ISSN 2959-6157

Integrating Multi-source Remote Sensing Technology to Improve Water Resource Management Methods at Poyang Lake

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Abstract:

With the progress of science and technology, the material life of human society is becoming more and more perfect. Still, it also causes the human living environment to become more and more harsh. Water resources are polluted to different degrees, affecting the sustainable development of ecology. Water resource management based on emerging technologies is urgent. The purpose of this paper is to analyze and evaluate the pollutants and types of pollution in the water body of Poyang Lake based on multi-source remote sensing data through the pollution indicators of colored soluble organic matter pollution, water body eutrophication, and heavy metal salt pollution. This paper concludes that Poyang Lake faces problems such as high organic pollution during the abundant water period, medium eutrophication of the water body, and excessive cadmium and manganese heavy metal salts. This paper finds that establishing relatively different pollution indicator systems is more conducive to analyzing and evaluating water resource pollution in different geographical areas. With the progress of remote sensing science, more and more remote sensing technology is applied to the governance and management process of water resource pollution.

Keywords: Multi-source; pollutants; Poyang Lake.

1. Introduction

With the continuous improvement of human production, the quality of human material life is getting higher and higher. Still, it also brings a lot of man-made ecological and environmental pollution problems. Water pollution is one of the more prominent problems in today's ecological environment pollution. More and more water bodies on earth are polluted to varying degrees, and more and more seriously, they are affecting the residents around the water bodies, including drinking water and water problems. Water is an indispensable material for the normal life activities of living organisms on earth. Suppose a large area contaminates the water pollution control. In that case, the earth's water resources will not only seriously affect the development of human society but also jeopardize the earth's ecosystem, threatening the survival of mankind. Therefore, it is essential to solve the problem of pollution of the Earth's water resources and improve the ecological environment.

Poyang Lake is the largest freshwater lake in China. It is the main water source for residents and is significant in regulating the local climate and maintaining the balance of the neighboring ecological environment. In the past two decades, the water body of Poyang Lake has been polluted to different degrees in different regions, which affects the water use of the residents around the lake. Many scholars have analyzed the pollution type and condition of the water body of Poyang Lake through field investigation and sampling analysis, but the traditional method of in situ sampling and analysis has limitations for such a vast water body. This method cannot accurately and comprehensively assess the pollution situation of the whole of Poyang Lake, leading to unreasonable water resource evaluation. This is one of the main challenges facing the management of water resource pollution in Poyang Lake.

With the development of remote sensing technology for earth observation, the amount of data acquired by different remote sensors in visible light, infrared, microwave, and other electromagnetic waves is increasing daily. These data constitute multi-source remote sensing data regarding time, space, spectrum, direction, and polarization. In remote sensing, single-sensor image data usually cannot extract enough information to meet the needs of certain applications. In contrast, multi-source remote sensing data can be fused to obtain more information and improve the utilization rate of remote sensing data. Remote sensing can monitor the pollution status of a large area of water bodies, providing rich information on water environment parameters with high spatial and temporal resolution and sustainable monitoring[1]. Since the early 1980s, the fusion of multi-source remote sensing image data has become a technical science with a relatively complete system and rich methodology. It is applied to major ecological environment monitoring and analysis.

Therefore, this paper takes Poyang Lake as an example to explore the application of multi-source remote sensing data in monitoring water pollution. Under the known location, area, water level, water storage capacity, runoff volume, etc., of Poyang Lake, the spectral data of the water body are provided by multispectral remote sensing images. Various pollutants are analyzed based on satellite remote sensing data, and reasonable water pollution management and management methods are given by combining ground observation data and water quality monitoring data.

