

Application and Outlook of Remote Sensing Technology in Water Environment Monitoring

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Abstract. Water environment monitoring is a critical tool for effective environmental protection and management. However, traditional methods often fall short in meeting the requirements of large-scale and real-time monitoring. To overcome these limitations, remote sensing technology has emerged as a non-contact, rapid, and efficient approach, playing a pivotal role in water environment monitoring. This paper provides a comprehensive overview of the principles and methodologies employed in remote sensing technology for monitoring water quality pollutants, detecting changes in water bodies, and preserving wetland ecosystems in the context of water environment monitoring. The practical application and significance of remote sensing technology are exemplified through a range of specific case studies. Moreover, the paper analyzes the existing status and challenges of domestic water environment remote sensing monitoring, while also presenting future development directions. The research and application outlined in this paper serve as a valuable reference, driving innovation and progress in water environment remote sensing monitoring in our country. Additionally, the findings of this study are of great significance in improving the efficiency and effectiveness of water environmental protection and management, as well as promoting the wider application of remote sensing technology within the environmental domain.

Keywords: Remote sensing technology, water environment monitoring, water quality pollutants, water body changes, wetland conservation.

1. Introduction

Water environment serves as a crucial foundation for human existence and development, playing a significant role in ecosystems. However, with rapid economic growth and population increase, water environment issues have become increasingly pressing, severely threatening human health and safety through water pollution, water scarcity, and degradation of aquatic ecosystems. Therefore, effective monitoring and assessment of the water environment is of paramount significance in protecting water resources, improving the water environment, and promoting sustainable development. Remote sensing technology refers to the use of sensors carried by aircraft or satellites to acquire information about the Earth's surface by receiving and analyzing electromagnetic signals reflected or emitted from the Earth's surface. With its characteristics of non-contact, rapid and efficient data acquisition, and wide coverage, remote sensing technology can provide information on water quality pollutants, water body changes, and wetland conservation, thereby supporting water environment protection and management. In recent years, with the advancement and application of remote sensing technology, an increasing number of researchers have started utilizing remote sensing techniques for water environment monitoring and assessment.

Currently, numerous review articles on remote sensing monitoring of water environments have been published domestically and internationally, summarizing and evaluating the application of remote sensing technology in water environment monitoring from different perspectives or levels. However, most of these articles focus on single indicators or single sensors, lacking comprehensive, systematic, and forward-looking analysis of the role of remote sensing technology in water environment monitoring. This paper aims to provide a comprehensive, in-depth, and updated review of remote sensing technology in water quality pollutant monitoring, water body change detection, and wetland conservation in the context of water environment monitoring. It analyzes the principles, methodologies, advancements, and challenges of remote sensing technology in these aspects and

presents future development trends. The paper aspires to offer a reference framework for researchers in related fields, facilitating the improved application of remote sensing technology in water environment monitoring.

This paper presents a comprehensive exploration of the application of remote sensing technology in monitoring water quality pollutants, detecting changes in water bodies, and conserving wetlands. It discusses the monitoring methods and advancements in tracking pollutants such as suspended solids, organic matter, chlorophyll-a, heavy metals, dissolved oxygen, and pH levels. Additionally, it investigates the use of remote sensing technology in detecting changes in water bodies, including surface temperature variations, water level changes, and morphological alterations. The paper further delves into the application of remote sensing technology in wetland conservation and water environment monitoring, encompassing topics such as water distribution and changes within wetlands, wetland habitat assessment and species monitoring, as well as simulation and prediction of wetland hydrological processes. It concludes by summarizing the current status and challenges of remote sensing monitoring of water environments on both domestic and international levels, and provides valuable recommendations and future development directions. Overall, this paper highlights the significant contributions and potential of remote sensing technology in monitoring water quality, assessing water body changes, and supporting wetland conservation efforts.

