basis for the management of water environment pollution by analyzing the sources, concentrations and trends of water pollution. Conventional water quality monitoring approachs are mainly manual field sampling and establishment of monitoring stations, etc., which have high construction costs and cannot meet the real-time monitoring needs of large-area waters. Remote sensing technology is widely used in water quality monitoring by virtue of its advantages of low monitoring cost, wide monitoring area, high data acquisition efficiency, and long time monitoring [2]. Currently,remote sensing in quality of water monitoring has been relatively mature, and at present, the commonly used data sources in the study mainly include multispectral data and hyperspectral data[3]. Among them, the application of multispectral data is earlier, in 2006, Zhu Lingya[4] used semi-empirical method to analyze and study the spectral characteristics and sensitive inversion bands of chlorophyll a and suspended solids, which are the main water quality parameters of lakes, by using measured spectral data and MODIS multispectral data. On this basis, a remote sensing inversion model of chlorophyll a and suspended solids was constructed evaluated and applied with MODIS data, and the changes in water quality of Lake Taihu were monitored with multi-temporal MODIS data. Until now multispectral data are still widely used by researchers, and in 2024, Lv Jun[5] et al. used Sentinel-2 satellite remote sensing images to conduct an inversion study of non-water-colored water quality parameters, such as five-day biochemical oxygen demand (BOD), ammonia nitrogen (AN), total phosphorus (TP), and total nitrogen (TN), for major water bodies in Nanning City.

This study focuses on the current status of the application of multispectral data in water quality monitoring, based on the China Knowledge Network database, summarizes and generalizes the shortcomings of the advantages of multispectral data in the type, processing and application, and sorts out and compares the basic methodology of the remote sensing data in the inversion process of water quality parameters. It is mainly divided into two parts: 1. Landsat8 satellite data and Sentinel-2 satellite data in multispectral data in remote sensing water quality monitoring. 2. three basic methods of remote sensing water quality monitoring with multispectral data, which are analytical, empirical, and semi-empirical and semi-analytical.

2, Multispectral data in remotely sensed water quality monitoring

With the rapid development of the field of remote sensing satellites, remote sensing images are widely used in various types of research, which have the advantages of large detection range, fast data collection, rich image information, dynamic monitoring of ground information, and so on, and therefore are widely used in urban planning monitoring, reservoir change monitoring, disaster monitoring, and ground resources and environment monitoring[6]. Among them, multispectral data are mainly used to extract features of interest through the spectral difference between the target and the background and are widely used for water quality monitoring such as chlorophyll growth status and concentration of suspended solids[7]. With fewer bands, multispectral data usually contain 3 to 10 bands covering key spectral regions from visible to near-infrared, which is a bridge between macro-monitoring and micro-analysis due to its moderate spatial and spectral resolution[2]. Data sources include the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) data from NASA's Landsat8, Multispectral Instrument (MSI) from ESA's Sentinel-2 in Europe, the U.S. ESA's Sentinel-2 Multispectral Instrument (MSI), NASA's MODIS series, and Airbus' SPOT series.

2.1 Landsat 8 satellite data

Landsat 8 satellite was successfully launched by the United States on February 11, 2013, which carries OLI land imager and TIRS thermal infrared sensor. Among them, the OLI land imager has excellent performance, and Landsat 8 has a significant advantage of higher temporal and spatial resolution compared with traditional remote sensing technologies[3]. The U.S. Landsat (Landsat) is a common data for long time series daily remote sensing to monitor the water quality of rivers and lakes, and its six optical bands range from blue light to short-wave infrared field[7], and scholars at home and abroad have used Landsat8 data to carry out water quality inversion studies. Jiang Bingbo et al[8] selected the OLI data in Landsat8

