Application of Remote Sensing Technology in the Field of Lake Pollution Control and Monitoring

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Abstract. Lake pollution has always been one of the significant environmental concerns for humanity. This article explores the hazards of lake pollution and analyzes whether remote sensing technology is meaningful for monitoring and controlling lake pollution in the context of abundant remote sensing resources. The results show that remote sensing technology can help people monitor the pollution status of lakes and assess the effectiveness of their management more easily. This article investigates the role of remote sensing technology in eutrophication, organic pollution, and heavy metal contamination, along with the challenges faced. It also examines the application of remote sensing technology in lake degradation, restoration, and management. It concludes that remote sensing technology can indeed play a role in lake pollution monitoring and control, offering benefits such as reduced labor, time, and spatial costs. The article aims to find more reasonable ways to address lake pollution control and lake environmental management issues while minimizing the ecological impacts of lake pollution.

Keywords: Lake pollution, remote sensing, lake governance, application, lake Eutrophication.

1. Introduction

Lake pollution poses severe hazards to the environment and human health. Contaminated lake water becomes turbid, odorous, and affects people's water supply needs. Aquatic organisms are also directly or indirectly impacted, with habitat destruction and loss of biodiversity. Lake ecosystems suffer from degradation, eutrophication, and harmful algal blooms, leading to insufficient oxygen supply and making it difficult for fish and other aquatic organisms to survive. Furthermore, lake pollution threatens human health through the consumption of contaminated water or ingestion of toxic substances through consuming contaminated aquatic organisms, as well as adverse effects on the respiratory system and skin from air pollutants. Economically, lake pollution affects industries such as fisheries, agriculture, and tourism, resulting in unemployment and economic losses. Therefore, protecting lake water quality is crucial, requiring enhanced pollution control and monitoring, measures to reduce pollutant emissions, restoration of lake ecosystem balance, and ensuring sustainable development and human well-being of lakes.

Remote sensing technology plays a significant role in the management of lake pollution. Through remote sensing technology, we can monitor and identify sources of lake pollution, providing accurate water quality information. Remote sensing technology can also monitor changes in water quality, assess the effectiveness of pollution control measures, and make timely adjustments to strategies, thereby improving efficiency. It can also help in early warning and predicting pollution risks, enabling the implementation of preventive and control measures to avoid further pollution spreading and ecological damage. Additionally, the spatial distribution data provided by remote sensing technology can assist decision-makers in planning and resource allocation, optimizing pollution source management strategies, and achieving sustainable lake management and conservation.

The main objective of this article is to analyze the role of remote sensing technology in the pollution and management of lakes, particularly its ability to reduce human resource, time, and spatial costs while maintaining effectiveness. Firstly, it introduces the environmental and biological hazards of lake pollution and the primary ways in which humans contribute to lake pollution. Then, it discusses the specific types of lake pollution that can be identified using remote sensing technology,

analyzing the characteristics, distinctions, and significance of each type of pollution source, and how it can assist in better pollution management. Finally, it summarizes examples of remote sensing technology currently being used to monitor lakes and relevant water bodies.

2. Monitoring and Identification of Lake Pollution Sources

Agriculture, domestic activities, and industrial operations are the primary sources of pollution affecting the water quality of lakes. Agricultural pollution includes the use of fertilizers, pesticides, and intensive farming practices, which enter lakes through surface runoff and contribute to eutrophication and organic pollution. Domestic pollution primarily originates from urban surface runoff, carrying organic matter, microorganisms, antibiotics, heavy metals, and nutrients that pose threats to lake water and its aquatic organisms. Industrial pollution involves the direct discharge of untreated or inadequately treated wastewater into lakes, with heavy metal elements such as mercury, lead, and chromium posing severe risks to both biota and human health. These pollution sources have complex effects on lake water quality, including eutrophication, organic pollution, and heavy metal contamination.

2.1. Lake Eutrophication

Eutrophication of water bodies is not determined by a single easily measurable indicator. In the application of remote sensing technology, the focus is primarily on utilizing indicators related to eutrophication, such as chlorophyll-a, suspended solids, permanganate index, transparency, total phosphorus, and total nitrogen, for remote sensing inversion calculations. The comprehensive analysis of these indicators can provide information on the degree of water body eutrophication. Assessing the eutrophication status of water bodies comprehensively using multiple indicators allows for a more comprehensive understanding.