2. Comparison between Remote Sensing Technology and Traditional Water Quality Monitoring Approaches

2.1. Limitations of Traditional Water Quality Monitoring Methods

Remote sensing technology is based on acquiring and interpreting the spectral information of electromagnetic energy reflected or radiated by the earth's surface. Remote sensing data obtained from platforms such as satellites, aircraft or drones can provide global water information. Remote sensing technology has the following advantages in water quality monitoring: wide-area coverage, which can obtain water quality information for extensive areas, regardless of geographical location and access difficulties; high spatial and temporal resolution, which can provide high-resolution water quality information, achieve continuous monitoring and observation of water bodies, and timely identify and respond to water quality issues; non-contact, which does not require direct contact with water bodies, avoiding the potential interference and pollution risks introduced by traditional monitoring methods; multi-source data fusion, which can be integrated with other data sources, such as meteorological data, topographic data, etc., to further improve the accuracy and comprehensiveness of water quality monitoring.

2.2. Basic Principles and Advantages of Remote Sensing Technology

Remote sensing technology is based on acquiring and interpreting the electromagnetic spectral information reflected or emitted from the Earth's surface. Remote sensing data obtained from platforms such as satellites, aircraft, or unmanned aerial vehicles can provide global-scale water information. Remote sensing technology possesses the following advantages in water quality monitoring: wide area coverage capability, enabling the acquisition of water quality information over large regions without being limited by geographical location or accessibility constraints; high spatial and temporal resolution, providing detailed water quality information and enabling continuous monitoring and observation of water bodies, facilitating timely identification and response to water quality issues; non-contact measurement, eliminating the need for direct contact with water bodies, thus avoiding potential human interference and contamination risks associated with traditional monitoring methods; data fusion from multiple sources, enabling integration with other data sources such as meteorological data and terrain data, further enhancing the accuracy and comprehensiveness of water quality monitoring.

3. Water Environment Pollutant Monitoring

3.1. Suspended Solids Monitoring

Suspended solids monitoring is one of the significant applications of remote sensing technology in water quality pollution monitoring. Suspended solids generally refer to particulate matter suspended in water, including suspended particles, sediments, organic debris, and plankton. The concentration and distribution of these suspended solids have crucial implications for water quality and the ecological environment. Remote sensing technology enables the monitoring and assessment of suspended solids by acquiring remote sensing image data of water bodies and employing relevant optical models and algorithms. Previous researchers have successfully validated the feasibility of this method by selecting bands 3 and 4 of Landsat TM/ETM+ that exhibit a good linear relationship with suspended solids concentration. The images were subjected to geometric correction, atmospheric correction, and other processing steps before being compared with in-situ measurements. However, due to the varied shape, nature, and influence of factors such as chlorophyll and yellow substances in the water, there is no unified standard or approach for suspended solids remote sensing algorithms. Therefore, it is necessary to select suitable bands and models based on different water characteristics and satellite sensors [1, 2].

3.2. Organic Pollutant Monitoring in Water Bodies

Organic substance pollution in water bodies poses a severe threat to the environment and human health, making the monitoring and management of organic pollutants in water bodies crucial. Traditional methods of water monitoring typically rely on field sampling and laboratory analysis. However, these methods suffer from limitations such as limited sampling points, high time costs, and limited monitoring coverage. In this context, remote sensing technology has emerged as a non-contact, rapid, and efficient monitoring approach, showcasing significant potential in the monitoring of organic pollutant in water bodies. Remote sensing technology can monitor organic pollutants by inversely estimating the absorption coefficient of colored dissolved organic matter (CDOM) and matching spectral data with field measurements. However, remote sensing technology still faces challenges and limitations in monitoring colorless dissolved organic matter and marine areas [1].

3.3. Organic Pollutant Monitoring in Water Bodies

Chlorophyll-a concentration in water bodies is an important indicator for assessing algal biomass and eutrophication levels. Chlorophyll-a is a pigment present in algae and plants that participates in the absorption and conversion of light energy through photosynthesis. Monitoring the concentration of chlorophyll-a in water bodies is significant for early warning and management of issues such as eutrophication and algal blooms. Remote sensing technology can be used to estimate chlorophyll-a concentration in water bodies and provide information on algal biomass and water quality eutrophication. Previous researchers have utilized reflectance spectra measurements of surface sediment in intertidal zones using an on-site spectrometer. Based on the characteristic wavelengths of the reflectance spectra, they constructed two indices, namely Normalized Difference Index of Benthic Microalgal Pigments (NDI-MPB) and Reflectance Trough Depth (T-depth), to invert chlorophyll-a concentration [3].