2. Introduction to remote sensing data sources

2.1 Types of remotely sensed data

2.1.1 Microwave Remote Sensing Data

Microwave remote sensing usually has a 1-1000 mm wavelength, commonly called microwaves in the electromagnetic spectrum. The longer wavelength of microwaves can penetrate clouds and fog. Therefore, remote sensing can work properly in rainy, foggy, or cloudy weather conditions. Also, microwave remote sensing can obtain image data at night and without sunlight. Microwave remote sensing is also divided into passive and active through its imaging method. The microwave remote sensing sensor itself emits and receives reflected signals in a way called active microwave remote sensing, the advantage of which is that it is not affected by the time and atmospheric environment and has a wide range of application scenarios; the microwave sensor itself does not emit microwave signals, but receives microwave radiation signals from the ground object in an imaging way called passive microwave remote sensing, and the disadvantage of which lies in the fact that it can't work correctly in the night and cloudy and rainy weather conditions. The microwave remote sensing systems currently in use include the ERS series of satellites launched by ESA, the Canadian RADARSAT-1 satellite, the Earth Resources Satellite-1 (JERS-1), and others, which are mainly used for observations related to national land resources surveys, global environmental monitoring, forestry, disaster prevention, coastal monitoring, and fisheries.

2.1.2 Thermal Infrared Remote Sensing Data

Objects on the Earth's surface are subject to solar radiation and have a certain surface temperature greater than absolute zero, forming thermal infrared radiation, which can be used as an important basis for identifying feature elements (Fig.1). Thermal infrared remote sensing data refers to the remote sensing data that uses thermal infrared sensors to detect the spectral characteristics of features in the thermal infrared spectral band [2]. Thermal infrared imaging is based on the principle that objects in a thermal infrared image are distinguished from each other by differences in their thermal jurisdiction. This principle also allows thermal infrared imaging as an information detection technique to work normally at night without being constrained by sunlight[3].

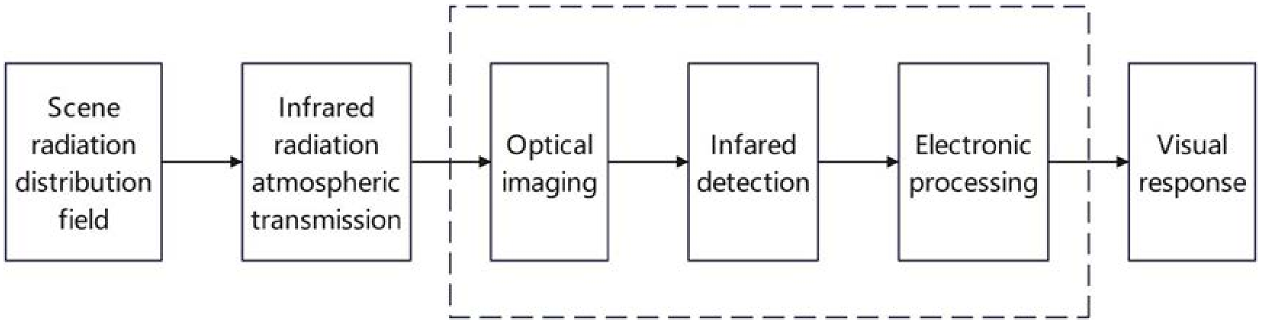

Fig. 1 shows the flow chart of the thermal imaging system

2.1.3 Hyperspectral Remote Sensing Data

Hyperspectral remote sensing is a technique that obtains spectrally continuous and narrow-width image data in the electromagnetic spectrum, also known as imaging remote sensing [4]. Hyperspectral remote sensing data is characterized by its small sampling interval of imaging bands, large number of sampling bands with high correlation, and high spatial resolution. Therefore, the image data are informative and can reflect the subtle characteristics of the target, making the research of quantitative analysis or qualitative analysis of the target from a distance malefactor a reality [5]. Meanwhile, compared with panchromatic and multispectral remote sensing, it improves the spectral resolution, and the means of reconstructing the spectral reflectance can get rich and continuous spectral information of the target. Using data mining, neural networks, and other flexible and diverse classification methods can increase the recognition of target elements and the information content of remote sensing data, making remote sensing applications more stable and widespread[6].

2.2 Advantages of multiple remote sensing data

Unlike single-source remote sensing data, multi-source remote sensing data fusion is more complete. It can consider the fusion objects and links from multiple perspectives so as to obtain the required high-quality information resources, which is more accurate, comprehensive, and reliable than the processing of single-source remote sensing data. Its technical advantages mainly include the following aspects[7].