Remote sensing technology can be used to monitor chlorophyll concentration in lakes by utilizing the reflectance information in remote sensing imagery data. This allows for the retrieval of chlorophyll concentration in lake water bodies. Chlorophyll is one of the important indicators of water eutrophication, and its concentration reflects the nutritional status of the water. Tu et al. [1] using remote sensing monitoring technology, remote sensing inversion models were established for the parameters of the Gan River Basin in Nanchang City and Lake Yao. The chlorophyll concentration in rivers and lakes was successfully inverted, validating the accuracy and reliability of the model. The study concluded that the model performed the best in determining chlorophyll-a concentration.

Remote sensing technology can monitor suspended solids, another indicator of lake eutrophication, as increased concentrations can result in turbid water. Remote sensing technology can help determine the degree of eutrophication in lakes by inverting the concentration of suspended solids from the image data. According to the study by Dekker et al., they pointed out that Thematic Mapper Band 4 showed good performance in the inversion of suspended sediment concentration [2]. The data from TM Band 4 can be effectively used to estimate the concentration of suspended sediments in water bodies.

Remote sensing technology can monitor water transparency, as eutrophication in lakes can lead to increased levels of phytoplankton and suspended solids, thus affecting water transparency. Remote sensing technology can be used to estimate the transparency of water bodies, which can then be used to assess the degree of lake eutrophication. Song et al. [3] developed a remote sensing model based on the ratio of red and blue bands using field measurement data and Landsat OLI satellite data to estimate the transparency of lakes. The model demonstrated high stability and enabled the inversion of lake transparency at a resolution of 30 meters, providing a global-scale assessment of lake transparency.

Remote sensing technology can monitor dissolved oxygen levels in lakes. Eutrophication in lakes often leads to an increase in phytoplankton and suspended solids, resulting in higher oxygen consumption. By monitoring the dissolved oxygen content in lakes using remote sensing technology,

it is possible to indirectly assess the degree of eutrophication in the water. Changes in dissolved oxygen can reflect the biological activity and oxygen supply in the water, serving as one of the indicators of eutrophication. Zhong et al. [4] conducted a study on the waters of Qinzhou Bay in Guangxi. They established a model for inverting dissolved oxygen concentration in Qinzhou Bay using both univariate and multivariate, linear and nonlinear regression analysis methods. Three band combinations, 1/B3, lnB3/(lnB1+lnB2), and B3/(B1+B2), showed good correlation with dissolved oxygen concentration. The dissolved oxygen inversion model constructed using the optimal sensitive bands and regression model exhibited good stability and accuracy.

2.2. Lake Organic Pollution

Remote sensing monitoring of organic pollution faces several challenges. While hydrocarbon-based organic compounds can be effectively detected using remote sensing techniques, it is difficult to distinguish organic substances with higher density or those dissolved in water based solely on the differences in reflectance between oil and water. Furthermore, research on using remote sensing to monitor other organic indicators such as chemical oxygen demand (COD) and biochemical oxygen demand (BOD) is still relatively limited at present. The primary focus of organic pollutant studies has been on Colored Dissolved Organic Matter (CDOM), while the reflectance characteristics of CDOM are similarly to water, making accurate monitoring challenging, especially in high-salinity environments. Therefore, remote sensing monitoring of organic pollution requires further research on new remote sensing methods and indicators to improve monitoring capabilities, along with the integration of other monitoring approaches for comprehensive assessments. Remote sensing technology is used to monitor CDOM, which is one of the dissolved organic compounds in lakes and is related to organic pollution levels. Monitoring the distribution and concentration of CDOM through remote sensing provides an indirect assessment of organic pollution in lakes. Fang Cao et al. [5] using MERIS satellite data, algorithm research was conducted in the northern Gulf of Mexico, Chesapeake Bay estuary, and coastal waters of the central Atlantic. The study utilized multispectral remote sensing reflectance to determine the optical absorption activity of CDOM at different wavelengths and ultimately established a relationship between CDOM absorption coefficient and dissolved organic carbon (DOC) concentration (equation (1)).

$$DOC=aCDOM(300)/(\exp(-15.05-33.95\times S275-295)+\exp(-1.502-104.3\times S275-295)) \quad (1)$$

Remote sensing technology is used to monitor Dissolved Organic Carbon (DOC), which includes organic substances dissolved in water such as humic substances, organic acids, and sugars. It is an important indicator in water, used to describe the content and composition of dissolved organic matter in water Changes in DOC concentration can reflect the sources of organic matter, degradation processes, and water quality variations. By monitoring DOC through remote sensing, the distribution of DOC in different regions of a lake can be obtained, allowing for the assessment of organic pollution levels. Cherukuru et al. [6] developed an empirical algorithm related to Dissolved Organic Carbon (DOC) concentration using field data. They inferred DOC concentration by analyzing the ratio of R412 to R488 bands and established a corresponding model (equation (2)).