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and the measured water quality data for correlation analysis to determine the multiple remote sensing data bands with the highest correlation, and then regression analysis was performed on the water quality data and the multiple band data, and finally the function inversion model applicable to the Shima River basin was established. After comparing the inversion prediction results with the measured water quality data on-site, the experimental results showed that the established water quality inversion model can monitor the COD concentration of water quality in the Shima River basin efficiently and rapidly. Cao Jiaju[9] utilized the spectral information of multi-temporal Landsat-8 remote sensing images to invert the water quality parameters, performed regression analysis and neural network analysis for permanganate, dissolved oxygen, pH and ammonia nitrogen, respectively, and selected the most applicable inversion model of water quality parameters, and evaluated the water quality of Dianchi Lake based on the obtained inversion model of water quality parameters. Zhang Hongjian et al[10] explored the statistical model between OLI data from Landsat8 remote sensing satellites and water quality indicators (WQI), and concluded that the OLI data can be used for the distribution of dissolved oxygen (DO), fluoride, ammonia nitrogen (NH3-N), total phosphorus (TP) and pH.

2.2 Sentinel-2 satellite data

The Sentinel-2A satellite was launched by the European Space Agency on June 23, 2015, which carries a multispectral programmable imager that can cover 13 spectral bands, which is suitable for inland or near-shore water quality monitoring. Wang Xinhui et al[11] used Sentinel-2A remote sensing images of some watersheds in the Qingpu and Songjiang districts of Shanghai in April 2018 and the measured water quality parameters of the river cross sections acquired synchronously, combined with the five main water quality parameters of dissolved oxygen, permanganate index, five-day biochemical oxygen demand, ammonia nitrogen, and total phosphorus, and established a model of remote sensing inversion of water quality based on factor analysis to obtain comprehensive water quality indicators for determining the water quality category. Indicators were used to determine the water quality categories. Liu Mengyao et al.[12] selected the Guangzhou section of the Pearl River for the study, analyzed the Sentinel-2 remote sensing data and the measured data from the state-controlled sections, and constructed a water quality parameter inversion model based on various statistical regression models by finding the optimal band factors, and compared and analyzed the inversion accuracy of each model. The most accurate inversion model was used to invert the concentrations of dissolved oxygen (DO), permanganate (CODMn), total phosphorus (TP), total nitrogen (TN), and turbidity (NTU) in the Guangzhou section of the Pearl River, allowing us to understand the overall situation of water quality in the Guangzhou section.

3. Basic methodology for remote sensing of multispectral data for water quality monitoring

The basic methods for remote sensing water quality detection are analytical, empirical, semi-empirical semi-analytical and neural network methods. This study focuses on three remote sensing water quality monitoring methods for multispectral data: analytical, empirical and semi-empirical semi-analytical methods.

3.1 Analytical method

The analytical technique is a bio-optical model-based water quality inversion method. The technique simulates the propagation of light in the atmosphere and water body using a radiative transfer model, determines the characteristic absorption and backscattering coefficients of water quality parameters using the water body's reflectance as determined by remote sensing, and creates a correlation model—a strong model with a strong physical nature—between the reflectance spectra and the water quality parameters[6]. Although the analytical model can provide a deep understanding of the optical characteristics of the water body, its calculation process is complicated and requires high accuracy of the input parameters, which leads to some difficulties in practical application[2].

3.2 Experience method

The empirical method is a common and easy-to-understand method for the application of multispectral data in water quality testing[9]. The empirical method requires correlation analysis between the measured data and the corresponding remote sensing data to establish an empirical model to invert the water quality parameters, which is less computationally intensive and less difficult to apply in practice. This kind of relational modeling is mostly restricted by environment and region, less feasible to be applied in different water bodies, and not suitable for water quality monitoring studies at spatial and temporal scales[13]. Wang Xinhui[11] and others established a multiple linear regression model between the reflectance data and water quality parameters in the image band. From the results of regression analysis, it is concluded that the relationship between dissolved oxygen, permanganate and bands is relatively close, and the final water quality remote sensing inversion model is calculated. In this study, due to the temporal and spatial variations between satellite data and measured data, there is a certain error in water quality monitoring, and there is a limitation of spectral types of water quality parameters, the constructed inversion model of water quality parameters is only applicable to one season, and only two water quality parameters have high inversion accuracy, and the model can not be generalised under the change of time and space, so it is not possible to dynamically monitor the water quality of the inland lake under the long time series.