(1) More precise measurements

Multi-source remote sensing surveying and mapping technology has high measurement accuracy and a wide range of applications, so it has become the main core technology for surveying and mapping work at the current stage. In the process of survey and inspection work, through the use of multi-source remote sensing technology, the resources can be accurately located in the shortest possible time. The use of multi-source remote sensing technology not only greatly reduces measurement error but also greatly reduces the investment in human resources. For example, when surveying coal resources, the use of multi-source remote sensing technology is able to realize all-round exploration, and the staff does not need to enter the site to accurately grasp the content and distribution of mineral resources in the mining area so that the risk of occurrence of coal mine safety problems has been greatly reduced.

(2) Stronger anti-interference capability

At the present stage, surveying and mapping work is basically carried out outdoors. Therefore, environmental, geological, and climatic factors may all impact the accuracy of traditional manual mapping results and affect the smooth implementation of subsequent work. However, the above factors do not affect the electromagnetic wave transmission of the object, so they will not affect the accuracy of the final measurement results. Therefore, multi-source remote sensing technology has a very strong anti-interference ability and, in most environments, can be an accurate survey. At the same time, the application of multi-source remote sensing technology can also accurately classify the differences between different areas and objects.

(3) Large coverage area

In the process of many surveys and mapping work, the geographical area to be surveyed is very large, and traditional manual surveying and mapping require not only investment in a lot of human resources but also a lot of time. Therefore, conventional manual mapping has great limitations, and the actual mapping efficiency is also very low. The application of multi-source remote sensing technology can solve these problems, as it has a huge mapping coverage area and can carry out real-time and dynamic monitoring of large areas. At the same time, it can greatly reduce the workload of the staff and has an outstanding effect on the improvement of measurement accuracy and efficiency.

(4) Unconstrained by landscape and topography

In the application of multi-source remote sensing technology, surveying and mapping work will not be affected by terrain, landforms, environment, and other factors and can truly realize all-weather, all-round dynamic monitoring. Staff can save a lot of surveying and mapping time through the multi-source remote sensing computer control terminals, which provide arbitrary access to the required surveying and mapping information. Therefore, the application of multi-source remote sensing technology in surveying and mapping work is an important embodiment of the further development of modern science and technology, which can promote the rapid development of the surveying and mapping industry.

2.3 Preprocessing of remotely sensed data

Remote sensing data preprocessing refers to the operational processing of remote sensing data before various analyses, using image processing methods to weaken or eliminate anomalies in the image and improve the quality of remote sensing image data [7]. The most common preprocessing includes radiometric preprocessing, atmospheric correction, and geometric correction.

Radiation preprocessing is to radiatively correct the luminance value of the image. In practice, the radiative correction is precisely by establishing the quantitative relationship between the digital signal output from the detector. The radiant luminance value is inputted into the unit to solve problems such as the abnormal phenomenon of the sensor's work or the attenuation of the electromagnetic wave caused by the influence of the atmosphere in the process of transmission due to some uncertain and objective factors [8].

As solar radiation enters the atmosphere, a series of physical reactions occur, making the solar radiation received by the sensor, of which the scattering and absorption reactions of the atmosphere are the most influential [9]. Atmospheric correction is through the acquisition of really physical parameters, such as radiance, surface temperature, etc., to eliminate the impact of atmospheric moisture, oxygen, particulate matter, and other factors caused by the reduction of the impact of the reflection of the ground, reduce due to the attenuation of the radiant energy in the process of atmospheric transmission, and then to obtain effective information on the ground [10].

At present, there are many atmospheric calibration methods. The relatively simple empirical linear method is to establish the relevant linear equations through the measured feature wave spectra, which is easy to operate but cannot obtain the real feature radiation information; for the radiative transfer model has a high accuracy of reflectance calculation, but its shortcomings are: too many parameters, restricted by the real-time atmospheric parameter acquisition, and a large amount of computation, etc. [11].