$$Lg(DOC)=282.01\exp(-1.72(R412/R488)) \quad (2)$$

2.3. Lake Heavy Metal Pollution

Remote sensing technology can monitor heavy metal pollution in water bodies through spectral analysis methods. When water bodies are subjected to heavy metal contamination, their spectral reflectance characteristics undergo changes, which can be obtained through spectral analysis. These changes include shifts in absorption peak positions, variations in reflectance, and alterations in spectral shapes. By comparing the spectra of polluted and unpolluted water bodies, differences in spectral features can be identified, allowing for the inference of heavy metal pollution in the water. The red edge effect analysis is a remote sensing method used to monitor changes in heavy metal pollution in water bodies. This method utilizes the red edge position in the spectrum, typically ranging

from 600 nm to 740 nm. Cui Wei et al. [7] through a study of multiple water sources in a heavy metal mining area, analyzed the changes in the red edge position of the water bodies using this method. It enabled the assessment of the physiological spectral characteristics of the water bodies and the inference of the impact of heavy metal pollution. The variability of the red edge position can reflect the presence and extent of heavy metal pollution in the water.

2.4. Difficulties in Lake Monitoring

Monitoring water temperature using remote sensing technology involves several steps. Firstly, atmospheric sounding data synchronized with the satellite or atmospheric models are used to estimate the atmospheric influence on surface thermal radiation. Then, the surface thermal radiation intensity is obtained by subtracting the atmospheric influence from the total thermal radiation observed by satellite sensors. Finally, the surface temperature is calculated using the surface emissivity and the Planck's law conversion formula [8]. It has been observed that high water temperature is often associated with eutrophication, as eutrophication leads to the growth of phytoplankton and algae, which generate heat through their metabolic processes, thus increasing water temperature. Additionally, organic pollution typically originates from discharge sources such as agricultural activities, industrial discharges, and urban wastewater. These pollutants can lead to an increase in organic matter content in lake water bodies. High water temperatures facilitate the decomposition and biological degradation processes of organic matter. Therefore, in the presence of organic pollution, water temperature may also increase.

Remote sensing technology alone may not be sufficient to determine specific pollution sources, as it provides only clues and preliminary inferences. It often requires the integration of geographical information, investigation of human activities and surrounding environments, and comprehensive analysis of other pollution indicators to accurately identify pollution sources. Furthermore, additional sampling and experimental analysis may be necessary to confirm the sources and assess the extent of pollution. The resolution of remote sensing imagery can also pose challenges, as the spatial resolution of the images may limit the detection and monitoring capabilities of small-scale pollution sources. Lower resolutions may struggle to capture small pollution sources, such as point source emissions or localized pollution areas. This necessitates the use of other data sources or improvements in remote sensing technology resolution to address these limitations.

3. Restoration and Management of Lake Degradation

Remote sensing technology plays a crucial role in monitoring the degradation and restoration of lakes. By acquiring remote sensing imagery of lakes, remote sensing technology can assess the water quality conditions and monitor issues such as eutrophication and organic pollution in the water bodies. Additionally, By analyzing vegetation indices such as the Normalized Difference Vegetation Index (NDVI), remote sensing technology can also monitor the vegetation coverage and changes in lakes. The changes in the water area of lakes can also be monitored using remote sensing imagery, aiding in the assessment of the degree of degradation and the trends of change in lakes. Furthermore, remote sensing technology can analyze changes in the lake shoreline and surface subsidence using surface deformation monitoring methods to provide information on lake degradation. By acquiring remote sensing imagery data of lakes and combining it with appropriate analysis methods, remote sensing technology can provide real-time monitoring of indicators such as water quality, vegetation changes, water area, and surface topography, thus offering robust support for the monitoring and evaluation of lake degradation issues. Figure 1 shows the degradation of Lake Dali Nur, the third-largest lake in Inner Mongolia [9].

