remote sensing

Editorial

Remote Sensing of Watershed: Towards a New Research Paradigm

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1. Introduction

Watersheds are critical natural systems that serve as the foundation for sustaining life on Earth [1]. They play a vital role in the hydrological cycle, supporting water supply, agriculture, ecosystems, and biodiversity [2–6]. However, Anthropocene has presented challenges to watersheds, including deforestation, land-use changes, pollution, and climate change [7,8]. To maximize the resilience of watersheds, it is essential to implement sustainable land-use practices and effective watershed management strategies [9]. Consequently, understanding watersheds' complex dynamics and their response to natural and anthropogenic stressors is essential for sustainable development and the well-being of human societies.

The advent of remote sensing has revolutionized watershed research, providing unprecedented insights into watershed dynamics and spatiotemporal patterns [10,11]. These techniques offer breakthrough advantages over traditional field-based methods, including covering large areas with low cost and high efficiency, monitoring remote and inaccessible regions, and obtaining data at different spatial, spectral, and temporal resolutions [12–14]. More specifically, remote sensing of watersheds encompasses a wide range of applications that involve acquiring and utilizing hydrological, ecological, and environmental information in watersheds [15–17], including watershed mapping [18], monitoring of underlying surface elements in the watershed [19], inversion of water cycle parameters [20], water resource assessment [21], acquisition of watershed ecological environment parameters [22], monitoring natural disasters [23], analyzing upstream and downstream [24], supporting water governance priorities [25], water resource development [26], and irrigation water management [27]. Recent research trends show that the application of remote sensing techniques has been transiting from mapping, monitoring, and assessment to governance and management [28], calling for deeper and wider explorations on related research focus.

Based on these research contexts, several shortages in terms of current studies appear. First, the concept of the watershed is usually multiscale [29,30]. Studies vary at the global scale, concentrating on large watersheds (for example, oceans) [31], global trends (for example, global warming) [32], and international cooperation [33], to the local scale, concentrating on a single watershed (for example, lake or wetland) [34], local specific context (for example, pollution or urbanization) [35], and local governance [36]. There is still a lack of multiscalar understanding of watersheds. Second, the watershed is a unique

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nature–human system that contains multiple interacting elements [37]. However, current studies usually concentrate on a single element or process of watersheds. Hence, a comprehensive view of the "total" element of watersheds is needed. Third, while remote sensing techniques are currently widely applied in environmental studies, the scope is largely limited to natural sciences, and interdisciplinary research, especially from the scope of social sciences, is urgently needed [38]. Fourth, concentrating on remote sensing techniques, the methodology is most targeted on a single platform and imagery and may not meet the multiscalar, multidimensional, and interdisciplinary research demands of the current and prospective watershed studies.

Drawing upon these research contexts, this Special Issue is dedicated to scientific reports on the remote sensing of watersheds. This issue focuses on applying remote sensing techniques in watersheds in terms of hydrology, ecology, environment, and human activities. It aims to contribute to the current understanding of integrating research scopes and developing advanced methods.

2. Key Findings of the Special Issue

This Special Issue includes 14 articles that focus on various aspects of watershed remote sensing and aim to address the gaps and challenges in the field. The articles cover various topics, including hydrology, land use/land cover, vegetation, soil, and topography. These articles present innovative research methods and techniques for utilizing remote sensing data to enhance our understanding of watershed processes and support resource management decision making.

In terms of research objective and scope, the majority of papers on this Special Issue are focused on natural phenomena, hydrological processes [39], air [40,41], and land use/vegetation [42–44]. Further related it to human activities, such as carbon emission [45], agriculture [46,47], ecosystem service [48], and even culture diffusion [49]. Furthermore, the research encompasses diverse geographical areas, including rivers [39], lakes [40,41], drylands [50], countries [45], and regions [43,46].

In terms of methods and data, a wide range of methods and data sources were employed in the studies featured in this Special Issue. The methods vary from the comparison and validation of different methods combining the research object and local context [40,48], spatial simulation models based on the research object integrating remote sensing data [47,48], and developing advanced methods or indices to understand research phenomena [39] precisely. Some studies also discussed underlying data uncertainty issues [48].

In terms of data sources, data from platforms, including satellite-based and drone-based, are applied [41,43]. Many studies applied multisource data. For example, Duan et al. (2022) aim to solve the missing data issues by integrating multiple satellite sources [40], and others rely on multisource data to gain a comprehensive understanding [51].

In general, this Special Issue has revealed the multiscalar, multidimensional, and interdisciplinary nature of the application of remote sensing in watershed studies. The studies propose a series of advanced data, models, and strategies to serve watershed research better. However, there are still limitations and areas for improvement. Future studies are encouraged to consider and address these shortcomings, further advancing the field of remote sensing in watershed studies.

3. Future Perspectives: Towards a New Paradigm

3.1. Integration of Multisource Data

The integration of multisource data is a promising direction in remote sensing for watersheds [52]. Combining data from various sensors, platforms, and resolutions can provide a more comprehensive understanding of watershed dynamics. For example, integrating optical, thermal, and radar imagery can offer complementary information on land cover, water resources, and vegetation. Similarly, merging remote sensing data with in situ measurements, socio-economic data, and other geospatial information can enhance the accuracy and reliability of watershed analyses. Developing robust data fusion methodologies and interoperable platforms is crucial for maximizing the potential of multisource data in watershed management.

3.2. Multiscale Modeling and Analysis

Watershed processes occur at various spatial and temporal scales, necessitating multiscale modeling and analysis approaches in remote sensing. By considering the interactions between processes at different scales, researchers can develop more accurate and representative models of watershed dynamics. For instance, combining high-resolution imagery for detailed local assessments with coarse-resolution imagery for regional analyses can offer valuable insights into land use and hydrological processes. Developing scalable remote sensing methods that can be applied across various spatial and temporal scales is essential for addressing the complex challenges associated with watershed management.

3.3. Analysis of the "Total Environment"

A comprehensive understanding of watershed dynamics requires the consideration of all elements of the "total environment," including physical, biological, and socio-economic components. Remote sensing techniques can contribute to this understanding by providing information on land use, water resources, ecosystems, and human activities. Future research should focus on developing integrated frameworks and methodologies that can analyze the interactions between these components and assess their combined impacts on watershed health. Such holistic approaches are crucial for developing sustainable watershed management strategies that balance the competing demands of various stakeholders.

3.4. Data Barriers and Data Sharing

Addressing data barriers and promoting data sharing is a critical perspective in remote sensing for watershed management. Ensuring that remote sensing data, derived products, and analytical tools are accessible to researchers, decision makers, and stakeholders can foster collaboration and facilitate informed decision making. This requires the development of open data platforms, standardized data formats, and data-sharing policies that encourage the exchange of information and knowledge. Overcoming data barriers can also help bridge the gap between scientific research and practical applications in watershed management.

3.5. Targeting Industrial Demands and Serving Decision Making

Remote sensing for watershed management should be oriented toward addressing the specific needs of the industry and decision makers. This includes developing tailored products, tools, and methodologies that can support decision-making processes in various sectors, such as water resource management, agriculture, urban planning, and environmental conservation. By focusing on practical applications and providing actionable insights, remote sensing can contribute to the development of evidence-based policies and strategies for sustainable watershed management.

In conclusion, the future of remote sensing for watershed management lies in the integration of multisource data, multiscale modeling and analysis, comprehensive assessments of the total environment, overcoming data barriers and sharing, and targeting industrial demands to serve decision-making processes. By embracing these perspectives, remote sensing can continue to play a pivotal role in advancing our understanding of watershed dynamics and informing sustainable management practices.

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