Due to the satellite's flight altitude, attitude, rotation of the earth, and other factors caused by the remote sensing imaging, the satellite image relative to the actual situation of the ground target geometric aberration, which is manifested in the image of the relative position of the pixel and the actual position of the ground object is inconsistent with the phenomenon of offset, extrusion, and other phenomena. The error correction for geometric distortion is called geometric correction, and orthographic correction is a higher level of geometric correction [12]. Since Landsat-8 has high resolution and Rational Polynomial Coefficient Rational Polynomial Coefficient (RPC) information, the geometric correction can be accomplished by ortho-correction to eliminate the above errors and then to achieve the requirement of high accuracy.

3. Applications of remote sensing to water quality monitoring

Water is one of the most important natural resources on which all life depends. The per capita amount of freshwater resources in China is only 2,300 cubic meters, which is only 1/4 of the world average, and it is one of the poorest countries in the world in terms of per capita water resources. Pollution of water resources threatens the ecological environment of local rivers and lakes and, in serious cases, hinders the healthy development of society.

3.1 Methodological principles

3.1.1 Satellite Data Preprocessing

Landsat8 images are commonly used in water pollution monitoring, with nine bands of OLI and two bands of TIRS. General studies mainly constructed the band ratio model based on the first five bands of OLI, which include the along-lake band (0.43-0.45μm), blue (0.45-0.52μm), green (0.52-0.60μm), red (0.63-0.68μm), and NIR (0.85-0.89μm). 0.60μm), red (0.63~0.68μm) and NIR (0.85~0.89μm). The image data of Poyang Lake with less than 10% cloud cover is selected. In order to achieve higher accuracy, the image data needs to be reprocessed. Landsat8 data have been geometrically and topographically corrected, so the radiometric calibration and atmospheric correction can be performed directly on them, and these operations can eliminate the interference from the sensor itself, atmosphere, solar altitude angle, topography, etc., and get the data with true reflectance. Radiometric calibration and atmospheric correction are performed using the Radiometric Calibration and FLAASH Atmospheric Correction modules of ENVI 5.3.

3.1.2 Trophic level index

The integrated trophic state index is widely used to evaluate eutrophication in Chinese lakes and reservoirs. It evaluates the eutrophication level of water bodies by calculating the sub-indicators such as chlorophyll a, total nitrogen, total phosphorus, transparency, and permanganate index. In this paper, the comprehensive trophic level index (TLI) method was used to evaluate the eutrophication level of Poyang Lake and the five water quality indexes, namely, chlorophyll a (Chl.a), TP, TN, transparency (SD) and permanganate index, were used to calculate the TLI.:

(1)

In the formula,is for Chl. a as the base parameter, correlation weights normalized by the jth parameter; TLI(j)is the composite trophic state index of the jth indicator,m is the number of evaluation indicators; Included among these,, the formulae for the calculations are referred to in the literature.

3.1.3 The process of establishing an inversion model

RF, CART, and SVM classification inversion models are established based on the GEE platform. The basic principle of RF is a combined classification model composed of many decision tree classification models. Through the randomColumn function, all the feature sets are randomly divided into a training set and test set according to 7:3, and the training set is selected to be the feature set with water quality class attributes after spatio-temporal matching with the measured data in June and July. The RF inversion modeling formula is established as follows:

(2)

Where denotes the combinatorial classification model, is a single decision tree classification model, Y indicates the target variable,is a schematic function。

The basic principle of CART is to form a decision tree in the form of a binary tree by cyclic analysis of the training data set. When the number of layers of the decision tree reaches the pre-set maximum value, or all the leaf nodes in the samples belong to the same category, or the number of samples is 1, the CART decision tree algorithm builds a tree to stops growing to complete the training of the classifier. Using the smileChart function, the formula for building a classification decision tree is:

(3)

The formula is the GINI index of the set D conditional on the known feature A.

The larger the value, the greater the uncertainty of the sample, here it is necessary to choose the sample that satisfies the taking the minimum value of the feature A.