3.4. Heavy Metal Pollution Monitoring

Monitoring heavy metal pollution in water bodies involves the identification, quantification, and monitoring of heavy metal contamination using remote sensing technology. Heavy metal pollution refers to the presence of metal elements in water bodies that exceed environmental standards, such as lead, mercury, cadmium, chromium, etc., which pose potential hazards to ecosystems and human health. Remote sensing technology can identify potential sources of heavy metal pollution and the affected areas by analyzing spectral characteristics, surface reflectance, and other spectral information of water bodies, in combination with geochemical models and statistical methods.

In recent studies, researchers have utilized data from the Aster satellite sensor to acquire remote sensing monitoring data of different water body regions in the study area. They used a handheld spectroradiometer to measure the spectral reflectance of water bodies. Subsequently, spectral analysis methods were employed to analyze the spectral characteristics of heavy metal pollution in water bodies, such as peak positions and reflectance values, to assess the extent and scope of heavy metal contamination [4].

3.5. Dissolved Oxygen Monitoring

Dissolved oxygen in water refers to the concentration of oxygen molecules dissolved in water, which is an important indicator of biological respiration and oxygen supply in water bodies. Monitoring dissolved oxygen in water can be used to assess the redox state of water, the health of aquatic ecosystems, and the extent of water pollution. Remote sensing technology can provide optical information and environmental parameters of water surfaces, and through optical models and algorithms, infer the spatial distribution and variation of dissolved oxygen concentration in water bodies. Dissolved oxygen inversion models based on Landsat 5 TM images have been established by collecting and analyzing water spectral data. This model was used to estimate and analyze the spatial and temporal distribution of dissolved oxygen in the upstream area of the Huangpu River [5].

3.6. pH Monitoring

pH value is an indicator used to describe the acidity or alkalinity of water, reflecting the concentration of hydrogen ions (H^+) in water. pH value has a significant impact on biological survival and chemical processes in water. Monitoring the pH value of water can help assess water quality status, the impact of acid rain, ecosystem health, and other aspects. Although remote sensing technology cannot directly measure the pH value of water, it can provide environmental information related to pH value to assist in assessing and predicting the acidity or alkalinity of water. Previous researchers have used satellite hyperspectral data (such as Hyperion) for atmospheric correction and noise reduction, converting radiance data into surface reflectance data. Subsequently, techniques such as maximum noise fraction transform and scatterplot analysis were used to segment low reflectance features, and based on the spectral characteristics of different water bodies, the water areas were classified into acidic water, alkaline water, and neutral water [6].

3.7. Opportunities and Challenges

The current status, challenges, and future directions of remote sensing monitoring of water environments in China. Currently, domestic remote sensing monitoring research primarily focuses on individual indicators, lacking comprehensive monitoring of parameters such as COD and BOD, as well as the monitoring of pollutants like heavy metals. In the future, remote sensing technology should be used for graded evaluation of water quality and presented to the public in the form of imagery to enhance environmental awareness. Although remote sensing technology has many advantages, it still needs to be combined with field monitoring data and models to improve accuracy and stability. The authors call for continuous innovation and improvement of satellite remote sensing technology in China to achieve efficient, comprehensive, and real-time monitoring of water environments, providing technical support for environmental protection and management.

4. Water Environment Pollutant Monitoring

Remote sensing technology can assist in monitoring the spatiotemporal changes of water bodies. For example, by monitoring the changes in water surface temperature, insights into the thermodynamic characteristics of water bodies, including thermal pollution and thermal radiation, can be obtained. Additionally, remote sensing techniques can detect variations in water levels and analyze the morphological changes of water bodies, enabling the assessment of hydrological

processes and water resource management. This information is crucial for water body management and protection, particularly in flood monitoring, drought monitoring, and water resource planning.