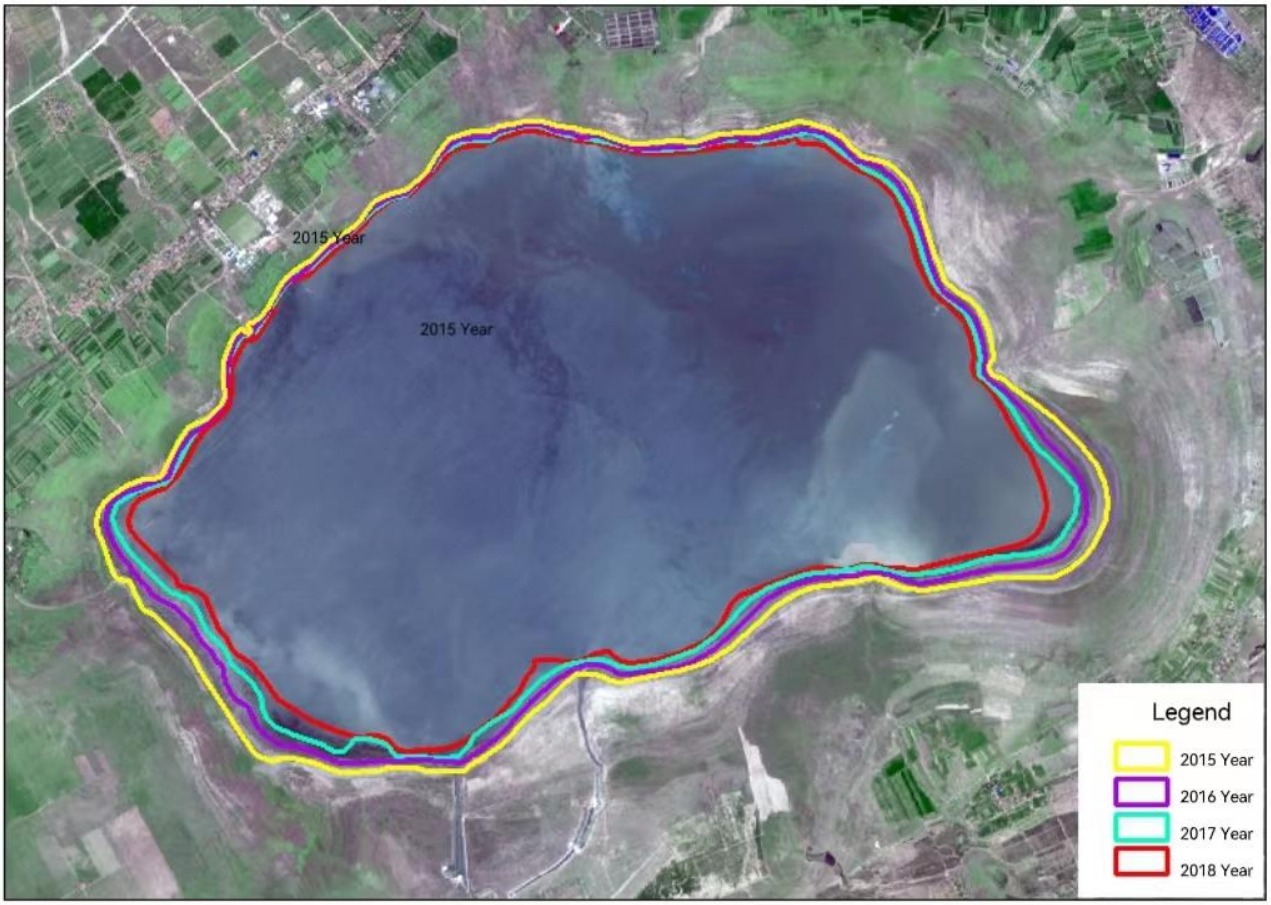


Fig. 1 The change map of Lake Dali Nur from 2015 to 2018.
https://www.mee.gov.cn/xxgk2018/xxgk/xxgk15/201807/t20180705_630335.html

The restoration of degraded lakes is an important task for protecting lake ecosystems and improving water quality. Restoration effectiveness assessment is the process of evaluating the effectiveness of restoration measures and management strategies. During the restoration process, remote sensing technology provides essential monitoring and assessment tools. By acquiring and analyzing remote sensing images, changes in water quality, vegetation cover restoration, and the evolution of lake boundaries can be monitored, thus assessing the effectiveness of the recovery and providing guidance for further management measures. Figure 2 is the Map of Poyang Lake Area and Inundation Intensity [10].