SVM is a binary classification model. The basic model is a maximally spaced linear classifier defined in the feature space. The main optimization problem of SVM is a convex optimization problem that satisfies strong duality and can be solved by maximizing the dyadic function. The model selection prioritizes a Gaussian kernel, which is more capable of handling complex problems compared to a linear kernel. The support vector machine inversion modeling formula is established as follows:

(4)

The classification decision function is obtained based on the input training set, and the optimal solution is obtained by choosing the penalty parameter C>0, choosing One of the components of gets .

3.2 Water quality monitoring and analysis of Poyang Lake

3.2.1 Colored soluble organic matter

Studies by domestic scholars on seasonal changes in various types of water bodies have shown that changes in the natural environment (e.g., rainfall, light) due to the seasons can have an impact on the content of organic matter in water. Although the specific mechanism of change cannot be directly distinguished according to the season for different types of water bodies, it is of great significance to carry out research on colored soluble organic matter (CDOM) according to the season. Poyang Lake, as a highly dynamic water condition lake with obvious flood season and dry season, different water conditions will affect the CDOM concentration, and seasonal change will also change the type and amount of phytoplankton in the water, which will affect the CDOM concentration. As shown in Table 1, from the inversion results of Qianwen Wu et al.[13],It is in an abundant water period in the summer and in a dry period in the fall and winter. The highest value of CDOM inversion during the abundant water period was at 1.0244- 1.380 among. During the dry period, CDOM concentration is at 0.9159-1.2495among. Observation of the inversion results and analysis leads to the conclusion that on the time scale, CDOM concentrations are overall lower in the dry period than in the abundant period.

Table 1. Imaging CDOM concentrations during periods of abundance and desiccation in different years[13]

year	1995	2000	2005	2010	2014	2017
Water season CDOM concentration	0.4922-1.0244	0.4723-1.1918	0.4825-1.18807	0.4922-1.2972	0.4621-1.1753	0.4568- 1.2901
average	0.5863	0.5571	0.5603	0.5562	0.5874	0.5920
Dry rseason CDOM concentration	0.4352-1.0314	0.4215-1.0136	0.4425-0.9958	0.4354-0.9159	0.4396-1.0957	0.4175 1.1907
average	0.5027	0.5131	0.5106	0.5266	0.5210	0.5125

3.2.2 Degree of eutrophication of water bodies

Xie Huiyu, Hu Mei et al. analyzed the concentration of suspended sediment (SS), chlorophyll-a (chl-a), yellow matter (CDOM), total nitrogen (TN), total phosphorus (TP), and permanganate index (PMI) obtained from the field of Poyang Lake, and found that the pollution of TP and TN seriously exceeded the limit of occurrence of "ShuiHua", and the measured concentration was basically in the class III water body or below. The nitrogen-phosphorus ratio calculation found that there were phosphorus-limited and nitrogen-limited waters. The measured concentrations were basically in class III water bodies and below, and the calculation of the nitrogen-phosphorus ratio found that there were two kinds of water in Poyang Lake: phosphorus-limited and nitrogen-limited. The correlation between CDOM and SS, Chl-a, and CDOM was weak. The measured spectral data showed that SS responded well in the red-near infrared wavelength range. By comparing the degree of adaptation of five methods, including the comprehensive trophic state index method, scoring method, and Nemero index method, the scoring method was chosen as the eutrophication evaluation method for Poyang Lake water body. The inversion results showed that the range of the eutrophication evaluation index was 45.6~65.1. The trophic level was between mesotrophic and moderately eutrophic, and the trend of the spatial distribution of the evaluation index was similar to the spatial distribution of the water quality parameters, which was similar to the trend of the spatial distribution of the water quality parameters in the lake entrance, sand mining area, eastern part of the lake. The spatial distribution of the evaluation index is similar to the overall trend of the spatial distribution of water quality parameters, and the evaluation index is higher at the mouth of the lake, in the sand mining area, in the east, in the south, and small lakes far from the main lake. The exogenous input of water quality parameters is an important source of TN, TP, and in Poyang Lake, and river input, industrial sewage, agricultural sewage, sand mining, and other human activities all affect the water quality and targeting to put forward the adjustment of enterprise policy, strengthening environmental legislation, increasing the treatment of river and human activities pollution, and realizing the informatization of water environment monitoring and other suggestions.