4.1. Monitoring Water Temperature Changes

The importance of lake water temperature and the advantages of satellite remote sensing. Lake water temperature influences many physical, chemical, and biological processes in lakes and serves as an important indicator for assessing lake functionality, ecological status, and climate change impacts. Traditional field measurement methods require substantial technical and financial resources and may not fully capture the spatiotemporal heterogeneity of large water bodies.

Remote sensing technology can provide insights into the thermodynamic characteristics of water bodies by monitoring changes in water surface temperature. The temperature of water bodies is influenced by various factors, including climate, seasonality, and human activities. Through the acquisition of thermal infrared remote sensing data from satellites or unmanned aerial vehicles (UAVs), water temperature can be quantitatively measured, and spatiotemporal patterns of water temperature changes can be established. This aids in monitoring instances of thermal pollution in water bodies and evaluating the impact of thermal radiation on aquatic ecosystems. Researchers have compared multiple satellite remote sensing datasets and found that MOD11 is recommended for studying lake water temperature due to its higher accuracy, temporal resolution, and user-friendliness, outperforming MOD28. Landsat 7 ETM+ is suitable for small lakes as it provides higher spatial resolution [7]. Researchers have previously utilized thermal infrared bands and split-window algorithms to retrieve the surface water temperature of Lake Taihu, investigating the temperature conditions associated with cyanobacterial blooms and the relationship between cyanobacterial growth and water temperature [8]. Coincidentally, researchers have utilized the atmospheric correction method along with the thermal infrared sensor (TIRS) data from the 10th band of Landsat-8 satellite to infer the surface temperature of East Lake. Fig. 1 Based on the derived vertical distribution pattern of lake water temperature, it can be deduced that there is an approximate direct proportion relationship between the reciprocal of the square of water depth and the surface water temperature in shallow lakes. By employing a semi-empirical regression approach and utilizing measured sample points of water depth, the relationship between water depth and temperature has been determined. With this relationship established, the entire water depth of the lake can be inferred from the water temperature data. Furthermore, by integrating the water level data obtained from the imagery of the same day, information regarding the underwater topography can be derived. Such an integrated methodology, executed rigorously within the academic framework, provides a more comprehensive understanding of the characteristics of lake water bodies [9].

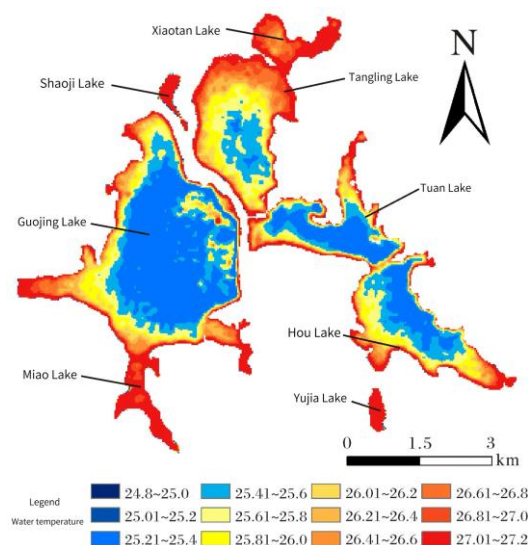


Figure 1. Water Temperature distribution of East Lake.

<http://ras.hbut.edu.cn/https/1Hufu062WaUJHzVXRioY244zHL1CyeyIV/>

4.2. Monitoring Water Temperature Changes

Remote sensing technology enables the monitoring of water level changes in water bodies, providing crucial information for hydrological processes and water resource management. By utilizing radar or optical remote sensing data, changes in the water body boundaries can be measured, allowing for inference of water level variations. Water level changes can be associated with factors such as rainfall, evaporation, and human activities. Real-time knowledge of water storage and flow conditions can be obtained by monitoring water level changes, supporting flood monitoring, drought early warning, and water resource planning. In recent research, for example, researchers utilized 140 Landsat satellite images spanning from 1972 to 2021 to extract the water area and shoreline of Lake Bosten. By establishing a correlation curve with measured water level data, they successfully retrieved water levels for missing dates, achieving dynamic monitoring of the water level in Lake Bosten [10].