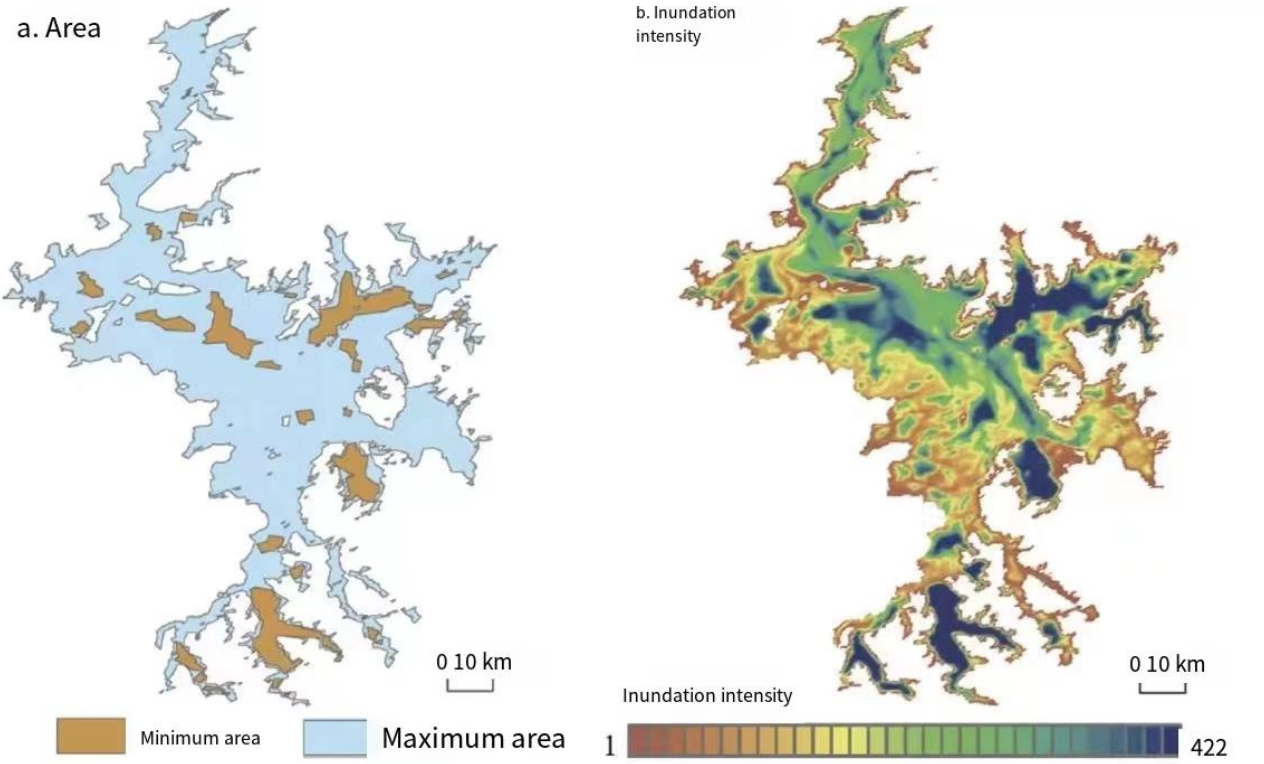


Fig. 2 Map of Poyang Lake Area and Inundation Intensity.
http://www.geog.com.cn/EN/10.11821/dlxb202003008

Sustainable lake management strategies are key to protecting and restoring lake ecosystems. These strategies include water resource management, land-use planning, environmental monitoring, water pollution control, lake wetland conservation, and ecological restoration. Remote sensing technology plays an important role in sustainable lake management by providing dynamic monitoring data, environmental indicators, and trend analysis of lakes, helping to formulate scientific management strategies and decisions. Regular monitoring of lake degradation and restoration enables timely adjustments to management measures, promoting the sustainable development and healthy recovery of lake ecosystems. In summary, remote sensing technology plays a critical role in lake degradation and restoration, providing vital support for the protection of lake ecosystems and improvement of water quality.

4. Conclusion

Lake pollution not only affects people through aspects such as taste and color but also poses health and livelihood risks to the aquatic and plant life near the lakes. The entire article discusses the application of remote sensing technology in the context of lake pollution and management. It including the application of remote sensing technology for monitoring indicators of eutrophication, such as chlorophyll concentration, suspended solids, transparency, and dissolved oxygen, as well as organic indicators including colored dissolved organic matter, dissolved organic carbon, and heavy metals in water bodies. and water quality parameters like heavy metals and water temperature. The article also highlights how remote sensing technology can assist managers in observing and managing lake remediation more effectively, allowing people to have a clearer understanding of lake pollution and the achievements of remediation efforts. However, remote sensing technology faces certain challenges and limitations in monitoring, indicating significant room for future development in lake pollution monitoring and management using remote sensing technology. The article concludes by proposing suggestions for the widespread application of remote sensing technology and its further advancement through continuous research, practical applications in more specific lakes and water

bodies, and the exploration of more accurate, economical, and efficient approaches to achieve a new era of water pollution control.

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