3.2.3 Heavy metal pollution

In the past 20 years, the pollution level and spatial distribution of trace elements in Poyang Lake Basin have changed, and the heavy metal pollution in Poyang Lake is generally characterized by the degradation of Cd and Hg pollution, the enhancement of Mn pollution and the insignificant change of other elements[14]. Ganjiang River is an important water source for agricultural irrigation and industrial production in Jiangxi Province. The Ganzhou area is a tungsten mining resource area with a hundred-year history of large-scale mining. It is also an important production area of ionic rare earth resources in China. After more than 40 years of development and rare earth mining pollution all over Ganzhou, related research shows that the Cd and W content in the mine pile upstream of Ganjiang River Zhangshui seriously exceeded the standard. The situation is similar to that of other Poyang Lake basins, which leads to severe metal pollution.

4. Discussion

Based on multi-source remote sensing data, this paper explores the application of several indicators of colored organic solvent pollution, the degree of eutrophication of water bodies, and heavy metal pollution to water quality pollution in the Poyang Lake Basin. This paper found that the degree of organic pollution in the water body during the dry water period was lower than that during the abundant water period. The spatial distribution of the three water quality parameters reflecting the eutrophication of the water body has a similar trend, with the sand mining area, estuary delta, and the eastern and southeastern part of the lake inlet as the main pollution areas, the western part of the pollution is mainly concentrated in the summer, and the pollution level of the inlet channel lake and the small lakes on the periphery of the lake far away from the main lake are also higher. The lake is in the overall spatial distribution of the south high and north low, as well as the outer high and the inner low. In the past 20 years, the factor of very high and high potential ecological risk in the Poyang Lake basin has changed from Hg to Cd, and the proportion of its points has changed significantly, with Hg decreasing from 22% to 0, and Cd increasing from 6% to 39%.

Multi-source remote sensing data play an important role in water resources monitoring. They can be used to predict natural disasters such as floods, ensure water quality safety, and assess water resource reserves, but there are still some problems waiting to be solved. For example, the limitations of satellite remote sensing technology, data noise, and the inherent limitations of the inversion method itself all lead to a decrease in the accuracy of water resources monitoring, which needs to be further investigated and cracked. In addition, the application of multi-source remote sensing data, especially combining high-resolution remote sensing data and time-series remote sensing data, can be further investigated. This can provide more detailed and accurate information on the water resources of Poyang Lake and help decision-makers better understand the distribution, change, and utilization of water resources. At the same time, the establishment of an intelligent water resources management system can be explored, using artificial intelligence and big data technology to process and analyze remotely sensed data and provide real-time decision-making support.

5. Conclusion

Multi-source remote sensing data play an important role in water resources monitoring. They can be used to predict natural disasters such as floods, ensure water quality safety, and assess water resource reserves, but there are still some problems waiting to be solved. For example, the limitations of satellite remote sensing technology, data noise, and the inherent limitations of the inversion method itself all lead to a decrease in the accuracy of water resources monitoring, which needs to be further researched and solved. Facing the global frontiers of science and technology, water resource monitoring needs to be interfaced with earth system science to promote interdisciplinary cross-fertilization and innovative development. This paper summarizes the water resources management of Poyang Lake based on multi-source remote sensing image data. However, there are still many directions that deserve in-depth research to improve the effectiveness and sustainability of water resources management; for example, the application of multi-source remote sensing data can be further researched, especially combining high-resolution remote sensing data and time-series remote sensing data. For example, we can further study the application of multi-source remote sensing data, especially combining high-resolution remote sensing data and time-series remote sensing data, which can provide more detailed and accurate information on water resources of Poyang Lake and help decision makers better understand the distribution, change, and utilization of water resources; we can explore the establishment of an intelligent water resources management system, which can process and analyze remote sensing data by using artificial intelligence and big data technology, and provide real-time decision-making support; in addition, we should strengthen the integration of water resources management and ecological protection, and enhance international cooperation and experience exchange.

Acknowledgements

All the authors contributed equally and their names were listed in alphabetical order.

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