4.3. Importance of Water Body Change Monitoring

Monitoring water body changes is crucial for water body management and protection. It provides timely information to monitor dynamic changes in water bodies and the evolving trends of water quality. Through water body change monitoring, issues such as water pollution, water resource utilization, and ecosystem restoration can be promptly identified, leading to appropriate management and protection measures. Additionally, water body change monitoring holds significant importance in areas such as flood management, water resource planning, and climate change research.

5. Wetland Conservation and Water Environment Monitoring

Wetlands, as one of the most important ecosystems on Earth, serve not only as a treasure trove of biodiversity but also play critical roles in regulating hydrological cycles, purifying water quality, protecting coastal areas, and storing carbon. However, due to the impact of human activities and climate change, wetland habitat degradation and species loss have become global environmental issues. To scientifically protect and effectively manage wetland resources, wetland habitat assessment and species monitoring are essential tasks. Traditional methods for wetland habitat assessment and species monitoring often face challenges such as high costs, long time requirements, and spatial scale limitations. With the rapid development of remote sensing technology and the widespread use of satellite remote sensing data, remote sensing has become a powerful tool for wetland habitat assessment and species monitoring. Remote sensing technology utilizes high-resolution remote sensing imagery data of wetlands and employs spectral, textural, and spatial characteristics of remote sensing data to accurately identify, classify, and monitor wetland habitats and species.

5.1. Importance of Water Body Change Monitoring

Remote sensing technology can provide information on the spatial distribution and changes of water bodies within wetlands. By analyzing remote sensing imagery data, water body types such as lakes, rivers, and marshes within wetlands can be identified, and changes in water body area, boundaries, and dynamics can be monitored. This is crucial for wetland water resource managers as it helps them understand the spatial distribution and change trends of water bodies within wetlands, enabling the development of rational water resource management strategies. In previous studies, the combination of multi-source remote sensing information technology and conventional hydrological data processing has been used to establish the "area-water level-water volume" relationship model for Lake Bosten, achieving high-dynamic simulation of parameters such as lake water level and volume. The results have shown good consistency with measured data, with small errors and high reliability. This demonstrates the technical advantages of remote sensing in comprehensive water resource monitoring and provides technical references for regional water resource investigations and monitoring [11].

5.2. Simulation and Prediction of Wetland Hydrological Processes

Remote sensing technology, combined with hydrological models, can simulate and predict the hydrological processes of wetlands, such as rainfall-runoff processes and water evaporation-transpiration processes. By utilizing the spatial distribution and change trends of remote sensing data, simulation and prediction results of hydrological processes can be provided to wetland water resource managers, assisting them in formulating rational water resource regulation strategies. In recent research, for example, using multi-source remote sensing data, information on wetland water bodies during the dry and wet seasons in the Ningxia Plain from 1996 to 2020, spanning nearly 25 years, was obtained. Seasonal variations in wetland water body area were analyzed. Additionally, the Standardized Precipitation Evapotranspiration Index was employed as a drought-flood indicator to quantify the wetland water bodies' response to seasonal climate drought [12].

6. Conclusion

Water environment serves as a crucial foundation for human existence and development, and it is an essential component of ecosystems. However, traditional methods of water environment monitoring have limitations in meeting the demands of large-scale and real-time monitoring. Therefore, remote sensing technology, as a non-contact, rapid, and efficient monitoring approach, plays a significant role in water environment monitoring.

This paper provides a comprehensive review of the principles and methods of remote sensing technology in water environment monitoring, along with illustrating its application effectiveness and significance through examples. The review focuses on three aspects: monitoring water quality pollutants, detecting water body changes, and conserving wetlands in the context of water environment monitoring. The review analyzes the principles, methodologies, advancements, and challenges of remote sensing technology in these aspects and presents future development trends. The research findings indicate that remote sensing technology can provide information on water quality pollutants, water body changes, and wetland conservation, thereby supporting water environment protection and management.

This paper provides a reference framework for research and application of remote sensing technology in water environment monitoring, contributing to the innovation and development of remote sensing technology in this field. It has valuable insights and guidance for researchers, managers, and decision-makers in related domains. Furthermore, the paper proposes ideas and recommendations for further deepening the research on water environment remote sensing monitoring.

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