3.3 Semi-empirical and semi-analytical approach

The semi-empirical and semi-analytical method is a combination of analytical and empirical methods, which first analyzes the correlation between water quality spectral parameters and remote sensing data bands, selects the best bands, and constructs a mathematical statistical analysis model to invert the water quality parameters. Liu Zhongwei et al[3] concluded that the combination of B2 band and B5 band (the difference of wavelengths) of Landsat8 satellite OLI remote sensing image data has a strong correlation with the COD concentration of water body in Shima River through band analysis, and accordingly established a cubic polynomial inversion model of water quality parameters, which is more accurate and with less error, and the inversion results can be used to quickly determine the status of water pollution. Yang Chen[14] selected the river water body surrounding Hefei City as the study object. Using the Landsat-8 satellite image data and the measured water quality parameter data, he created a remote sensing inversion model on the river water quality parameters surrounding the city. He then used the inversion model to predict the water quality parameters and conducted an evaluation of the river water body's eutrophication level. Both studies demonstrated the practicability and effectiveness of the semi-empirical semi-analytical method in the establishment of the inverse model for the actual water quality parameters, and both of them resulted in models with high accuracy for predicting and judging the water quality conditions in the region. The semi-empirical semi-analytical method combines the advantages of both analytical and empirical methods, but the semi-empirical method requires high synchronization of measured data and remote sensing data, and the models developed are highly region-dependent and less generalizable.

4.Shortcomings and prospects

Multi-spectral data in remote sensing water quality monitoring research, this study summarizes the shortcomings and prospects in multi-spectral data and basic methods:

First, multispectral data for satellite remote sensing data is easier to obtain, but due to equipment and technical problems, the data accuracy is medium, although suitable for water quality research at mesoscale,but there will be some errors in the establishment of the water quality inversion model with the water quality data obtained from the actual measurements, resulting in poor accuracy of the model and lower credibility of the prediction results.

Secondly, multispectral data cannot accurately derive all water quality parameters in water quality inversion model construction and prediction, which has limitations in water quality monitoring, and can be combined with hyperspectral data and UAV remote sensing to obtain remote sensing data and research results with higher accuracy.

Finally, the existing remote sensing water quality monitoring methods rely on a large number of measured data to carry out accuracy inversion, and due to the continuous changes in the river and lake water bodies and the interference of external factors there will be a certain degree of error, water quality parameter inversion model has spatial and temporal limitations, and we hope that in the future to optimize the remote sensing water quality detection methods, weakening the dependence on the measured data, and strengthen the dynamic monitoring and prediction of water quality in rivers and lakes.

5. Conclusion

This study focuses on the research of multispectral data for water quality monitoring, and summarizes the multispectral data that can be used in remote sensing water quality monitoring, especially Landsat and Sentinel satellite data, which have been heavily used by researchers due to their characteristics of being free of charge and fast data collection. Three basic methods of multispectral remote sensing water quality monitoring are analyzed, and the shortcomings of each method are pointed out. In general, the existing remote sensing water quality monitoring methods rely too much on the support of measured water quality data to construct inverse models of water quality parameters, which have spatial and temporal limitations. Because hyperspectral data and UAV remote sensing data are more difficult to obtain, many researchers cannot obtain high-quality and high-precision data, the study on the application of multispectral remote sensing water quality monitoring in water quality of rivers and lakes summarizes and analyzes the advantages and shortcomings of using more easily accessible data in the water quality monitoring research, and analyzes the underlying methodology, and hopes that in the future, the quality and accuracy of

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the data are constantly improving, and the remote sensing in a long time-series can be realized Water quality dynamic monitoring.

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